

Pearson

BTEC Level 3 Diploma in

Rail Engineering Technician

Knowledge

Specification

BTEC Specialist qualification

First registration November 2017

Issue 4

About Pearson

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We provide content, assessment and digital services to learners, educational institutions, employers, governments and other partners globally. We are committed to helping equip learners with the skills they need to enhance their employability prospects and to succeed in the changing world of work.

We believe that wherever learning flourishes so do people.

This specification is Issue 4. Key changes are summarised on the next page. We will inform centres of any changes to this issue. The latest issue can be found on our website.

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Summary of changes to Pearson BTEC Level 3 Diploma in Rail Engineering Technician Knowledge specification Issue 4

Summary of changes made between previous issue and this issue	Page number
Further clarification has been provided on the combination of units in Pathway 1. Learners take two units from this pathway: either two units from 6, 7, 22 or two units from 22, 38, 39.	6

Earlier issue shows previous changes.

If you need further information on these changes or what they mean, please contact us via our website at: qualifications.pearson.com/en/support/contact-us.html.

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1 Introducing the qualification

What are BTEC Specialist qualifications?

BTEC Specialist qualifications are work-related qualifications available from Entry to Level 3. The qualifications put learning into the context of the world of work, giving students the opportunity to apply their research, skills and knowledge in relevant and realistic work contexts. This applied, practical approach means learners build the knowledge, understanding and skills they need for career progression or further study.

Qualification purpose

The Pearson BTEC Level 3 Diploma in Rail Engineering Technician Knowledge is for learners who are working in, or who are intending to work in the rail engineering sector. Learners may be employed as apprentices in the role of Rail Engineering Technician and working towards gaining their apprenticeship.

A Rail Engineering Technician may work onsite or in a depot or technical office in one of the following roles:

Track Technician, Overhead Line Technician, Electrification Technician, Traction and Rolling Stock Technician, Signalling Technician, Telecoms Technician, Rail Systems Technician.

Their work could involve:

- construction, installation, renewal, enhancement and modification of the railway
- fault-finding and diagnosis to prevent or address equipment failures
- maintenance and replacement of systems and components
- functional and operational testing and inspection of the railway using specialist equipment
- ensuring assets are installed, replaced or maintained to specification and maintaining required records.

The qualification gives learners the opportunity to:

- develop the technical knowledge and understanding required to meet the Rail Engineering Technician Apprenticeship Standard. This includes areas such as working safely in rail engineering, mathematics for engineering technicians and specialist units in traction and rolling stock and electrification
- achieve a nationally-recognised Level 3 qualification.

Apprenticeships

The Pearson BTEC Level 3 Diploma in Rail Engineering Technician Knowledge is a mandatory requirement within the Rail Engineering Technician Apprenticeship Standard. Learners must achieve all mandatory qualifications within the Apprenticeship Standard before progressing to the end-point assessment (EPA).

An apprenticeship consists of the following components: on-programme training requirements; gateway 'assessment'; EPA.

The on-programme training is made up of 20% of time spent away from the 'normal' working area on off-the-job training, and 80% of the time in the working environment carrying out training and assessment to develop the skills, knowledge and behaviours required for a rail engineering technician as defined by the standard and assessment plan.

This qualification allows learners, training providers and employers to structure the 20% off-the-job training requirement.

As part of the Apprenticeship Standard, learners must also have achieved English and mathematics at Level 1 (either GCSE or Functional Skills) and ideally have sat the assessment at Level 2 before progressing to the EPA.

The published *Rail Engineering Technician Apprenticeship Standard and Assessment Plan* can be found at: <https://www.gov.uk/government/publications/apprenticeship-standard-rail-engineering-technician>

Progression opportunities

Learners who achieve the Pearson BTEC Level 3 Diploma in Rail Engineering Technician Knowledge can progress to achieving the full apprenticeship certification that confirms competency in the job role(s) stated on the previous page. In the longer term, learners can progress to more senior or complex job roles such as Advanced and Senior Technician in Rail Engineering. On completing the apprenticeship, learners can also apply to become members of relevant professional engineering institutions for EngTech membership status.

Alternatively, learners who have achieved the qualification and not completed the full apprenticeship requirements with further work and training, could progress to trainee job roles or to other more general engineering qualifications such as BTEC Nationals and BTEC Specialist qualifications.

Industry support and recognition

The Pearson BTEC Level 3 Diploma in Rail Engineering Technician Knowledge was developed through close collaboration with the Rail Engineering Trailblazer employer group, professional bodies and other awarding organisations.

This qualification is recognised by:

- employers:
 - Alstom Transport UK Limited
 - Amey
 - Babcock International Group – Network Engineering
 - Carillion plc
 - DB Schenker Rail UK Limited
 - DEG Signal Ltd
 - Eurostar International Ltd
 - High Speed Two Limited
 - Hitachi Rail Europe Ltd
 - Merseyrail Electrics 2002 Limited
 - MGB Engineering Ltd
 - Network Rail
 - Siemens Rail
 - Automation Holdings Limited
 - Signalling Solutions Ltd
 - Stagecoach South Western Trains Limited
 - Telent Technology Services Ltd
 - Transport for London
 - VolkerRail Ltd
- Sector Skills Council: Semta, the Sector Skills Council for Engineering and NSARE (National Skills Academy for Railway Engineering).

Funding

Qualifications eligible and funded for post-16-year-olds can be found on the funding Hub.

2 Qualification summary and key information

Qualification title	Pearson BTEC Level 3 Diploma in Rail Engineering Technician Knowledge
Qualification Number (QN)	603/2537/9
Regulation start date	25/10/2017
Operational start date	01/11/2017
Approved age ranges	16-18 19+
Total qualification time (TQT)	552 hours.
Guided learning hours (GLH)	360.
Assessment	Internal assessment.
Grading information	The qualification and units are graded Pass/Merit/Distinction.
Entry requirements	No prior knowledge, understanding, skills or qualifications are required before learners register for this qualification.

3 Qualification structure

Pearson BTEC Level 3 Diploma in Rail Engineering Technician Knowledge

The requirements outlined in the table below must be met for Pearson to award the qualification.

Minimum number of units that must be achieved	6
Number of Mandatory units that must be achieved (Units 1, 2 and 3)	3
Minimum number of Pathway Core units that must be achieved (EITHER Unit 4 OR Unit 5)	1
Minimum number of Pathway Mandatory units that must be achieved (learners must select both units from the same pathway)	2

Please note that the additional units listed on page 8 are available for use if required, but do not form part of the requirements of the qualification.

Unit number	Mandatory units (complete all units)	Level	Guided learning hours
1	Working Safely Within Rail Engineering	3	60
2	Mathematics for Engineering Technicians	3	60
3	Engineering Solutions and Innovation	3	60
Unit number	Pathway Core units (at least one of the following)	Level	Guided learning hours
4	Electrical and Electronic Principles in Engineering	3	60
5	Mechanical Principles of Engineering Systems	3	60

Pathway Mandatory			
Unit number	Pathway 1 Traction and Rolling Stock pathway units Learners take TWO units from this pathway: EITHER two units from 6, 7, 22 OR two units from 22, 38, 39	Level	Guided learning hours
6	Overground Rail Vehicle Traction and Associated Systems	3	60
7	Overground Rail Passenger Comfort, Safety and Security	3	60
22	Engineering Maintenance Procedures and Techniques	3	60
38	Underground Rail Vehicle Traction and Associated Systems	3	60
39	Underground Rail Passenger Comfort, Safety and Security	3	60
Unit number	Pathway 2 Electrification pathway units Learners take both units from this pathway	Level	Guided learning hours
8	Features and Applications of Electrical Machines	3	60
9	Rail Electrification Technologies	3	60
Unit number	Pathway 3 Track pathway units Learners take both units from this pathway	Level	Guided learning hours
29	Railway Infrastructure Construction and Maintenance	3	60
30	Rail Surveying, Materials and Systems	3	60

Unit number	Pathway 4 Overhead Line pathway units Learners take TWO units from this pathway: Unit 31 and EITHER Unit 32 OR Unit 33	Level	Guided learning hours
31	Overhead Line Infrastructure Construction and Maintenance	3	60
32	Rail Overhead Line Technologies (Construction)	3	60
33	Rail Overhead Line Technologies (Maintenance)	3	60
Unit number	Pathway 5 Signalling pathway units Learners take both units from this pathway	Level	Guided learning hours
34	Functions and Characteristics of Railway Signalling Systems	3	60
35	Electronic Circuits for Rail Signalling	3	60
Unit number	Pathway 6 Telecoms pathway units Learners take both units from this pathway	Level	Guided learning hours
36	Telecommunication Technologies	3	60
37	Telecommunication Principles	3	60

Unit number	Additional units These units may be used if required, but do not count towards the achievement of the minimum units for the qualification	Level	Guided learning hours
8	Features and Applications of Electrical Machines	3	60
10	Electronic Measurement and Testing	3	60
11	Further Electrical Principles	3	60
12	Properties and Applications of Engineering Materials	3	60
13	Engineering Drawing for Technicians	3	60
14	Further Mechanical Principles and Applications	3	60
15	Communications for Engineering Technicians	3	60
16	Engineering Project	3	120
17	Further Engineering Mathematics	3	60
18	Electro-pneumatic and Hydraulic Systems and Devices	3	60
19	Computer-Aided Drafting in Engineering	3	60
20	Selecting and Using Programmable Controllers	3	60
21	Principles and Applications of Electronic Devices and Circuits	3	60
22	Engineering Maintenance Procedures and Techniques	3	60
23	Monitoring and Fault Diagnosis of Engineering Systems	3	60
24	Electrical Technology	3	60
25	Business Operations in Engineering	3	60
26	Principles and Applications of Analogue Electronics	3	60
27	Construction and Applications of Digital Systems	3	60
28	Electronic Fault Finding	3	60
40	Engineering Design	3	60

4 Programme delivery

Centres are free to offer this qualification using any mode of delivery that meets learners' and employers' needs. It is recommended that centres make use of a wide range of training delivery methods, including direct instruction in classrooms, simulated demonstrations, research or applied projects, e-learning, directed self-study, field visits and role play. Whichever mode of delivery is used, centres must make sure that learners have access to the resources identified in the specification and to the subject specialists delivering the units.

Centres must adhere to the Pearson policies that apply to the different models of delivery. Our *Collaborative Arrangements for the Delivery of Vocational Qualifications Policy* is available on our website.

Those planning the programme should aim to involve employers as far as possible in the delivery of the qualification. This could be by:

- spending time with employers to better understand their organisational requirements and the methods of training that are most suitable, taking into consideration their available resources and working patterns
- collaborating with employers to ensure that learners have opportunities in the workplace to implement the knowledge and skills developed through the training programme
- having regular meetings with employers to discuss learner progress, providing feedback and agreeing how any issues will be resolved
- developing projects or assessments with input from employers
- developing up-to-date and relevant teaching materials that make use of scenarios relevant to the sector and relevant occupations
- using 'expert witness' reports from employers to support assessment
- making full use of the variety of experience of work and life that learners bring to the programme.

Where legislation is taught, centres must ensure that it is current and up to date.

5 Centre resource requirements

As part of the approval process, centres must make sure that the resource requirements below are in place before offering the qualification.

General resource requirements

- Centres must have appropriate physical resources (for example IT, learning materials, teaching rooms) to support the delivery and assessment of the qualification.
- Staff involved in the delivery and assessment process must have relevant expertise and occupational experience.
- There must be systems in place that ensure continuing professional development (CPD) for staff delivering and assessing the qualification.
- Centres must have in place appropriate health and safety policies relating to the use of equipment by learners.
- Centres must have in place robust internal verification systems and procedures to ensure the quality and authenticity of learners' work as well as the accuracy and consistency of assessment decisions between assessors operating at the centre. For information on the requirements for implementing assessment processes in centres, please refer to the *BTEC UK Quality Assurance Centre Handbook* on our website.
- Centres must deliver the qualifications in accordance with current equality legislation. For further details on Pearson's commitment to the Equality Act 2010, please see *Section 7 Access and recruitment*. For full details of the Equality Act 2010, please go to www.legislation.gov.uk

Specific resource requirements

As well as the general resource requirements given above, there are specific resources that centres must provide. They are listed by unit below.

Unit	Resources required
2	Electronic scientific calculator
3	Technical documents and drawings for parts of traction systems.
4	A well-equipped electrical and electronics laboratory with up-to-date electrical/electronic instruments such as digital and analogue multimeters function generators and oscilloscopes. Centres will also need to provide appropriate circuit components, as identified in the <i>Unit content</i> , together with the means to physically construct circuits.
5	Tensile testing equipment, dynamics trolleys, linear expansivity apparatus, apparatus to determine density and apparatus for verification of Boyle's and Charles' laws.
6	Technical documents and drawings for parts of traction systems.
7	Diagnostic software for train door systems and Passenger Information Systems (PIS). A workshop equipped with electrical machines and associated switchgear and control equipment. Learners will require access to a range of AC and DC motors and generators. A selection of different types of transformer (for example step-down, step-up, isolating variable voltage) will also be required. In addition, to permit testing of motor speed controllers, learners will require one or more variable speed controllers (for both AC and DC motors) together with variable loads and machine braking systems.
9	Laboratories with mechanical and electrical/electronic equipment.

6 Assessment requirements

The table below gives a summary of the assessment methods used in the qualification.

Units	Assessment method
All units	Internal assessment (centre-devised assessments).

Language of assessment

Learners must use English only during the assessment of this qualification.

A learner taking the qualification may be assessed in British or Irish Sign Language where it is permitted for the purpose of reasonable adjustment.

Further information on the use of language in qualifications is available in our *Use of languages in qualifications policy*, available on our website, qualifications.pearson.com.

Internal assessment

Internally assessed units are subject to standards verification. This means that centres set and mark the final summative assessment for each unit, using the examples and support that Pearson provides.

To pass each internally assessed unit, learners must:

- achieve all the specified learning outcomes
- satisfy all the assessment criteria by providing sufficient and valid evidence for each criterion
- prove that the evidence is their own.

Centres must ensure:

- assessment is carried out by assessors with relevant expertise in both the occupational area and assessment. For the occupational area, this can be evidenced by a relevant qualification or current (within three years) occupational experience that is at an equivalent level or higher than this qualification. Assessment expertise can be evidenced by qualification in teaching or assessing and/or internal quality assurance or current (within three years) experience of assessing or internal verification
- internal verification systems are in place to ensure the quality and authenticity of learners' work, as well as the accuracy and consistency of assessment.

Learners who do not successfully pass an assignment, are allowed to resubmit evidence for the assignment or to retake another assignment.

Assessment of knowledge units

To pass each knowledge unit, learners must independently complete assignment(s) that show that the learning outcomes and assessment criteria for the unit have been met.

Format of assignments for knowledge units:

- all learning outcomes and assessment criteria must be covered
- assignments can include both practical and written tasks
- assignments are independently completed as a distinct activity after the required teaching has taken place
- the brief is issued to learners with a defined start date, a completion date and clear requirements for the evidence they are required to produce
- all or parts of units can be combined into a single assignment. Learning outcomes must not be split into more than one assignment.

Each unit contains suggested tasks that centres can use to form the basis of assignments for learners to complete. It is expected that centres will contextualise these and ensure that the final version is checked by their internal verifier.

Assessment through assignments

For internally-assessed units, the format of assessment is an assignment taken after the content of the unit, or part of the unit if several assignments are used, has been delivered. An assignment may take a variety of forms, including practical and written types. An assignment is a distinct activity, completed independently by learners, that is separate from teaching, practice, exploration and other activities that learners complete with direction from tutors and assessors.

An assignment is issued to learners as an assignment brief with a defined start date, a completion date and clear requirements for the evidence that they need to provide. Assignments can be divided into tasks and may require several forms of evidence. A valid assignment will enable there to be a clear and formal assessment outcome based on the assessment criteria.

Designing effective assignments

To ensure that final assessment decisions meet the required standard, assignments must be fit for purpose as a tool to measure learning against the defined content and assessment criteria.

Centres should make sure that assignments enable learners to produce valid, sufficient, authentic and appropriate evidence that relates directly to the specified criteria within the context of the learning outcomes and unit content. Centres need to ensure that the generation of evidence is carefully monitored and controlled and that it is produced to an appropriate timescale. This helps to make sure that learners are achieving to the best of their ability and that at the same time the evidence is genuinely their own.

An assignment that is fit for purpose and suitably controlled is one in which:

- the tasks that the learner is asked to complete provide evidence for a learning outcome that can be assessed using the assessment criteria
- the time allowed for the assignment is clearly defined and consistent with what is being assessed
- the centre has the required resources for all learners to complete the assignment fully and fairly
- the evidence the assignment will generate will be authentic and individual to the learner
- the evidence can be documented to show that the assessment and verification has been carried out correctly.

Recommended assignments are provided in the *Further information for tutors and assessors* section of each unit. In designing assignments, centres need to work within the structure of these assignments. They need to consider the following points when developing their assignment briefs.

- Centres may choose to combine all or parts of different units into single assignments provided that all units and all their associated learning outcomes are fully addressed in the programme overall. If this approach is taken, centres need to make sure that learners are fully prepared so that they can provide all the required evidence for assessment, and that centres are able to track achievement in the records.
- An outcome must always be assessed as a whole and must not be split into two or more assignments.
- The assignment must be targeted to the learning outcomes but the learning outcomes and their associated criteria are not tasks in themselves. Criteria are expressed in terms of the outcome shown in the evidence.
- Centres do not have to follow the order of the outcomes of a unit in developing assignments but later learning outcomes often require learners to apply the content of earlier learning outcomes and they may require learner to draw their learning together.
- Assignments must be structured to allow learners to demonstrate the full range of achievement at all grade levels. Learners need to be treated fairly by being given the opportunity to achieve a higher grade if they have the ability to do so.
- As assignments provide a final assessment, they will draw on the specified range of teaching content for the learning outcomes. The specified content is compulsory. The evidence for assessment need not cover every aspect of the teaching content as learners will normally be given particular examples, case studies or contexts in their assignments. For example, if a learner is carrying out one practical performance, or an investigation of one organisation, then they will address all the relevant range of content that applies in that instance.

Providing an assignment brief

A good assignment brief is one that motivates learners to provide appropriate evidence of what they have learned through providing challenging and realistic tasks. An assignment brief should include:

- a vocational scenario, context, or application for the tasks to be completed
- clear instructions to the learner about what they are required to do – normally set out through a series of tasks
- an audience or purpose for which the evidence is being provided
- an explanation of how the assignment relates to the unit(s) being assessed.

Forms of evidence

Centres may use a variety of forms of evidence, provided that they are suited to the type of learning outcome being assessed. For many units, the practical demonstration of skills is necessary and for others learners will need to carry out their own research and analysis. The units give information on what would be suitable forms of evidence.

Centres may choose to use different suitable forms for evidence to those proposed. Overall, learners should be assessed using varied forms of evidence.

Some of the main forms of evidence include:

- written tasks or reports
- projects
- time-constrained simulated activities with observation records and supporting evidence
- observation and recordings of performance in the workplace
- sketchbooks, work logbooks, reflective journals
- presentations with assessor questioning.

The form(s) of evidence selected must:

- allow the learner to provide all the evidence required for the learning outcomes and the associated assessment criteria at all grade levels
- allow the learner to produce evidence that is their own independent work
- allow a verifier to independently reassess the learner to check the assessor's decisions.

For example, when using performance evidence, centres need to think about how supporting evidence can be captured through recordings, photographs or task sheets.

Centres need to take particular care that learners are enabled to produce independent work. For example, if learners are asked to use real examples, then best practice would be to encourage them to use examples of their own experiences.

For information on the requirements for implementing assessment processes in centres, please refer to the *BTEC UK Quality Assurance Centre Handbook* on our website.

Making valid assessment decisions

Authenticity of learner work

Once an assessment has begun, learners must not be given feedback on progress towards fulfilling the targeted criteria.

An assessor must assess only work that is authentic, i.e. learners' own independent work. Learners must authenticate the evidence that they provide for assessment through signing a declaration stating that it is their own work.

Assessors must ensure that evidence is authentic to a learner through setting valid assignments and supervising learners during assessment period. Assessors must take care not to provide direct input, instructions or specific feedback that may compromise authenticity.

Assessors must complete a declaration that:

- the evidence submitted for this assignment is the learner's own
- the learner has clearly referenced any sources used in the work
- they understand that false declaration is a form of malpractice.

Centres may use Pearson templates or their own templates to document authentication.

During assessment, an assessor may suspect that some or all of the evidence from a learner is not authentic. The assessor must then take appropriate action using the centre's policies for malpractice. More information is given later in this section.

Making assessment decisions using unit-based criteria

Assessment decisions for the qualification are based on the specific criteria given in each unit and set at each grade level. The assessment criteria for a unit are hierarchical and holistic. For example, if an M criterion requires the learner to show 'analysis' and the related P criterion requires the learner to 'explain', then to satisfy the M criterion a learner will need to cover both 'explain' and 'analyse'. The unit assessment grid shows the relationships between the criteria so that assessors can apply all the criteria to the learner's evidence at the same time.

Assessors make judgements using the criteria and must show how they have reached their decisions in the assessment records. The evidence from a learner can be judged using all the relevant criteria at the same time. The assessor needs to make a judgement against each criterion that evidence is present and sufficiently comprehensive.

For example, the inclusion of a concluding section may be insufficient to satisfy a criterion requiring 'evaluation'.

Assessors should use the following information and support in reaching assessment decisions:

- the *Essential information for assessment* section of each unit, which gives examples and definitions related to terms used in the assessment criteria
- the centre's Lead Internal Verifier and assessment team's collective experience supported by the information provided by Pearson.

When a learner has completed the assessment for a unit then the assessment team will give an assessment outcome for the unit. This is given according to the highest level for which the learner is judged to have met all the criteria. Therefore:

- to achieve a Distinction, a learner must have satisfied all the Distinction criteria (and therefore the Pass and Merit criteria); these define outstanding performance across the unit as a whole
- to achieve a Merit, a learner must have satisfied all the Merit criteria (and therefore the Pass criteria) through high performance in each learning aim
- to achieve a Pass, a learner must have satisfied all the Pass criteria for the learning outcomes, showing coverage of the unit content and therefore attainment at the stated level of the qualification. The award of a Pass is a defined level of performance and cannot be given solely on the basis of a learner completing assignments. Learners who do not satisfy the Pass criteria should be reported as Unclassified.

Dealing with late completion of assignments

Learners must have a clear understanding of the centre's policy on completing assignments by the stated deadlines. Learners may be given authorised extensions for legitimate reasons, such as illness at the time of submission, in line with centre policies.

For assessment to be fair, it is important that learners are all assessed in the same way and that some learners are not advantaged by having additional time or the opportunity to learn from others.

If a late completion is accepted, then the assignment should be assessed normally using the relevant assessment criteria.

Issuing assessment decisions and feedback

Once the assessment team has completed the assessment process for an assignment, the outcome is a formal assessment decision. This is recorded formally and reported to learners.

The information given to the learner:

- must show the formal decision and how it has been reached, indicating how or where criteria have been met
- may show why attainment against criteria has not been demonstrated
- must not provide feedback on how to improve evidence
- must be validated by an Internal Verifier before it is given to the learner.

Resubmissions and retakes

On 1 September 2014, Pearson introduced a framework to support centres in delivering high-quality internal assessments for BTEC Firsts and Nationals, the framework can be found on the BTEC delivery pages of our website. Within this framework, only one opportunity for resit can be authorised by the Lead Internal Verifier and retakes are not available. These rules do not apply to BTEC Specialist programmes at Entry Level to Level 3 but we do recommend the approach as best practice. As the rules are, therefore, not mandatory for BTEC Specialist programmes, they will not be checked as part of the standards verification and quality assurance process for this/these qualification(s).

Administrative arrangements for internal assessment

Records

Centres are required to retain records of assessment for each learner. Records should include assessments taken, decisions reached and any adjustments or appeals. Further information can be found in our *UK Information Manual*. We may ask to audit centre records, so they must be retained as specified.

7 Centre recognition and approval

Centres must have approval prior to delivering or assessing any of the units in this qualification.

Centres that have not previously offered BTEC Specialist qualifications need to apply for, and be granted, centre recognition as part of the process for approval to offer individual qualifications.

Guidance on seeking approval to deliver BTEC qualifications is given on our website.

Approvals agreement

All centres are required to enter into an approval agreement with Pearson, in which the head of centre or principal agrees to meet all the requirements of the qualification specification and to comply with the policies, procedures, codes of practice and regulations of Pearson and relevant regulatory bodies. If centres do not comply with the agreement, this could result in the suspension of certification or withdrawal of centre or qualification approval.

8 Access to qualifications

Access to qualifications for learners with disabilities or specific needs.

Equality and fairness are central to our work. Our *Equality, diversity and inclusion policy* requires all learners to have equal opportunity to access our qualifications and assessments, and that our qualifications are awarded in a way that is fair to every learner.

We are committed to making sure that:

- learners with a protected characteristic (as defined by the Equality Act 2010) are not, when they are taking one of our qualifications, disadvantaged in comparison to learners who do not share that characteristic
- all learners achieve the recognition they deserve from their qualification and that this achievement can be compared fairly to the achievement of their peers.

For learners with disabilities and specific needs, the assessment of their potential to achieve the qualification must identify, where appropriate, the support that will be made available to them during delivery and assessment of the qualification.

Centres must deliver the qualification in accordance with current equality legislation. For full details of the Equality Act 2010, please visit www.legislation.gov.uk

Reasonable adjustments and special consideration

Centres are permitted to make adjustments to assessment to take account of the needs of individual learners. Any reasonable adjustment must reflect the normal learning or working practice of a learner in a centre or a learner working in the occupational area.

Centres cannot apply their own special consideration – applications for special consideration must be made to Pearson and can be made on a case-by-case basis only.

Centres must follow the guidance in the Pearson document *Guidance for reasonable adjustments and special consideration in vocational internally assessed units*.

9 Recognising prior learning and achievement

Recognition of Prior Learning (RPL) considers whether a learner can demonstrate that they can meet the assessment requirements for a unit through knowledge, understanding or skills they already possess and so do not need to develop through a course of learning.

Pearson encourages centres to recognise learners' previous achievements and experiences in and outside the workplace, as well as in the classroom. RPL provides a route for the recognition of the achievements resulting from continuous learning.

RPL enables recognition of achievement from a range of activities using any valid assessment methodology. If the assessment requirements of a given unit or qualification have been met, the use of RPL is acceptable for accrediting a unit, units or a whole qualification. Evidence of learning must be sufficient, reliable and valid.

Further guidance is available in our policy document *Recognition of prior learning policy and process*, available on our website.

10 Quality assurance of centres

For the qualification in this specification, the Pearson quality assurance model will consist of the following processes.

Centres will receive at least one visit from our Standards Verifier, followed by ongoing support and development. This may result in more visits or remote support, as required to complete standards verification. The exact frequency and duration of Standards Verifier visits/remote sampling will reflect the level of risk associated with a programme, taking account of the:

- number of assessment sites
- number and throughput of learners
- number and turnover of assessors
- number and turnover of internal verifiers
- amount of previous experience of delivery.

If a centre is offering a BTEC Specialist qualification alongside other qualifications related to the same Apprenticeship Standard, wherever possible, we will allocate the same Standards Verifier for both qualifications.

Following registration, centres will be given further quality assurance and sampling guidance.

For further details, please see the work-based learning quality assurance handbooks, available in the support section of our website:

- *Pearson centre guide to quality assurance – NVQs/SVQs and competence-based qualifications*
- *Pearson delivery guidance & quality assurance requirements – NVQs/SVQs and competence-based qualifications.*

11 Understanding the qualification grading

This section explains the rules that we apply in providing an overall qualification grade for each learner. The final grade awarded for a qualification represents a holistic performance across all of the qualification. As the qualification grade is an aggregate of the total performance, there is some element of compensation in that a higher performance in some units will be balanced by a lower outcome in others.

In the event that a learner achieves more than the required number of optional units, the mandatory units, along with the optional units with the highest grades, will be used to calculate the overall result, subject to the eligibility requirements of the qualification.

Awarding and reporting for the qualification

The awarding and certification of these qualifications will comply with the requirements of the Office of Qualifications and Examinations Regulation (Ofqual).

Units are assessed using a grading scale of Distinction, Merit, Pass and Unclassified. All mandatory and optional units contribute equally to the overall qualification grade. There is no unit grade of D*.

Eligibility for an award

To achieve any qualification grade learners must:

- achieve a Pass grade, or higher in all units within a valid combination, and
- achieve the minimum number of points at a grade threshold.

It is the responsibility of the centre to ensure that a correct unit combination is adhered to.

Calculation of the qualification grade

The table below shows the minimum thresholds for calculating each grade. The table will be kept under review over the lifetime of the qualification. In the event of any change, centres will be informed before the start of teaching for the relevant cohort and an updated table will be issued on our website.

Points thresholds

U	0
Pass	36
Merit	52
Distinction	74

Learners who do not meet the minimum requirements for a qualification grade to be awarded will be recorded as Unclassified (U) and will not be certificated. They may receive a Notification of Performance for individual units. Our *Information manual* (available on our website) gives more information.

Points available for internal units

The table below shows the number of **points** available for internal units. For each internal unit, points are allocated depending on the grade awarded.

	All internal units
U	0
Pass	6
Merit	10
Distinction	16

Claiming the qualification grade

Subject to eligibility, Pearson will automatically calculate the qualification grade for learners when the internal unit grades are submitted and the qualification claim is made. Learners will be awarded qualification grades for achieving sufficient number of points in the ranges shown in the table under the *Calculation of qualification grade* heading on the previous page.

To allow for a weaker performance in some units to be balanced by a stronger performance in others, there is an element of compensation built into the grading model.

Examples of grade calculations

Example 1: Achievement of Diploma with a P grade

Unit	GLH	Type	Grade	Points
Unit 1	60	Internal	Pass	6
Unit 2	60	Internal	Pass	6
Unit 3	60	Internal	Pass	6
Unit 4	60	Internal	Pass	6
Unit 5	60	Internal	Pass	6
Unit 6	60	Internal	Merit	10
Totals	360		P	40

The learner has achieved a Pass or above in all units.

Example 2: Achievement of a Diploma with a D grade

Unit	GLH	Type	Grade	Points
Unit 1	60	Internal	Merit	10
Unit 2	60	Internal	Merit	10
Unit 3	60	Internal	Distinction	16
Unit 4	60	Internal	Distinction	16
Unit 5	60	Internal	Distinction	16
Unit 6	60	Internal	Distinction	16
Totals	360		D	84

The learner has sufficient points for a D grade.

Example 3: Achievement of a Diploma with an Unclassified result

Unit	GLH	Type	Grade	Points
Unit 1	60	Internal	Merit	10
Unit 2	60	Internal	Merit	10
Unit 3	60	Internal	Unclassified	0
Unit 4	60	Internal	Pass	6
Unit 5	60	Internal	Merit	10
Unit 6	60	Internal	Merit	10
Totals	360		U	46

The learner has a U in Unit 3.

The learner has sufficient points for a P grade but has not met the requirement for a Pass, or above, in all units.

12 Units

This section of the specification contains the units that form the assessment for the qualification.

For explanation of the terms within the units, please refer to *Section 16 Glossary*.

It is compulsory for learners to meet the learning outcomes and the assessment criteria to achieve a Pass. Content is compulsory unless it is provided as an example and is therefore marked 'e.g.'. All compulsory content must be delivered, but assessments may not cover all content.

Where legislation is included in delivery and assessment, centres must ensure that it is current and up to date.

Unit 1: Working Safely Within Rail Engineering

Level:	3
Unit type:	Mandatory
Guided learning hours:	60

Unit introduction

The rail industry is a complex example of heavy engineering. Every year, billions of journeys are made both by passengers and by freight being transported around rail networks. Governments, Train Operating Companies (TOCs), rail infrastructure owners and rail safety and economic regulators all work to ensure that rail networks operate successfully for customers.

As a heavy engineering industry, applying relevant safe working practices is essential when working in the rail sector, whether in an engineering workshop, maintenance depot or on a railtrack. In this unit, you will gain a knowledge and understanding of the legal framework relating to the health and safety responsibilities of employers, employees, the general public and others. You will become familiar with the enforcement routes for breaches of health and safety legislation, including prosecution, costs and fines. You will explore hazard identification, risk assessment methods, and the requirement to investigate and report near misses, accidents, and dangerous occurrences.

The rail industry must have due regard for the environment when carrying out its activities. This unit gives you knowledge of the environmental legislation that impacts on the rail sector. You will be introduced to environmental management practices and how rail engineering organisations minimise harmful effects on the environment arising from their activities.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

- 1 Understand health and safety legislation and regulation
- 2 Know about hazards and risks in the workplace
- 3 Understand methods used when reporting and recording accidents and incidents

Unit content

1 Understand health and safety legislation and regulation

Key features of legislation and regulations: directives, e.g. Health and Safety Framework Directive (89/391/EEC); legislation, e.g. Health and Safety at Work etc. Act 1974, Railway and Transport Safety Act (2003), Railway Act (2005), Regulatory Reform (Fire Safety) Order 2005; regulations, e.g. Management of Health and Safety at Work Regulations 2006, Provision and Use of Work Equipment Regulations (PUWER) 1998, Control of Substances Hazardous to Health (COSHH) Regulations 2002, Lifting Operations and Lifting Equipment Regulations (LOLER) 1998, Manual Handling Operations Regulations 1992, Personal Protective Equipment at Work Regulations 1992, Confined Spaces Regulations 1997, Electricity at Work Regulations 1989, Control of Noise at Work Regulations 2005, Workplace (Health, Safety and Welfare) Regulations 1992, Health and Safety (First Aid) Regulations 1981, The Railways and Other Guided Transport Systems (Safety) Regulations 2006, The Health and Safety (Enforcing Authority for Railways and Other Guided Transport Systems) (2006), The Railway Safety Levy Regulations (2006).

Roles and responsibilities of those involved: employers; employees; Health and Safety Executive (HSE), HM Inspectorate of Railways, Office of Rail and Road, e.g. span of authority, right of inspection, guidance notes and booklets; others, e.g. management, subcontractors, public, suppliers, customers, visitors.

Key features of environmental legislation and directives: Environmental Protection Act 1990, Pollution Prevention and Control Act 1999, Clean Air Act 1993; regulations, e.g. Controlled Waste Regulations 2012, Dangerous Substances and Preparations (Safety) Regulations 2006.

Content and application of environmental management systems: ISO 14000 family of standards as a management tool; ISO 14004:2016 provides guidelines on the elements of an environmental management system and its implementation, and examines principle issues involved; ISO 14001:2015 specifies the requirements for such an environmental management system.

Consequences of breaching legislation and regulation: cost of safety 'iceberg model'; criminal prosecution, corporate manslaughter, fines and imprisonment.

2 Know about hazards and risks in the workplace

Differences between hazards and risks: a hazard is something that can cause harm and a risk is the likelihood that any hazard will actually cause somebody harm, e.g. high, medium or low likelihood.

Methods to identify hazards within the workplace: consideration of the workplace and its potential for harm, e.g. confined spaces, working over water or at heights, electrical hazards, chemicals, noise; use of accident data; regular safety inspections.

Preparation of risk assessments: items/area to be assessed, e.g. machine operation, work area; five steps (principal hazards, who is likely to be injured/harmed, evaluate the risks and decide on adequacy of precautions, record findings, review assessment and revise where necessary).

Use of control measures: control hierarchies and the concept of 'reasonably practicable', e.g. remove need (design out), use of recognised procedures, substances control, guarding, lifting assessments and manual handling assessments, regular inspection, use of personal protective equipment (PPE), training of personnel, induction, other personal procedures for health, safety and welfare.

3 Understand methods used when reporting and recording accidents and incidents

Importance of reporting and recording accidents and incidents: why employers keep records of serious accidents, incidents and emergencies; responsibilities of competent persons; cost of accidents, e.g. direct, indirect, human consequences; trends, e.g. major causes, fatal and serious injury, methods of classification, statistics.

Recording and reporting procedures: regulations on accident recording and reporting, e.g. Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (RIDDOR) 2013; procedures to be followed after an accident; accident investigation principles; accident book; evidence gathering techniques; interviewing and questioning; report formatting; root causes; explanation of contributory factors; company procedures; procedures to deal with near misses or dangerous occurrences.

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P1 Describe the responsibilities of the employee and employer with regard to workplace health and safety	M1 Explain how employees and employers contribute to complying with health and safety legislation and directives within a railway engineering organisation's workplace, including the consequences of not abiding with legislation	
P2 Describe the key features of the relevant legislation and directives with regard to environmental management		
P3 Explain the difference between a risk and a hazard		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P4 Describe the process of carrying out a risk assessment within the working environment	M2 Analyse the suitability of a typical risk assessment for a given railway engineering work situation	D1 Evaluate the content of a risk assessment in terms of available control measures
P5 Explain the importance of reporting and recording accidents and incidents	M3 Explain how accurate data on accidents and incidents contributes to improving health, safety and welfare in the workplace	D2 Evaluate a given rail accident report and suggest improvements to rail workplace system to avoid a recurrence
P6 Describe the procedures used to record and report accidents, dangerous occurrences or near misses		

Essential guidance for tutors

Assessment

It is likely that at least three assessment instruments will be required for this unit. The learner evidence required satisfying the pass, merit and distinction criteria will be written, or verbal with an accompanying tutor observation record or video.

To achieve a pass, learners will:

For P1, outline the roles and responsibilities of the employee and employer for health and safety in a rail engineering workplace, including the principal responsibilities of employers and employees under health and safety legislation. They will identify the roles of key health and safety personnel in the rail workplace and the responsibilities arising from five pieces of health and safety legislation selected from the unit content. One of these pieces of legislation must be the Health and Safety at Work etc. Act 1974. Learners should be encouraged to access this document and other legislation and regulations using the internet. To contextualise this area of study, learners should have access to relevant information from an actual rail workplace or be provided with a realistic scenario. Evidence for this criterion could be presented in the form of a table, organisation chart or a poster providing guidance to rail engineering technicians on the responsibilities of both employees and the employer. To achieve P1, learners need to also describe the roles and responsibilities of different organisations involved with workplace health and safety in the rail engineering sector. Learners will cover, as a minimum, the roles of the Health and Safety Executive, HM Inspectorate of Railways and the Office of Rail and Road, the body that is responsible for regulating safety in the rail industry.

To satisfy P2, learners need to outline the key features of three pieces of environmental legislation relevant to the rail engineering sector and selected from the unit content, giving valid descriptions of the main purpose of each. Learners will explain the environmental management quality standards that are used to manage procedures and practices and to minimise a rail engineering organisation's potential harmful impact on the environment from its activities. To contextualise this area of study, learners should have access to relevant environmental management information from an actual rail workplace or realistic scenario. Evidence for this criterion might be presented in the form of a guidance document to be used to induct new technicians into a rail engineering workplace.

One activity could be used to achieve both P3 and P4. Learners might, under controlled conditions, complete a presentation on how to undertake a risk assessment. Evidence of this activity would include slides with a supporting tutor observation record or video. For P3, learners should explain the difference between a risk and a hazard. Learners need to cover quantitative and qualitative approaches to the characterisation of risk, including the use of low, medium and high qualitative assessment of likelihood, and the use of alternative numerical-based methods. To fully satisfy P3, learners should describe how to identify the hazards present in a given

rail workplace situation, the people who may be at risk, and the possible consequences if the hazards are ignored. Learners must have access to a rail engineering workplace or a realistic scenario that might include supporting visual material such as photographs, a video or DVD. Case studies taken from the Rail Accident Investigation Branch will bring a fresh and factual approach to addressing the task, as will interviews with others working in the rail engineering industry. This is an ideal workplace observation exercise where learners can identify real hazards with a potential to harm. The use of secondary sources is permitted where this is not possible.

The evidence for P4 is descriptive. Learners need to describe the main principles and features of a typical risk assessment for a given rail workplace situation. A standard tabular format for risk assessments will provide a suitable basis for the required evidence. Learners are not required to produce their own risk assessments at this stage, and examples drawn from the rail engineering industry will be sufficient. The use of the Five Steps to Risk Assessment is recommended as Health and Safety Executive guidance, but is not mandatory. The method used must, however, be coherent and consistent. To achieve P4, learners need to select control measures for a given workplace situation to reduce risks and meet legal requirements, using workplace health and safety policies. Learners must select control measures, which may be categorised as low, medium or high. This may be linked to the risk assessment carried out for M2, but this is not mandatory as some learners may not achieve M2. It is, therefore, acceptable for learners to work from alternative scenarios.

The evidence for P5 is descriptive as learners need to explain the importance of recording accidents and incidents. To achieve this criterion, learners should clearly outline the difference between an accident and an incident as defined by the Reporting of Injuries, Diseases and Dangerous Occurrence Regulations 2013 (RIDDOR 2013).

To satisfy P6, learners need to describe accident recording and reporting procedures. This should include the procedures used to record and report accidents, dangerous occurrences and near misses to a supervisor or manager. Learners should also describe when an accident or incident is reportable to a health and safety enforcing authority under the Reporting of Injuries, Diseases and Dangerous Occurrence Regulations 2013 (RIDDOR 2013). There is no requirement to analyse the procedures at this stage.

To achieve a merit, learners will:

For M1, apply their knowledge of health and safety workplace requirements, as demonstrated for P1, to explain how employees and employers contribute to promote a positive workplace safety culture. Appropriate evidence might involve learners selecting and reviewing a realistic rail workplace scenario to explain five ways in which employees and employers could work safely together. Learners will also draw conclusions about not adhering to health and safety legislation, regulations and procedures within railway engineering organisations. The evaluation should consider

the economic, legal, and human cost of failing to commit to safety. Learners might draw and annotate the cost of the safety 'iceberg model' as evidence of achievement.

To satisfy M2, learners need to analyse a typical risk assessment for a given rail workplace situation or a realistic scenario. This should expand on the issues addressed in P3 and P4.

Finally, merit criterion M3 requires learners to explain how the collection of accurate data and information on accidents and incidents contributes to improving health, safety and welfare in a rail workplace. Learners should use health and safety statistics to explain how future health, safety and welfare legislation and provision can be influenced by accurate data relating to previous accidents and incidents. Each of the following should be discussed (as relevant to the situation): gender, age, type of injury (minor, major, and fatal), location, occupation and cause of accident. Learners should use the data to show how keeping accurate records can lead to noticeable improvements.

To achieve a distinction, learners must meet all of the pass and merit grade criteria and the two distinction grade criteria.

For D1, learners need to justify the contents of a risk assessment, for example the one appraised for M2, in terms of available control measures and what is 'reasonably practicable'. Learners need to expand on the risk assessment to justify the decisions made in terms of the consequences of risk, as indicated by accident data and what is considered 'reasonably practicable'. This should be based on a clear definition of what is meant by 'reasonably practicable'.

For D2, learners need to be able to evaluate a given rail accident report and suggest improvements that could be made to workplace systems to avoid a recurrence. Learners should evaluate a real or simulated rail accident report and suggest how the workplace could be improved in light of the report in terms of health, safety and welfare.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2 and M1	Health and Safety, and Environmental Management Responsibilities at Work	A written activity requiring learners to produce a guidance document for employees on the responsibilities of employers and employees at work in the rail industry, including: people assigned specific duties relating to health and safety, the role of specific health and safety organisations, introduction to key legislation and consequences of non-compliance, and the requirements for environmental management.	A written report with appropriate supporting diagrams and data.
P3, P4, M2 and D1	Risk Assessment	Learners are asked to give a presentation on how to undertake a risk assessment. As part of this activity, they are required to appraise the suitability of a risk assessment for a given railway engineering work situation.	Presentation, under controlled conditions, with evidence to include slides and a supporting tutor observation record or video.

Criteria covered	Assignment title	Scenario	Assessment method
P5, P6, M3 and D2	Accident Investigation	A written activity requiring learners to prepare an accident reporting procedure and guidance document for a scenario railway company. As part of this activity, they are required to prepare and evaluate a case study accident report.	A written report with supporting sample accident reporting forms.

Essential resources

Access to information and communication technology resources (including the internet) is essential for the delivery of this unit, as is a well-stocked source of reference material.

Indicative reading for learners

Textbooks

Bonnett C – *Practical Railway Engineering* (Imperial College Press, 2005)
ISBN 9781860945151

Boyce A, Cooke E, Jones R and Weatherill B – *BTEC Level 3 National Engineering Student Book* (Pearson, 2010) ISBN 9781846907241

Boyce A, Cooke E, Jones R and Weatherill B – *BTEC Level 3 National Engineering Teaching Resource Pack* (Pearson, 2010) ISBN 9781846907265

Glover J – *Principles of Railway Operation* (Ian Alan Publishing Limited, 2013)
ISBN 9780711036314

Tooley M and Dingle L – *BTEC National Engineering* (Routledge, 2010)
ISBN 9780123822024

Webpages

www.gov.uk/government/organisations/rail-accident-investigation-branch - Rail Accident Investigation Branch

www.hse.gov.uk – The Health and Safety Executive

Unit 2: Mathematics for Engineering Technicians

Level:	3
Unit type:	Mandatory
Guided learning hours:	60

Unit introduction

One of the main responsibilities of engineers is to solve problems quickly and effectively. To do so, they need to be able to solve mathematical, scientific and associated engineering problems at least at technician level.

This unit enables learners to build on knowledge gained at GCSE and use it in a more practical context for their chosen discipline. They will develop their knowledge and understanding of algebraic methods, from investigating the use of indices in engineering to the use of the algebraic formula for solving quadratic equations. Learners will be introduced to the radian as another method of angular measurement, the shape of the trigonometric ratios and the use of standard formulae to solve problems involving surface areas and volumes of regular solids. They will explore ways in which to represent statistical data in a variety of ways, calculating the mean, median and mode. Finally, they will learn the basics underpinning the arithmetic of elementary calculus. This unit will also act as a basis for progression to further study.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

- 1 Be able to use algebraic methods
- 2 Be able to use trigonometric methods and standard formulae to determine areas and volumes
- 3 Be able to use statistical methods to display data
- 4 Be able to use elementary calculus techniques.

Unit content

1 Be able to use algebraic methods

Indices and logarithms: laws of indices $a^m \times a^n = a^{m+n}$, $\frac{a^m}{a^n} = a^{m-n}$, $(a^m)^n = a^{mn}$;

laws of logarithms: $\log A + \log B = \log AB$, $\log A^n = n \log A$, $\log A - \log B = \log \frac{A}{B}$;

common logarithms (base 10), natural logarithms (base e), exponential growth and decay.

Equations and graphs: linear equations, e.g. $y = mx + c$; straight-line graph (coordinates on a pair of labelled Cartesian axes, positive or negative gradient, intercept, plot of a straight line); quadratic graph $y = ax^2 + bx + c$; experimental data, e.g. Ohm's law; pair of simultaneous equations in two unknowns (two linear or one linear and one quadratic).

Factorisation and quadratics: multiply expressions in brackets by a number, symbol or by another expression in a bracket; by extraction of a common factor, e.g. $ax + ay$, $a(x + 2) + b(x + 2)$; by grouping, e.g. $ax - ay + bx - by$; quadratic expressions, e.g. $a^2 + 2ab + b^2$; roots of an equation, e.g. quadratic equations with real roots by factorisation, and by the use of formula.

2 Be able to use trigonometric methods and standard formulae to determine areas and volumes

Circular measure: radian; conversion of degree measure to radians and vice versa; angular rotations (multiples of π radians); problems involving areas and angles measured in radians; length of arc of a circle $s = r\theta$; area of a sector

$$A = \frac{1}{2} r^2 \theta$$

Triangular measurement: functions (sine, cosine and tangent); sine/cosine wave over one complete cycle; graph of $\tan A$ as A varies from 0° and 360° confirming $\tan A = \frac{\sin A}{\cos A}$; values of the trigonometric ratios for angles between 0° and 360° ; periodic properties of the trigonometric functions; the sine and cosine rule; practical problems, e.g. calculation of the phasor sum of two alternating currents, resolution of forces for a vector diagram.

Mensuration: standard formulae to solve surface areas and volumes of regular solids, e.g. volume of a cylinder $V = \pi r^2 h$, total surface area of a cylinder

$TSA = 2\pi r h + 2\pi r^2$, volume of sphere $V = \frac{4}{3} \pi r^3$, surface area of a sphere $SA = 4\pi r^2$,

volume of a cone $V = \frac{1}{3} \pi r^2 h$, curved surface area of cone $CSA = \pi r l$

3 Be able to use statistical methods to display data

Data handling: data represented by statistical diagrams, e.g. bar charts, pie charts, frequency distributions, class boundaries and class width, frequency table; variables (discrete and continuous); histogram (continuous and discrete variants); cumulative frequency curves.

Statistical measurement: arithmetic mean; median; mode; discrete and grouped data.

4 Be able to use elementary calculus techniques

Differentiation: differential coefficient; gradient of a curve $y = f(x)$; rate of change; Leibniz notation $\left(\frac{dy}{dx}\right)$; differentiation of simple polynomial functions, exponential functions and sinusoidal functions; problems involving evaluation, e.g. gradient at a point.

Integration: integration as reverse of differentiating basic rules for simple polynomial functions, exponential functions and sinusoidal functions; indefinite integrals; constant of integration; definite integrals; limits; evaluation of simple polynomial functions; area under a curve, e.g. $y = x(x - 3)$, $y = x^2 + x + 4$

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P1 Manipulate and simplify three algebraic expressions using the laws of indices and two using the laws of logarithms		
P2 Solve a linear equation by plotting a straight-line graph using experimental data and use it to deduce the gradient, intercept and equation of the line	M1 Solve a pair of simultaneous linear equations in two unknowns	D1 Solve a pair of simultaneous equations, one linear and one quadratic, in two unknowns
P3 Factorise by extraction and grouping of a common factor from expressions with two, three and four terms respectively	M2 Solve one quadratic equation by factorisation and one by the formula method	

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P4 Solve circular and triangular measurement problems involving the use of radian, sine, cosine and tangent functions		
P5 Sketch each of the three trigonometric functions over a complete cycle		
P6 Produce answers to two practical engineering problems involving the sine and cosine rule		
P7 Use standard formulae to find surface areas and volumes of regular solids for three different examples respectively		
P8 Collect data and produce statistical diagrams, histograms and frequency curves		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P9 Determine the mean, median and mode for two statistical problems		
P10 Apply the basic rules of calculus arithmetic to solve three different types of function by differentiation and two different types of function by integration.	M3 Apply the rules for definite integration to two engineering problems that involve summation.	D2 Apply graphical methods to the solution of two engineering problems involving exponential growth and decay, analysing the solutions using calculus.

Essential guidance for tutors

Assessment

The centre's assessment strategy used will need to cover all the learning outcomes and associated pass criteria but not necessarily all the topics included in the unit content.

Criterion P1 could be assessed in the form of a short, written test and could possibly also include criterion P3.

P2 could be assessed through an assignment using data from *Unit 4: Electrical and Electronic Principles in Engineering*, which ideally would be delivered concurrently with this unit. If this is not possible, learners should be given a range of data sufficient for them to plot the graph and work out the gradient, intercept and the equation. Data forcing them to draw the line of best fit, as opposed to a set of points directly on the graphical line, might be most appropriate.

For P4, learners could be given a range of different values and be assessed by an assignment or a short formal test. The problems given should collectively cover radian, sine, cosine and tangent functions. When considering the content part of this learning outcome, it is important that these problems give learners the opportunity to convert multiples of π radians to degrees and vice versa. The circular measurement problems also need to cover the length of an arc and area of a sector, as well as areas and angles measured in radians. Obviously, the triangular measurement problems are more basic and only expect application of the three functions.

P5 requires learners to sketch each of the three trigonometric ratios, which is probably best done as a classroom exercise. Similarly, P6 could take the form of a written assignment where learners must produce answers to two practical engineering problems involving the sine and cosine rule (for example, calculate the phasor sum of two alternating currents and evaluate the resultant and the angle between two forces).

Criterion P7 requires learners to calculate the surface areas and volumes for three different regular solids. This could be achieved through an assignment or perhaps by combining it with other criteria in a short formal test.

An assignment could be used for P8, where learners collect meaningful data (for example, classification of workers within their company) and display this information using different graphical methods (for example, bar charts). They also need to produce a histogram and plot frequency curves (for example, resistance values of 100 resistors or external diameter of pins).

For P9, learners must provide evidence that they are able to determine and then explain the relevance of the mean, median and mode for a set of discrete and grouped data (for example, the time taken to produce components on a machine rounded to the nearest ten seconds and the 100 resistor values or diameters of pins from P8). This could be achieved through an assignment. P10 may be assessed through a short formal test, with learners being given a list of the standard differential coefficients and integrals to use.

For M1, learners will need to provide evidence that they can solve a pair of simultaneous linear equations in two unknowns (for example, equations formed after the application of Kirchhoff's laws, power transmitted for different belt tensions in a mechanical system). This could be extended to D1 by the introduction of a quadratic equation to be solved simultaneously with a linear equation.

It would be appropriate to use the same assessment method and instrument as P2, possibly combining these two criteria as one assessment activity.

M2 could also be assessed by assignment as it requires learners to evaluate the roots of a quadratic equation by factorisation and by the formula method (for example, evaluation of an equation formed after the realisation of a practical situation).

Both the criteria required to achieve D2 could be assessed through a written assignment. Learners need to apply the graphical methods to the solution of two engineering problems involving exponential growth and decay (for example, growth of voltage in a capacitor, radioactive decay, application of Taylor's tool life equation $C = VT^n$) and then analyse the results by applying the appropriate method of differential calculus to check the results.

M3 requires learners to demonstrate that they can accurately evaluate two engineering problems involving definite integration (for example, area under a velocity-time graph, area under a voltage-current graph).

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, M1, M2	Algebraic Methods	A written activity/test requiring learners to complete five tasks, one for each criterion.	A report containing written solutions to each of the five tasks carried out under controlled conditions.
P4, P5, P6, P7	Trigonometric Methods and Standard Formulae	A written activity requiring learners to use trigonometric methods and standard formula to determine areas and volumes.	A report containing the results of calculations and graphic evidence to support the use of trigonometric methods and standard formula for the determination of areas and volumes.

Criteria covered	Assignment title	Scenario	Assessment method
P8, P9	Statistical Methods	A written activity requiring learners to collect and display data using different graphical methods, and also to evaluate the mean, median and mode for a set of discrete and grouped data.	A report containing bar charts, pie charts and the results of calculations to determine the mean, median and mode for a set of discrete and grouped data.
P10, M3, D1,	Calculus Techniques	A written activity requiring learners to produce calculations, graphical solutions and analysis to demonstrate the use of calculus techniques.	A report containing the solutions to calculations, graphs and analysis of several calculus techniques. Carried out under controlled conditions.

Essential resources

For this unit, learners will need to possess an electronic scientific calculator and have access to software packages that support understanding of the principles and their application to engineering.

Indicative reading for learners

Textbooks

Bird J – *Engineering Mathematics* (Routledge, 2014) ISBN 9780415662802

Boyce A, Cooke E, Jones R and Weatherill B – *BTEC Level 3 National Engineering Student Book* (Pearson, 2010) ISBN 9781846907241

Boyce A, Cooke E, Jones R and Weatherill B – *BTEC Level 3 National Engineering Teaching Resource Pack* (Pearson, 2010) ISBN 9781846907265

Fuller A, Greer A, Taylor G W – *BTEC National Mathematics for Technicians* (Nelson Thornes, 2004) ISBN 9780748779499

Tooley M and Dingle L – *BTEC National Engineering* (Routledge, 2010) ISBN 9780123822024

Website

www.stemnet.org.uk – Science, Technology, Engineering and Mathematics Network

Unit 3: Engineering Solutions and Innovation

Level:	3
Unit type:	Mandatory
Guided learning hours:	60

Unit introduction

As the demand for rail travel and transportation of freight increases, train-operating companies and the engineering companies that support them need to develop approaches to improve the effectiveness of engineering solutions, project management, problem solving and quality assurance. Companies need to identify methods of improving their efficiencies, including methods of reducing waste and making more effective use of their resources.

Ensuring that the correct approaches are used to solve problems can improve the availability of rail vehicles, as the root cause of faults can be identified and then resolved. Lessons learned from such activities can then be carried forward to the development of solutions to further problems. Rail engineering companies improve their efficiencies through the use of project management techniques, often in co-operation with bodies such as Network Rail, or with other train operating companies and neighbouring landowners. Rail engineering companies also need to consider quality as part of their management of operations, including the use of total quality management and ISO 9001 standards.

This unit enables learners to develop their knowledge of the quality management techniques that are employed by rail engineering organisations. It introduces methods that are used to introduce workplace improvement techniques and approaches to project management that can be used to improve the efficiencies of operations. The unit develops learners' understanding of problem-solving techniques prior to completion of a problem-solving activity.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

- 1 Understand quality assurance management
- 2 Understand workplace improvement
- 3 Understand the basic principles of project management
- 4 Understand problem solving.

Unit content

1 Understand quality assurance management

Quality management and quality assurance: fitness for purpose or meeting customer expectations, undertaking quality control when carrying out the procedures identified in quality assurance, undertaking quality assurance as the writing and implementation of the procedures that ensure quality control takes place, stages of application of quality.

Inspection: the detection of any deviation from what is expected, adjustments made to ensure the final quality is in line with customers' expectations, the stages of inspection; types of inspection, e.g. measuring, examining, testing; inspection documentation, e.g. checklists, inspection reports.

Quality standards: BS EN ISO 9001, an internationally-recognised quality assurance standard - involvement of all levels within a company, rationalised systems and procedures, improved costs, improved efficiency, consistent quality of product or service, customer confidence.

Quality planning: establishing quality requirements (customer expectations), allocation of responsibilities (at all levels), agreeing production times to ensure quality can be met, agreeing budgets to support quality activities, the setting up of systems to measure quality and report progress, identification and calibration of quality equipment, ability to take corrective actions if non-conformity is found.

Total Quality Management (TQM): a way of thinking about goals, organisations, processes and people to ensure that the right things are carried out right first time. This thought process can change attitudes, behaviour and, hence, results for the better.

2 Understand workplace improvement

Tools used for continuous improvement: flow charts, cause and effect diagrams, check sheets, Pareto charts, histograms, scatter diagrams, control charts, plan-do-check-act procedure (PDCA)

Wastes in the workplace: e.g. defects, overproduction, over-processing, waiting, transportation, inventory, motion, non-utilised talent.

Elimination of wastes: suggesting ways in which the above list can be eliminated or reduced, e.g. value stream mapping, Pareto analysis, 5 Whys, 5S, changeover reduction.

Visual management: safety signs, standard operating procedures (SOPs) on boards, improvement notices, company information, types of information (company standards and instructions, e.g. specifications, drawings and records).

Standardised company documents: reduction in error, ease of reporting, capturing the required information, document control.

3 Understand the basic principles of project management

Project life cycle: the stages and factors of a project – ‘initiation, planning, execution and closure’; predecessors, dependents, critical path, deliverables.

Project roles and responsibilities: project sponsor, project manager, project co-ordinator, stakeholders, team members.

Stakeholder management: contracts, updates, identification of key staff, communication.

Project control and monitoring: monitor and record achievement; recording and analysing data or performance records; modifying/updating charts/planners; recording project goals and milestones; initial concepts; project solution technical decisions and information; techniques, e.g. critical path analysis, Gantt charts.

Success factors for projects: cost, delivery, quality, stakeholder satisfaction.

Projects are reviewed: lessons learned, continuous improvement, deliverables (planned versus actual), costings, return on investment (ROI).

4 Understand problem solving

Root cause analysis: compare root cause to casual factors, identification of all factors, the factor that, if removed, prevents the fault from occurring.

Approach to problem solving: fishbone diagram, cause and effect, half split, six-point technique, input-output, substitution.

Monitoring solutions to problem solving: record solution, effectiveness of solution, potential improvements for future, prevention of future problems.

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P1 Describe the key concepts and principles of quality management within the rail industry.	M1 Explain how the concepts of quality assurance and quality management contribute to a TQM system within the rail industry.	D1 Evaluate the effectiveness of total quality management (TQM) as a tool to meet customer expectations in the rail industry.
P2 Describe approaches that can be used for continuous improvement within work areas.	M2 Explain the benefits of implementing continuous improvement techniques within the rail industry.	
P3 Describe different types of waste from work activities and cost-effective ways to eliminate waste.		
P4 Explain project life cycle, the stages and factors of a project and project roles and responsibilities.		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P5 Explain how projects are controlled and managed, including success criteria.	M3 Discuss the effectiveness of project management techniques used in the rail industry.	
P6 Explain the principles of root cause analysis and the importance of getting to the root cause of problems.		
P7 Apply a structured procedure to problem solving.	M4 Analyse the outcomes of a problem-solving activity within the rail industry.	D2 Justify the approach taken for a problem solving activity within the rail industry.
P8 Describe factors to be considered when proposing solutions to problems.		
P9 Explain to the importance of monitoring and reviewing problem solving processes.		

Essential guidance for tutors

Assessment

It is likely that at least four assessment instruments will be required for this unit. Evidence for this unit can be gathered from a variety of sources, including written reports, oral presentations or role-play activities with supporting tutor observation records, and research tasks.

To achieve P1, learners will need to describe the key concepts of quality management, including quality planning, quality control, quality planning and quality improvement as indicated in the unit content. Learners will need to apply these concepts to a rail scenario, for example a maintenance activity on rolling stock or a design activity for a section of rail infrastructure such as the track. Learners will also need to describe the key principles of the ISO9001 standard, with reference to the aims and objectives of the standard and how it is implemented by a rail organisation. Learners will need to consider the role of inspection as part of a quality system, such as identifying any deviation from what is expected, along with the stages of, and types of, inspection that can be used. Finally, learners should describe the key principles of Total Quality Management (TQM), including reference to goals, organisations, processes and people. Learner might achieve this criterion by researching, preparing, and delivering an oral presentation with evidence being supported by a tutor observation record.

The evidence to address P2 and P3 could be achieved by learners completing a research task to investigate continuous improvement techniques and then preparing a written report.

For P2, learners will need to identify a range of tools that are used for continuous improvement within a rail engineering environment, for example flow charts, cause and effect diagrams, check sheets, Pareto charts. Learners will also need to describe the role of visual management in the rail workplace, such as the use of safety signs or improvement notices. Finally, learners will describe the importance of standardised company documentation within a rail engineering workplace, for example how the use of a standardised operating procedure document will reduce the likelihood of errors occurring.

P3 requires that learners identify different types of waste associated with a given rail engineering activity, for example related to inventory and large amounts of consumable stock, or the activities that form a servicing procedure. Learners will then need to identify and describe cost-effective ways to eliminate waste in a rail engineering environment, for example carrying out a value stream mapping exercise to identify reasons for delays when activities are being carried out.

The evidence to satisfy criteria P4 and P5 might take the form of a portfolio based upon a case study rail project. For P4, learners will need to explain a project life cycle, for example a track replacement activity, a maintenance task on a locomotive or a multiple unit, including the activities that occur at each stage and the factors that need to be considered. This might be achieved by learners preparing a

project programme for a chosen task. This should include each of the stages in the unit content and identify factors such as predecessors, dependents, critical path, and deliverables. Learners will also need to explain the roles and responsibilities in detail of each of the five project team members listed in the unit content along with the principles of stakeholder management, including reference to contracts, updates, communication and key staff.

To satisfy P5, learners will need to explain how rail projects are controlled and managed. Learners might monitor progress against the programme prepared as part of P4. Learners will also need to describe project success criteria for a given rail engineering project, linking this with an explanation of the reasons for completing a project review.

The evidence to satisfy P6, P7, P8 and P9 could be achieved by means of a written case study examining problem-solving techniques applied to a rail engineering scenario, following a combination of tutor-led theory sessions and perhaps a visit to an applicable rail facility.

For P6, learners will need to explain the principles of root cause analysis, including the benefits of implementation. They will also need to explain the importance of getting to the root cause of a problem.

To achieve P7, learners will apply a structured approach to solving a rail engineering scenario-based problem, for example intermittent errors on a Passenger Information System, faults associated with a door closing system or traction units lacking reliability. Learners will apply root cause analysis, perhaps adopting the use of a visualisation tool for evaluating the potential root cause of a problem, such as a fish bone diagram.

For P8, learners will produce a commentary that describes the factors that need to be considered when proposing solutions to the given scenario problem. Learners will be expected to describe the requirement to define the problem, identify various solutions, select the best alternative and plan implementation. Learners might consider an unreliable track circuit, defining the problem, identifying methods which could be used to improve the reliability of the track circuit, establishing the best solution and then planning the required improvements.

To achieve P9, learners must explain why it is important to monitor the effectiveness of corrective actions that have been taken to reduce the effects of the scenario problem. Learner will explain the need to review the problem-solving process used so that future activities can be performed based on how effective the approach taken has been.

To achieve a merit grade, learners must meet all the pass criteria and the merit grade criteria.

To achieve M1, learners will need to explain how the concepts of quality assurance and quality management contribute to an effective TQM system in a rail organisation (or appropriate case study), for example considering the use of inspections at various stages of a process or the implementation of procedures to ensure quality control takes place.

To achieve M2, learners will need to provide an explanation of the benefits of implementation of continuous improvement techniques in the rail industry, for example referring to the use of a just-in-time system for spare parts reducing the amount of inventory that is held.

To satisfy M3, learners will need to examine the effectiveness of project management techniques that are used in rail engineering.

M4 is intended as an extension activity to P7. Learners need to analyse the outcomes of a problem-solving activity. This will involve learners drawing conclusions related to the cause of the problem, identifying potential future implications, and finding improvements that could be applied to prevent the problem reoccurring.

To achieve a distinction, learners must meet all of the pass and merit grade criteria and the distinction grade criteria.

For D1, learners will need to evaluate the effectiveness of TQM as a tool to ensure customer satisfaction within the rail engineering sector. Learners will draw conclusion on how TQM contributes to the effective operation of the rail network, and influences customer satisfaction.

To achieve D2, learners will justify the methods and approach applied to solve the given rail problem scenario introduced for P7. This will involve learners evaluating the effectiveness of the problem-solving approach or method and considering how they might change their approach when faced with a similar future problem.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, M1, D1	Quality Systems	A mixed activity requiring learners to research and examine the quality systems that can ~be used by a rail engineering organisation.	Presentation slides supported with tutor observation record.
P2, P3, M2	Continuous Workplace Improvements	An investigation into the techniques that can be employed by a rail engineering organisation to apply continuous improvement. This should include consideration of types of waste and methods to reduce waste, visual control methods and approaches to standardise documentation.	A written report containing supporting sketches and diagrams.

Criteria covered	Assignment title	Scenario	Assessment method
P4, P5, M3	Project Management	An investigation of a railway-based engineering project that considers the roles of key team members within a project, project life cycle and the fundamentals of project management, including approaches to project control and defining success factors.	A portfolio containing written evidence and a project programme.
P6, P7, P8, P9, M4, D2	Solving Problems	A problem-solving activity to propose solutions to a rail engineering-based scenario through the use of a root cause analysis. The assignment will describe the factors to be considered when proposing solutions and the importance of monitoring and reviewing problem-solving processes.	A written report containing supporting sketches and diagrams.

Essential resources

Access to information and communication technology resources (including the internet) is essential for the delivery of this unit, as is a well-stocked source of reference material, including quality assurance documentation used within the rail industry.

Learners should be given a variety of technical documents and drawings for parts of traction systems.

Indicative reading for learners

Textbooks

Bonnett C – *Practical Railway Engineering* (Imperial College Press, 2005)
ISBN 9781860945151

Glover J – *Principles of Railway Operation* (Ian Alan Publishing Limited, 2013)
ISBN 9780711036314

Hoyle D – *ISO 9000 Quality System Handbook* (Routledge, 2009)
ISBN 9781856176842

Nicholas J – *Project Management for Engineering, Business and Technology* (Routledge, 2016) ISBN 9781138937345

Steimel A – *Electric Traction – Motive Power and Energy Supply: Basics and Practical Experience* (Oldenburg, 2008) ISBN 9783835631328

Unit 4: Electrical and Electronic Principles in Engineering

Level:	3
Unit type:	Pathway Core
Guided learning hours:	60

Unit introduction

The modern world relies on electrical and electronic devices. From mobile telephones to jet aeroplanes, these devices have had an enormous impact on the way we live today. Without early engineers such as Faraday and Lenz, who studied the then new concept of electricity, many of the inventions we now take for granted would not have been developed.

The unit starts by developing and extending learners' understanding of fundamental electrical and electronic principles through analysis of simple direct current (DC) circuits. Learners are then taken through the various properties and parameters associated with capacitance and inductance before finally considering the application of single-phase alternating current (AC) theory. The unit will encourage learners to take an investigative approach through practical construction, measurement and testing of circuits and, where applicable, the use of computer-based circuit analysis and simulation.

For learners wishing to follow an electrical/electronic programme, this unit is an essential building block that will provide the underpinning knowledge required for further study of electrical and electronic applications.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

- 1 Be able to use circuit theory to determine voltage, current and resistance in direct current (DC) circuits
- 2 Be able to apply the concepts of capacitance in DC circuits
- 3 Know the principles and properties of magnetism
- 4 Be able to use single-phase alternating current (AC) theory.

Unit content

1 Be able to use circuit theory to determine voltage, current and resistance in direct current (DC) circuits

DC circuit theory: voltage, e.g. potential difference, electromotive force (emf); resistance, e.g. conductors and insulators, resistivity, temperature coefficient, internal resistance of a DC source; circuit components (power source, e.g. cell, battery, stabilised power supply; resistors, e.g. function, types, values, colour coding; diodes, e.g. types, characteristics, forward and reverse bias modes); circuit layout (DC power source, resistors in series, resistors in parallel, series and parallel combinations); Ohm's law, power and energy formulae, e.g. $V = IR$, $P = IV$, $W = Pt$, application of Kirchhoff's voltage and current laws.

DC networks: networks with one DC power source and at least five components, e.g. DC power source with two series resistor and three parallel resistors connected in a series parallel arrangement; diode resistor circuit with DC power source, series resistors and diodes.

Measurements in DC circuits: safe use of a multimeter, e.g. setting, handling, health and safety; measurements (circuit current, voltage, resistance, internal resistance of a DC power source, testing a diode's forward and reverse bias).

2 Be able to apply the concepts of capacitance in DC circuits

Capacitors: types (electrolytic, mica, plastic, paper, ceramic, fixed and variable capacitors); typical capacitance values and construction (plates, dielectric materials and strength, flux density, permittivity); function, e.g. energy stored, circuits (series, parallel, combination); working voltage.

Charging and discharging of a capacitor: measurement of voltage, current and time; tabulation of data and graphical representation of results; time constants.

DC network that includes a capacitor: e.g. DC power source with two/three capacitors connected in series, DC power source.

3 Know the principles and properties of magnetism

Magnetic field: magnetic field patterns, e.g. flux, flux density (B), magnetomotive force (mmf) and field strength (H), permeability, B/H curves and loops; ferromagnetic materials; reluctance; magnetic screening; hysteresis.

Electromagnetic induction: principles, e.g. induced electromotive force (emf), eddy currents, self and mutual inductance; applications (electric motor/generator, e.g. series and shunt motor/generator; transformer, e.g. primary and secondary current and voltage ratios); application of Faraday's and Lenz's laws.

4 Be able to use single-phase alternating current (AC) theory

Single-phase AC circuit theory: waveform characteristics, e.g. sinusoidal and non-sinusoidal waveforms, amplitude, period time, frequency, instantaneous, peak/peak-to-peak, root mean square (rms), average values, form factor; determination of values using phasor and algebraic representation of alternating quantities, e.g. graphical and phasor addition of two sinusoidal voltages, reactance and impedance of pure R, L and C components.

AC circuit measurements: safe use of an oscilloscope, e.g. setting, handling, health and safety; measurements (periodic time, frequency, amplitude, peak/peak-to-peak, rms and average values); circuits, e.g. half and full wave rectifiers.

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P1 Use DC circuit theory to calculate current, voltage and resistance in DC networks	M1 Use Kirchhoff's laws to determine the current in various parts of a network having four nodes and the power dissipated in a load resistor containing two voltage sources	
P2 Use a multimeter to carry out circuit measurements in a DC network		
P3 Describe the forward and reverse characteristics of two different types of semiconductor diode		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P4 Describe the types and function of capacitors	M2 Explain capacitance, charge, voltage and energy in a network containing a series-parallel combination of three capacitors	
P5 Carry out an experiment to determine the relationship between the voltage and current for a charging and discharging capacitor		
P6 Calculate the charge, voltage and energy values in a DC network for both three capacitors in series and three capacitors in parallel		
P7 Describe the characteristics of a magnetic field		D1 Evaluate the performance of a motor and a generator by reference to electrical theory
P8 Describe the relationship between flux density (B) and field strength (H)		
P9 Describe the principles and applications of electromagnetic induction	M3 Explain the application of electromagnetic induction in motors and generators	

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P10 use single-phase AC circuit theory to determine the characteristics of a sinusoidal AC waveform	M4 compare the results of adding and subtracting two sinusoidal AC waveforms graphically and by phasor diagram.	D2 analyse the operation and the effects of varying component parameters of a power supply circuit that includes a transformer, diodes and capacitors.
P11 use an oscilloscope to measure and determine the inputs and outputs of a single-phase AC circuit.		

Essential guidance for tutors

Assessment

Much of the evidence for the pass criteria can be achieved by practical experimentation with real components and circuits and computer-based software packages, where appropriate.

It is likely that at least five assessment instruments will be required for this unit. If practical work and tests are also used, then the total number of pieces of assessed work could be even more than this. This should be carefully considered so that it does not place an unduly high assessment burden on learners or the tutor.

Wherever possible, practical work should lead to a final product that can be handed in for assessment at the end of the session without further need for report writing. This will help control authenticity of evidence and also keep the assessment activities short, sharp and relevant.

Clearly, the ability to safely use a multimeter (P2) will require process evidence, i.e., it will need to be observed by the tutor during relevant practical activities. Tutors could capture this evidence by using an appropriate record of observation and oral questioning of each learner during the practical activities used for delivery.

The assessment of the use of circuit theory to calculate current, voltage and resistance in DC networks (P1) could be achieved by using a paper-based or computer-based method. However, it is essential that centres combine any testing of this sort with practical hands-on experience of real circuits and components. This could be achieved by prototyping circuits using simulation software to establish theoretical circuit values, followed by learners building the circuit and physically checking theory against actual results by measurement. Whichever method is used, centres need to ensure that sufficient product evidence is available of the circuit being used/developed and the formulae selected/used to determine the required current, voltage or resistance values. This is particularly important where computer software is used that does not have a facility to print results or where printouts do not show sufficient detail to meet the criteria.

The description of the forward and reverse characteristics of two types of semi-conductor diode (P3) will require the use of a multimeter, power supply, ammeter with shunt, and a switch resistor box.

For P4, learners will need to describe the full range of types of capacitors (electrolytic, mica, plastic, and paper, ceramic, fixed and variable), including typical capacitance values, construction (plates, dielectric materials and strength, flux density, permittivity), their function and working voltages.

P5 requires learners to carry out a laboratory experiment to investigate the charging and discharging of a capacitor through a resistor. A simple but effective way of doing this is to use a power supply unit, a 500 μF electrolytic capacitor, a stopwatch or clock and an AVO type multimeter, using the internal resistance of the meter as the resistor.

Learners could then be asked to plot the graph of the growth of capacitor voltage against time and evaluate the time constant by comparing the results with standard theory.

P6 involves the calculation of charge, voltage and energy values for DC networks that include a DC power source with two/three capacitors connected in series and a DC power source with two/three capacitors connected in parallel.

The characteristics of magnetic fields for P7 could be demonstrated on an OHP by using magnets and iron filings. Learners could sketch the results and then make appropriate comparisons with expected theoretical results. For P8, learners need to explain the relationship between flux density (B) and field strength (H) with particular emphasis on BH curves and the use of different materials such as silicon iron and mild steel.

The evidence for P9 will be descriptive and requires learners to provide basic explanations of the principles and concepts of electromagnetic induction such as the movement of a conductor within a magnetic field.

P10 and P11 could link AC theory and practice with learners observing and measuring some of the fundamental characteristics of a single wave AC circuit.

This will require the use of a multimeter and an oscilloscope to make appropriate comparisons of frequency, maximum and rms values.

M1 relates to the use of Kirchhoff's laws and here, again, learners should be encouraged to check their results by using a computer software package and/or practical experiment. This criterion naturally follows on from the work on resistors in series and parallel in DC circuits and, as such, could perhaps be incorporated into an assignment covering P1, P2 and M1. For M2, learners need to explain capacitance, charge, voltage and energy for specific capacitors in a series parallel combination. This extends the understanding from the pass grade criterion and could naturally form a next step in an assignment/assessment activity devised for P6. M3 is an extension of P9, requiring an explanation of the application of electromagnetic induction in motors and generators. M4 is intended as an exercise in the graphical addition of two sinusoidal voltages or currents, checking the values theoretically by calculation and also by practical means. This criterion could be linked to *Unit 3: Mathematics for Engineering Technicians* and, once learners have been taught the sine and cosine rules, could be used to provide evidence for both units.

D1 requires learners to evaluate the performance of motors and generators by referencing electrical theory. This can be achieved practically using appropriate experimental rigs that allow learners to compare their results with known characteristics for specific machines.

For D2, a basic power supply could be simulated to allow all the respective properties to be investigated without the hazards of high voltages or currents present. This could be achieved using a function generator as a source of sinusoidal alternating voltage, along with a small isolating transformer, diode rectifiers (half wave and bridge) smoothing capacitors and load resistors.

As suggested earlier, and illustrated in the assignment grid, it would be appropriate to use a five-assessment model to assess this unit.

The first is a theoretical assignment under controlled conditions could assess P1 and M1.

A second practical assignment could be used to assess P2 and P3, again possibly under controlled conditions.

Assignment 3 is to assess P4, P5, P6 and M2 and could be a mixed assignment, preferably not completed under controlled conditions.

The fourth assignment could be a mixed assignment to assess P7, P8, P9, M3 and D1.

Finally, assignment 5 assesses P10, P11, M4 and D2, and could be of a practical nature carried out under controlled conditions.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, M1	DC Circuit Theory/Resistor Networks and Kirchhoff's Laws	An activity requiring learners to complete two tasks, one for each criterion. Task 1 involves learners evaluating current, voltage and resistance in a DC network. Task 2 uses Kirchhoff's laws to determine the current and power dissipated in a load resistor.	A report containing the results of calculations to evaluate current, voltage, resistance and power for a DC network using DC circuit theory and Kirchhoff's laws. Carried out under controlled conditions.
P2, P3	DC Circuit Theory/Measurement and Diodes	A practical activity requiring learners to complete measurements using a multimeter in a DC network for Task 1 and compare the forward and reverse characteristics of two different types of semi-conductor diode for Task 2.	For both tasks, learners will be required to complete pre-prepared response sheets with their measurements and make required responses, together with a brief conclusion. Carried out under controlled conditions.

Criteria covered	Assignment title	Scenario	Assessment method
P4, P5, P6, M2	Capacitors	<p>A mixed activity comprising four tasks. The first should describe the types and function of capacitors.</p> <p>The second should be an experiment to determine the relationship between voltage and current for a charging and discharging capacitor.</p> <p>The third and fourth should involve the learner carrying out calculations to evaluate capacitance, charge voltage and energy in DC networks.</p>	<p>A report containing written responses to the descriptive task, tabulated results and graphs for the practical, together with calculations for the DC networks.</p>

Criteria covered	Assignment title	Scenario	Assessment method
P7, P8, P9, M3, D1	Magnetism, Transformers and Motor/Generators	<p>A mixed activity comprising four tasks. The first three are to describe the characteristics of a magnetic field, explain the relationship between flux density and field strength, and to describe the principles and applications of electromagnetic induction.</p> <p>The final task is to evaluate the performance of a motor and generator.</p>	<p>A written report containing labelled diagrams illustrating magnetic fields, graphical plots of BH curves and diagrams with descriptions to illustrate the principles and applications of electromagnetic induction.</p> <p>For the distinction criteria, learners will be required to provide comprehensive answers to pre-prepared response sheets, together with diagrams, graphs and calculations.</p>

Criteria covered	Assignment title	Scenario	Assessment method
P10, P11, M4, D2	Single Phase AC	<p>A practical activity requiring learners to complete four tasks. First, using single-phase AC theory, to consider the characteristics of a sinusoidal AC waveform and, second, to use an oscilloscope to evaluate the inputs and outputs of a single-phase AC circuit. Third, to compare the results of the addition and subtraction of two sinusoidal AC waveforms.</p> <p>Fourth, to analyse the operation of a power supply.</p>	A written report using pre-prepared response sheets and graph paper carried out under controlled conditions.

Essential resources

It is essential that learners have access to a well-equipped electrical and electronics laboratory with up-to-date electrical/electronic instruments such as digital and analogue multimeters, function generators and oscilloscopes. Centres will also need to provide appropriate circuit components, as identified in the unit content, together with the means to physically construct circuits.

With the increased use of computer-based methods for circuit design and simulation, centres are strongly advised to consider the provision of suitable hardware and software.

Indicative reading for learners

Textbooks

Bird J O – *Electrical and Electronic Principles and Technology* (Routledge, 2013)
ISBN 9780415662857

Bird J O – *Electrical Circuit Theory and Technology* (Routledge, 2013)
ISBN 9781466501096

Boyce A, Cooke E, Jones R and Weatherill B – *BTEC Level 3 National Engineering Student Book* (Pearson, 2010) ISBN 9781846907241

Boyce A, Cooke E, Jones R and Weatherill B – *BTEC Level 3 National Engineering Teaching Resource Pack* (Pearson, 2010) ISBN 9781846907265

Robertson C R – *Fundamental Electrical and Electronic Principles* (Routledge, 2008)
ISBN 9780750687379

Unit 5: Mechanical Principles of Engineering Systems

Level:	3
Unit type:	Pathway Core
Guided learning hours:	60

Unit introduction

The use and application of mechanical systems is an essential part of modern life. The design, manufacture and maintenance of these systems are the concern of engineers and technicians who must be able to apply a blend of practical and theoretical knowledge to ensure that systems work safely and efficiently. Science underpins all aspects of engineering and a sound understanding of its principles is essential for anyone seeking to become an engineer.

In this unit, learners will be introduced to the behaviour of loaded engineering materials and the analysis of a range of static engineering systems. They will gain an understanding of dynamic systems through the application of Newtonian mechanics. Finally, they will deal with the effects of heat transfer, the expansion and compression of gases and the characteristic behaviour of liquids at rest and in motion.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

- 1 Be able to determine the effects of loading in static engineering systems
- 2 Be able to determine work, power and energy transfer in dynamic engineering systems
- 3 Be able to determine the parameters of fluid systems
- 4 Be able to determine the effects of energy transfer in thermodynamic systems.

Unit content

1 Be able to determine the effects of loading in static engineering systems

Non-concurrent coplanar force systems: graphical representation, e.g. space and free body diagrams; resolution of forces in perpendicular directions, e.g. $F_x = F\cos\theta$, $F_y = F\sin\theta$; vector addition of forces, resultant, equilibrant, line of action; conditions for static equilibrium ($\Sigma F_x = 0$, $\Sigma F_y = 0$, $\Sigma M = 0$)

Simply supported beams: conditions for static equilibrium; loading (concentrated loads, uniformly distributed loads, support reactions).

Loaded components: elastic constants (modulus of elasticity, shear modulus); loading (uniaxial loading, shear loading); effects, e.g. direct stress and strain, including dimensional change, shear stress and strain, factor of safety.

2 Be able to determine work, power and energy transfer in dynamic engineering systems

Kinetic parameters: e.g. displacement (s), initial velocity (u), final velocity (v), uniform linear acceleration (a)

Kinetic principles: equations for linear motion with uniform acceleration

$$v = u + at, s = ut + \frac{1}{2}at^2, v^2 = u^2 + 2as, s = \frac{1}{2}(u + v)t$$

Dynamics parameters: e.g. tractive effort, braking force, inertia, frictional resistance, gravitational force, momentum, mechanical work ($W = Fs$), power dissipation (average power = $\frac{W}{t}$, instantaneous power = Fv), gravitational potential energy

($PE = mgh$), kinetic energy ($KE = \frac{1}{2}mv^2$)

Dynamic principles: Newton's laws of motion, d'Alembert's principle, principle of conservation of momentum, principle of conservation of energy.

3 Be able to determine the parameters of fluid systems

Thrust on a submerged surface: hydrostatic pressure, hydrostatic thrust on an immersed plane surface ($F = \rho gAx$); centre of pressure of a rectangular retaining surface with one edge in the free surface of a liquid.

Immersed bodies: Archimedes' principle; fluid, e.g. liquid, gas; immersion of a body, e.g. fully immersed, partly immersed; determination of density, e.g. using floatation, specific gravity bottle.

Flow characteristics of a gradually tapering pipe: e.g. volume flow rate, mass flow rate, input and output flow velocities, input and output diameters, continuity of volume and mass for incompressible fluid flow.

4 Be able to determine the effects of energy transfer in thermodynamic systems

Heat transfer: heat transfer parameters, e.g. temperature, pressure, mass, linear dimensions, time, specific heat capacity, specific latent heat of fusion, specific latent heat of vaporisation, linear expansivity; phase, e.g. solid, liquid, gas; heat transfer principles, e.g. sensible and latent heat transfer, thermal efficiency and power rating of heat exchangers; linear expansion.

Thermodynamic process equations: process parameters, e.g. absolute temperature, absolute pressure, volume, mass, density; Boyle's law:

($pV = \text{constant}$), Charles' law ($\frac{V}{T} = \text{constant}$), general gas equation

($\frac{pV}{T} = \text{constant}$), characteristic gas equation ($pV = mRT$)

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P1 Calculate the magnitude, direction and position of the line of action of the resultant and equilibrant of a non-concurrent coplanar force system containing a minimum of four forces acting in different directions	M1 Calculate the factor of safety in operation for a component subjected to combined direct and shear loading against given failure criteria	
P2 Calculate the support reactions of a simply supported beam carrying at least two concentrated loads and a uniformly distributed load		
P3 Calculate the induced direct stress, strain and dimensional change in a component subjected to direct uniaxial loading and the shear stress and strain in a component subjected to shear loading		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P4 Solve three or more problems that require the application of kinetic and dynamic principles to determine unknown system parameters	M2 Determine the retarding force on a freely falling body when it impacts on a stationary object and is brought to rest without rebound, in a given distance	D1 Compare and contrast the use of d'Alembert's principle with the principle of conservation of energy to solve an engineering problem
P5 Calculate the resultant thrust and overturning moment on a vertical rectangular retaining surface with one edge in the free surface of a liquid		D2 Evaluate the methods that might be used to determine the density of an irregular shaped solid material
P6 Explain Archimedes' Principle	M3 Determine the upthrust on an immersed body	
P7 Use the continuity of volume and mass flow for an incompressible fluid to determine the design characteristics of a gradually tapering pipe		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P8 Calculate the dimensional change when a solid material undergoes a change in temperature and the heat transfer that accompanies a change of temperature and phase	M4 Determine the thermal efficiency of a heat transfer process from given values of flow rate, temperature change and input power	
P9 Solve two or more problems that require application of thermodynamic process equations for a perfect gas to determine the unknown parameters of the problems	M5 Determine the force induced in a rigidly held component that undergoes a change in temperature	

Essential guidance for tutors

Assessment

The criterion P1 requires the solution of a single non-concurrent force system that contains a minimum of four active forces. It will be expected that two of these forces will be set to act in directions other than the horizontal and vertical. This will necessitate the resolution of forces in perpendicular directions, for example the use of $F_x = F\cos\theta$ and $F_y = F\sin\theta$, as the first step in the solution to the problem. A typical problem might be an engineering component under the action of at least four non-concurrent forces whose magnitudes and directions are given. One of the forces might be its own weight but at least two of them should act in directions other than the horizontal and vertical. Learners will be expected to produce space and free body diagrams, resolve forces horizontally and vertically and take moments of the forces about some suitable reference point. The magnitude and direction of the resultant force and the position of its line of action could then be found through vector addition, application of Pythagoras' theorem and consideration of the resultant turning moment.

P2 will use similar skills to those required for P1 but, in this case, they will be applied to a simply supported beam carrying two point loads, as a minimum, and a uniformly distributed load. These specifications will provide centres with a variety of loading possibilities that can be used for assessment purposes. During the delivery phase for this part of the unit, a greater range of loading may be considered but centres need only work with the minimum for assessment purposes. Neither the content nor criteria stipulate that the point loads should be anything other than perpendicular to the beam. During delivery, however, it may be useful to demonstrate the resolution of forces applied at an angle to the beam and to calculate the magnitude and directions of the support reactions.

The assessment for criterion P3 will require a task to calculate the direct stress, direct strain and the accompanying dimensional change in a directly loaded component. It will also require a task to calculate the shear stress and shear strain in a component or material subjected to shear loading. Centres should consider how the tasks set for P3 could be extended to incorporate an opportunity to achieve M1. This might involve consideration of the factor of safety in operation for an angled joint that is bolted or riveted such that the fastenings are subjected to both tensile and shearing forces.

It will require the setting of at least three dynamic system tasks to ensure that the range of kinetic and dynamic principles is applied to achieve P4. Centres should not fragment the application of kinetic and dynamic principles to the extent that they oversimplify the problems. It is the interrelationships between the kinetic and dynamics principles that are as important as the use of any single equation. The principles applied in P4 can be directly linked to M2, although achievement of M2 will require a further task to be set to consider the impact of a freely falling body.

Suitable examples of this type of problem are listed in the delivery section of these guidance notes. A final task to achieve the distinction criterion D1 will be required to enable learners to consider and solve an engineering problem using the two alternative approaches (i.e. d'Alembert's principle and the principle of conservation of energy), and compare the two methods.

P5 may be achieved by calculating resultant thrust and overturning moment on a rectangular retaining surface, examples of which are listed in the delivery section. P6 requires an explanation of Archimedes' Principle.

M3 may be achieved by calculating the upthrust on a totally immersed body using Archimedes' principle. An understanding of fluid principles is needed to achieve D2, which requires learners to evaluate the methods used to determine the density of an irregular shaped solid object.

The criterion P7 examines learners' basic understanding of fluid flow. It may be achieved by considering the design of a gradually tapering pipe to suit given dimensional and flow constraints.

The criteria P8 and P9 have been designed to assess the thermodynamics aspects of the unit. P8 will require tasks to determine the dimensional change in an engineering component that accompanies a change in temperature, and the sensible and latent heat transfer that accompanies a change of temperature and phase in a substance. P9 will require tasks involving the range of thermodynamic process equations applicable to the expansion and compression of an ideal gas. The area of work covered by P8 – the effects of heat transfer – is extended in the merit criteria M4 and M5.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, M1	Static Systems	Problems involving engineering components subjected to static force systems.	A written report containing an introductory explanation to each step in the sequence of calculations and findings.

Criteria covered	Assignment title	Scenario	Assessment method
P4, M2, D1	Dynamic Systems	Problems involving force, work and power in dynamic engineering systems.	A written report containing an introductory explanation to each step in the sequence of calculations and findings.
P5, P6, P7, M3, D2	Fluid Systems	Problems involving hydrostatic thrust and fluid dynamics. Experimental methods used to determine density.	A written report containing an introductory explanation to each step in the sequence of calculations and findings, and an evaluation of the methods used to determine density.
P8, P9, M4, M5	Thermodynamic Systems	Problems involving heat transfer and dimensional change in thermodynamic systems and involving the expansion and compression of gases.	A written report containing an introductory explanation to each step in the sequence of calculations and findings.

Essential resources

As this is a very practical-based unit, centres should provide access to laboratory facilities with a sufficient range of investigation and demonstration equipment wherever possible. In particular, tensile testing equipment, dynamics trolleys, linear expansivity apparatus, apparatus to determine density and apparatus for verification of Boyle's and Charles' laws would be of significant value.

Indicative reading for learners

Textbooks

Bird J – *Science for Engineering* (Routledge, 2012) ISBN 9780415517881

Boyce A, Cooke E, Jones R and Weatherill B – *BTEC Level 3 National Engineering Student Book* (Pearson, 2010) ISBN 9781846907241

Boyce A, Cooke E, Jones R and Weatherill B – *BTEC Level 3 National Engineering Teaching Resource Pack* (Pearson, 2010) ISBN 9781846907265

Darbyshire A – *Mechanical Engineering BTEC National Level 3 Specialist Units* (Routledge, 2010) ISBN 9780080965772

Tooley M and Dingle L – *BTEC National Engineering* (Routledge, 2010) ISBN 9780123822024

Unit 6: Overground Rail Vehicle Traction and Associated Systems

Level:	3
Unit type:	Pathway 1 Mandatory
Guided learning hours:	60

Unit introduction

As passenger numbers and freight loadings continue to increase, it is important to the nation's wealth that there is an effective and efficient railway system in place that operates safely. Railway networks provide links between key transport hubs such as cities, ports and airports, using traction and rolling stock that are powered by a range of AC, DC and diesel traction units.

Ensuring that overground traction and rolling stock operates safely and efficiently results in a railway network that is able to transport passengers and freight to their destinations without disruption. While locomotive power can be provided using a range of methods, all railway vehicles must have braking systems that ensure the safety of the train, and must be mounted on suspensions that are suitable and appropriate for the vehicle.

This unit enables learners to develop their knowledge of the types of suspension that are used for rail vehicles, including different types of bogie and wheelset. It introduces the features that ensure braking systems operate safely and the factors that influence the efficiency of braking systems. The unit develops learners' understanding of both AC and DC electrical traction, considering both infrastructure and on-train equipment, before examining diesel traction units, including operation and maintenance.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

- 1 Understand traction and rolling stock suspension systems
- 2 Understand the fundamentals of traction and rolling stock braking systems
- 3 Understand the fundamentals of traction and rolling stock axles, wheels and bearings
- 4 Understand AC and DC electric power collection and transmission
- 5 Understand diesel hydraulic and diesel electric power generation and transmission.

Unit content

1 Understand traction and rolling stock suspension systems

Design factors: weight, e.g. axle loads (light rail, high speed, multiple units, locomotives); purpose, e.g. passenger, freight, light rail, high speed; wheelset arrangements, e.g. inboard axle boxes, outboard axle boxes, axle bridges, independent wheels.

Suspension systems: dampers, e.g. active dampers, hydraulic dampers, mechanical dampers; levelling valves; over heights; springs, e.g. primary springs, secondary springs, spring types (leaf springs, parabolic leaf spring, cylindrical spring, flexi-coil), rubber springs.

Bogie styles: styles, e.g. 2-axle, Jacobs, powered, steerable; assemblies; shoe gear mountings, e.g. suspended, spring-loaded.

Bogie mountings: pivots; fixed; suspension.

2 Understand the fundamentals of traction and rolling stock braking systems

Braking systems: friction, dynamic, pulse width modulation (PWM), brake safety systems, blending.

Operation of braking systems: air/electric brake systems; round train circuits; variable load valves.

Friction pads: cast iron; high temperature; organic; sintered.

Wheel slide prevention system: system, dump valves, interaction with dynamic brake.

Sanding de-icing systems: increases adhesion and grip, triggers for use.

Implications of fault: implications being unable to release brakes while on the line; implications of failure of round train circuits.

3 Understand the fundamentals of traction and rolling stock axles, wheels and bearings

Components of a wheelset: axle; wheel; bearings.

Wheel types: styles, e.g. conical, tapered; size and use, e.g. multiple units/passenger coaches/high-speed vehicles, locomotives, freight cars; profiles; flanges.

Bearing types: cylindrical roller; ball, e.g. angular contact, four-point contact, deep groove; tapered; tapered roller.

Maintenance: process of changing out wheelsets, e.g. processes, routine maintenance, risk assessments; faults, e.g. flats, tread run-out, cracks, tread cavities, tread rollover; inspections, e.g. in-situ tests, inspection methods; frequency (time/distance); implications of 'flats'; methods of extending life of wheelsets.

4 Understand AC and DC electric power collection and transmission.

Features of AC traction supply: voltages, e.g. 25kV; relationships between voltage, current and frequency; transformers (voltage outputs); earth return and bonding, e.g. earthing through wheels, bonding; systems in place to offload and prevent arc dragging at neutral sections, e.g. APC magnets, vacuum circuit breakers.

AC traction unit types and system/components: use of AC traction motors; motor convertor module, 3-phase inverter, charging circuits.

Pantographs: construction and function of high-speed pantographs.

Maintenance of AC traction units: types and periods of maintenance regimes used; performance, reliability characteristics and maintenance implications of AC and DC traction motors.

Features of DC traction supply: supply voltages, e.g. 750V, 1.5kV; relationships between voltage, current and frequency; 750V DC collection equipment, e.g. third rail and collector shoe gear (top contact, side contact, bottom contact), OHLE and pantographs; earth return and bonding.

Traction motors: use of AC traction motors; speed control for DC traction motors.

Factors impacting on performance of DC electrification: sub-zero temperatures, snowfall; equipment to reduce effects of snowfall, e.g. sleet brushes, third rail scrapers or heated liquid.

DC traction unit types and system/components: thyristor control; filter circuits, e.g. RFI suppression; static converter; traction inverters.

Maintenance of DC traction units: types and periods of maintenance regimes used.

5 Understand diesel hydraulic and diesel electric power generation and transmission

Traction unit types: diesel hydraulic; diesel electric power; diesel mechanical
operation of diesel engines: power control systems, e.g. electro-mechanical systems; turbo chargers; torque converters; fuel injection.

Performance, reliability characteristics of traction units: diesel hydraulic; diesel electric.

Operational factors: cost; environment.

Maintenance: annual preventative maintenance, e.g. components to inspect, frequency of inspection.

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P1 Describe the design, construction, maintenance and operation of train suspension	M1 Compare how two different suspension systems might fail in operation and how maintenance could reduce damage to track and vehicles	D1 Evaluate how design, construction and maintenance of suspension systems affect failure rates
P2 Describe the features of air/electric brake system, including their operation and safety provision	M2 Explain the operation of an air or electric brake system and how the choice of friction pad contributes to its safe operation	
P3 Describe why automatic sanding is necessary		
P4 Describe different types of wheelset and their specific use, identifying all components and their in-situ inspection		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P5 Describe the process of changing out wheelsets for routine maintenance and all risks associated with the operation		
P6 Explain the importance of a regular maintenance programme for traction and ways in which wheelset life may be extended		
P7 Describe AC and DC traction supply in terms of the relationship between voltage and current	M3 Compare the performance, reliability characteristics and maintenance implications of AC and DC traction motors	
P8 Describe the features of AC and DC traction units and their collection equipment		
P9 Describe the main performance issues resulting from sub-zero temperatures and snowfall	M4 Explain methods used to minimise performance issues resulting from sub-zero temperatures and snowfall	D2 Evaluate one method for minimising performance issues resulting from sub-zero temperatures or snowfall

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P10 Describe how a diesel engine with turbocharger performance is controlled, showing mathematically how operation of the control system produces a variation in power output	M5 Explain how turbochargers affect the performance of a diesel engine and how performance is controlled	D3 Evaluate the impact on diesel engine performance of turbochargers and the effects on control systems
P11 Describe, with the aid of diagrams, how a diesel hydraulic power unit and a diesel electric power unit operates		
P12 Describe a planned annual preventative maintenance programme for a diesel engine, listing the components to be inspected and the periodicity of inspections		

Essential guidance for tutors

Assessment

It is likely that at least six assessment instruments will be required for this unit. Evidence for this unit may be gathered from a variety of sources, including written reports or oral presentation with supporting tutor observation record or video.

For P1, learners should be able provide a description of the design, construction, maintenance and operation of at least two types of train suspension, including descriptions of the purpose of systems fitted to different types of train vehicle, along with comparisons between different types of body/bogie mounting. Learners will also explain the implications of suspension failure in terms of damage to both the track and rail vehicle.

Learners could be set a single assessment task that links together P2 and P3 based upon a given case study air/electrical brake system. To achieve P2, learners will need to describe the operation of the braking system, including the function of variable load valves. Learners must describe the different types of friction pad that could be used with air or electric brake systems. Learners will explain the safety features of braking systems, including demonstrating how round train circuits are used to ensure safe operation of trains and the implications of failures of these circuits. Learners must also describe the systems that take over operation of the braking system if there is operator error and the systems that prevent wheel slide. To satisfy P3, learners must describe with reasons why overground railway stock needs to have automatic sanding systems.

The evidence to satisfy the pass criteria for P4, P5 and P6 could be achieved by means of a portfolio containing written evidence, sketches, diagrams, drawings, presentation slides and, where appropriate, tutor observation records. For P4, learners will need to describe the typical use of different types of wheelset, identifying all components and describing their in-situ inspection, for example visual inspections for tread run-out or wheel flats. Learners should include illustrations of the different wheel profiles that can be used on railway vehicles, explaining the link between the wheel profile and their use. For example, tapered profile wheels are used on passenger vehicles in order to assist with stability and for travelling around curves.

To achieve P5, learners will need to describe the processes that must be completed when changing out wheelsets for routine maintenance, identifying and explaining the risks associated with the processes. To satisfy P6, learners must explain the importance of carrying out regular maintenance on wheelsets and the implications of completing maintenance for rolling stock. Learners will need to include a consideration of the implications of a 'flat' on wheelsets, for example removal of a vehicle from service or reduced running speeds, and also discuss ways in which the life of a wheelset can be extended.

Learners might be set a single task to satisfy both P7 and P8, perhaps producing a portfolio as assessment evidence. For P7, learners must describe both AC and DC electrical traction supply, with appropriate calculations, including the relationship between voltage, current and power. Learners must consider methods used to offload and prevent arc dragging at neutral sections for both third rail systems and overhead systems, for example the use of trackside magnets.

To satisfy P8, learners must describe the features of AC and DC traction units, including on-train collection equipment. Learners might use illustrated diagrams to explain the construction and function of a pantograph for high-speed vehicles and the shoe gear for 750V third rail systems. Learners should describe how the main transformer in a traction unit works, giving reasons for the need for a range of different voltage outputs. Learners must describe how AC traction motors can be used on a railway with a DC supply. Finally, learners will describe the need for bonding and earth return, including details of the systems in place for both a third rail DC supply and a typical 25kV AC system.

To achieve P9, learners must describe performance issues associated with snowfall and sub-zero temperatures. Learners must describe the impact on track equipment, passenger services, and the operation of AC and DC traction units.

The evidence to achieve the pass criteria for P10, P11 and P12 could be a single written assignment with supporting diagrams and calculation. For P10, learners will describe the operational control of a diesel engine with turbocharger. Learners must complete calculations to demonstrate mathematically how engine performance is controlled to produce a variation in output. To satisfy P11, learners should describe the operation of diesel hydraulic power units and diesel electric power units, producing a fully annotated diagram of each type of unit. Finally, to achieve P12, learners must describe the planned annual preventative maintenance for a diesel engine, including the production of a list of components to be inspected, and the frequency of inspections. Learners should describe the process to be followed, although there is no need to describe how individual components are inspected.

To achieve a merit grade, learners must meet all of the pass criteria and the merit grade criteria.

To achieve M1, learners will compare the ways in which two different suspensions systems fitted to different types of rail vehicle might fail, for example comparing a system with active damping to one with mechanical damping. Learners must explain how maintenance can reduce the effects of failure to both the track and vehicles.

To achieve M2, learners will need to explain the operation of either an air brake system or an electric brake system. This will need to include each of the aspects of the system described for P2 and P3, and include a consideration of how the choice of friction pad contributes to the safe operation of the selected braking system.

For M3, learners will compare AC and DC traction motors, considering their relative performance, reliability and maintenance characteristics.

To satisfy M4, learners should explain the methods employed to limit the impact of winter conditions on traction units such as the use of sleet brushes or third rail scrapers.

For M5, learners need to explain how turbochargers improve the performance of diesel engines and how performance is controlled.

To achieve a distinction, learners must meet all of the pass and merit grade criteria and all of the distinction grade criteria.

To satisfy D1, learners will evaluate how different designs, construction types and the use of maintenance affect the failure rates of the suspension systems described for P1 and M1. Learners should use reliability data to support their judgements.

For D2, learners must evaluate one of the methods explained in M4 for minimising performance issues arising from sub-zero temperatures or snowfall. Learners should draw conclusions concerning the impact and operational benefits of the deployed method.

To achieve D3, learners must present an evaluation of the impact on engine performance of turbochargers, for example improving efficiency or reducing fuel consumption.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, M1, D1	Suspension Systems	A mixed activity requiring learners to research and examine the suspension systems used for different types of railway vehicle.	A written report containing supporting sketches and, diagrams.

Criteria covered	Assignment title	Scenario	Assessment method
P2, P3, M2	Overground Railway Braking Systems	An investigation into the braking systems used on overground rail vehicles. This should include two parts, one of which should focus on a given type of braking system, including the implications of failure. A second part should consider the associated safety systems that form part of the train braking system.	A written report containing technical illustrations and diagrams to help describe concepts.
P4, P5 and P6	Wheelsets	An investigation of wheelsets and their maintenance for given types of rail vehicles. The assessment is likely to be in two parts, one of which considers the design requirements of different rail vehicles, the second investigating maintenance and the consequences of damage to wheels.	A portfolio containing written evidence, sketches, diagrams, drawings, presentation slides and, where appropriate, tutor observation records.

Criteria covered	Assignment title	Scenario	Assessment method
P7, P8, and M3	AC and DC Traction	An activity to examine both AC and DC traction unit supply and on-train collection equipment.	A portfolio containing written evidence, calculations, sketches and diagrams.
P9, M4 and D2	Operating in Winter Conditions	The report will consider performance issues associated with sub-zero conditions and snowfall.	A written report containing supporting sketches and diagrams.
P10, P11, P12, M5 and D3	Diesel Traction	An activity to examine the operation of diesel traction units, including different forms of traction unit. This should be accompanied by the production of a maintenance plan for a diesel traction unit.	An illustrative report that examines diesel traction, supported by mathematical models and annotated technical drawings.

Essential resources

Access to information and communication technology resources (including the internet) is essential for the delivery of this unit, as is a well-stocked source of reference material.

Learners should be given a variety of technical documents and drawings for parts of traction systems.

Indicative reading for learners

Textbooks

Bonnett C – *Practical Railway Engineering* (Imperial College Press, 2005)
ISBN 9781860945151

Glover J – *Principles of Railway Operation* (Ian Alan Publishing Limited, 2013)
ISBN 9780711036314

Steimel A – *Electric Traction – Motive Power and Energy Supply: Basics and Practical Experience* (Oldenburg 2008) ISBN 9783835631328

Unit 7: Overground Rail Passenger Comfort, Safety and Security

Level:	3
Unit type:	Pathway 1 Mandatory
Guided learning hours:	60

Unit introduction

Essential to the ability for people to travel the length and breadth of the country is the provision of a safe, reliable and resilient transport network. Most countries across the world, including the UK, the USA, China, Japan and Germany, benefit from extensive rail networks. Successfully operated, these networks help to reduce traffic congestion on highways, reduce the need for air travel, promote commerce and benefit the environment, e.g. assisting to reduce vehicle exhaust fumes.

Ensuring that overground passenger rail networks are comfortable, safe and secure is key to their continued use by passengers. Passengers must receive clear information on approaching stations, disruptions to rail services, and instructions in the event of an emergency while travelling. Systems must be in place so that customers can board and alight rail carriages speedily, using, in the main, automatic doors. Overground rail carriages must be ventilated and maintained at a suitable temperature for users and be monitored using closed-circuit television (CCTV) to ensure passenger safety.

This unit enables learners to develop their knowledge of the purpose, installation, use and maintenance of different comfort, safety and security systems. It introduces the electrical and pneumatic control systems used on overground rail vehicles. The unit develops learners' understanding of the key components and the methods used for fault-finding on essential systems. These systems include railway doors, toilets, and the vehicle trim used on rail overground vehicles.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

- 1 Understand passenger safety and security systems
- 2 Understand heating ventilation and air conditioning systems
- 3 Understand train interior and exterior, saloon and cab door systems
- 4 Understand train toilet systems
- 5 Understand train vehicle trim.

Unit content

1 Understand passenger safety and security systems

Purpose of closed-circuit television systems: protecting the health and safety of rail employees, customers and members of the public, e.g. enables the driver or central control room to confirm people are clear of vehicle doors; preventing and detecting crime and antisocial behaviour; monitoring rail traffic and passenger number in real time; providing coverage of vehicle saloons, doorways, vestibules, gangways, publicly accessible catering areas and other public spaces.

Components, function and technical requirements of a closed-circuit television system: explain the different types of cameras, their characteristics, capabilities and positioning, e.g. analogue and IP cameras; different lenses, e.g. fixed, automatic iris, zoom, adjustable fixed, infrared; moveable camera mounts and controllers; monitors and displays, including switcher unit; wireless and fixed cable systems.

Types and function of closed-circuit television system recording media: explain the use of different types of recording media, including video content analysis, e.g. automatic smoke detection, people-counter systems, e.g. count people passing pre-defined areas, digital video recorder (DVR) and network video recorder (NVR); media types, e.g. hard disk drives, memory cards, flash drives, SDD.

Appropriate use of closed-circuit television systems to respect privacy: explain how the Data Protection Act 1988, Human Rights Act 1988 (e.g. Articles 6, 8, 10, 11 and 14) Freedom of Information Act 2000, The Information Commissioner's Code of Practice impacts on the operation of closed-circuit television systems; the requirements of 'privacy' zones'; responsibilities and actions to be taken if a request for information is received.

Key components of a Passenger Information System, their operation and function: public address system; passenger emergency call system and talkback, e.g. alerts the driver to a problem with the train and/or applies the emergency brakes to the vehicle; LED information panels, e.g. provides information on the next station or stop; driver/crew audio system; reservation displays.

Automatic announcements: provided by onboard computer, pre-recorded speech segments transmitted to the public address system (PA); use of LED displays, ability for software to enable communication with only a selected part of the train, e.g. first-class passengers or where the train is due to split at a particular station; links with SDO through the use of radio-frequency identification (RFID) tags to indicate which doors to use to alight.

Importance to safety and comfort of a functioning Passenger Information System: managing congestion in rail facilities, informing passengers about changes to timetable and disruptions, method to communicate instructions in response to an emergency situation, e.g. displaying information on means of emergency exit, providing passengers with useful information, e.g. information on routes or fares,

coach numbers and stopping information; links between passenger alarms and emergency brakes.

Fault-finding: using downloads, diagnostic software, system schematics and Manufacturing Verification Build (MVB) analysis, if applicable.

2 Understand heating, ventilation and air conditioning systems

Components and function of HVAC systems: components, including compressor, evaporator, condenser, capillary tubes, thermostatic expansion vessel, reversing valve, exhaust ducts and fans, air diffusers and intakes; function of system, including heating, ventilation, air conditioning, emergency ventilation; the refrigeration vapour and compression cycle; types of refrigeration, e.g. mechanical, chemical, venture.

Operation and control of HVAC systems: two-stage heating and cooling; operating conditions, e.g. operates in all environments and climatic conditions, maintains and restores interior temperature with loading/unloading of carriage and recovers heat losses due to the train's motion; power supply; freeze protection circuits and thermostats; methods to stagger start refrigerant compressor motors; temperature sensor types and location, e.g. automatic microprocessor temperature controls within passenger seating area and an evaporator coil to detect ice build-up; manual temperature control adjustment device and location; zone heating and cooling demand; use of pressure transducers.

HVAC maintenance and safe working procedures: fault-finding, e.g. use of laptop computer and HVAC diagnostic firmware, operational tests, maintenance frequency, unit replacement, e.g. use of lifting equipment to remove/install HVAC units, spill trays, electrical isolation and static discharge, fire and gas detection; noise protection; avoiding contact with hot/cold surfaces, purging system, anti-microbial treatment.

3 Understand train interior and exterior, saloon and cab door systems

Types of door system: saloon doors, cab doors, interior or gangway doors, cab back wall doors, front gangway half door, toilet doors, TMO door.

Components, function and operation of door systems: pneumatic systems that use compressed air to control train doors and components, including pneumatic actuators, compressor, filter, pressure regulator, lubricator, cylinder pistons, directional control valve; electrical door systems and components, including electric actuators, locking mechanisms, encoder, relays, motors and electric circuits; features of door systems, e.g. door leaf, manual lock, guide rail, door catch, swivel arm, external emergency access device, Bowden cable, rotary latch mechanism, pneumatic panel, door drive mechanism, door glass; selective door operation controlled by global positioning systems (GPS) and driver only operation; materials, including aluminum casting and aluminum honeycomb composites.

Design of door safety systems: central locking systems which ensure trains do not start until doors are locked and passengers cannot open them while the vehicle is moving; warning alarm and light systems to inform passengers to stand clear as doors close; drag detection systems, obstacle detection systems; sensitive edge; finger protection rubber.

Fault-finding: train management systems, using downloads, door diagnostic unit software, system schematics and mean variance (MV) analysis, if applicable; wrong side failure and implication to exterior saloon door system, e.g. door opens at the wrong time.

Correct saloon door set-up: advantages and disadvantages of head-mounted door or floor-mounted activators; types of door locking mechanism; impact on the serviceability of door components, e.g. noise, dust, unit life in high traffic areas. Safety implications, including speed of opening, obstruction sensors and force applied upon opening.

4 Understand train toilet systems

Operating principles of train toilet systems: vacuum; retention tanks; water recycling toilet systems; provision of water for hand washing and flush.

Components of train toilet systems: water tank unit; waste water system; toilet, including materials (stainless steel, ceramic); microprocessor control unit; pipework and cabling; controls, e.g. call for aid, toilet flush, water/soap/hand dryers, door controls.

Legislation and regulations: EuroSpec, 'Specification for toilets of railway vehicles'; accessibility requirements, e.g. Rail Vehicle Accessibility Regulations 1998 and 2010, Technical Specification for Interoperability relating to Persons with Reduced Mobility (PRM TSI); ATOC guidance, e.g. odour prevention, protection against legionella.

Maintenance: components that need to be inspected; inspection criteria; preventative maintenance activities; replacement of active components; health and safety considerations when changing components.

5 Understand train vehicle trim

Passenger counting systems: types, e.g. thermal counters, video counters, infrared beam counters, pressure pads; use of counters, including carriage occupancy monitoring, detection and analysis of passenger flow, link to ventilation and heating systems.

Passenger train glazing systems: impact resistance specification for windscreens; laminated glass; glass spall; prevention of graffiti, etching and vandalism.

Emergency lighting: power supply, e.g. independent battery; colour of lighting, e.g. white; minimum requirements for period of lighting after the loss of main supply; location of lighting, e.g. egress points, 750mm above the floor in the saloon, escape routes and adjacent to emergency equipment.

Train lighting: reasons why train operating companies (TOCs) would want main interior lighting to switch off for units that are not in service.

Passenger train interiors: orientation of fittings, e.g. tables, seating (table seats, airline seats, longitudinal seating, 3+2 commuter seating), cycles storage, provision for wheelchairs; number of passengers who can be accommodated with different layouts; provision of power sockets for passengers.

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P1 Describe the function of components in a typical Closed-Circuit Television system.	M1 Explain the importance of Closed-Circuit Television systems and Passenger Information Systems in terms of passenger security, privacy and comfort.	
P2 Describe the key components of Passenger Information Systems and how fault-finding is completed.		
P3 Describe of the relationship between passenger alarms and emergency brakes.		
P4 Describe the function of components in a typical rolling stock HVAC system and their safe operation and maintenance.	M2 Explain the importance of maintaining an HVAC unit in serviceable condition.	D1 Evaluate the potential impact on passengers and a train operator of the failure to maintain an HVAC unit in serviceable condition.
P5 Describe the components and operating principles of exterior and interior door systems.	M3 Compare and contrast the safety implications of selecting a pneumatic or electrical door operating system.	D2 Evaluate the limitations of pneumatic and electrical door operating systems.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P6 Demonstrate the ability to fault find on the cab and saloon interior and exterior door systems using downloads, diagnostic software, system schematics and MVB analysis if applicable.		
P7 Describe the components, operation and safe maintenance of a train toilet system.		
P8 Describe any current legislation with regard to on-train toilets and how this affects rolling stock design.		
P9 Describe a typical passenger counting system and explain the reasons why a TOC would choose to install or use such a system.		
P10 Describe the required properties of the glazing used on passenger trains.		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P11 Explain the minimum lighting requirements of a passenger train if it were to lose its main source of electrical power.		
P12 Explain how, by altering the orientation of interior fittings, such as tables and seating, a TOC can accommodate different numbers of passengers on a typical unit.		

Essential guidance for tutors

Assessment

This unit is suitable to be delivered in conjunction with *Unit 6 Overground Rail Vehicle Traction and Associated Systems*. Completing both units, learners will benefit by gaining a more complete knowledge of overground rail vehicles; combining learning about vehicle traction power units, and carriage comfort and security systems.

It is likely that at least five assessment instruments will be required for this unit, one for each learning outcome. If practical work and tests are also used then the total number of pieces of assessed work could be even more than this. This should be carefully considered so that it does not place an unduly high assessment burden on learners or the tutor.

Wherever possible, practical work should lead to a final outcome that can be handed in for assessment at the end of the session without further need for report writing. This will help control authenticity of evidence and also keep the assessment activities short, sharp and relevant.

A single activity could be used to link and capture evidence for P1 and P2. Learners could be required to prepare a guidance document on the use of the closed-circuit television (CCTV) and the Passenger Information System for a new model of passenger vehicle proposed for a train operator. Learners will draw a diagram of the layout of a typical CCTV system, including all components detailed in the unit content and their interconnection. To satisfy P1, learners will need to annotate the diagram, clearly identifying the function of each component and its technical requirements, for example for a CCTV camera component, this would include details of the mounting, possible positions, types of coverage that is required, lighting requirements and the types of lens. To accompany this, learners will be required to explain the different types of recording media used in CCTV systems, fully covering the unit content, such as video content analysis that can automatically detect smoke or flames. For P2, learners could draw a diagram of a typical Passenger Information System showing all the key components listed in the unit content. Again, to fulfil the criteria, learners will need to annotate the diagram describing the function and operation of each of the components covering the unit content, for example the use of LED display panels to provide information on the next station or stop, and their manual or automatic operation by on-train staff or from remote control centres. To fully satisfy P2, learners must also demonstrate an understanding of how to fault-find on a Passenger Information System. This could be achieved through a practical activity using simulated diagnostic software to find typical faults such as distorted images on a monitor display or loss of audio. Tutors could use printouts from the software or an observation record as evidence of achievement.

To achieve M1, learners could complete an extension task. The task could require learners to prepare a sales letter to the rail operator providing an explanation of how their CCTV system and Passenger Information System would assist passenger safety and security, covering the key purposes in the unit content, i.e. crime prevention and monitoring passenger numbers. In addition, learners would also be required to provide guidance on the implications of the use of the CCTV system in terms of privacy, covering both legislation and the use of 'privacy zones', for example in toilet areas.

P3 requires that learners demonstrate an understanding that the passenger alarm located in a carriage can either directly stop the train or send an alarm to the driver so that they can stop the train. Learners need to describe the mechanism by which both alternatives stop the train, for example the alarm may directly cause a break in the continuity of the brake pipes (whether vacuum or air brakes) resulting in an immediate loss of brake pressure (or vacuum), causing the brakes to be applied and the train to halt.

Learners could achieve P4 through an appropriately structured practical involving dismantling or assembling an HVAC training rig. Tutors could capture evidence by using an appropriate record of observation and oral questioning of each learner during the practical activities used for delivery. Alternatively, learners could achieve P4 using a paper-based assessment such as preparing a systems diagram or by means of an HVAC system computer-based simulation training software package. Whichever method is used, centres need to ensure that sufficient evidence is available to satisfy the pass criteria as outlined in this unit guide. To satisfy P4, learners will need to describe the full range of components of an HVAC and air-conditioning refrigeration system (compressor, evaporators, condenser, capillary tubes, thermostatic expansion vessel, reversing valve, exhaust ducts, fans, air intakes and diffusers) their function and stages of operation. Learners will also need to compare and contrast mechanical, chemical and venturi methods of refrigeration. Learners must also describe the key hazards and associated safety controls required when working on or around HVAC systems; these include lifting equipment and procedures for the removal/installation of HVAC units, use of drip pans for spills, measures for avoiding contact with extreme hot/cold surfaces, fire and gas detection and electrical unit isolation. Learners could prepare a risk assessment as evidence to satisfy the criteria.

M2 requires an explanation of the importance of maintaining an HVAC system in serviceable condition. Learners should consider the importance of appropriate maintenance on the performance and safety of key HVAC components. To achieve a distinction, learners will, for D1, evaluate the impact on both passengers and rail operators of the failure of an HVAC system. Learners might consider the impact on passenger comfort and safety, operation of train services, passenger patronage and a rail operators' financial bottom line. The evidence for each of these linked criteria is likely to be a written evaluation.

A second practical assessment could be used for P5 involving dismantling or assembling parts of a door-opening system for a pneumatic and electrical train door. Tutors could capture evidence by using an appropriate record of observation and oral questioning of each learner during the activity or, alternatively, a video could be taken of each learner. Learners would need to describe the principles of how a pneumatic door operates (e.g. use of compressed air or inert gas under pressure to produce a force in a cylinder to move a piston) and an electrical door (for example conversion of electrical energy to a force using encoder, activators, relays and motors). They will also need to explain how these systems are used in saloon and cab doors. Learners must describe key door components, materials used, and their operation as given in the unit content, including the electrical/electronic methods of control, including Selective Door Operation and Driver Only Operation. Learners must also describe the safety devices fitted to exterior saloon doors, including central locking, closure, drag-detection and obstacle detection systems.

As part of the practical activity to satisfy P6, learners could use door diagnostic software to find standard faults, e.g. failure of a door's audio closure warning signal or light.

M3 is an extension of P5 and P6, where learners must compare and contrast the safety implications of selecting a pneumatic or electrical door operating system for a given type of passenger vehicle, e.g. electric actuators do not suffer from air pressure leaks and tend to be quieter than pneumatic actuators. For D2, learners will evaluate the limitations of pneumatic and electrical door operating systems, considering space requirements for installation, noise, potential for leaks, maintenance requirements and the length of the in-service life span of each system before replacement is required.

One activity could be set for learners that addresses both P7 and P8. This assignment could ask learners to explain the operating principles of a toilet system and to produce a maintenance plan. To attain P7, learners must include an explanation of the various components that are used in on-train toilet systems and their operation as listed in the unit content. Learners must describe the health and safety requirements for working on train toilet systems and how systems are maintained. Learners will need to list the components that must be inspected, the criteria for inspection, and the essential maintenance activities that must be carried out, including the replacement of active components. To satisfy P8, learners must describe current legislation that relates to on-train toilets, for example accessibility legislation, and how this affects rolling stock design through the provision of accessible toilets.

The evidence for P9 is descriptive. Learners should provide details of typical passenger count systems (for example thermal, video and infrared beam counters) and why these are used by train operating companies, including managing congestion, controlling the operation of train doors, managing the frequency of services and monitoring passenger loadings. Written evidence would satisfy the completion of this criterion.

The evidence for P10 is, again, descriptive. Learners should cover the properties of laminated glass, including impact resistance and spall criteria, and the material's selection for use in the glazing of carriage windows and a train engine unit's windscreen. As evidence for this criterion, learners might produce a PowerPoint presentation to train other technicians on glazing rail vehicles.

P11 requires learners to explain the emergency lighting requirements for a passenger train. This criterion could be achieved by learners producing a wiring diagram for an auxiliary lighting system. Learners need to explain the requirements for an independent power supply, lux levels, the position of lighting and, where appropriate, the colour to be specified to avoid potential confusion with signals.

P12 requires learners to make use of diagrams to explain how altering the orientation of interior fittings can allow a train operating company (TOC) to provide capacity for different numbers of passengers, for example extra luggage provision on airport services, higher density seating on commuter services, or the use of tip-up seats to maximise the provision of seating. To achieve P12, learners will also need to describe the arrangement of electrical sockets in each carriage.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, M1	Rail Vehicle Safety and Information Systems	For a given new model of overground passenger rail vehicle, learners explore the requirements for closed-circuit television and Passenger Information Systems, and interpret and prepare a guidance document for the train operator company, including network diagrams.	A written report providing the learner's interpretation of the components, features, technical requirements and appropriate operation of the system. Annotated engineering diagrams of the CCTV and PIS systems, with supporting written report. Output from diagnostic software and/or tutor observation record.
P4, M2 and D1	Heating, Ventilation and Air Conditioning Systems for Passenger Carriages	A mixed activity requiring learners to dismantle or assemble an HVAC training rig, preparing beforehand a written risk assessment.	A portfolio of evidence containing tutor observation record and a written risk assessment.

Criteria covered	Assignment title	Scenario	Assessment method
P5, P6, M4 and D2	Passenger, Saloon and Cab Train Door Systems	A practical activity requiring learners to dismantle or assemble a train door system, and use door diagnostic software to find faults.	A portfolio of evidence that includes notes and diagrams, supported by video or an observation record, and supporting output from diagnostic software.
P7 and P8	Train Toilet Systems	A scenario-based activity requiring learners to investigate train toilet systems, applicable legislation and the production of a maintenance schedule for a given type of unit.	A portfolio of evidence containing a written maintenance schedule, with reference to legislation and guidance.

Criteria covered	Assignment title	Scenario	Assessment method
P9, P10, P11 and P12.	Passenger Carriage Trim	A mixed activity comprising three tasks. The first task requires learners to describe typical passenger counting systems. For the second task learners prepare a training presentation for other technicians explaining the properties of glazing for rail vehicles. The third task requires learners to consider the layout and orientation of interior fittings present in passenger saloons, including tables, seats, emergency lighting, automated control of unit lighting and the provision of power sockets for passenger use.	A portfolio of evidence that includes a written report, presentation slides, calculations, and diagrams.

Essential resources

Access to information and communication technology resources (including the internet) is essential for the delivery of this unit, as is a well-stocked source of reference material.

Learners should be given access to diagnostic software for train door systems and Passenger Information Systems. It is desirable that centres also provide access to an HVAC and train door training rig.

Indicative reading for learners

Textbooks

Bonnett C – *Practical Railway Engineering* (Imperial College Press, 2005)
ISBN 9781860945151

Boyce A, Cooke E, Jones R and Weatherill B – *BTEC Level 3 National Engineering Student Book* (Pearson, 2010) ISBN 9781846907241

Boyce A, Cooke E, Jones R and Weatherill B – *BTEC Level 3 National Engineering Teaching Resource Pack* (Pearson, 2010) ISBN 9781846907265

Kruegle H – *CCTV Surveillance Video Practice and Technology* (Elsevier 2007)
ISBN 9780750677684

Tooley M and Dingle L – *BTEC National Engineering* (Routledge, 2010)
ISBN 9780123822024

Unit 8: Features and Applications of Electrical Machines

Level: 3

Unit type: Pathway 2 Mandatory; Additional

Guided learning hours: 60

Unit introduction

All electrical machines use applications of electro-magnetic principles where electric currents create magnetic fields which either attract or repel each other. This is the basis of all electric motors, whether they operate on alternating current (AC), direct current (DC) or are universal motors that operate on both. Transformers are devices that also use the principle of electromagnetism. These are generally very efficient and their output power can be almost 100 per cent of the input power, depending on the application.

This unit has been designed to help learners understand the complexities of electromagnetism and its applications to everyday electrical devices, systems and apparatus. Learners will consider a range of machines, their application and their control. In addition, the unit will help learners understand relevant electrical hazards, legislation, regulation and standards.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

- 1 Know the electrical hazards and the legislation, regulations and standards related to working with electrical apparatus
- 2 Understand features and applications of alternating current (AC) machines
- 3 Understand features and applications of direct current (DC) machines
- 4 Know how electrical machine control circuits and systems operate.

Unit content

1 Know the electrical hazards and the legislation, regulations and standards related to working with electrical apparatus

Electrical hazards: safe working procedures, e.g. isolation (safe isolation, switch off, lock off, display notices, testing for dead with test lamp and proving unit), earthing, interlocking, warning notices, permit to work; risk assessment when working on electrical apparatus, e.g. hazard evaluation and recording of risk, controlling risk; personal protective equipment (PPE), e.g. insulated gloves, mats, tools, barriers.

Legislation, regulations and standards: e.g. Health and Safety at Work etc. Act 1974, Electricity at Work Regulations 1989, Personal Protective Equipment at Work Regulations 1992, Electrical Equipment (Safety) Regulations 1994, Machinery Directives, Health and Safety Executive (HSE) publications, e.g. GS38, Codes of Practice, British and International Standards, BS 7671 17th Edition IEE Wiring Regulations.

2 Understand features and applications of alternating current (AC) machines

Alternating current (AC) motors: single and polyphase; construction, principles of operation, starting characteristics and torque; types (induction motors, split-phase, capacitor start, capacitor start and run, shaded pole, universal, variable frequency drives); applications of AC motors, e.g. conveyor belt drives, pumps, machine shop equipment, fixed loads, variable loads.

AC generator: types, e.g. single-phase, polyphase; construction and principles of operation; applications, e.g. stand-by generators, remote site generators, vehicle alternators with regulation and rectification.

Transformers: principles of operation; efficiency and losses; construction of single and double wound; types, e.g. step-up, step-down, safety isolating transformer; applications, e.g. incoming mains step-down, portable transformer for hand tools, safety isolating transformer for electrical test-bench work, machine power supplies.

3 Understand features and applications of direct current (DC) machines

Direct current (DC) motors: types, e.g. series, shunt, compound (long and short shunt), brushless; construction, principles of operation, starting characteristics and torque; applications, e.g. motor vehicle starters and window operation, toys and models, industrial drives, crane hoists, fixed loads, variable loads.

DC generators: construction and principles of operation; production and control of DC voltages and current; applications, e.g. motor vehicles, speed control/ feedback systems (tacho-generators).

4 Know how electrical machine control circuits and systems operate

Stop/start/retain relay control: relay/contactors with retaining/latching contact; start, stop, overload, 'inch' (non-latching) control; remote stop/start; safety relays for production/manufacturing equipment, e.g. several guards closed sensors, oil level detectors, temperature sensors, body heat (passive infra-red) detectors; control circuits, e.g. AC machine control (direct on line (DOL), star-delta, soft start and other solid state techniques such as triac, inverter drives, slip ring rotor resistance control, auto transformer, power factor correction), DC machine control (starting methods and speed control such as face plate, solid state systems); emergency stop, e.g. closed contact device to stop the machine/system from running or starting and turn power off under emergency conditions; emergency stopping, e.g. dynamic braking by either DC injection braking or timed phase reversal, solenoid operated mechanical brakes, instantly stopping the machine.

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P1 Describe hazards that may exist when working with two different pieces of electrical apparatus		
P2 Describe control measures that should be used to reduce the risk of harm to self and others when working with two different pieces of electrical apparatus		
P3 Describe aspects of legislation, regulations and standards that relate to work being carried out on two different pieces of electrical apparatus		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P4 Explain the features, characteristics and application of two different types of AC motor	M1 Explain the operational features of a speed control system for an AC machine	D1 Compare the applications of a DC and an AC motor for two contrasting modern electrical installations
P5 Explain the features, characteristics and an application of one type of AC generator		
P6 Explain the features, characteristics and application of two different types of transformer		
P7 Explain the features, characteristics and application of two different types of DC motor	M2 Explain the operational features of a speed control system for a DC machine	
P8 Explain the features, characteristics and an application of a DC generator		
P9 Describe the operation and use of a stop/start/retain relay control circuit for an AC or DC machine.	M3 Explain the use of a safety relay system and how its use addresses the issues raised in relevant legislation, regulations and standards.	D2 Compare the construction and operation of two different types of stop/start/retain relay control circuit for either an AC or a DC machine.

Essential guidance for tutors

Assessment

P1, P2 and P3 are linked and are likely to be achieved through investigations based on the same two different items of electrical equipment, for example transformers, isolators, AC and DC motors. Evidence could be presented in the form of a written report or as a presentation to a group using appropriate visual aids.

When describing hazards and control measures for P1 and P2, learners should include all the aspects identified in the unit content.

For P3, learners should include relevant quotes from their sources and specific references, and it is important that these are shown to be specific to the work being undertaken and not just general quotes.

For P4, learners need to carry out investigations based on two different types of AC motor (for example induction, split-phase, capacitor start, capacitor start and run, shaded pole, universal, variable frequency drives, single or polyphase motors). Ideally, these should be combined into one single investigation of two different motors rather than two separate investigations. This will avoid the need to assess the criterion twice before it can be reported as achieved. Learners need to describe the features, characteristics (for example construction, principles of operation, starting characteristics and torque) and a typical application for each type of AC motor considered. Evidence could include written descriptions plus relevant drawings, circuit diagrams, photographs and exploded views (as appropriate), annotated to aid the description.

P5 and P6 require a similar approach. However, it is important to note that while P5 only requires one AC generator to be considered, for P6, like P4 above, learners must describe two different types of transformer (for example step-up, step-down or safety isolating transformers).

P7 and P8 simply replicate the criteria for P4 and P5 but for two different DC motors (for example series, shunt, compound (long and short shunt), brushless) and one DC generator. As above, P7 should be done as one activity to avoid splitting the criterion.

P9 requires learners to describe the operation and use of a stop/start/retain relay control circuit. This can be an AC or DC machine and can be chosen by the tutor or the learner. The choice of AC or DC control circuit is only limited by the need to draw as extensively as possible from the unit content to cover such aspects as safety relays and emergency stop/stopping requirements. The assignment should be based on a practical investigation if possible and learners should provide a careful description of the circuit that they have investigated. This should include an itemised list of components (together with a description of the function of each component) and should be supported by a suitably annotated circuit diagram.

To achieve M1 and M2, learners should explain the operational features of the speed control systems for an AC machine and a DC machine respectively. Learners will need to consider the speed control aspects of machines in specific applications, which will draw from and build on the knowledge and understanding developed through P4–P8.

For M3, learners will need to explain the use of a safety relay system and how the system addresses the issues raised in relevant legislation, regulations and standards. The system considered could be the same as that described for P9. Learners must set the circuit in a particular context or application and demonstrate that they understand the importance of the circuit in that application.

Learners must also have recognised the relationship of such a circuit to the requirements of relevant legislation, regulations and standards. Note that there is a further link from the work undertaken for P9 and M3 to that required for D2 (see notes below) and this might form the basis of a single assignment.

To satisfy D1, learners should show that they can bring together their understanding of P4–P8 by comparing the applications of a DC and an AC motor for two contrasting modern electrical installations. Learners should investigate two sufficiently complex and contrasting installations that enable them to draw from and show that they can apply the understanding that they have gained at pass and merit level. Typical applications might be a variable-speed motor drive for an electric vehicle and a high-torque constant-speed drive used in an industrial conveyor belt.

Learners should justify the type of DC and AC motor as well as its supply configuration (for example triac speed controller) and output drive system (for example gearbox or belt reduction system). They should also make reference to the operating principles and actual machine characteristics (for example starting torque, on-load torque, efficiency).

D2 builds on the work undertaken for P9 and M3. As such, the circuit considered for P9 could be one of the stop/start/retain relay control circuits that is used for comparison and against which a second is compared. However, centres may prefer to get learners to consider two completely different relay control circuits to provide them with a wider range of experience.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3	Electrical Hazards and Legislation and Regulations	A technician has been asked to show potential electrical hazards to a new learner and explain the legislation and regulations with which they need to be familiar.	A written report or a presentation.
P4, P5, P6, P7, P8, M1, M2, D1	AC and DC Electrical Machines	A technician has been asked to write a report explaining and comparing the key features of a range of new AC and DC machines.	A written report.
P9, M3, D2	Machine Control Circuits and Systems	A technician has been asked to describe the operation of a stop/start/retain relay control to a new member of staff.	A written report.

Essential resources

Centres will need a workshop equipped with electrical machines and associated switchgear and control equipment. Learners will require access to a range of AC and DC motors and generators. A selection of different types of transformer (for example, step-down, step-up, isolating variable voltage) will also be required.

In addition, to permit testing of motor speed controllers, learners will require one or more variable speed controllers (for both AC and DC motors) together with variable loads and machine braking systems.

Learners will also require access to appropriate statutory and non-statutory regulations, health and safety legislation, as well as catalogues, data sheets and relevant equipment specifications.

Indicative reading for learners

Textbooks

Bird J – *Electrical and Electronic Principles and Technology* (Routledge, 2013)
ISBN 9780415662857

Hughes A – *Electric Motors and Drives: Fundamentals, Types and Applications*
(Newnes, 2013) ISBN 9780080983325

Schultz G – *Transformers and Motors* (Newnes, 1997) ISBN 9780750699488

Unit 9: Rail Electrification Technologies

Level:	3
Unit type:	Pathway 2 Mandatory
Guided learning hours:	60

Unit introduction

It is critical to the development of the rail system that rail electrification technologies, and the many component parts used in electrification, are understood by those working within it. Rail workers require a secure knowledge and understanding of the materials and mechanisms that are used within the rail industry along with the rail electrification technologies used in the railway system.

This unit will introduce learners to infrastructure, switch gear and on-train systems. They will explore the theory needed to understand the mechanical systems that are used in the railways, such as the different lubrications in use and their purpose, including the lubrication systems which prevent components overheating and seizing. They will examine the application of the many proprietary components, including fasteners and standard seals, packing and bearing, and their applications in various engineering assemblies. They will investigate mechanical power transmission systems and shafts, and explore systems of linkage mechanisms such as four bar linkages, and different cams and followers.

Learners will explore actuation and handling systems, using pneumatics or hydraulics to examine on-train systems and the maintenance of these. They will consider steam, refrigeration and air conditioning plant service systems, with an examination of items such as steam power generation plant and the system layout for power generation and process operations. Learners will investigate the ways in which materials are used within the maintenance of rail overhead line technologies. They will develop an understanding of metallics, ceramics and polymers, including their properties and processes, such as mechanical, physical and thermal properties, and the effects that processes have on these.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

- 1 Understand mechanical systems
- 2 Understand materials in the rail environment
- 3 Understand the function of high voltage and low voltage switchgear.

Unit content

1 Understand mechanical systems

Lubricant purposes and types: purpose, e.g. reduction of frictional resistance, reduction of wear, heat dissipation, prevention of corrosion, prevention of contamination; types, e.g. mineral, vegetable and synthetic oils and greases, graphite, compressed gases, cutting fluids.

Lubrication systems and maintenance: operation of lubrication systems, e.g. gravity feed, forced feed, splash lubrication, capillary action, grease cups and nipples, grease packing, compressed air/gas bearings; maintenance, e.g. replenishment and renewal of lubricants, safe storage and handling.

Applications in the rail industry: e.g. motors and engines, transmission, machine tool, pump, compressor, wheel flange lubrication, switch point lubrication, electrical contact greases (overhead lines, pulley bearings and cables), fan bearings, axles.

Uses and applications of a range of engineering components: seals, e.g. rotary lip seals, mechanical seals, piston rings; packing, e.g. packed glands, gaskets, shims; bearings, e.g. plain journal, thrust, ball, roller (such as parallel or tapered), needle.

Fastenings: screwed fastenings, e.g. metric bolts, studs and set screws, self-tapping screws, locking devices; rivets, e.g. snap head, pan head and countersunk heads, bifurcated and pop rivets.

Applications in the rail industry: e.g. motors and engines, transmission systems, power collection equipment, overhead line infrastructure, track and point work, lineside equipment, signalling, machine tool, pump, compressor, mechanical systems involving rotation and fluid containment, maintenance and replacement.

Uses and operation of mechanical power transmission systems: cams and followers, e.g. radial plate cams, cylindrical cams, face cams, knife-edge followers, flat plate followers, roller followers; linkage mechanisms, e.g. cranks and sliders, four-bar linkage, Watt's linkage, Whitworth quick return motion; belt drives, e.g. flat, V-section, synchronous, tensioning device; chain drives, e.g. roller (such as single, duplex, triplex), Morse rocker joint, tensioning devices; gear trains, e.g. gear types (such as spur, helical, herring bone, bevel, spiral bevel, hypoid), simple, compound, worm, combinations, epicyclic.

Transmission and brakes: drive shafts and couplings, e.g. sections (such as solid, hollow), flanged couplings, splined couplings, angle couplings (such as Hooke universal, constant velocity); fluid couplings; torque converters; brakes, e.g. friction, disc, dynamometers (such as friction, fluid, electromagnetic), air brakes, vacuum brakes.

Actuation and handling systems: pneumatic and hydraulic actuation systems, e.g. system layout for automated plant and process operations, system components; safety and maintenance; mechanical handling systems, e.g. workshop gantry cranes, workstation jib cranes.

Steam, refrigeration and air conditioning plant service systems: steam power generation plant, e.g. system layout for power generation and process operations, system components, feedwater treatment, safety and maintenance; substations; refrigeration systems, e.g. system layout for vapour compression and absorption systems, refrigerants, system components, safety and maintenance; air conditioning systems, e.g. system layout for full summer and winter cycle air conditioning, system components, safety and maintenance.

2 Understand materials in the rail environment

Classification of materials: metals (ferrous, non-ferrous, alloy); polymers (thermosetting, thermoplastic); ceramics; composites.

Mechanical properties: strength (tensile, shear, compressive); hardness; toughness; ductility; malleability; elasticity; brittleness.

Physical properties: density; melting temperature.

Thermal properties: expansivity; conductivity.

Electrical and magnetic properties: conductivity; resistivity; permeability; permittivity.

Effects of processing metals: recrystallisation temperature; grain structure, e.g. hot working, cold working, grain growth; alloying elements in steel, e.g. manganese, phosphorous, silicon, sulphur, chromium, nickel.

Effects of processing thermosetting polymers: process parameters, e.g. moulding pressure and time, mould temperature, curing.

Effects of processing ceramics: e.g. water content of clay, sintering, pressing force, firing temperature.

Effects of processing composites: fibres, e.g. alignment to the direction of stress, ply direction; delamination; matrix/reinforcement ratio on tensile strength; particle reinforcement on cermets.

3 Understand the function of high voltage and low voltage switchgear

Tools: lifting beams, trolleys; maintenance tools, pumps, jacks; electrical test equipment, e.g. injection test sets, partial discharge test devices, dielectric strength oil analysers.

Application of track switchgear: high voltage, e.g. traction isolating switches; low voltage, e.g. track section switches, track isolating switches, circuit breakers.

Hazards associated with track switchgear: regulations, e.g. manual handling equipment, the Control of Substances Hazardous to Health (COSHH) 2002, personal protective equipment; oil; mechanical, e.g. mechanisms; gas, e.g. sulfur hexafluoride (SF₆), CO₂, carcinogenic issues.

Component failure modes and causes: switchgear failures, e.g. damage to mechanical parts; partial discharge, testing, e.g. air, gas, SF₆, hybrid, vacuum; protection-related failures, e.g. Buchholz relays, overcurrent earth fault, overpressure, lockout, treeing, low pressure, low vacuum; contact failures, e.g. main, rose, contact erosion; spring charge auxiliary contact failures; nanotechnology; failure modes, e.g. poor construction of conductive electrical components.

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P1 Describe the purpose and application of lubricants in the use of lubrication systems		
P2 Describe the operation of seals, packing and bearings.		
P3 Describe the operation of different types of cam and follower and linkage mechanisms	M1 Compare and contrast the operation of two different types of cam and follower and linkage mechanisms	
P4 Describe the arrangement and operation of locomotive drive and brakes		
P5 Describe the layout and operation of pneumatic actuation systems, hydraulic actuation systems and manual handling systems	M2 Compare and contrast operation of pneumatic actuation systems, in contrast to hydraulic actuation systems	D1 Evaluate a manual handling system, in comparison to pneumatic actuation systems or hydraulic actuation systems

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P6 Describe the layout and operation of power generation plant, refrigeration and air conditioning systems applied to substations.		
P7 Describe mechanical, physical, thermal, electrical and magnetic properties of materials used in rail engineering		
P8 Describe the effects of processing on the properties and behaviour of materials used in rail engineering	M3 Explain the effects on processing of the properties and the principles of the modes of failure of materials used in rail engineering	
P9 Describe the purpose, safe operation and maintenance of high and low voltage switchgear	M4 Explain the risks associated with maintenance activities on track switchgear and how these relate to switchgear component failure modes and causes	D2 Analyse a hazard associated with maintenance activities on track switchgear and how this relates to switchgear component failure modes and causes
P10 Describe switchgear component failure modes and causes		

Essential guidance for tutors

Assessment

Much of the evidence for the criterion can be achieved by practical activities, tutor-led sessions and visits to real environments to study maintenance techniques. It is likely that at least six assessment instruments will be required for this unit.

For P1 and P2, centres should consider a combined assignment activity, or have a series of closely linked tasks to describe the purpose and application of lubricants within the operation and maintenance of lubrication systems used in rail, for example switch point lubricators, and the operation of seals, packing and bearings.

For P3, learners should describe a minimum of two different types of cam follower and two different types of linkage system. For P4, learners should describe a minimum of one type of drive system, for example the use of torque converters, and one type of brake. These should be supported by annotated sketches.

For P5, learners should describe a pneumatic and hydraulic actuation system, for example the pantograph on an electric locomotive or multiple unit. They should create a system layout for an automated operation, showing all system components, with the correct notation, for example a 3/2 pilot operated, spring return, pneumatic valve.

For P6, learners should describe the layout and operation of power generation plant, refrigeration and air conditioning systems applied to substations. If it is safely possible, this could be linked to a visit to a substation.

P7 could be achieved by means of an assignment written following a combination of tutor-led practicals to explore the mechanical, thermal, electrical and magnetic properties of materials and related theory to the rail industry, for example in the selection of materials for the contact wire in the overhead catenary.

Assessment of P8 could involve learners in both practical and theoretical tasks in which they relate the effects of processing on the properties of materials with rail engineering applications, for example processes that alter the grain structure of steels due to hot or cold working.

To achieve P9, learners could research the purpose, operation and different applications of low voltage and high voltage switchgear. Learners need to select at least two different types of switchgear, such as gas or vacuum. Learners will also need to include reference to plant safety issues, for example residual voltages and electric shock, and specialist tooling requirements.

Criterion P9 and P10 can be linked in one task to both identify hazards and associated activities with component failure modes and their causes within switchgear. Learners will need to select at least two different types of switchgear, such as gas or vacuum.

To achieve a merit grade, learners must meet all of the pass grade criteria and the four merit criteria.

For M1, compare and contrast a minimum of two different types of cam follower and two different types of linkage system, linking these to an actual application or a rail industry use. These should be supported by annotated sketches.

For M2, learners should consider a typical rail-related pneumatic system and a hydraulic system and provide a comparison of the two systems, for example considering braking systems.

To address M3, learners will also consider the principles of failure and degradation processes and how these are reflected in local applications within a rail environment, for example rail defects, or defects in tracks, sleepers, or through a comparison of fatigue, ductile and brittle failures in the rail industry. Learners will need to highlight the appearance of these failures.

The task for P9 and P10 could be expanded to address M4, with learners explaining the hazards and associated activities with the component failure mode and causes within switchgear. This needs to be developed from the two different types of switchgear selected for P9 and P10.

To achieve a distinction grade, learners must meet all of the pass grade criteria, the four merit criteria and the two distinction grade criteria.

For D1, learners should evaluate a manual handling system in respect to a pneumatic or hydraulic system. Once again, these should come from real-world rail industry examples and could be linked to the tasks for P5 and M2. This could relate to maintenance of rolling stock and the use of hoists and lifts.

For D2, a single switchgear system, such as oil, needs to be selected and will be, preferably, different to the selections for P9, P10 and M4. Learners will then analyse the hazard and associated activities with the component failure mode and cause within a switchgear system.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1 and P2	The Purpose and Types of Lubrication System, and their Maintenance	Explore the application of various lubrication systems, including seals, bearings and gaskets, in an engineering environment, and investigate the required maintenance activities.	A written report providing the learner's interpretation of the information and features found. Engineering sketches prepared by the learner.
P3, P4, M1	The Uses and Operation of Mechanical Power Transmission Systems	Consider the movements of mechanical power transmission systems, through their interconnecting components.	A written report providing the learner's interpretation of the information and features found. Engineering sketches prepared by the learner.
P5, M2, D1	Pneumatic, and Hydraulic Actuation and Manual Handling Systems	Explore the application of various pneumatic, and hydraulic actuation and manual handling systems through their interconnecting components.	A written report with suitable reference to application of various pneumatic, and hydraulic actuation and manual handling systems.

Criteria covered	Assignment title	Scenario	Assessment method
P6	The Layout and Operation of Power Generation Plant, Refrigeration and Air Conditioning Systems Applied to Substations.	Explore the layout and operation of various power generation plant, refrigeration and air conditioning systems applied to substations.	A written report with suitable reference to the layout and operation of various power generation plant, refrigeration and air conditioning systems.
P7, P8, M3	The Effects of Processing on the Properties and the Principles and how these Affect the Modes of Failure of Materials Used in Rail Engineering	Investigate the effects on processing of the properties and the principles of the modes of failure of materials used in rail engineering.	An investigative report, with suitable reference to processing, on the properties and the principles of the modes of failure of materials, including examples, annotated photographs and sketches.
P9, P10, M4, D2	The Function of High Voltage and Low Voltage Switchgear	Investigate the purpose, operation and application of switchgear to plant safety and the requirement to use specialist tools.	An investigative report, with suitable reference to purpose, operation and application of switchgear to plant safety, including examples, annotated photographs and sketches.

Essential resources

Access to laboratories, mechanical and electrical/electronic equipment, workshops, supporting information and communication technology resources (including the internet) is essential for the delivery of this unit, as is a well-stocked source of reference material.

Indicative reading for learners

Textbooks

Bird J O – *Electrical and Electronic Principles and Technology* (Newnes, 2004)
ISBN 0750665505

Bird J O – *Electrical Circuit Theory and Technology* (Newnes, 2004)
ISBN 0750657847

Bonnett C – *Practical Railway Engineering* (Imperial College Press, 2005)
ISBN 1860945155

Higgins R – *Materials for Engineers and Technicians* (Newnes, 2006)
ISBN 0750668504

Robertson C R – *Fundamental Electrical and Electronic Principles*
(Butterworth-Heinemann, 2001) ISBN 0750651458

Timings R L – *Engineering Materials, Volume 1* (Longman, 1998) ISBN 0582319285

Timings R L – *Engineering Materials, Volume 2* (Longman, 2000) ISBN 0582404665

Tooley M and Dingle L – *BTEC National Engineering* (Routledge, 2010)
ISBN 9780123822024

Unit 10: Electronic Measurement and Testing

Level:	3
Unit type:	Additional
Guided learning hours:	60

Unit introduction

Practical electronic engineering demands the extensive use of electronic test equipment and measurement techniques. These range from basic measurements of parameters such as voltage, current and resistance to highly sophisticated software-controlled measurements based on advanced mathematical techniques such as fast Fourier transformation (FFT). Particular attention has to be paid to ensure that the test procedure, as well as the test and measurement equipment used, is fit for purpose and properly calibrated.

This unit will give learners an understanding of a range of electronic measurement equipment such as voltmeters, ammeters, analogue/digital multimeters and oscilloscopes or specialist diagnostic equipment. Learners will examine electronic test equipment such as the signal generator, digital counter/frequency meter, alternating current (AC) bridge, logic probe, logic pulsar and current tracer. They will develop an understanding of the function, features and characteristics of electronic measurement and test equipment. They will also gain practical experience of their use when carrying out electronic testing and measurements in a wide range of electronic engineering applications. This will include selecting, connecting and operating different types of test equipment and applying measurement techniques.

Learners will have the opportunity to apply common testing methods and assess errors inherent in the instruments used. They will be expected to explain the effects of instrument characteristics such as accuracy, display resolution and loading and how these affect the measured quantity. Additionally, learners will be introduced to the use of virtual test instruments and software to make measurements and analyse measurement data. They will examine equipment such as a digital storage oscilloscope, spectrum analyser, digital voltmeter, digital frequency meter, arbitrary waveform generator or logic analyser. Learners will be expected to make measurements using virtual instruments and analyse the captured data using appropriate software.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

- 1 Understand the function, features and characteristics of electronic measurement and test equipment
- 2 Be able to select and use electronic measurement and test equipment to make meaningful measurements on an electronic circuit
- 3 Know the principles of calibration and configuration of electronic test equipment
- 4 Be able to select and use virtual test instruments and software to make measurements and analyse measurement data.

Unit content

1 Understand the function, features and characteristics of electronic measurement and test equipment

Function of equipment: as appropriate to the measurement and test equipment, e.g. accurate measurement of alternating current (AC) and direct current (DC) voltage and current, resistance, waveform and distortion measurement, accurate measurement of waveform parameters (period, duty cycle, on-time, off-time, rise time, fall time, frequency, pulse repetition frequency (PRF), impedance, logic level).

Features of equipment: as appropriate to the measurement and test equipment, e.g. displays and display technology, input and output connectors, attenuators, manual and automatic range selection (autoranging), in-built calibration facilities, portability, power sources, external bus interfaces.

Characteristics of equipment: measurement and test equipment specifications, e.g. input impedance, output impedance, resolution, accuracy, distortion, bandwidth, input signal range, output level, sample rate, trigger sources.

Measurement instruments: meters (voltmeter, ammeter); analogue/digital multimeter; oscilloscope, to include specialist or manufacturer diagnostic/measuring equipment.

Electronic test equipment: signal generator, e.g. audio frequency (AF), radio frequency (RF) and pulse generators, waveform/function generators; digital counter/frequency meter; AC bridge; logic probe; logic pulsar; current tracer.

2 Be able to select and use electronic measurement and test equipment to make meaningful measurements on an electronic circuit

Selection of equipment: selection based on instrument specifications, characteristics and limitations, e.g. output, level, input sensitivity, frequency range, accuracy, resolution and distortion.

Measurement techniques: test-point voltage and waveform measurement; supply voltage and current measurement; power, impedance and phase angle measurement using variable loads; frequency and PRF measurement; rise and fall time measurement; distortion and noise measurement (qualitative only); use of test specifications, e.g. in the case of a variable DC power supply, measurement of the actual output voltage delivered at a specified load current when the power supply has been set to a specified voltage under no-load conditions; in the case of an audio amplifier, measurement of the output power delivered to an externally connected load of specified resistance, using a specified test frequency and waveform and at a specified level of distortion.

Measurements: use of test points, test leads and probes; minimisation of loading effects; use of appropriate instrument ranges; precautions to be taken when measuring high voltages and currents; precautions to be taken when working on low voltage and computerised systems; effect of DC levels on AC signals and waveforms; effect of signals present at DC test points; effect of drift and temperature; need for calibration; relevant test specification and measurement techniques, e.g. sampling, averaging.

Electronic equipment: industrial/consumer electrical and electronic equipment, including low-voltage DC power supplies, e.g. linear, switched-mode types; amplifiers, e.g. AF, RF, small-signal, power; oscillators, e.g. sinusoidal, square wave, crystal controlled; radio equipment, e.g. radio receivers, low-power transmitters and transceivers; digital electronic equipment, e.g. microcontrollers, microcomputers, programmable logic controllers; manufacturer specific equipment; video equipment, e.g. television and video players/recorders.

3 Know the principles of calibration and configuration of electronic test equipment

Calibration principles: procedures, e.g. check, adjust, systematically standardise measuring instrument, set-up arrangement; reference standards, e.g. standard resistors, standard inductor; theory, e.g. accuracy, uncertainty; impact of calibration on quality, productivity and safety; applications, e.g. during manufacture, following installation, periodic scheduled maintenance, in response to identified deviation, after repair or change in environment; terminology, e.g. zero shift, range (or span) error, combined zero shift and range error, non-linearity.

Health and safety issues: e.g. precautions to be observed when setting and adjusting mains supply voltages, replacing/charging/disposing of batteries, dismantling and reassembling equipment, removal/replacement of external and internal covers, making adjustments on 'live' equipment, continuity of earth (grounding or bonding) of electrical equipment, safety cut-outs and residual current device (RCD), earth leakage circuit breaker (ELCB).

Configuration issues: pre-conditions and checks to ensure that system/equipment is safe to test and instruments safe to use; test equipment set-up, e.g. use of the equipment manufacturer's procedures, using commissioning guides.

4 Be able to select and use virtual test instruments and software to make measurements and analyse measurement data

Virtual measurement and test system: e.g. digital storage oscilloscope, spectrum analyser, digital voltmeter, digital frequency meter, arbitrary waveform generator, logic analyser.

Measurement techniques, connection, hardware and software: tests carried out on electronic equipment using virtual test and measuring instruments; instrument connection, e.g. external/internal PC interface, instrument connection standards (parallel port, serial port, USB, PCI/PXI bus, IEEE-488, PCMCIA); use of hardware and software to carry out measurements, e.g. voltage, frequency, frequency spectra measurements (for sinusoidal and non-sinusoidal waveforms); measurement software, data storage and data transfer, e.g. to a spreadsheet, automated measurement/data collection techniques.

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P1 Explain the function, features and characteristics of a measurement instrument		
P2 Explain the function, features and characteristics of three different pieces of electronic test equipment		
P3 Select and use test equipment and measuring techniques to take measurements from three different pieces of electronic equipment	M1 Use a manufacturer's recommended procedure, together with laboratory instruments and standards, to calibrate and configure an item of electronic test equipment	D1 Evaluate the accuracy of own test measurements and relate them to limitations of the test equipment, test procedures, or possible emerging fault conditions
P4 Explain the importance of test specifications as an aid to ensuring the validity and consistency of measurements		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P5 Describe the principles and need for the calibration of an item of electronic test equipment	M2 Explain the importance of resolution, accuracy, sensitivity bandwidth and input impedance on the performance of a piece of test equipment	D2 Devise and demonstrate a calibration procedure for an item of electronic test equipment.
P6 Explain the health, safety and configuration issues that need to be considered when connecting test equipment to an item of electronic equipment that requires testing		
P7 Use a virtual measurement and test system to carry out a test on a piece of electronic equipment		
P8 Describe the measurement techniques, instrument connection, hardware and software used.	M3 Use appropriate software to display and analyse voltage/ time data captured from a virtual oscilloscope.	

Essential guidance for tutors

Assessment

To achieve P1 and P2, learners will need to describe the function, features and characteristics of one measurement instrument and three different pieces of electronic test equipment. The evidence for this could be block diagrams/sketches (with appropriate annotation) and short notes. The actual function, features and characteristics explained will be dependent on the electronic test equipment selected, but examples of the types of things to consider are given in the unit content.

P3 requires learners to select and use test equipment and measuring techniques to take measurements from three different pieces of electronic equipment. These can be low-voltage DC power supplies, amplifiers, oscillators, radio equipment, digital electronic test, measurement or diagnostic equipment or display equipment. Further examples of each of these are provided in the unit content.

Learners will need to perform practical measurements in an electronic laboratory or electronic workshop. Given a particular measurement requirement (for example to investigate the frequency range of an oscillator), learners should then select the appropriate items of test and measurement equipment to carry out the task. Both the selected item(s) of test equipment and the measuring technique(s) should be appropriate to each measured quantity. For example, an oscilloscope and $\times 10$ probe would not be appropriate for the accurate measurement of the output frequency produced by an oscillator. The three different pieces of electronic equipment should enable as wide a range of test equipment and measuring techniques to be applied as possible. All three pieces could come from one category (for example consumer electrical and electronic equipment) as long as the chosen equipment enables the use of a sufficient range of test equipment and measuring techniques. It is expected that all the content listed under measurement techniques and measurements will have been covered by the time learners have carried out the measurements on all three pieces of equipment.

Evidence for P3 is likely to take the form of tutor observations and learners' records of the selection and use of equipment and techniques employed. Suitably annotated photographic records could also be used (for example a photograph of the equipment being tested, the test equipment and the test set-up, all suitably labelled to highlight the key features of the test/measurements).

For P4, learners should provide a written or verbal presentation to explain the importance of test specifications as an aid to ensuring the validity and consistency of measurement. Centres should ensure that learners have access to a variety of test specifications for common measurements (for example determining the output impedance of a power supply by voltage/current measurement when a suitably rated variable load is applied). The achievement of this criterion could be effectively linked with the practical work in any one of the tests carried out for P3.

P5 requires learners to describe the principles and need for calibration of an item of electronic test equipment. Again, one of the tests undertaken for P3 could provide the focus for this criterion. The description, which is likely to be a written report, must include the electronic test equipment calibration procedures that need to be carried out, the reference standards required and any relevant theory. Examples of each of these and typical applications are given in the unit content. As an aid to understanding the calibration process, centres should demonstrate the calibration procedures for equipment used in the laboratory (for example oscilloscopes, digital multimeters, signal generators, etc.)

For P6, learners must describe the health, safety and configuration issues that need to be considered when connecting test equipment to an item of electronic equipment that requires testing. The health and safety issues considered will depend on the equipment being tested. The configuration issues considered must, as a minimum, enable learners to take into account the required pre-conditions and checks to ensure that it is safe to test the system/equipment, for example the selection of an adequately rated load in terms of both impedance and power rating when testing an audio amplifier or the need to check that an oscilloscope probe is correctly matched to the oscilloscope that it is to be used with. Learners will also need to ensure instruments are safe to use (for example use of a high-voltage probe when measuring DC voltages in excess of 500 V) and test equipment set-up correctly, for example use of equipment manufacturer's procedures, using commissioning guides. Again, it would make sense to link this criterion to one of the tests undertaken for P3.

To satisfy P7 and P8, learners should use a virtual measurement and test system to carry out a test on a piece of electronic equipment. They should provide a written or verbal description of the procedure used, explaining the connections made, the software settings, and the measuring techniques used. A typical example would be the use of a virtual digital storage oscilloscope used in conjunction with a personal computer (PC). Learners should connect and configure the instrument in conjunction with the software running on the PC and select, for example, appropriate sampling rates, input ranges and display and data capture settings. Evidence of an individual learner's work can most conveniently be presented in the form of a selection of screen dumps that have been suitably annotated by the learner.

For M1, learners are required to calibrate and configure a test instrument (such as a waveform generator), using the manufacturer's recommended procedures and appropriate laboratory instruments and standards. Learners should be supplied with relevant documentation (for example manufacturer's handbook) and laboratory standards (such as a standard frequency or time generator). Evidence is likely to be a logbook record of the calibration exercise or a technical report of the calibration activity. Tutor observation records should be used to support either of these forms of evidence. There is a clear link between this merit criterion and P5.

To achieve M2, learners need to explain the importance of resolution, accuracy, sensitivity bandwidth and input impedance on the performance of a piece of test equipment. This could be achieved as a natural extension to one of the tasks carried out for P3.

To satisfy M3, learners should use a virtual storage oscilloscope (using a PC with appropriate interface hardware and software) to display and analyse a waveform. Note that the emphasis should be on the analysis of the waveform rather than its display. A typical example might involve the production of a frequency spectrum for the sampled waveform using FFT techniques. Once again, learners should keep a record of their work in a logbook, supported by tutor observation records. Relevant screen dumps and printouts that have been suitably annotated by the learner could also be incorporated.

Learners' work towards D1 should require them to evaluate the accuracy of their own test measurements and relate them to limitations of the test equipment, test procedures, or possible emerging fault conditions. For example, learners should be aware of the inability of an oscilloscope to accurately display a transient pulse due to the oscilloscope's own finite rise time and bandwidth. Another example would be the need to be aware of the effects of aliasing on the captured and displayed waveform when sampling a fast waveform.

For D2, learners need to devise and demonstrate a calibration procedure for an item of electronic test equipment. A typical example might be a procedure to calibrate a $\times 10$ oscilloscope probe using a fast rise time square wave generator, a high-speed oscilloscope, and a matching $\times 10$ probe. Evidence is likely to be in the form of a technical report although it would be beneficial if the devised calibration could be linked into the work done for P5 and M2.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2	Measurement Instruments and Test Equipment	Learners are requested to generate an information booklet and an accompanying report for new staff.	A written assignment.

Criteria covered	Assignment title	Scenario	Assessment method
P3, P4, P5, P6, M1, M2, D1, D2	Selecting, Using and Calibrating Electronic Test Equipment	Learners have been asked to show a new learner how to take measurements from electronic equipment and talk them through the calibration of test equipment and relevant health, safety and configuration issues.	A practical assignment with additional written tasks.
P7, P8, M3	Virtual Testing	Learners have been asked by their employer to carry out tests on a piece of electronic equipment.	A practical assignment.

Essential resources

Centres will need to provide access to an electronics laboratory fitted with a range of electronic test and measurement equipment (such as multimeters, signal generators, oscilloscopes, or specialist manufacturer equipment within industry etc.) A limited number of specialist items of electronic test equipment and calibration sources (for example, standard cells and off-air signal sources) should also be available. Specialist items of electronic equipment (such as AC bridges, earth continuity testers, logic analysers, component testers etc.) may be required as appropriate to the needs of local industry.

A small number of computer-based virtual instruments should also be available together with the appropriate hardware and software (for example LabVIEW, DASyLab, DADiSP, MATLAB etc.) Test and measurement applications should be installed on these systems.

Indicative reading for learners

Textbooks

Hughes E – *Electrical and Electronic Technology* (Pearson Education, 2012)
ISBN 9780273755104

Tooley M – *Electronic Circuits: Fundamentals and Applications* (Routledge, 2006)
ISBN 9780750669238

Tooley M – *PC Based Instrumentation and Control* (Routledge, 2005)
ISBN 9780750647168

Unit 11: Further Electrical Principles

Level:	3
Unit type:	Additional
Guided learning hours:	60

Unit introduction

Electrical technicians need to apply practical and theoretical principles of electrical engineering to the development, manufacture and servicing of complex electrical and electronic systems. They can expect to perform technical functions involved in assembling, installing, repairing and maintaining electrical equipment. These could include the calibration, prototyping, modification and general maintenance of electrical equipment in accordance with manufacturer's instructions and company technical procedures. Other tasks could include using electrical test equipment on various types of instruments, equipment and systems and replacing faulty components and parts using safe working practices and precision instruments.

The unit will extend learners' understanding of simple direct current (DC) circuits that can be solved by Ohm's law and Kirchhoff's laws. This will require learners to apply advanced circuit analysis theorems such as Thévenin's, Norton's and the maximum power transfer theorems for DC networks. Learners will also develop their understanding of DC transients and of series and parallel alternating current (AC) circuits. They will consider series and parallel circuits that include resistors (R), inductors (L) and capacitors (C) in AC circuits. The unit will also introduce learners to the theory and advantages of three-phase AC systems. This will include power measurements in a three-phase AC system and the construction and principles of operation of a three-phase AC induction motor.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

- 1 Be able to apply direct current (DC) circuit analysis methods and consider the types, construction and characteristics of a DC motor and generator
- 2 Understand the transient behaviour of resistor-capacitor (RC) and resistor-inductor (RL) DC circuits
- 3 Be able to apply single-phase alternating current (AC) theory
- 4 Be able to apply three-phase alternating current (AC) theory.

Unit content

1 Be able to apply direct current (DC) circuit analysis methods and consider the types, construction and characteristics of a DC motor and generator

Direct current (DC) circuit theorems: Thévenin's theorem, e.g. application of theorem to a parallel circuit having two sources of electromotive force (emf) and three resistors; Norton's theorem, e.g. application of theorem to a parallel circuit having two sources of emf and three resistors; maximum power transfer theorem, e.g. application of theorem to a series circuit with a source of emf, internal resistance and a load resistor; application to a more complex circuit where Thévenin needs to be applied first.

Direct current (DC) motor: type, e.g. shunt, series, compound; construction, e.g. windings, motor starter circuits, speed control (series resistance in the armature circuit); characteristics, e.g. emf-generated, torque, back emf, speed and power, efficiency.

Direct current (DC) generator: type, e.g. separately-excited, shunt, series compound; construction, e.g. main frame or yolk, commutator, brushes, pole pieces, armature, field windings; characteristics, e.g. generated voltage/field current (open circuit characteristics), terminal voltage/load current (load characteristic), $V = E - I_a R_a$

2 Understand the transient behaviour of resistor-capacitor (RC) and resistor-inductor (RL) DC circuits

Transient behaviour of RC circuit: variation of current and voltage with time when charging/discharging; time constant; graphical determination of growth and decay of voltage and current when charging/discharging; practical RC circuit to demonstrate transient behaviour; demonstrate the effect of the circuit time constant on a rectangular waveform, e.g. integrator and differentiator circuits; calculations, e.g. time constant, growth of capacitor voltage, initial and steady state values of current, decay of resistor voltage.

Transient behaviour of RL circuit: variation of current and voltage with time when connected/disconnected to a DC voltage source; time constant; graphical determination of growth and decay of current and voltage when connected/disconnected to a DC voltage source; practical RL circuit to demonstrate transient behaviour; calculations, e.g. time constant, growth of current, decay of induced voltage, current decay.

3 Be able to apply single-phase alternating current (AC) theory

Series R, L and C alternating current (AC) circuits: current and phase angle in series combinations of RLC circuits (RL, RC, RLC); construction of phasor diagrams and relationship with voltage and impedance triangles for each of the three types of R, L and C combinations; power factor ($\cos\Phi$) and power triangle, e.g. apparent power ($S = VI$), true or active power ($P = VI\cos\Phi$) and reactive power ($Q = VI\sin\Phi$); conditions for series resonance, e.g. inductive reactance equals capacitive reactance ($X_L = X_C$); Q factor (voltage magnification), e.g.

$$Q = \frac{V_L}{V}, Q = \frac{1}{R} \sqrt{\frac{L}{C}} \text{ and its importance in high and low frequency circuits.}$$

Parallel: evaluation of the voltage, current and phase angle in parallel combinations of resistance, inductance and capacitance, e.g. RL, RC, LC and RLC; construction of phasor diagrams for impedance and phase angle; conditions for parallel resonance in an RLC circuit, e.g. supply current and voltage in phase;

impedance at resonance, e.g. dynamic resistance $R_D = \frac{L}{CR}$;

Q factor (current magnification), e.g. $Q = \frac{I_C}{I}$; filter circuits, e.g. high pass, low pass, band pass, band stop.

4 Be able to apply three-phase alternating current (AC) theory

Three-phase AC theory: principles of single-phase and three-phase supplies, e.g. rotation of a single coil in a magnetic field, rotation of three identical coils fixed 120° apart in a magnetic field; star and delta methods of connection for power distribution systems; three and four wire systems; voltage relationships for star and delta connections under balanced conditions of load; calculation of power in balanced and unbalanced three-phase loads, e.g. $P = \sqrt{3}V_L I_L \cos\theta$,

$$P = 3I_p^2 R_p$$

Power measurements in a three-phase AC system: e.g. delta system – one wattmeter method, star system – two wattmeter method.

Three-phase AC induction motor: construction, e.g. stator, rotor, poles; principle of operation e.g. production of torque, synchronous speed, number of poles, starting methods, characteristics (speed/torque/efficiency versus current curves); concept of a rotating magnetic field, e.g. application of a three-phase supply to the stator windings, flux generated by each phase of the stator winding.

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P1 Use DC circuit theorems to solve one circuit problem using Thévenin's theorem, one using Norton's theorem and one using the maximum power transfer theorem for DC networks	M1 Explain the need for a DC motor starter and discuss its operation	
P2 Explain the construction and characteristics of a DC motor and a DC generator		
P3 Explain the transient behaviour of current and voltage in an RC circuit, verifying through calculation		
P4 Explain the transient behaviour of current and voltage in an RL circuit, verifying through calculation		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P5 Use single-phase AC theory to calculate the current, voltage, impedance, power and phase angle in one of each of the series combinations of R, L and C circuits		
P7 Use single-phase AC theory to calculate the input current, voltage, impedance and phase angle for a parallel combination of R, L and C	M2 Discuss the advantages of power factor correction in an RLC circuit for a commercial consumer, giving a practical example by reference to specific calculations	D1 Analyse the effects of resonance and Q factor in both a series RLC and a parallel RLC circuit
P6 Investigate the performance of two filter circuits experimentally		
P8 Use three-phase theory to explain the advantages of three-phase systems and star and delta methods of connection	M3 Compare two different methods of power measurement in a three-phase system for both balanced and unbalanced loads.	D2 Evaluate the performance of a three-phase induction motor by reference to electrical theory.
P9 Carry out a practical power measurement on a three-phase system		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P10 Describe the construction, principle of operation and concept of a rotating magnetic field of a three-phase AC inductor motor.		

Essential guidance for tutors

Assessment

A good deal of the assessment evidence for this unit can be achieved by practical experimentation, with real components and circuits and/or computer-based software packages where appropriate.

Because of the nature of the learning outcomes and unit content, up to six assessment instruments may be required. If a structured programme of practical work and short tests is also used, then the actual total number of pieces of assessed work could be even more than this. However, careful consideration should be given when designing the assessment not to place an unduly high assessment burden on learners or the tutor. Wherever possible, practical work should lead to a final product that can be assessed without further need for report writing.

Practical activities in the laboratory will need careful supervision. Tutors can capture this evidence by using appropriate records of observation and oral questioning for each learner.

For P1, learners will need to solve circuits involving Thévenin's theorem, Norton's theorem and the maximum power transfer theorem. Before attempting this criterion, learners could be introduced to the idea of a constant voltage source and a constant current source by using a suitable practical demonstration. Further development of this could lead to the link between Thévenin and Norton and then on to the use of Thévenin, before applying the maximum power transfer theorem.

P2 involves the explanation and comparison of a motor and a generator. Learners could possibly be shown actual motors/generators and be issued with incomplete diagrams for completion and annotation.

P3 and P4 require learners to explain the transient behaviour of current and voltage in an RC and an RL circuit both practically and theoretically. Use of a simple bread-boarding technique for both criteria would be ideal here.

For both P5 and P7, an in-class assessment involving the evaluation of current, voltage, impedance and phase angle could be utilised. Learners could be given different circuit values and be encouraged to check their answers with a suitable software programme.

The investigation of the performance of two filter circuits (P6) could be achieved by using a signal generator with a low voltage output ($V_{IN} = IV$) connected to an RC network. Learners could then measure the output (V_{OUT}) as the frequency is raised from, for example, 100 Hz to 10 000 Hz.

P8 requires learners to explain the advantages of three-phase systems (for example smaller conductors, two available voltages). The latter of these leads into the two forms of connection (star and delta). Assessment could take the form of an incomplete handout to be submitted at the end of a lecture or film about the advantages and forms of connection.

P9 requires learners to carry out practical power measurements in three-phase systems. A suitable three-phase resistance load bank together with a three-phase, four wire low voltage supply and three wattmeters could be used to enable learners to measure the power using one, two and three wattmeters for the different configurations.

Evidence for P10 is likely to be in the form of an investigative report. Again, it may be helpful to give learners an incomplete diagram for them to complete and annotate. For the principles of operation and concept of a rotating magnetic field of a three-phase induction motor it may be necessary to include a number of key words (e.g. synchronous speed, pairs of poles) and point to one specific type of three-phase induction motor (e.g. squirrel-cage rotor).

All except the smallest of motors require some type of starter to prevent heavy currents being drawn from the supply on starting. M1 is intended to evaluate this requirement in detail and consider the need for a DC motor starter (e.g. DC faceplate starter) and to discuss its operation. It is expected that learners will draw from the work done at pass and produce a referenced technical report, supported by a suitably labelled diagram to aid their discussion of the operation.

For M2, learners need to discuss the advantages of power factor correction in an RLC circuit for a commercial consumer, giving a practical example by reference to specific calculations. These could include reduced cost to the consumer with reference to a practical example. This could follow a practical demonstration of how the supply current reduces on the introduction of power factor correction, but can increase if over-corrected. M3 could be linked to the practical carried out for P9.

The analysis of the effects of resonance and Q factor in both a series RLC and a parallel RLC circuit (D1) builds on and could be linked to P5 and P7. Evidence for D1 could also be provided by considering the difference in resonance frequency, for example when the value of the resistance is varied.

D2 requires learners to evaluate the performance of a three-phase induction motor by reference to electrical theory, for example squirrel cage by reference to electrical theory. This could be achieved practically by using appropriate experimental rigs that allow the learner to compare their results with the known characteristics for specific machines.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1	DC Circuit Analysis and Generators	An activity requiring learners to complete three tasks that together solve circuit problems, compare a DC motor and generator, and evaluate the performance of a three-phase induction motor.	A report containing solutions to circuit theorems and written responses about DC motor/generator and three-phase induction motor characteristics. Carried out under controlled conditions.
P3, P4	DC Transients	A written activity that requires learners to explain the transient behaviour of an RC and RL circuit with a numerical verification.	A report containing written responses about the transient behaviour of RC/RL circuits supported by numerical calculations carried out under controlled conditions.
P5, P7, M2, D1	AC Single-Phase Series and Parallel Circuits	A written activity requiring learners to carry out calculations relating to the behaviour of series and parallel R, L and C single-phase AC circuits.	A report containing the results of calculations to determine specific parameters of series and parallel R, L and C single-phase AC circuits carried out under controlled conditions.
P6	Filter Circuits	A practical investigation for learners to measure the response of two simple filter circuits.	A report containing written responses and graphical evidence regarding the response of simple filter circuits.

Criteria covered	Assignment title	Scenario	Assessment method
P8, P9, M3, D2	Three-phase AC Theory	A combined written and practical activity requiring learners to explain the advantages of three-phase systems, the star and delta method of connection followed by a practical power measurement with a comparison of two different methods for both balanced and unbalanced loads together with an evaluation of its performance.	A report containing written responses to the advantages of three-phase systems, an illustration of the methods of connection and measurements of the practical work carried out.
P10	Three-phase AC Induction Motor	A written activity describing the construction, operation and concept of a rotating magnetic field for a three-phase (AC) induction motor.	A report containing neat diagrams and descriptions relating to a three-phase (AC) induction motor.

Essential resources

Learners will need access to a well-equipped electrical/electronics laboratory with up-to-date instruments such as digital/analogue multimeters, function generators and oscilloscopes. Centres will also need to provide appropriate circuit components as identified in the unit content together with the means to physically construct circuits.

Centres are strongly advised to consider the provision of suitable hardware and software to enable the use of computer-based methods for circuit design and simulation.

Indicative reading for learners

Textbooks

Bird J O – *Electrical and Electronic Principles and Technology* (Routledge, 2013)
ISBN 9780415662857

Bird J O – *Electrical Circuit Theory and Technology* (Routledge, 2013)
ISBN 9780415662864

Robertson C R – *Further Electrical and Electronic Principles* (Routledge, 2008)
ISBN 9780750687478

Unit 12: Properties and Applications of Engineering Materials

Level:	3
Unit type:	Additional
Guided learning hours:	60

Unit introduction

In-depth knowledge of the structure and behaviour of engineering materials is vital for anyone who is expected to select or specify them for applications in the engineering industry.

This unit will give an understanding of the structures, classifications and properties of materials used in engineering and will enable learners to select materials for different applications. It is appropriate for learners engaged in manufacturing and mechanical engineering, particularly where materials are sourced in the form of stock to be used in a production process. The unit covers a range of materials - some of which learners may not be familiar with initially – and learners will have the opportunity to identify and describe the structures of metals, polymers, ceramics and composites, classifying them according to their properties. They will describe the effects of processing on the behaviour of given materials, also investigating smart materials whose properties can be altered in a controlled fashion through external changes such as temperature and electric and magnetic fields.

Learners will apply their understanding of the physical and mechanical properties of materials, design requirements, cost and availability to specify materials for given applications. All materials have limits beyond which they will fail to meet the demands placed on them. The common modes of failure will be both demonstrated and explained to enable learners to recognise where an informed choice can make the difference between the success or failure of a product.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

- 1 Know the structure and classification of engineering materials
- 2 Understand material properties and the effects of processing on the structure and behaviour of engineering materials
- 3 Be able to use information sources to select materials for engineering uses
- 4 Understand about the modes of failure of engineering materials.

Unit content

1 Know the structure of and classification of engineering materials

Atomic structure: element; atom, e.g. nucleus, electron; compound; molecule; mixture; bonding mechanisms, e.g. covalent, ionic, metallic.

Structure of metals: lattice structure; grain structure; crystals; crystal growth; alloying, e.g. interstitial, substitutional; phase equilibrium diagrams, e.g. eutectic, solid solution, combination; intermetallic compounds.

Structure of polymeric materials: monomer; polymer; polymer chains, e.g. linear, branched, cross-linked; crystallinity; glass transition temperature.

Structure of ceramics: amorphous; crystalline; bonded.

Structure of composites: particulate; fibrous; laminated.

Structure of smart materials: crystalline; amorphous; metallic.

Classification of metals: ferrous, e.g. plain carbon steel, cast iron (grey, white, malleable, wrought iron), stainless and heat-resisting steels (austenitic, martensitic, ferritic); non-ferrous, e.g. aluminium, copper, gold, lead, silver, titanium, zinc; non-ferrous alloys, e.g. aluminium-copper heat-treatable – wrought and cast, non-heat-treatable – wrought and cast, copper-zinc (brass), copper-tin (bronze), nickel-titanium alloy.

Classification of non-metals (synthetic): thermoplastic polymeric materials, e.g. acrylic, polytetrafluoroethylene (PTFE), polythene, polyvinyl chloride (PVC), nylon, polystyrene; thermosetting polymeric materials, e.g. phenol-formaldehyde, melamine-formaldehyde, urea-formaldehyde; elastomers; ceramics, e.g. glass, porcelain, cemented carbides; composites, e.g. laminated, fibre-reinforced (carbon fibre, glass-reinforced plastic (GRP), concrete, particle-reinforced, sintered; smart materials, e.g. electro-rheostatic (ER) fluids, magneto-rheostatic (MR) fluids, piezoelectric crystals.

Classification of non-metals (natural): e.g. wood, rubber, diamond.

2 Understand material properties and the effects of processing on the structure and behaviour of engineering materials

Mechanical properties: strength (tensile, shear, compressive); hardness; toughness; ductility; malleability; elasticity; brittleness.

Physical properties: density; melting temperature.

Thermal properties: expansivity; conductivity.

Electrical and magnetic properties: conductivity; resistivity; permeability; permittivity.

Effects of processing metals: recrystallisation temperature; grain structure, e.g. hot working, cold working, grain growth; alloying elements in steel, e.g. manganese, phosphorous, silicon, sulphur, chromium, nickel.

Effects of processing thermoplastic polymers: polymer processing temperature; process parameters, e.g. mould temperature, injection pressure, injection speed, mould clamping force, mould open and closed time.

Effects of processing thermosetting polymers: process parameters, e.g. moulding pressure and time, mould temperature, curing.

Effects of processing ceramics: e.g. water content of clay, sintering pressing force, firing temperature.

Effects of processing composites: fibres, e.g. alignment to the direction of stress, ply direction; delamination; matrix/reinforcement ratio on tensile strength; particle reinforcement on cermets.

Effects of post-production use: smart materials, e.g. impact (piezoelectric), electric field (electro-rheostatic), magnetic field (magneto-rheostatic), temperature (shape memory alloys), colour change (temperature or viscosity).

3 Be able to use information sources to select materials for engineering uses

Information sources: relevant standard specifications, e.g. British Standards (BS), European Standards (EN), International Standards (ISO); material manufacturers' and stockholders' information, e.g. data sheets, catalogues, websites, DVDs.

Design criteria: properties, e.g. mechanical, physical, thermal, electrical and magnetic; surface finish; durability, e.g. corrosion resistance, solvent resistance, impact resistance, wear resistance.

Cost criteria: initial cost, e.g. raw material, processing, environmental impact, energy requirements; processing, e.g. forming, machining, casting, joining (thermal, adhesive, mechanical); quantity; mode of delivery. e.g. bulk, just-in-time (JIT); recycling.

Availability criteria: standard forms, e.g. sheet and plate, bar stock, pipe and tube, sectional, extrusions, ingots, castings, forgings, pressings, granular, powder, liquid.

4 Understand about the modes of failure of engineering materials

Principles of ductile and brittle fracture: effects of gradual and impact loading, e.g. tensile, compressive, shear; effects of grain size; transition temperature; appearance of fracture surfaces.

Principles of fatigue: cyclic loading; effects of stress concentrations, e.g. internal, external; effects of surface finish; appearance of fracture surfaces.

Principles of creep: primary; secondary; tertiary; effects of temperature; strain versus time curve; creep limit; effect of grain size; effect of variations in the applied stress.

Tests: destructive, e.g. tensile, hardness, impact, ductility, fatigue, creep; non-destructive, e.g. dye penetrant, ultrasonic, radiographic (x-ray, gamma ray), magnetic powder, visual.

Degradation processes: on metals, e.g. oxidation, erosion, stress corrosion; on polymers, e.g. solvent attack, radiation and ageing; on ceramics, e.g. thermal shock, sustained high temperature.

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P1 Describe the structure (including the atomic structure) associated with a given metal, polymer, ceramic, composite and smart material		
P2 Classify given engineering materials as either metals or non-metals according to their properties		
P3 Explain mechanical, physical, thermal and electrical and magnetic properties and state one practical application of each property in an engineering context		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P4 Explain the effects on the properties and behaviour of processing metals, polymers, ceramics and composites and of post-production use of smart materials	M1 Explain how the properties and structure of different given engineering materials affect their behaviour in given engineering applications	
P5 Use information sources to select a different material for two given applications, using the criteria considered in the selection process	M2 Explain the criteria considered in the selection process	D1 Justify selection of an engineering material for one given application
P6 Explain the principles of the modes of failure known as ductile/ brittle fracture, fatigue and creep	M3 Explain how two given degradation processes affect the behaviour of engineering materials	
P7 Perform and record the results of one destructive and one non-destructive test method using one metal and one non-metallic material	M4 Explain how one destructive and one non-destructive test procedure produces useful results.	D2 Evaluate the results of one test procedure.
P8 Explain a different process of degradation associated with each of metals, polymers and ceramics.		

Essential guidance for tutors

Assessment

Centres have the option to decide on the number of tasks and the order in which the criteria are covered.

The evidence to satisfy the pass criteria P1, P2 and P3 could be achieved by means of a written assignment following a combination of tutor-led practical and theory sessions and individual research. P2 would require the range of materials given to include at least one ferrous, one non-ferrous, one non-ferrous alloy, one thermoplastic polymer, one thermosetting polymer, an elastomer, one ceramic, one composite, one smart material and one natural material.

Achievement of P4 and M1 could involve learners in both practical and theoretical tasks in which they relate the effects of processing on the properties of materials with real engineering applications. For smart materials, they need to consider the effects on the properties of the materials' use after production. Examples here may be related to their change in properties from the effects of external stimuli.

For example, when a force is applied to a piezoelectric material it produces an electric charge which can be used to trigger a car's airbag in the event of an accident. In many applications the behaviour is reversible, for example a colour change in response to a change in temperature or a variation in the viscosity of a liquid in response to the application of an electric or magnetic field. To satisfy P5, it is likely that learners would apply the knowledge and understanding gained in meeting criteria P1 - P4. Written responses would satisfy these criteria.

P7 could be met using a combination of practical and research activities involving tutor-led demonstrations of available laboratory tests. Learners could then carry out a series of tests and produce a written record of the test results. A witness statement could confirm the learner's involvement. Depending on available resources, it may be best to carry out the destructive test on the non-metallic material and the non-destructive test on the metallic material. This would allow a wider choice of tests for the latter. To achieve P6 and P8, learners could be given the opportunity to research modes of failure and degradation processes reflected in local conditions, for example a marine environment, or, for employed apprentices, failure and degradation pertinent to their companies' products.

To achieve the merit grade M1, learners will need to explain how the structure and properties of given materials will affect their behaviour in use. This evidence would be best demonstrated by a written task related to the activities carried out to meet P1, P2 and P3. For M2, learners should consider design, cost and availability criteria in their explanation. To satisfy M3, learners could produce a written explanation of the test procedures followed in P7 and the usefulness of the results. In producing evidence for some of this criterion, it may be appropriate to include the responses to oral questions.

However, centres should ensure that such questions and the responses are recorded for verification and also that they are not the sole source of evidence. M4 could be achieved through an extension of the task given for P8. The processes used in the explanation could be selected to meet local conditions or industrial applications.

To achieve distinction criterion D1, learners need to justify their selection of one of the materials used to satisfy P5, giving reasons why other materials considered for the application were not selected. To satisfy D2, learners are expected to complete a written task to evaluate the results of one of the tests used to meet P7 and M4. The evidence would depend on the test used but it could include the mathematical results of a tensile test, the values of a hardness test or detailed information gained from a non-destructive test.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3	Structure and Classification of Engineering Materials	Questions relating to the structure and classification of the range of engineering materials.	A written report containing reasoned answers to the set questions.
P4, M1	Properties of Engineering Materials	Questions relating to the properties and behaviour of engineering materials.	A written report containing reasoned answers to the set questions.
P5, M2, D1	Selection of Engineering Materials	Selection of engineering materials for given applications.	A written report listing selection criteria, information sources and justification for selected materials.
P6, P8, M3	Failure and Degradation of Engineering Materials	Questions relating to the range of failure modes and degradation processes in engineering materials.	A written report containing reasoned answers to the set questions.
P7, M4, D2	Testing Engineering Materials	Carry out and report the results of destructive and non-destructive tests on engineering materials.	A written report containing an explanation of test procedure and evaluation of test results.

Essential resources

Centres will need a selection of exemplar materials and components for viewing, tactile inspection and discussion. Degraded and failed component specimens will also be of value. Centres will also require access to equipment to conduct at least one destructive and one non-destructive test and related materials as specified in the unit content.

Indicative reading for learners

Textbooks

Darbyshire A – *Mechanical Engineering BTEC National Level 3 Engineering Specialist Units* (Routledge, 2010) ISBN 9780080965772

Higgins R – *Materials for Engineers and Technicians* (Routledge, 2014)
ISBN 9781138778757

Timings R L – *Engineering Materials, Volume 1* (Longman, 1998)
ISBN 9780582319288

Timings R L – *Engineering Materials, Volume 2* (Longman, 2000)
ISBN 9780582404663

Tindell H – *Engineering Materials, Crowood Metalworking Guides*
(The Crowood Press, 2014) ISBN 9781847976796

Unit 13: Engineering Drawing for Technicians

Level:	3
Unit type:	Additional
Guided learning hours:	60

Unit introduction

It is important that a product is manufactured correctly and to specification according to its design. To achieve this, it is crucial that the people making the product in a workshop are provided with well-presented engineering drawings, produced to international standards and conventions. This avoids errors of interpretation that can lead to the scrapping of expensive parts. An understanding of how graphical methods can be used to communicate information about engineering products is an important step for anyone thinking of taking up a career in engineering.

This unit gives learners an introduction to the principles of technical drawings and their applications using hand drawing and computer-aided design (CAD) techniques. Initially, learners will produce freehand sketches of simple engineering products using pictorial methods that generate three-dimensional (3D) images. A range of standard components, such as fixing devices, will be sketched together with other solid and hollow items. Learners will progress to a more formalised drawing technique that conforms to British Standards and will put this into practice through a number of drawing exercises. A consistent presentation style will be used as learners draw single part components and simple engineering assemblies. These drawings will contain all the information needed to manufacture or assemble products, including information such as dimensions, manufacturing notes and parts lists. The use of conventions to represent standard items will be investigated, such as screw threads and springs in mechanical type drawings or circuit symbols such as solenoids and resistors in electrical/electronic type drawings.

Having learned the principles of engineering drawing, learners will then move on to using a two-dimensional (2D) CAD system for the production of drawings using basic set-up, drawing and editing commands. They will produce a drawing template which can be saved to file, as this reinforces the concept of standardisation and consistency of presentation. This is followed by drawing exercises of single-part components, a simple multi-part assembly and circuit diagrams. Overall, the

unit will develop learners' ability to create technical drawings and will allow them to compare the use of manual and computer-aided methods of producing engineering drawings.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

- 1 Be able to sketch engineering components
- 2 Be able to interpret engineering drawings that comply with drawing standards
- 3 Be able to produce engineering drawings
- 4 Be able to produce engineering drawings using a computer-aided design (CAD) system.

Unit content

1 Be able to sketch engineering components

Sketches: regular solids, e.g. cube, rectangular block, 90° angle bracket; hollow objects, e.g. circular tube, square section tube; standard components, e.g. nuts, bolts, screws, pulleys; engineering components, e.g. pulley support bracket, machine vice.

Sketching techniques: sketching equipment, e.g. paper (plain, squared, isometric), pencil, eraser; pictorial, e.g. oblique drawing (cavalier and cabinet), isometric; orthographic, e.g. single and linked views; sketching in good proportion; dimensions, e.g. overall sizes, detail.

Benefits and limitations of using pictorial techniques: benefits, e.g. speed of production, visual impact; limitations, e.g. lengths and shapes not true, not produced to a recognised standard, dimensions difficult to read; consequences of interpretation errors, e.g. incorrect manufacture, incorrect assembly, cost to scrap.

2 Be able to interpret engineering drawings that comply with drawing standards

Interpret: obtaining information from engineering drawings, e.g. component features, dimensions and tolerances, surface finish, manufacturing detail, assembly instructions, parts list, circuit operation.

Drawing standards: British Standards, e.g. BS 8888, BS 3939, BS 2917, PP 7307; company-standardised layouts, e.g. drawing number, title and issue number, projection symbols (first angle, third angle), scale, units, general tolerances, name of person responsible for producing drawing; line types, e.g. centre, construction, outline, hidden, leader, dimension; lettering, e.g. titles, notes; orthographic projection, e.g. first angle, third angle; views, e.g. elevation, plan, end, section, auxiliary; representation of common features, e.g. screw threads, springs, splines, repeated items; section views, e.g. hatching style, webs, nuts, bolts and pins, solid shafts; symbols and abbreviations, e.g. A/F, CHAM, Φ , R, PCD, M; circuit symbols, e.g. electrical, electronic, hydraulic, pneumatic.

3 Be able to produce engineering drawings

Detail drawings of single-piece engineering components: projection method; scale; title block; line work; views; sections; dimensions; tolerances; surface finish; notes.

Assembly drawings: line work, e.g. centre lines, construction, outline, cutting plane, sectional view, hatching; representation of standard components, e.g. nuts, bolts, screws, keys; parts referencing, e.g. number referencing, parts list; notes, e.g. assembly instructions, installation features, operating instructions.

Circuit diagrams: circuits, e.g. electrical, electronic, hydraulic, pneumatic; components, e.g. transformers, rectifiers, solenoids, resistors, capacitors, diodes, valves, pumps, actuators, cylinders, receivers, compressors.

4 Be able to produce engineering drawings using a computer-aided design (CAD) system

Prepare a template: standardised drawing sheet, e.g. border, title block, company logo; save to file.

CAD systems: computer systems, e.g. personal computer, networks; output devices, e.g. printer, plotter; storage, e.g. server, hard disc, CD, pen drive; 2D CAD software packages, e.g. AutoCAD, Microstation, Cattia, Pro/Engineer, Pro/Desktop.

Produce engineering drawings: set-up commands, e.g. extents, grid, snap, layer; drawing commands, e.g. coordinate entry, line, arc, circle, snap, polygon, hatch, text, dimension; editing commands, e.g. copy, move, erase, rotate, mirror, trim, extend, chamfer, fillet.

Store and present engineering drawings: save work as an electronic file, e.g. hard drive, server, pen drive, DVD; produce paper copies, e.g. print, plot, scale to fit.

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P1 Create sketches of engineering components using a range of techniques	M1 Assess the suitability of the different techniques for the sketches	
P2 Describe the benefits and limitations of using pictorial techniques to represent a given engineering component		
P3 Interpret the main features of a given engineering drawing which complies with drawing standards	M2 Explain the importance of working to recognised standards when producing engineering drawings	
P4 Produce detailed drawings of three given single-piece components that comply with drawing standards	M3 Explain how the sketches comply with drawing standards	

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P5 Produce an assembly drawing of a product containing three parts that complies with drawing standards		
P6 Produce a circuit diagram that complies with drawing standards, with at least five different components which use standard symbols	M4 Explain how a given engineering drawing would be used and the reasons it is suitable for its intended audience	D1 Evaluate the use of different methods of producing engineering drawings, including manual and computer-aided methods
P7 Prepare a template drawing of a standardised A3 sheet using a CAD system and save to file	M5 Explain the hardware components of a typical industry standard CAD system.	D2 Evaluate the functionality of a CAD software package.
P8 Produce, store and present 2D CAD drawings of a given single-piece component and an assembly drawing of a product containing three parts.		

Essential guidance for tutors

Assessment

Assessment of this unit could be through the use of five assignments. To achieve a pass, learners are expected to show competence in a number of graphical techniques and to be able to apply these to the production of engineering drawings which meet recognised standards.

The first assignment, to cover P1, P2 and M1, could consist of a small portfolio of sketches and written descriptions. Items drawn must include regular solids and hollow objects, standard and engineering components. The techniques used must be valid and involve sketching equipment, pictorial and orthographic representation and sketching in good proportion with the addition of some dimensions (as specified in the unit content). An assessment of these techniques will meet the requirement for M1.

The second assignment, to cover P3 and M2, will need to be carefully structured and should be based on a drawing of a component or assembly rather than a circuit diagram so that the unit content can be properly covered. M2 builds on the evidence presented for P3 and these two criteria could be assessed using a single assignment. The wider issues of standardisation and manufacturing for the global market place should be addressed with learners supporting their explanations with case study evidence.

The third assignment could cover P4, P5 and M3 with the three single-piece components in P4 being used for the assembly drawing in P5. This would then make the assignment more realistic in terms of what happens in industry. M3 would require an explanation of how the sketches in P4 comply with drawing standards.

The fourth assignment could cover P6, M4 and D1, with learners being given a choice of the type of circuit they produce depending on their interest (i.e. from electrical, electronic, hydraulic and pneumatic). The circuit can be drawn by hand but using CAD may be the preferred method if a library of components is available. M4 requires an explanation of the use of engineering drawings to communicate information effectively. D1 could be carried out as a separate task, requiring an evaluation of the various drawing techniques used by learners and link directly with the criteria P1, P5, P6 and P8. To add depth to their evidence, learners could be asked to look more widely at what is used in industry – particularly the use of 3D CAD systems which generate solid models. This would then bring them full circle back to the start of the unit, where they were producing pictorial sketches.

P7, P8, M5 and D2 can be covered by a fifth assignment, which could ask for increased competence in the application of standards when producing drawings. To help authenticate learners' work, additional evidence could be in the form of witness statements, tutor observation records and 'screen dumps' which show the range of commands used during the development of the drawings. M5 and D2 could form a separate task as part of this assignment, requiring an explanation of CAD hardware and an evaluation of CAD software functionality.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1	Producing Engineering Sketches	Learners are required to produce sketches of a range of different objects.	A practical assignment requiring learners to produce a portfolio of engineering sketches with accompanying written descriptions.
P3, M2	Interpreting and Using Drawing Standards	Learners are required to read and interpret an engineering drawing in order to report the key features of the component, circuit or assembly to a colleague.	A written assignment for which learners need to produce a short report detailing the main features of a given engineering drawing that complies with drawing standards. A further task would require them to explain the importance of engineering standards.

Criteria covered	Assignment title	Scenario	Assessment method
P4, P5, M3	Producing Engineering Drawings	Learners are required to produce an engineering drawing of three components and an assembly drawing for use by the manufacturing department of their company.	A practical assignment in which learners produce component and assembly drawings.
P6, M4, D1	Producing Circuit Drawings	Learners are required to produce a circuit diagram for use by the manufacturing department of their company.	A practical assignment in which learners produce a circuit diagram.
P7, P8, M5, D2	Producing Engineering Drawings Using CAD	Learners are required to prepare and produce 2D CAD drawings for use by the manufacturing department of their company.	A practical assignment in which learners produce 2D CAD drawings of a component and an assembly.

Essential resources

To meet the needs of this unit, it is essential that centres have, or have access to, manual drawing equipment and a CAD system that uses a 2D commercial engineering software package. Centres will also need extracts and illustrations from appropriate drawing standards and conventions.

Indicative reading for learners

Textbooks

Cheng R – *Using Pro/Desktop 8* (Delmar, 2004) ISBN 9781401860240

Conforti F – *Inside Microstation* (Delmar, 2005) ISBN 9781418020842

Fane B – *AutoCAD 2014 for Dummies* (John Wiley and Sons, 2013)
ISBN 9781118603970

Simmons C, Maguire D and Phelps N – *Manual of Engineering Drawing*
(Butterworth-Heinemann, 2009) ISBN 9780750689854

Tooley M and Dingle L – *BTEC National Engineering* (Routledge, 2010)
ISBN 9780123822024

Unit 14: Further Mechanical Principles and Applications

Level:	3
Unit type:	Additional
Guided learning hours:	60

Unit introduction

All machines and mechanisms consist of interconnected parts working together to produce a desired output. Engineers involved in the design, testing and servicing of mechanical systems need to have a firm grasp of their underpinning principles in order to appreciate the choice of components, the forces acting on them and the way that they relate to each other.

The study of stationary structures and their components is often referred to as 'statics'. Learners will firstly cover the mechanical principles that underpin the design of framed structures, simply supported beams and structural components. The aim is to give learners the means to evaluate the integrity and safety of engineering structures and to lay the foundation for structural analysis at a higher level.

A great many engineering systems are designed to transmit motion and power. These include machine tools, motor vehicles, aircraft and a range of domestic appliances. The study of the motion in mechanical systems is known as 'kinematics' and the study of the forces at work and the power they transmit is known as 'dynamics'. Learners will extend their knowledge of the mechanical principles associated with these studies. They will develop a basic knowledge of rotational motion and the effects of centripetal force in simple rotating systems. They will also be introduced to simple machines used as lifting devices. An understanding of the mechanical principles involved in the operation of these devices and mechanisms will provide a foundation for the analysis of more complex power transmission systems at a higher level of study.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

- 1 Be able to determine the forces acting in pin-jointed framed structures and simply supported beams
- 2 Be able to determine the stress in structural members and joints
- 3 Be able to determine the characteristics of rotating systems
- 4 Be able to determine the operating characteristics of simple lifting machines.

Unit content

1 Be able to determine the forces acting in pin-jointed framed structures and simply supported beams

Pin-jointed framed structures: solution, e.g. graphical (such as use of Bow's notation, space and force diagram), analytical (such as resolution of joints, method of sections, resolution of forces in perpendicular directions) ($F_x = F\cos\theta$, $F_y = F\sin\theta$), vector addition of forces, application of conditions for static equilibrium ($\Sigma F_x = 0$, $\Sigma F_y = 0$, $\Sigma M = 0$).

Forces: active forces, e.g. concentrated loads; uniformly distributed loads (UDL); reactive forces, e.g. support reactions, primary tensile and compressive force in structural members.

Simply supported beams: distribution of shear force and bending moment for a loaded beam, e.g. concentrated loads, UDL; types of beam arrangement, e.g. beam without overhang, beam with overhang and point of contraflexure.

2 Be able to determine the stress in structural members and joints

Single and double shear joints: fastenings, e.g. bolted or riveted joints in single and double shear; joint parameters, e.g. rivet or bolt diameter, number of rivets or bolts, shear load, expressions for shear stress in joints subjected to single and double shear, factor of safety.

Structural members: members, e.g. plain struts and ties, series and parallel compound bars made from two different materials; loading, e.g. expressions for direct stress and strain, thermal stress, factor of safety.

3 Be able to determine the characteristics of rotating systems

Rotating systems with uniform angular acceleration: systems, e.g. simple (such as rotating rim, flywheel, motor armature, pump or turbine rotor), complex (such as systems where combined linear and angular acceleration is present, hoist and vehicle on an inclined track); kinetic parameters, e.g. angular displacement, angular velocity, angular acceleration, equations for uniform angular motion ($\omega_2 = \omega_1 + at$, $\theta = \omega_1 t + \frac{1}{2} at^2$, $\omega_2^2 = \omega_1^2 + 2a\theta$, $\theta = \frac{1}{2} (\omega_1 + \omega_2)t$); dynamic parameters, e.g. radius of gyration, moment of inertia ($I = mk^2$), inertia torque ($T = I\alpha$), friction torque, application of d'Alembert's principle, mechanical work ($W = T\theta$), power (average power = $\frac{W}{t}$, instantaneous power = $T\omega$), rotational kinetic energy ($KE = \frac{1}{2} I\omega^2$), application of principle of conservation of energy.

Rotating systems with uniform centripetal acceleration: systems, e.g. simple (such as concentrated mass rotating in a horizontal or vertical plane, vehicle on a hump-backed bridge, aircraft performing a loop), complex (such as centrifugal clutch, vehicle on a curved track); kinetic parameters, e.g. expressions for centripetal acceleration ($a = \omega^2 r$, $a = \frac{v^2}{r}$); dynamic parameters, e.g. expressions for centripetal force ($F_c = m\omega^2 r$, $F_c = \frac{mv^2}{r}$)

4 Be able to determine the operating characteristics of simple lifting machines

Parameters of lifting machines: kinetic parameters, e.g. input motion, output motion, velocity or movement ratio, overhauling; dynamic parameters, e.g. input effort, load raised, mechanical advantage or force ratio, law of a machine, efficiency, limiting efficiency.

Lifting machines: lifting machines, e.g. simple (such as inclined plane, screw jack, pulley blocks, wheel and axle, simple gear train winch), differential (such as differential wheel and axle, Weston differential pulley block, compound gear train winch).

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P1 Illustrate graphically the magnitude and nature of the support reactions and primary forces acting in the members of a framed structure with at least four pin-jointed members	M1 Analyse the magnitude and nature of the support reactions and primary forces acting in the members of a framed structure with at least four pin-jointed members	D1 Determine the values of distribution of shear force and bending moment and locate a point of contraflexure for a simply supported beam with overhang carrying at least two concentrated loads and a continuous uniformly distributed load
P2 Determine the values of distribution of shear force and bending moment for a simply supported beam without overhang carrying at least three concentrated loads		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P3 Determine the values of required parameters for a single shear lap joint and a double shear butt joint for given service conditions	M2 Determine the values of induced stresses and dimensional changes that occur in the materials of a series connected compound bar and a parallel connected compound bar when subjected to direct loading	
P4 Determine the induced direct stress, dimensional change and factor of safety values in operation for a rigidly held plain structural member when subjected to a combination of direct and thermal loading		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P5 Determine the outcomes of applied torque, work done and power dissipated in a uniformly accelerated simple rotating system to overcome the effects of inertia and friction	M3 Determine the performance value of a complex rotating system due to the effects of centripetal acceleration	D2 Determine the applied torque, work done and power dissipated outcomes in a uniformly accelerated complex rotating system in which both linear and rotational motion is present, to overcome the effects of inertia, friction and gravity.
P6 Determine the centripetal acceleration and centripetal force values in a simple rotating system		
P7 Determine the outcomes of kinetic and dynamic parameters of operation of two different simple lifting machines from given data.	M4 Evaluate the kinetic and dynamic parameters of operation of a differential lifting machine.	

Essential guidance for tutors

Assessment

Ideally, assessment of this unit will be achieved through application of the mechanical principles covered to the relevant engineering settings. This could be achieved through integration with other engineering principles units, practical work that provides learners with opportunities to produce individual evidence for assessment against the criteria, and individual project/assignment tasks. Whichever approach is taken, it is important to ensure that the criteria are achieved autonomously. Where centres consider a test/examination necessary to achieve authentic evidence, they need to ensure that the test items are set in a way to enable the criteria to be met in full. Centres also need to consider how such an assessment will provide opportunities to meet the merit and distinction criteria, and how to provide learners with further learning and assessment should they initially fail to achieve in the test/examination.

If learners make an arithmetic error in the solution to a problem, it is for the centre to decide the significance of such an error, assess the work accordingly and provide suitable feedback. For example, if a learner has chosen the correct approach and manipulated the necessary formulae and data correctly, but has made and carried through a minor arithmetic error, then the final 'inaccurate' solution to the problem may be deemed to be good enough to meet the criterion. However, if the final solution to the problem is so obviously wrong that it should have prompted further checks for accuracy, then the solution could be deemed to be unacceptable and reassessment considered. The incorrect application of units and/or dimensions are a typical cause of such major errors, which can lead to relatively large-scale errors of the magnitude 10^3 or greater.

It is possible to assess the criteria P1, P2, M1 and D1 through an assignment requiring the graphical and analytical solution of a given pin-jointed framed structure and the analysis of given simply supported beams. The magnitude and nature of the framed structure support reactions and internal forces may be illustrated graphically (P1) and confirmed analytically (M1). Learners should make use of Bow's notation in their analysis.

The simply supported beam for P2 should contain at least three concentrated loads and be supported at its free ends. The simply supported beam for D1 should overhang one of its supports and contain at least two concentrated loads and a continuous uniformly distributed load. Learners should be required to adopt an analytical approach to locate the point of contraflexure.

A second assignment could assess the criteria P3, P4 and M2. The first task might be to determine the parameters for a single shear lap joint and for a double shear butt joint (P3) for given service conditions. This might involve calculation of the rivet/bolt diameter required for a given load or the safe working load for a particular joint. The joints should contain at least three rivets/bolts (six in total for the butt joint).

A second task might be to calculate the direct stress induced in a rigidly fixed member due to direct loading and temperature change (P4). A further task could involve evaluation of the stresses and dimensional changes occurring in series and parallel connected compound bars (M2) when subjected to direct loading.

A third assignment could be used to assess the criteria P5, P6, M3 and D2. The first task might involve consideration of a simple rotating system, such as a flywheel, which is accelerated against the effects of inertia and friction (P5). A second task might involve consideration of a more complex system such as a hoist or a vehicle on an incline in which both linear and angular motion is present (M3).

The third task might be to determine the centripetal acceleration and centripetal force present in a simple rotating system (P6). A final task would require learners to determine effects of centripetal acceleration and force in a more complex rotating system (D2). This might involve determining the speed of engagement and power transmitted by a centrifugal clutch. Alternatively, learners could evaluate the active and reactive forces on a vehicle travelling round a curved level track, maximum safe speed and the banking angle required for no tendency to side-slip at a given speed. The term performance in the criterion is therefore relevant to the particular rotating system given/used.

A final assignment containing two tasks could be used to achieve the P7 and M4 criteria. The first task would involve determination of velocity ratio, mechanical advantage and efficiency of two simple lifting machines for given input conditions (P7). Exemplar machines are ranged in the unit content.

In a second task, the M4 merit criterion could be achieved by means of a practical or simulated investigation of a differential lifting device. This should involve the determination of velocity ratio and the gathering of a sufficiently wide range of load and effort values for analysis of the machine performance. Graphs of load versus effort and load versus efficiency can then be plotted from the manipulated and tabulated test data. The law of the machine can be derived from the load versus effort graph and the theoretical value of the limiting efficiency obtained. An evaluation of this limiting value can then be made by comparison with that indicated on the load versus efficiency graph. An evaluation can also be made as to the likelihood of overhauling. Again, exemplar machines for this task are ranged in the unit content.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1, D1	Forces and Moments in Static Systems	Analysis of pin-jointed framed structures and simply supported beams.	A written report containing required graphics and an appropriate introductory explanation to each step in the sequence of calculations and findings.
P3, P4, M2	Stress in Static System Components	Determination of parameters for riveted joints and determination of stress in plain and compound structural members.	A written report containing an appropriate introductory explanation to each step in the sequence of calculations and findings.
P5, P6, M3, D2	Dynamic Systems	Determination of dynamic system parameters and performance.	A written report containing an appropriate introductory explanation to each step in the sequence of calculations and findings.

Criteria covered	Assignment title	Scenario	Assessment method
P7, M4	Lifting Machines	Determination of the parameters and performance of simple lifting machines.	A written report containing an appropriate introductory explanation to each step in the sequence of calculations and findings.

Essential resources

Centres could provide access to laboratory facilities with a range of equipment for investigation and demonstration purposes wherever possible. In particular, flywheels or other rotor systems for the determination of moment of inertia and radius of gyration, turntable apparatus for the investigation of centripetal acceleration and force and a range of simple lifting machines would be useful.

Indicative reading for learners

Textbooks

Bird J – *Science for Engineering* (Routledge, 2012) ISBN 9780415517881

Bolton W – *Engineering Science* (Routledge, 2006) ISBN 9780750680837

Darbyshire A – *Mechanical Engineering BTEC National Level 3 Engineering Specialist Units* (Routledge, 2010) ISBN 9780080965772

Tooley M and Dingle L – *BTEC National Engineering* (Routledge, 2010) ISBN 9780123822024

Unit 15: Communications for Engineering Technicians

Level:	3
Unit type:	Additional
Guided learning hours:	60

Unit introduction

The ability to communicate effectively is an essential skill in all aspects of life.

The usual methods of communication – speaking, reading and writing – receive considerable attention and learning time during all stages of education.

For engineers, these skills are of no less importance, but there are further complications with the need to also convey technical information such as scale, perspective and standards of working.

The drive towards greater use of information and communication technology (ICT) is very much a part of modern life and this again is certainly the case for engineering. The engineering industry is in the front line of working towards paperless communication methods, for example the electronic transfer of data from the concept designer straight to the point of manufacture.

This unit will give a foundation for employment in a wide range of engineering disciplines (for example manufacturing, maintenance, communications technology), in addition to giving a foundation for further study. It aims to develop learners' ability to communicate using a diverse range of methods. These include visual methods, such as drawing and sketching, and computer-based methods, such as two-dimensional (2D) computer-aided design (CAD) and graphical illustration packages. It will also develop learners' ability to write and speak in a framework of technology-based activities, using relevant and accurate technical language appropriate to the task and the audience.

The unit will introduce learners to a variety of skills and techniques to obtain and use information, for example the presentation of technical reports, business and technical data and the use of visual aids for presentations. Learners will consider how to make best use of ICT in technological settings that are relevant to their programme of study or area of employment.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

- 1 Be able to interpret and use engineering sketches/circuit/network diagrams to communicate technical information
- 2 Be able to use verbal and written communication skills in engineering settings
- 3 Be able to obtain and use engineering information
- 4 Be able to use information and communication technology (ICT) to present information in engineering settings.

Unit content

1 Be able to interpret and use engineering sketches/circuit/network diagrams to communicate technical information

Interpret: obtain information and describe features, e.g. component features, dimensions and tolerances, surface finish; identify manufacturing/assembly/process instructions, e.g. cutting lists, assembly arrangements, plant/process layout or operating procedures, electrical/electronic/communication circuit requirements; graphical information used to aid understanding of written or verbal communication, e.g. illustrations, technical diagrams, sketches.

Engineering sketches/circuit/network diagrams: freehand sketches of engineering arrangements using 2D and 3D techniques, e.g. components, engineering plant or equipment layout, designs or installations; electrical/ electronic circuit diagrams, system/network diagrams; use of common drawing/circuit/network diagram conventions and standards, e.g. layout and presentation, line types, hatching, dimensions and tolerances, surface finish, symbols, parts lists, circuit/component symbols, use of appropriate standards (British (BSI), International (ISO)).

2 Be able to use verbal and written communication skills in engineering settings

Written work: note taking, e.g. lists, mind mapping/flow diagrams; writing style, e.g. business letter, memo writing, report styles and format, email, fax; proofreading and amending text; use of diary/logbook for planning and prioritising work schedules; graphical presentation techniques, e.g. use of graphs, charts and diagrams.

Verbal methods: speaking, e.g. with peers, supervisors, use of appropriate technical language, tone and manner; listening, e.g. use of paraphrasing and note taking to clarify meaning; impact and use of body language in verbal communication.

3 Be able to obtain and use engineering information

Information sources: non-computer-based sources, e.g. books, technical reports, institute and trade journals, data sheets and test/experimental results data, manufacturers' catalogues; computer-based sources, e.g. inter/intranet, DVD-based information (manuals, data, analytical software, manufacturers' catalogues), spreadsheets, databases.

Use of information: e.g. for the solution of engineering problems, for product/service/topic research, gathering data or material to support own work, checking validity of own work/findings.

4 Be able to use information and communication technology (ICT) to present information in engineering settings

Software packages: word processing; drawing, e.g. 2D CAD, graphics package; data handling and processing e.g. database, spreadsheet, presentation package, simulation package such as electrical/electronic circuits, plant/process systems; communication, e.g. email, fax, inter/intranet, video conferencing, optical and speech recognition system.

Hardware devices: computer system, e.g. personal computer, network, plant/process control system; input/output devices, e.g. keyboard, scanner, optical/speech recognition device, printer, plotter.

Present information: report that includes written and technical data, e.g. letters, memos, technical product/service specification, fax/email, tabulated test data, graphical data; visual presentation, e.g. overhead transparencies, charts, computer-based presentations (PowerPoint).

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P1 interpret an engineering drawing/circuit/network diagram		
P2 produce an engineering sketch/circuit/network diagram		
P3 use appropriate standards, symbols and conventions in an engineering sketch/circuit/network diagram		
P4 communicate information effectively in written work	M1 evaluate a written communication method and identify ways in which it could be improved	D1 justify choice of a specific communication method and the reasons for not using a possible alternative
P5 communicate information effectively using verbal methods		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P6 use appropriate information sources to solve an engineering task	M2 review the information sources obtained to solve an engineering task and explain why some sources have been used but others rejected	
P7 use appropriate ICT software packages and hardware devices to present information.	M3 evaluate the effectiveness of an ICT software package and its tools for the preparation and presentation of information.	D2 evaluate the use of an ICT presentation method and identify an alternative approach.

Essential guidance for tutors

Assessment

Unit 16: Engineering Project could provide an excellent vehicle for an integrated approach to the assessment of this unit. The project work undertaken will require learners to use communication skills to interpret information, prepare sketches and drawings, give presentations, develop and use data sheets, produce technical reports and letters etc. Other units in the programme could also be used to provide effective and relevant learning and formative or even summative assessment opportunities. However, using *Unit 16: Engineering Project* for assessment has the advantage of providing a structured focus for the work and a coherent source of relevant evidence.

To achieve a pass, learners should interpret (P1) and produce (P2) engineering sketches (2D and 3D)/circuit/network diagrams and sketches. This will need to be at a level sufficient for them to understand and communicate technical information. This must include identification and use of appropriate standards, symbols and conventions (P3). The use of sketches/circuit/network diagrams in the criteria P1 and P2 is intended to indicate a choice that will depend on the focus of the learning programme in which this unit is being delivered. For example, a learner on a mechanical programme is likely to choose to interpret and produce sketches of components, while a learner studying electrical/electronics is more likely to interpret and produce circuit diagrams.

A single assessment activity could be used to link and capture evidence for the first three pass criteria (P1, P2 and P3). The activity would need to ensure that learners had an opportunity to obtain information, describe features, identify instructions and make use of graphical information (P1). For example, the task could be to work with written operating instructions that include supporting diagrams and sketches (2D and 3D). From the initial investigation, the activity could then require learners to produce their own drawing and sketches (P2). The criterion P3 would need to be applied to both the interpretation (identify) and the production (use) of their working document.

Learners should use written (P4) and verbal (P5) communication methods. The written work must include evidence of note taking, the ability to use a specific writing style, proofread and amend text, use a diary/logbook and use graphical presentation techniques. It might be that all of these will not necessarily occur in a single task/activity. If not, it would be acceptable for a number of pieces of assessment evidence to be brought together to meet this criterion.

The use of verbal methods (P5) will require learners to demonstrate speaking and listening skills and an understanding of the impact and use of appropriate body language. The evidence for this should come from one task/activity so that all three aspects are being dealt with at the same time. This could be a meeting with either peers and/or a supervisor, or could come from a presentation delivered by the learner to a group.

It would be important to ensure that the learner had to take questions from the group to enable the tutor to capture evidence of their ability to listen. The evidence for this criterion is likely to be a tutor observation record or witness statement.

P6 can be assessed using any structured activity that requires learners to identify and use appropriate information sources to solve an engineering task. It is essential that the information comes from both computer-based and non-computer-based sources. The evidence for this criterion could be as simple as suitably referenced work (a bibliography would not be sufficient). However, it would be preferable to have a record of the original source and a hard copy, annotated to show the information identified and used for the task (or at least an example of this process).

The final pass criterion (P7) could be assessed using any relevant tasks that require learners to select and use appropriate ICT software packages and hardware devices to present information. It is essential that the task or tasks chosen for this criterion give learners opportunities to use appropriate software to cover all the ICT applications listed in the content, i.e. there must be evidence of learners' selection and use of ICT for word processing, drawing, data handling and communication (such as email). The requirement for hardware devices is limited to the choice and use of a computer system and relevant input/output devices that would be needed for the task carried out. It is expected that the range of information presented using ICT will include a technical report and visual presentation material, for example overhead transparencies, chart, computer-based presentation (PowerPoint).

As already suggested, *Unit 16: Engineering Project* could provide an excellent vehicle for assessment of this unit since it could provide a central focus and therefore a source of coherent assessment evidence. Any alternatives should try to establish a similar coherence and avoid fragmentation of the pass criteria wherever possible.

To achieve a merit, learners should evaluate a written communication method and identify ways in which it could be improved (M1). This could be learners' own written work or the written work of someone else. The important aspect of this criterion is the learners' ability to use their skills and understanding of communication methods to appraise the work and identify enhancements.

In addition, learners will need to review the information sources obtained to solve an engineering task and explain why some sources have been used but others rejected (M2). This criterion is about reflection and the need to carefully consider, measure and express the value (or not) of other people's work as a source of information. Learners need to have identified both non-computer-based and computer-based information sources for P6 and it is this material that they should be reviewing for M2.

Achievement might well be implicit if the task undertaken for P6 has reached a satisfactory solution. However, the expected evidence for this criterion would be a copy of the source material used, suitably annotated to explain its value or why it has been rejected.

Finally, merit criterion M3 requires learners to evaluate an ICT software package and its tools for the preparation and presentation of information. This criterion requires learners to have taken time to reflect on their work and consider the use of software tools available (for example good/consistent use of font size/colour, alignment of text, positioning on the page, use of automated labels, legends and titles for graphs).

To achieve a distinction, learners should justify their choice of a specific communication method and the reasons for not using a possible alternative (D1). This could be any communication method that the learner has chosen to use (for example drawings, written, verbal).

It does require learners to have considered at least one possible alternative during the initial selection of the method used. Learners will therefore need to be briefed to collect evidence of this selection process, which might otherwise be lost or ignored (for example initial outlines/drafts, notes of any consultation with others on method to be employed). The key issue for this criterion is learners' ability to reflect and evaluate. At pass level, learners will have shown their ability to communicate information effectively and, at merit, to be critical of the content of their own or other people's work. At distinction level, they should be critical of the choice of communication method used.

D2 requires learners to evaluate their use of an ICT presentation method and identify an alternative approach. This criterion is about the method of presentation and not the method of communication. It also has a direct link with related pass (P7) and merit (M3) criteria. At pass, learners need to use ICT to present information and, at merit, to evaluate the effectiveness of the presentation.

For D2, learners should consider the overall approach taken. For example, could a word-processed technical report have been presented using a computer-based presentation package, such as PowerPoint, including automated routines and animated graphics or video clips? The evidence for this is likely to be a written evaluation. A rough outline illustrating their identified alternative approach or even a small section of the original reworked using an alternative approach could be used to support the written evaluation.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2 and P3	Communicating Technical Information	Explore a product/circuit/network and interpret and prepare appropriate engineering sketches/circuit/network diagrams.	A written report providing the learner's interpretation of the information and features found. Engineering sketches/circuit/network diagram prepared by the learner.
P4, P5, M1 and D1	Writing, Talking and Listening	A series of tasks focused on written work and verbal communication methods.	A portfolio of evidence containing examples of note taking, writing styles, use of diary/logbook and use of graphical presentation techniques. Tutor observation of speaking, listening and use of body language.

Criteria covered	Assignment title	Scenario	Assessment method
P6, M2	Finding and Using Information	Solving an engineering problem through research and use of information.	A written report with suitable reference to the range of sources found and used, including non-computer-based and computer-based resources.
P7, M3, D2	The Use of ICT in Engineering	Presenting engineering information using ICT.	A written report on the selection and use of computer hardware devices. A portfolio of evidence of the use of word processing, drawing, data handling and communication software packages to present engineering information.

Essential resources

Access to information and communication technology resources (including the internet) is essential for the delivery of this unit, as is a well-stocked source of reference material.

Learners should be given a variety of sample written materials (letters, memos, technical reports, data sheets, catalogues) and sketches. Centres will need to provide access to appropriate presentation and graphics software (for example Microsoft PowerPoint, Visio), spreadsheet/database software (for example Microsoft Excel/Access) and computer hardware (for example scanners, printers, optical character recognition and speech recognition software, barcode readers).

Indicative reading for learners

Textbooks

Boyce A, Cooke E, Jones R and Weatherill B – *BTEC Level 3 National Engineering Student Book* (Pearson, 2010) ISBN 9781846907241

Boyce A, Cooke E, Jones R and Weatherill B – *BTEC Level 3 National Engineering Teaching Resource Pack* (Pearson, 2010) ISBN 9781846907265

Tooley M and Dingle L – *BTEC National Engineering* (Routledge, 2010)
ISBN 9780123822024

Unit 16: Engineering Project

Level:	3
Unit type:	Additional
Guided learning hours:	120

Unit introduction

In the modern world engineers and technicians are often involved fully or in part with identifying problems and finding suitable solutions. These engineering problems may range from a very large project, such as designing and building a hydroelectric power station, to smaller projects, such as designing and producing a paper clip to keep notes secure. No matter how large or small, these problems need to be project managed in order to find engineered solutions. This unit will provide learners with opportunities to present their own solutions to engineering projects and should enable them to feel confident in carrying out project work within their chosen engineering discipline at the technician level.

The unit aims to integrate the knowledge and skills learners have gained throughout their programme of study, into a major piece of work that reflects the type of performance expected of an engineering technician. The project is intended to develop the learner's ability to identify and plan a course of action and follow this through to produce a viable solution/outcome to an agreed specification and timescale.

The end result of the project could be an engineering product, device, service or process or a modification to an existing process or product. As in the real world, the outcome of the project and its presentation are very important, although this project is also about developing the process skills necessary to carry out the project. Throughout the project learners will need to apply the technical skills developed in the other units in the qualification.

Learning outcomes

On completion of this unit a learner should:

- 1 Be able to keep records, specify a project, agree procedures and choose a solution
- 2 Be able to plan and monitor a project
- 3 Be able to implement the project plan within agreed procedures
- 4 Be able to present the project outcome.

Unit content

1 Be able to keep records, specify a project, agree procedures and choose a solution

Project records: written e.g. notes, sketches, drawings; plans and modified plans; targets (setting, monitoring); use of planning tools e.g. paper based, electronic; recording initial concepts e.g. lists, notes, mind mapping, flow diagrams, sketches.

Initial concepts: setting limits e.g. time, cost, feasibility, need; value–cost–benefit analysis; generating ideas e.g. group discussion, brainstorming, mind mapping; research techniques; lines of communication.

Specification: type of project e.g. product design, plant layout/maintenance, production methods or similar engineering-related topics; technical information e.g. functionality, reliability, operational conditions, process capability, scale of operation, size, capacity, cost, style, ergonomics, present and future trends; health and safety issues; environmental and sustainability issues; quality standards and legislation; timescales; physical and human resource implications.

Procedures: roles and responsibilities e.g. decision making, budget planning and control; reporting methods; resource allocation and limits.

Techniques: comparison methods e.g. statistical, graphical, quality and resource requirements/limitations, process capability, fitness-for-purpose; analysis e.g. cost–benefit, feasibility.

2 Be able to plan and monitor a project

Planning: long-term planning e.g. planners, charts and scheduling techniques (flow charts, Gantt charts, critical path methods, software packages); setting priorities; useful resource information e.g. human and physical.

Monitoring: monitor and record achievement e.g. use of logbook and/or diary for record keeping (names, addresses, telephone numbers, meeting dates, email and other correspondence lists); use of logbook e.g. for recording and analysing data or performance records, modifying/updating charts/planners, recording project goals and milestones, initial concepts, project solution technical decisions and information.

3 Be able to implement the project plan within agreed procedures

Implement: proper use of resources e.g. equipment, tools, materials, within agreed timescale, use of appropriate techniques for generating solutions, adapting project plan where appropriate, maintaining appropriate records.

Checking solutions: use of evaluative and analytical techniques e.g. graphs, matrix methods, statistics, Gantt charts, sequencing, scheduling, critical path methods, computer software packages.

4 Be able to present the project outcome

Presentation: deliver a presentation to a small group e.g. audience including known (peer group, tutors) and unknown (actual or simulated customer or client) participants; use of preparation techniques, presentation styles and techniques; preparation and use of visual aids e.g. overhead transparencies, software packages and projectors, charts, models, video/DVD clips.

Project report: logbook/diary record of all events; written technical report including relevant drawings/ circuit diagrams, sketches, charts, graphs etc appropriate to the project solution; use of information and communication technology (ICT) as appropriate to present findings e.g. CAD, DTP, spreadsheets, databases, word processing.

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P1 prepare and maintain project records from initial concepts through to solution that take account of and record changing situations	M1 maintain detailed, concurrent records throughout the project that clearly show progress made and difficulties experienced	D1 independently manage the project development process, seeking support and guidance where necessary
P2 prepare a project specification	M2 use a wide range of techniques and selection criteria to justify the chosen option	D2 evaluate the whole project development process, making recommendations for improvements.
P3 agree and prepare the procedures that will be followed when implementing the project	M3 evaluate the project solution and suggest improvements	
P4 use appropriate techniques to evaluate three potential solutions and select the best option for development	M4 present coherent and well-structured development records and final project report.	
P5 outline the project solution and plan its implementation		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P6 monitor and record achievement over the life cycle of the project		
P7 implement the plan and produce the project solution		
P8 check the solution conforms to the project specification		
P9 prepare and deliver a presentation to a small group outlining the project specification and proposed solution		
P10 present a written project report.		

Essential guidance for tutors

Assessment

Assessment of this unit will be based primarily on the learner's logbook/diary and other evidence of the work carried out and the processes adopted. Use will also be made of the learner's specification document, presentation and technical project report.

It should be noted that the logbook/diary is intended to be a working document and should contain the learner's notes and records as they are made at the time. It does not need to be a well-presented/neat document, but should be an effective tool to capture events and information as and when they happen and provide a useful source of reference for the learner when preparing their presentation and final written report. The tutor/project supervisor could also annotate the logbook/diary to indicate and record their observations and interactions with the learner, for example use of ICT, the logical formulation of ideas, use of technical knowledge, analysis and the outcomes/recommendations from these meetings.

Learners will need to include, possibly as an annexe (under separate cover) to the technical report, their own sketches, drawings/circuit diagrams, notes, lists, charts, raw calculations etc. to support their project report findings. Appropriate methods of presentation and management of the total evidence package should be discussed and used by the learner.

Learners may well be working closely with their own company/employer on their project and may be required to adopt the company's own 'house style' for the presentation of the report. This would of course be acceptable, since it will be in line with standard industry practice and report writing protocols and because it is the content of the report (i.e. its technical information, logical presentation methods and coherence) that is assessed, not its style.

Care should be taken to identify learners who may be genuinely terrified of standing in front of a group to make a presentation. The experience of making such a presentation is valuable and is recommended. However, as a minimum, learners only have to make an informal presentation to one or two people (which would reflect the typical minimum required in employment at this level) to achieve the unit.

As many of the activities undertaken by learners will be practical and skills-based, it is important to think about the method of capturing and presenting such evidence for assessment purposes. Often, witness testimony or records of tutor observation will be necessary. Copies of these will need to be placed in the final portfolio of evidence.

In order to achieve P1, learners will need to prepare and maintain project records from initial concepts through to solution that take account of and record changing situations. Evidence could be collected by tutors from the learner's logbook. It is suggested that learners prepare and submit a written project specification for scrutiny in order to provide evidence for the achievement of P2 (i.e. that they have produced a specification to an acceptable standard). As part of the project specification learners could also include written evidence for the procedures (P3) that they have agreed to follow, after discussion with their tutor, when implementing their project solution. Particular emphasis should be placed on ensuring that learners consider budgetary constraints and resource/time limitations. Evidence for the achievement of P4, concerning the evaluation of potential solutions and the techniques used to select the best option, might best be obtained from scrutiny of the learner's logbook, or again form part of the written project specification/interim report.

To achieve learning outcome 2 learners will need to outline their chosen project solution and plan for its implementation (P5), in addition to monitoring and recording achievement over the life cycle of the project (P6). Evidence of achievement will again be through the logbook. Tutors may also wish to record some of this performance as an observation record or use witness statements.

The observations might well take place when learners are using computer-aided or manual planning tools in the learning centre. Additional evidence for P6 might come from the annotation of planning documentation or plans in the learner's logbook, that show the changing situations.

Learning outcome 3 is concerned primarily with the implementation of the project solution while adhering to agreed procedures (P7) and checking throughout the implementation phase that the solution produced conforms with the project specification (P8). The type of project chosen by the learner will, to a degree, dictate the methods used to provide evidence of achievement. Learners who are engaged on design/build or physical testing/modification type projects on a system or component, will be spending most of their project implementation phase in workshops and/or laboratories. Therefore, tutors will need evidence from observation records and from the physical solution itself. Evidence of achievement of P7 for those learners engaged in the production of a modified procedure/service, will provide evidence of achievement via their logbook records, presentation and final written report.

No matter what type of project learners choose, the primary source of evidence for achievement of P8 is likely to be the learner's logbook, where comparisons can be made with the agreed procedures to see whether or not learners abided by these procedures when producing their project solution.

In order to meet learning outcome 4, learners will need to prepare and deliver a presentation outlining their project specification and proposed solution to a small group (P9) and present a written project report with supporting documentation (P10). Evidence for P9 will be obtained from a combination of hard copies of the presentation, such as handouts, slides etc. and witness statements, together with the results of observation records from those present. The evidence for the achievement of P10 will come from the written report itself. Clear guidelines as to what is expected need to be given to learners well before the submission of their report.

To achieve M1, learners need to be able to work with greater autonomy and will have produced, and kept to, a workable plan. This will be demonstrated by their ability to maintain records throughout the project that are detailed, concurrent and clearly show progress made and the difficulties experienced. For M2 learners will need to have arrived at their project choice having used a wide range of techniques and from the use of these be able to justify their chosen option. The range of techniques used will need to show both statistical and graphical comparison methods for the potential solutions. Evidence will come from the learner's logbook and/or from the submitted written specification/interim report, (as was the case for achievement of P3).

Evidence for the achievement of M3 will come from observation records (particularly for design and build type solutions), scrutiny of logbook records and from the learner's reflections, written in the final report. It is expected that having evaluated their solution against the specification and/or from field evaluation and customer feedback, learners will then be able to suggest improvements that genuinely enhance the value of their project solution. Learners will have to present coherent and well-structured development records and final project report to achieve M4. The report structure is expected to adhere to standard technical report writing protocols, in order to achieve the criteria. The development records are likely to be included, as part of the learner's logbook and this should be submitted for final scrutiny, at the same time as the report.

To achieve a distinction, learners will have been able to work consistently towards a successful outcome and in doing so they will have independently managed the project development process, seeking support and guidance where necessary (D1). They will have shown the ability to reflect on their work throughout the project. Through this, they will have been able to evaluate the whole of the project development process and provide suggestions as to what they would have done differently to make improvements (D2). The evidence for both criteria is likely to come from the logbook and portfolio notes with the addition of witness statements and observation records for D1 and a separate written statement or statement in the final report, clearly evaluating the project making recommendations for improvements for D2.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, M1	Prepare and maintain project records	Tutor to scrutinise learner's project records and/or take account of observation records or witness testimony.	Through scrutiny of learner's logbook, observation records and/or witness testimony. Detailed and concurrent records need to be demonstrated to achieve M1.
P2, P3, P4, M2	Project specification and selection of best project option	Tutor to consider submitted work and scrutinise learner records and/or take account of observation records or witness testimony.	Marked submission of project specification to acceptable standard, including written procedures to be adopted and evidence for the evaluation of solution. A wide range of statistical and graphical comparison methods demonstrated to meet criterion M2.

Criteria covered	Assignment title	Scenario	Assessment method
P5, P6	Production of project plan and monitor project over its lifecycle	Tutor to scrutinise project records and take account of observation records or witness testimony	Scrutinise learner's long-term plans and logbook, identify and sanction achievement and changes made to plan, over the life of the project.
P7, P8, M3	Implement the project and produce the project solution	Tutor to observe learner progress in the implementation of project plan and in the production of project solution.	Through scrutiny of learner's logbooks and observation records for implementation of project solution and written/observational evidence for evaluation of solution in order to meet M3 criterion.
P9, P10, M4	Presenting the project outcome	Observation of oral presentation and consideration of written report and other project records and deliverables.	Through observation records and written oral presentation material and the marking of the final written report and consideration of all other project deliverables. Identification of well-structured and coherent development records and final report in order to meet M4.

Criteria covered	Assignment title	Scenario	Assessment method
D1, D2	Independently manage and critically evaluate the whole project	Tutor/supervisor observation records or independent witness statements and take account of learners' project records and written submissions.	Scrutinise learner's logbook and take account of observation records (D1) and mark written submission (D2).

Essential resources

Learners will need access to a wide variety of physical resources, dependent on the type of project they pursue. Many of these resources are detailed within the other units in the qualification. There is also a need to provide some form of access to audio-visual aids as well as access to libraries and computer aided learning centres. Learners may also require access to workshops, laboratories and specialist catalogues and other documentation. Centres should also subscribe to engineering journals and stock other useful literature, specific to the branches of engineering being covered.

Indicative reading for learners

Textbooks

Boyce A, Cooke E, Jones R and Weatherill B – *Edexcel BTEC Level 3 National Engineering Student Book* (Pearson, 2010) ISBN 9781846907241

Boyce A, Cooke E, Jones R and Weatherill B – *Edexcel BTEC Level 3 National Engineering Teaching Resource Pack* (Pearson, 2010) ISBN 9781846907265

Lock D – *Project Management* (Gower Publishing, 2007) ISBN 9780566087721

Melton T– *Project Management Toolkit, the Basics for Project Success* (Butterworth-Heinemann, 2007) ISBN 9780750684408

Melton T– *Real Project Planning: Developing a Project Development Strategy* (Butterworth-Heinemann, 2007) ISBN 9780750684729

Project Management Institute – *A Guide to the Project Management Body of Knowledge* (Project Management Institute, 2009) ISBN 9781933890517

Smith N J – *Engineering Project Management* (Blackwell Publishing, 2007) ISBN 9781405168021

Tooley M and Dingle L – *BTEC National Engineering* (Routledge, 2010) ISBN 9780123822024

Unit 17: Further Engineering Mathematics

Level:	3
Unit type:	Additional
Guided learning hours:	60

Unit introduction

Mathematics can be used to evaluate the intended and actual performance of a product or system at every stage of its life cycle. For example, mathematics may be used during the design of a product to determine whether it performs to specification. Statistics may be used during manufacturing processes as part of the quality control (QC) system and to determine the in-service reliability of a product. Statistics can also be used to evaluate the vast amounts of data that can be gathered about products and customers using mobile communications and the Internet of Things (IoT).

In this unit, learners will use algebraic techniques to solve engineering problems involving sequences, series, complex numbers and matrices. You will investigate the use of statistics as a data-processing and analysis tool, for example applying techniques used by a quality assurance engineer to monitor the output from a manufacturing process.

As a future engineer, you will need to understand and develop skills to solve problems using algebraic and statistical procedures. These are transferable skills and you will use them to support your study of other units in this course. This unit will help to prepare you for an apprenticeship or for employment in a range of engineering disciplines as a technician. You could also progress to a higher-level course, such as a Higher National Diploma (HND) or a degree in an engineering discipline.

Learning outcomes

On completion of this unit a learner should:

- 1 Examine how sequences and series can be used to solve engineering problems
- 2 Examine how matrices and determinants can be used to solve engineering problems
- 3 Examine how complex numbers can be used to solve engineering problems
- 4 Investigate how statistical and probability techniques can be used to solve engineering problems.

Unit content

1 Examine how sequences and series can be used to solve engineering problems

Arithmetic and geometric progressions

- Definitions:
 - sequence as an ordered collection of numbers a, b, c, d
 - progression as a sequence that increases in a particular pattern, i.e. there is a constant relationship between a number and its successor
 - series as the sum of the values in a sequence $a + b + c + d \dots$
 - terminology – first term a , last term l , connection by law.
- Routine operations involve:
 - arithmetic progression (AP):
common difference d
general expression for a sequence in AP:
 $a, (a + d), (a + 2d), (a + 3d), \dots, (a + nd)$
 n th term (last term) $l = a + (n - 1)d$
sum of an AP to n th term (arithmetic series):
$$s = a + (a + d) + (a + 2d) + \dots + (l - d) + l = \frac{1}{2}n(a + l)$$
 - geometric progression (GP):
common ratio r
general expression for a sequence in GP $a, ar, ar^2, ar^3, \dots, ar^n$
 - sum of a GP to n th term (geometric series):
$$s = a + ar + ar^2 + ar^3 + \dots + ar^n = \frac{a(1 - r^n)}{(1 - r)}$$

convergence
sum to infinity.
- Non-routine operations involve:
 - engineering applications, e.g. lathe spindle speeds, cost of deep drilling, depreciation costs of capital equipment, gear box ratios, manufacturing estimation.

Binomial expansion

- Definitions:
binomial expression that takes the form $(a + b)^n$

- binomial theorem: when n is a positive integer

$$(a+b)^n = a^n + na^{n-1}b + \frac{n(n-1)}{2!}a^{n-2}b^2 + \frac{n(n-1)(n-2)}{3!}a^{n-3}b^3 + \dots + b^n \quad (\text{a finite series})$$

which can be written as $(a+b)^n = \sum_{k=0}^{k=n} {}_n C_k a^{n-k} b^k$ where ${}_n C_k = \frac{n!}{(n-k)!k!}$

alternative form $(1+x)^n = 1 + nx + \frac{n(n-1)}{2!}x^2 + \frac{n(n-1)(n-2)}{3!}x^3 + \dots + x^n$

- binomial theorem when n is not a positive integer:

$$(1+x)^n = 1 + nx + \frac{n(n-1)}{2!}x^2 + \frac{n(n-1)(n-2)}{3!}x^3 + \dots + x^n \quad \text{for } -1 < x < 1 \text{ only}$$

(an infinite series)

- Routine operations involve:
 - construction of Pascal's triangle
 - expansion of $(a+b)^n$ for positive values of n using Pascal's triangle.
- Non-routine operations involve:
 - expansion of $(1+x)^n$ for non-positive integer values of n using the binomial theorem
 - calculation of the n th term using the binomial theorem
 - engineering applications, e.g. small errors, small changes, percentage changes, approximation of errors.

Power series

- Definitions:
 - a power series as $f(x) = a_0 + a_1x + a_2x^2 + a_3x^3 + \dots + a_nx^n$
 - a Taylor series as $f(x) = f(a) + f'(a)(x-a) + \frac{f''(a)}{2!}(x-a)^2 + \dots + \frac{f^{(n)}(a)}{n!}(x-a)^n$
- Routine operations involve:
 - a Maclaurin series as a Taylor series with $a = 0$
 - convergence and divergence
 - conditions for convergence and divergence.
- Non-routine operations involve:
 - numerical value for e using a power series
 - proof that $\frac{dy}{dx}(e^x) = e^x$ using series
 - engineering applications, e.g. error in area or volume for small error in measurement of length, oscillator frequency for an electrical circuit if components have small errors in their values.

2 Examine how matrices and determinants can be used to solve engineering problems

Matrices

- Definitions:
 - matrix type – element and order (row × column)
 - matrix terminology – element, row, column, order (row × column), equality, zero (null matrix), identity (unit) matrix, transpose, square, leading diagonal, triangular.
- Routine operations involve:
 - addition, subtraction, multiplication by a real number
 - inverse of a (2 × 2) matrix
 - solution of sets of simultaneous equations with two variables using inverse matrix methods.
- Non-routine operations involve:
 - multiplication of matrices
 - solution of sets of simultaneous equations with two variables using Gaussian elimination.

Determinants

- Definitions:
 - the determinant of a matrix as a useful value that can be computed from the elements of a square matrix, denoted by $\det(A)$ or $|A|$
 - a singular matrix is one with the determinant $|A| = 0$
- Routine operations involve:
 - the determinant of a (2 × 2) matrix $A = \begin{pmatrix} a & b \\ c & d \end{pmatrix}$ using $|A| = ad - bc$
 - the inverse of a two-dimensional matrix $A = \begin{pmatrix} a & b \\ c & d \end{pmatrix}$ using $A^{-1} = \frac{1}{|A|} \begin{pmatrix} d & -b \\ -c & a \end{pmatrix}$
- Non-routine operations involve:
 - the determinant of a (3 × 3) matrix $A = \begin{pmatrix} a & b & c \\ d & e & f \\ g & h & i \end{pmatrix}$ using
$$|A| = a \begin{vmatrix} e & f \\ h & i \end{vmatrix} - b \begin{vmatrix} d & f \\ g & i \end{vmatrix} + c \begin{vmatrix} d & e \\ g & h \end{vmatrix}$$
 - use of Cramer's rule to solve for sets of simultaneous equations with two variables
 - engineering applications, e.g. simultaneous linear equations with more than two variables (electrical circuits, vector arrays, machine cutter paths).

3 Examine how complex numbers can be used to solve engineering problems

Complex numbers

- Definitions:
 - algebraic form (Cartesian, rectangular notation): $(a + jb)$
 - real part, imaginary part, j notation, j -operator, powers of j
 - modulus: $|a + jb| = \sqrt{a^2 + b^2}$
 - argument: $arg(a + jb) = \tan^{-1}\left(\frac{b}{a}\right)$
 - polar form $r \angle \theta$; θ is usually expressed in radians but may be in another angular measure
 - complex conjugate of $y = a \pm jb$ as $y^* = a \mp jb$
- Routine operations involve:
 - placement of complex numbers on an Argand diagram
 - addition and subtraction in rectangular form
 - multiplication by a constant coefficient
 - conversion between rectangular and polar forms ($r \rightarrow p$ and $p \rightarrow r$) using trigonometry and a scientific calculator
 - multiplication and division of complex numbers in polar form.
- Non-routine operations involve:
 - multiplication in rectangular form
 - division in rectangular form using the complex conjugate
 - de Moivre's theorem: $(r \angle \theta)^n = r^n \angle n\theta$
 - engineering applications, e.g. vectors, electrical circuit phasor diagrams, algebraic form (Cartesian, rectangular notation): $(a + jb)$
 - real part, imaginary part, j notation, j -operator, powers of j
 - modulus: $|a + jb| = \sqrt{a^2 + b^2}$
 - argument: $arg(a + jb) = \tan^{-1}\left(\frac{b}{a}\right)$
 - polar form $r \angle \theta$; is usually expressed in radians but may be in another angular measure
 - complex conjugate of $y = a \pm jb$ as $y^* = a \mp jb$

4 Investigate how statistical and probability techniques can be used to solve engineering problems

Statistical techniques

- Routine operations involve:
 - discrete data, continuous data, ungrouped data, grouped data, rogue values
 - presentation of data: bar charts, pie charts, histograms, cumulative frequency curves
 - measures of central tendency (location): arithmetic mean, median, mode
 - measures of dispersion: variance, standard deviation, range and inter-percentile ranges
 - linear relationship between independent and dependent variables, scatter diagrams, approximate equation of line of regression $y = mx + c$ represented graphically.

- Non-routine operations involve:
 - equation of linear regression line $y = mx + c$ where

$$m = \frac{N \sum_{i=1}^N (x_i y_i) - \sum_{i=1}^N (x_i) \sum_{i=1}^N (y_i)}{N \sum_{i=1}^N x_i^2 - \left(\sum_{i=1}^N x_i \right)^2} \quad \text{and} \quad c = \bar{y} - m\bar{x}$$

$$\bar{x} = \frac{\sum_{i=1}^N x_i}{N} \quad \text{and} \quad \bar{y} = \frac{\sum_{i=1}^N y_i}{N}$$

- correlation coefficient using Pearson's correlation

$$r_{x,y} = \frac{N \sum_{i=1}^N x_i y_i - \sum_{i=1}^N x_i \sum_{i=1}^N y_i}{\sqrt{N \sum_{i=1}^N x_i^2 - \left(\sum_{i=1}^N x_i \right)^2} \sqrt{N \sum_{i=1}^N y_i^2 - \left(\sum_{i=1}^N y_i \right)^2}}$$

- Use of spreadsheets and/or scientific calculators to calculate the equation of the line of regression and correlation coefficient, e.g. tabulating calculations, using trendline and CORREL() functions in a spreadsheet, or a standard scientific calculator.
- Use of spreadsheets and/or scientific calculators to identify the most appropriate type of regression line, e.g. linear, logarithmic, exponential or variable power.

Probability distributions

- Routine operations involve:
 - normal distribution – shape and symmetry, skew, tables of the cumulative distribution function, mean, variance
 - normal distribution curve – areas under it relating to integer values of standard deviation.
- Non-routine operations involve:
 - confidence intervals for normal distribution and probability calculations.

Statistical investigation

- The use of appropriate mathematical methods to solve the given engineering problem.
- Engineering applications, e.g. inspection and quality assurance, calculation of central tendencies and dispersion, forecasting, reliability estimates for components and systems, customer behaviour, condition monitoring and product performance.
- Reflection on the problem-solving process and the solution obtained, making refinements if necessary.
- Presentation of the solution to the given engineering problem.

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P1 solve given problems using routine arithmetic and geometric progression operations	M1 solve given problems accurately, using routine and non-routine arithmetic and geometric progression operations	D1 evaluate, using technically correct language and a logical structure, engineering problems using non-routine sequence and series operations, while solving accurately all the given problems using routine and non-routine operations
P2 solve given problems using routine power series operations	M2 solve given problems accurately, using routine and non-routine power series operations	D2 evaluate, using technically correct language and a logical structure, engineering problems using non-routine matrices, determinant and complex operations, while solving accurately all the given problems using routine and non-routine operations

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P3 solve given problems using routine matrices and determinant operations	M3 solve given problems accurately, using routine and non-routine matrices and determinant operations	
P4 solve given problems using routine complex number operations	M4 solve given problems accurately, using routine and non-routine complex number operations	
P5 solve an engineering problem using routine central tendency, dispersion and probability distribution operations	M5 solve an engineering problem accurately, using routine and non-routine central tendency, dispersion and probability distribution operations, providing an explanation of the process	D3 evaluate the correct synthesis and application of statistics and probability to solve engineering problems involving accurate routine and non-routine operations.
P6 solve an engineering problem using routine linear regression operations.	M6 solve engineering problems accurately, using routine and non-routine regression operations, providing an explanation of the process.	

Essential guidance for tutors

Assessment

For P1 and P2, learners must demonstrate the correct use of routine operations (skills and methods) when working with given problems based on sequences and series.

Overall, minor arithmetic and scaling errors are acceptable, as are 'carry through' errors, provided that the basic method is sound. For example, a term in a sequence may be incorrectly calculated but the value used correctly in subsequent calculation of the series, affecting the final value. Learners will demonstrate an appreciation of the need for the correct use of units but there may be errors in their application. There will also be evidence of simple checks to determine if numerical answers are 'reasonable'.

For P3 and P4, learners must demonstrate the correct use of routine operations (skills and methods) when working on given problems based on matrices, determinants and complex numbers.

Overall, minor arithmetic errors are acceptable, as are 'carry through' errors, provided that the basic method is sound. Learners will demonstrate an appreciation of the need for the correct use of units but there may be errors in their application. Learners will include evidence of simple checks to determine if numerical answers are 'reasonable'.

For P5 and P6, learners will present the solutions of engineering problems involving measures of central tendency, dispersion and probability distribution. Ideally, they will research their own problems but if this is not possible then they can be given to learners. The solutions may not be complete and there may be some inaccuracies or omissions but there should be evidence of some proficiency of method. Learners will apply the appropriate routine operations (skills and methods) needed to process statistical data. For example, when evaluating sampled dimensional data from a machining operation, learners will present data appropriately and determine routine values such as the mean and standard deviation for a sample but may not compare the values with historical data. They will tabulate measurements and present data in a scatter graph and they may estimate the line of regression graphically.

Overall, the report should be logically structured. It may contain some arithmetic errors that 'carry through', for example the value of the mean of a set of sampled dimensional data from a machining operation may be incorrect, but that value used correctly to find the standard deviation. The methods chosen may not be optimal but the chosen statistical methods should be applied correctly. Minor errors and omissions are acceptable. For example, the axis titles on a scatter graph may be missing units. There will be an appreciation of correct use of units but there may be errors or inconsistency in their application. Learners will include evidence of simple checks to determine if numerical answers are 'reasonable'.

For M1 and M2, learners will accurately apply appropriate routine and non-routine operations (skills and methods) needed to solve given problems based on sequences and series.

Overall, the numerical work will be to an appropriate degree of accuracy, as specified by the assessor. For example, appropriate significant figures and decimal places. Solutions must be structured logically and the correct mathematical terminology and relevant units will be used, with limited number of minor errors or omissions in non-routine operations.

For M3 and M4, learners will accurately apply appropriate routine and non-routine operations (skills and methods) needed to solve given problems based on matrices, determinants and complex numbers.

Overall, the numerical work will be to an appropriate degree of accuracy, as specified by the assessor. For example, appropriate significant figures and decimal places. Solutions must be structured logically and the correct mathematical terminology and relevant units will be used, with limited number of minor errors or omissions in non-routine operations.

For M5 and M6, learners will present accurate solutions for engineering problems related to measures of central tendency, dispersion and probability distribution, breaking them down into planned stages to obtain solutions. They will apply appropriate routine and non-routine operations (skills and methods) needed to process statistical data accurately. For example, tabulation of data, graphical presentation, accurate calculations of mean and standard deviation comparing measured values with historical data, accurately produced annotated scatter graph (with chart title, axis titles including units and gridlines) and calculation of line of regression and correlation coefficient for a linear relationship and regression line for a non-linear relationship.

Overall, the numerical work will be to an appropriate degree of accuracy, as specified by the assessor or appropriate for the chosen problems being solved. Solutions will contain an explanation of the process that will be logically structured, and the correct mathematical terminology and relevant units will be used. There may be limited number of minor errors or omissions in non-routine operations. For example, when evaluating sampled dimensional data from a machining operation, learners may determine the mean and standard deviation for a sample and find a degree of correlation between samples, but not draw conclusions from, the values.

To achieve D1, learners will demonstrate mastery in the application of algebraic techniques to the correct solution of given problems involving sequences and series. Where appropriate to the non-routine problems, learners will correctly and efficiently manipulate formulae and present reasoned and balanced evaluations.

Overall, the evidence will be easily understood by a third party with a mathematical background, who may or may not be an engineer. Learners will use mathematical methods and terminology precisely and apply relevant units when working with mathematical expressions that model engineering situations. Small and large numerical values will be correctly presented in an appropriate format, for example engineering notation or standard form. Learners must demonstrate that they are able to work to specified numerical precision, as specified by the assessor, through the use of appropriate significant figures.

For D2, learners will demonstrate mastery in the application of algebraic techniques to the correct solution of given problems involving matrices, determinants and complex numbers. Where appropriate with the non-routine problems, learners will correctly and efficiently manipulate formulae and present reasoned and balanced evaluations.

Overall, the evidence will be easily understood by a third party with a mathematical background, who may or may not be an engineer. Learners will use mathematical methods and terminology precisely and apply relevant units when working with mathematical expressions that model engineering situations. Small and large numerical values will be correctly presented in an appropriate format, for example engineering notation or standard form. Learners must demonstrate they are able to work to specified numerical accuracy through the use of appropriate significant figures, as specified by the assessor.

In order to achieve D3, learners will demonstrate mastery in the application of the processing and evaluation of statistical data generated from engineering sources. The identified problems must be sufficiently complex to allow learners to apply both routine and non-routine operations (skills and methods) to their solution. For example, in terms of measures of central tendency and dispersion learners may evaluate one set of measured and four sets of equivalent historical data such as dimensional data from a machining operation or reliability data sourced from products in service. Before starting to process any data, learners will establish that the data sets are large enough to enable reliable analysis to be carried out. For regression, they will propose a theoretical relationship between two variables, collect data, calculate a mathematical relationship between dependent and independent variables using appropriate analytical and graphical methods, and reflect on the accuracy of the initial proposal for a linear and a non-linear relationship.

Overall, the evidence will be easily understood by a third party with a mathematical background, who may or may not be an engineer. There will be correct use of mathematical terminology and the application of relevant units. Learners will work to specified numerical precision, as determined by the assessor or that are appropriate for their chosen problems being solved, through the use of appropriate significant figures or decimal places. Small and large numerical values will be correctly presented in an appropriate format, i.e. engineering notation or standard form.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1, M2, D1	Sequences and Series to Solve Engineering Problems	An activity requiring learners to solve problems based on sequences and series.	An informal report containing the results of learners' analysis and calculation; carried out under controlled conditions.
P3, P4, M3, M4, D2	Matrices, Determinants and Complex Numbers to Solve Engineering Problems	An activity requiring learners to solve problems based on matrices, determinants and complex numbers.	An informal report containing the results of learners' analysis and calculation; carried out under controlled conditions.
P5, P6, M5, M6, D3	Statistical and Probability Techniques to Solve Engineering Problems	An activity requiring learners to solve engineering problems based on statistical data.	An informal report containing the results of learners' analysis and calculation of measured and supplied data; carried out under controlled conditions. Where appropriate, processing of statistical data can be done by spreadsheet.

Essential resources

For this unit, learners must have access to:

- maths support websites, e.g. www.mathcentre.ac.uk/students/topics
- spreadsheet software and/or a scientific calculator such as Casio FX-85GT.

Indicative reading for learners

Textbooks

Bird J – *Engineering Mathematics* (Routledge, 2014) ISBN 9780415662802

Greer A and Taylor G W – *BTEC National Further Mathematics for Technicians* (Nelson Thornes, 2005) ISBN 9780748794102

Tooley M and Dingle L – *BTEC National Engineering* (Routledge, 2010)
ISBN 9780123822024

Unit 18: Electro-pneumatic and Hydraulic Systems and Devices

Level:	3
Unit type:	Additional
Guided learning hours:	60

Unit introduction

An understanding of how fluid power systems are used to control the operation of machinery and equipment is important for anyone thinking of a career in engineering.

Pneumatic (pressurised air or gas) systems are widely used in manufacturing engineering to operate equipment such as packaging machines, automated assembly machines, clamping and lifting devices. There are many other everyday applications where air operated equipment is found, for example for opening doors on buses. Hydraulic (pressurised liquid) systems are used where greater amounts of power are involved, a good example of this being the linear actuators that move the arms on excavators and other types of earthmoving equipment.

This unit will give learners a broad understanding of the design and safe operation of pressurised fluid systems that use electrical control devices to make them work. This will include reading and producing simple fluid power circuit diagrams, understanding the principles of maintenance, and the use of test routines to identify faults in these systems.

Learners will investigate the impact that current legislation has on the design and safe operation of fluid power circuits, so that when carrying out practical work they are able to work safely. High pressure systems and devices, particularly air-based ones, have hidden dangers. Because hydraulic oil is carcinogenic, learners will be made aware of the regulations covering the handling and disposal/recycling of this substance.

This is followed by a look at a selection of the components used in fluid power systems and how they can be represented using universally recognised circuit diagram symbols. The components studied will include those used to generate a supply of high pressure air or hydraulic fluid, prime movers such as linear actuators (cylinders) and control devices such as valves and sensors.

Learners will be introduced to some of the calculations that need to be carried out before designing and setting up a system. These include some basic pressure and volume calculations involving gases, determination of the correct size of cylinder to produce a specified extending force, and calculation of fluid flow rates needed to keep a system operating effectively. Learners will then investigate how components can be linked together to form systems for a specific purpose.

The final section of the unit looks at how fluid power systems are maintained in service and what happens if they develop faults. The emphasis here is on applying safe working practices, using predetermined systematic schedules and keeping accurate records for future reference.

Note that the use of 'e.g' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

- 1 Know about the legislation, regulations and safety precautions that apply when working with fluid power systems
- 2 Know the construction and operation of fluid power devices and how they are represented as symbols in circuit diagrams
- 3 Be able to apply fluid power principles in the design of circuits
- 4 Be able to carry out maintenance, inspection, testing and fault-finding on fluid power systems.

Unit content

1 Know about the legislation, regulations and safety precautions that apply when working with fluid power systems

Legislation and regulations: legislation, e.g. Health and Safety at Work etc. Act 1974, Employment Act 2002, Factories Act 1961, Fire Precautions Act 1971, Deposit of Poisonous Waste Act 1972, European Conformity (CE marking); regulations, e.g. Employment Equality (Age) Regulations 2006, Management of Health and Safety at Work Regulations 1999, Provision and Use of Work Equipment Regulations (PUWER) 1998, Control of Substances Hazardous to Health (COSHH) Regulations 2002, Lifting Operations and Lifting Equipment Regulations (LOLER) 1998, Manual Handling Operations Regulations (MHOR) 1992, Personal Protective Equipment (PPE) at Work Regulations 1992, Confined Spaces Regulations 1997, Electricity at Work Regulations 1989, Control of Noise at Work Regulations 2005, Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (RIDDOR) 1995, Workplace (Health, Safety and Welfare) Regulations 1992, Health and Safety (First-Aid) Regulations 1981, Carriage of Dangerous Goods and Use of Transportable Pressure Equipment Regulations 2009, Simple Pressure Vessels (Safety) Regulations 1991 (SI 1994/3098), The Simple Pressure Vessels Directive (Directive 87/404/EEC) (SPVD); Supply of Machinery (Safety) (Amendment) Regulations 2005 (SI 2005/831).

Safety precautions: risk assessment of fluid power systems; assembling and testing electro-pneumatic and hydraulic systems and devices, e.g. isolation of services (such as electrical, air, oil), escape of fluids at high pressure which may cause contact injury, hydraulic oil contact with the skin, sudden movement of linear actuators causing entrapment injuries; personal protective equipment (PPE), e.g. safety glasses, gloves, overalls, footwear.

2 Know the construction and operation of fluid power devices and how they are represented as symbols in circuit diagrams

Fluid power devices: fluid conditioning, e.g. supply tank, filter, pump, cooler, compressor, dryer, receiver, accumulator; fluid supply, e.g. pipework, fittings, seals, drainage points; electrical supply systems, e.g. mains, low voltage regulated power supply units, AC, DC; fluid control valves, e.g. directional (manual and solenoid), pilot, 4 port, 5 port, pressure reducing, non-return, flow rate; actuators linear, rotary; motors e.g. electric, air, hydraulic; position sensors, e.g. reed switch, pressure switch, inductive, microswitch; system control, e.g. programmable logic controller (PLC), electro mechanical.

Symbols: relevant and current standards, e.g. BS3939, BS ISO 1219-1:2012, European Fluid Power Committee (CETOP); symbols for common components, e.g. fluid conditioning, fluid supply, electrical supply, control valves, actuators, motors, sensors, control.

Circuit diagrams: diagrams, e.g. pneumatic, hydraulic, block diagrams, system layout, displacement step diagrams; reference material, e.g. component and equipment data sheets, BS ISO 1219-1:2012, software (such as FluidSIM or Automation Studio).

3 Be able to apply fluid power principles in the design of circuits

Fluid power principles: properties and behaviour of air and hydraulic fluids; gas laws, e.g. Boyle's, Charles', Gay-Lussac's, general gas, dew point; fluid flow, e.g. Bernoulli's principle, volumetric rate, receiver volume, actuator flow requirements; fluid pressure e.g. units of measurement, Pascal's law, inlet and outlet pressure, pressure drop, actuator efficiency, clamping force; formulae ($P_1V_1T_2 = P_2V_2T_1$, displaced volume = piston area × stroke, volumetric flow rate = $\frac{\text{displaced volume}}{\text{time}}$, absolute pressure = gauge + atmospheric pressure, force = pressure × area, actuator force = pressure × area × efficiency).

Circuits: pneumatic, e.g. multi-cylinder sequential operation, single-cylinder reciprocation with dwell, position and clamp an object using a two-cylinder arrangement, rotary actuator with reversing action; hydraulic, e.g. multi-cylinder sequential operation, single-cylinder reciprocation with dwell and regeneration, hydraulic motor with reversing action.

4 Be able to carry out maintenance, inspection, testing and fault-finding on fluid power systems

Maintenance: routines, e.g. frequency of maintenance, manuals and reference documentation, keeping of accurate records using paper- or software-based systems; components (electro-pneumatic, hydraulic); systems, e.g. electro-pneumatic, electro-hydraulic.

Inspection: functional, e.g. at component level, as a system, performance against specification; keeping of accurate records; report, e.g. component drawing, system circuit diagram, digital images, inspection checklist, record of visual observations made against checklist, conclusions, recommendations.

Testing: performance, e.g. against specification, reliability; keeping of accurate records; report, e.g. system circuit diagram, system specification, test schedule, list of test equipment, record test results, record visual observations, compare test results with system specification, recommendations for future actions.

Fault finding: identify faults in fluid power systems, e.g. manual diagnosis, visual examination, unit substitution, input to output, injection and sampling, half-split technique, six-point technique, self-diagnostic techniques using programmable electronic equipment, effect of malfunctions; fault-finding aids, e.g. functional charts, diagrams, flow charts, troubleshooting charts, component data sheets, operation and maintenance manuals, specialised equipment; record faults, e.g. paper based, software based, analyse data; report, e.g. system circuit diagram, record test results, record visual observations, compare test results with system specification, record faults and cross reference to circuit diagram, identify type of fault, strategy for rectification of fault.

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P1 list the aspects of health and safety legislation and regulations that apply when working with given fluid power equipment and systems		
P2 describe the safety precautions that apply when working with fluid power equipment and systems		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P3 describe, with the aid of suitable diagrams, the construction and operation of a given electro-pneumatic device and a given electrohydraulic device	M1 compare the construction and operation of a pneumatic system with that of a hydraulic system	D1 assess the relevance of current standards, such as CETOP, to the construction and operation of fluid power devices
P4 use standards to identify electro-pneumatic and hydraulic components shown as symbols in given circuit diagrams and reference materials		
P5 carry out calculations that relate to the fluid power principles used in the design of circuits		
P6 produce a circuit diagram to meet a given electro-pneumatic system specification		
P7 produce a circuit diagram to meet a given hydraulic system specification		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P8 use routines and carry out maintenance on given electro-pneumatic and hydraulic components and a given electro-pneumatic or electro-hydraulic system	M2 explain the routines used when carrying out maintenance on a given electro-pneumatic or electro-hydraulic system M3 produce a report of showing findings.	
P9 carry out inspection, testing and fault-finding on a given electro-pneumatic or electrohydraulic system in line with checklists.		D2 evaluate the use of self-diagnostic techniques to monitor the performance of fluid power systems used in industry.

Essential guidance for tutors

Assessment

It may be appropriate to structure the assessment of this unit as five assignments, using four to cover the pass and merit criteria and the fifth one the two distinction criteria.

The first assignment could cover P1 and P2 and should be structured so that learners remain focused on the content of learning outcome 1. Learners are expected to use their own words when referring to legislation and, while much of their research will be done using the internet, it is important that what they present is not just a simple cut and paste exercise. Evidence to support knowledge of safety precautions could be generated by giving learners a list of situations/scenarios and then asking them to detail what needs to be done to work safely. This leads into risk assessment and learners could be asked to carry out an assessment for equipment which they will be using later in the unit.

Grading criteria P3, P4, M1 and D1 complement each other and could be assessed through a second assignment that covers the whole of the content for learning outcome 2. P3 asks for information about the construction and operation of equipment and, provided that any written explanation is supported by diagrams there is no requirement for learners to present fully detailed drawings of the devices considered.

To meet the requirements of P4, learners could be given a suitable set of circuit diagrams and manufacturers' reference material for the equipment described for P3. This would determine the amount of components and symbols needed to meet the requirement of P4. Examples of such devices are found in the unit content and delivery guidance. M1 encompasses P3 and P4 and requires a comparison of the construction and operation of the two systems. This comparison can be extended to assess the relevance of standards such as ISO and CETOP to the construction and operation of fluid power devices.

P5, P6 and P7 are linked and could be assessed using a third assignment that will involve calculation and the production of circuit diagrams which meet given design specifications. These can be hand drawn but it is better if learners use a software package so that simulation can be carried out to ensure correct operation of the circuits. This could be evidenced in the form of screen prints consolidated by a witness statement or observation record.

Grading criteria P8, P9, M2 and D2 could be assessed using a fourth assignment. Evidence of learners' competence when carrying out practical tasks will need to be recorded using witness statements, observation records and digital images.

The tasks set to generate evidence for P8 should involve the use of a small range of components and just one fluid power system (i.e. pneumatic or hydraulic). Similarly, when producing evidence for P9, it is only necessary to work with one type of system.

Both criteria require learners to keep accurate records and use relevant documentation in addition to carrying out the practical tasks. Learners who built the circuits that they designed to achieve P6 and P7 could work on these when gathering evidence for P8 and P9.

M2 and M3 build on P8 and P9 requiring an explanation and a report showing findings. Finally, D2 requires an evaluation of self-diagnostic techniques to monitor performance. This could include, for example, electronic programmable equipment to carry out the monitoring and an evaluation of its effectiveness.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2	Legislation and Safety Precautions	Learners to carry out a risk assessment for fluid power equipment in an engineering situation.	A written assignment in which learners detail the legislation and safety precautions that apply to a piece of fluid power equipment that they are going to use.
P3, P4, M1, D1	Construction and Operation of Fluid Power Devices	Use and interpret circuit diagrams to identify and describe the operation of fluid power devices and components.	A written assignment with tasks requiring learners use diagrams to describe fluid power devices and identify components.

Criteria covered	Assignment title	Scenario	Assessment method
P5, P6, P7	Fluid Power Principles and Circuits	Learners have been asked to produce circuit diagrams to meet the requirements of a customer specification in an engineering situation.	A practical assignment requiring learners to produce two circuit diagrams and carry out calculations.
P8, P9, M2, M3, D1, D2	Carrying Out Fluid Power Maintenance, Inspection, Testing and Fault-finding	Learners have been asked by their supervisor to carry this out on fluid power systems.	A practical assignment supported by a logbook/report of activities carried out plus observation records.

Essential resources

To meet the needs of this unit it is essential that centres have access to the following:

- industrial-standard electro-pneumatic and hydraulic equipment and systems
- fluid power circuit design software, e.g. FluidSIM or Automation Studio
- test equipment and measuring instruments
- relevant British and international standards
- health and safety publications.

Indicative reading for learners

Textbooks

Darbyshire A – *Mechanical Engineering BTEC National Level 3 Engineering Specialist Units* (Routledge, 2010) ISBN 9780080965772

Kay M – *Practical Hydraulics* (CRC Press, 2007) ISBN 9780415351157

Turner I – *Engineering Applications of Pneumatics and Hydraulics* (Routledge, 1995) ISBN 9780340625262

Zhang Q – *Basics of Hydraulic Systems* (CRC Press, 2008) ISBN 9781420070989

Parr A – *Hydraulics and Pneumatics: A Technician's and Engineer's Guide* (Butterworth-Heinemann, 2011) ISBN 9780080966748

Chapple PJ – *Principles of Hydraulic System Design* (Coxmoor Publishing Co, 2008) ISBN 9781901892154

Unit 19: Computer-Aided Drafting in Engineering

Level:	3
Unit type:	Additional
Guided learning hours:	60

Unit introduction

Computer-aided drafting is fast becoming the primary means of communicating design information in many industry sectors, particularly in engineering and manufacturing. Two-dimensional (2D) CAD drawings and three-dimensional (3D) CAD data can be shared with computer numerical control (CNC) machines using computer-aided manufacturing (CAM) software. 3D models can be rendered to produce photo-realistic representations, or can be animated to produce moving views of products and components as they would appear in service. Additionally, models can be used to analyse features such as mass, volume and mechanical properties.

This unit will enable learners to produce a variety of CAD drawings, from single-part 2D components to complex 3D models. Advanced techniques, such as using pre-prepared symbols to construct circuit diagrams and assembly drawings, will provide opportunities for learners to develop their skills. Learners will investigate the use of CAD in industry, the hardware and software required and the links with other software packages. In doing this, learners will appreciate the advantages of CAD over more conventional methods of drawing production.

Finally, learners will generate 3D models, make comparison with 2D CAD drawings and evaluate the impact of this technology on manufacturing companies and their customers.

The unit as a whole provides an opportunity to carry out practical CAD activities using a full range of commands and drawing environments. In addition, learners will gain an understanding of the use and impact of CAD on the manufacturing industry.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

- 1 Know the national and international standards and conventions that CAD drawings and design need to comply with
- 2 Understand the advantages of using CAD in comparison with other methods
- 3 Know about the software and hardware required to produce CAD drawings
- 4 Be able to produce and interpret CAD drawings
- 5 Be able to use CAD software to produce 3D drawings and views.

Unit content

1 Know the national and international standards and conventions that CAD drawings and design need to comply with

Requirements of current national and international standards and conventions: engineering drawing practice: BS 8888:2013, BS 5070-3 1988, BS EN 13622:2002, ISO standards.

Features of CAD drawings that need to comply with national and international standards: drawing sheet sizes and layouts, projection – first and third angle types of line, lettering and numbering, dimensioning, section cross hatching.

Standard representations: welding symbols, electrical symbols, pneumatic/hydraulic symbols, mechanical symbols.

2 Know the advantages of using CAD in comparison with other methods

Advantages of CAD: quality; accuracy; time; cost; electronic transfer of information; links with other software, e.g. CAD/CAM, rendering software, animation software, finite element analysis (FEA).

Other methods: manual drafting; model making.

3 Know about the software and hardware required to produce CAD drawings

Software: operating systems; CAD software packages, e.g. AutoCAD, AutoCAD/Inventor, Microstation, Catia, Pro/ENGINEER, Solidworks; minimum system requirements, e.g. hard disk space, memory required, processor, video card.

Hardware: keyboard; mouse; other input devices, e.g. light pen, digitiser, joystick, thumbwheel; monitor; printer; other output devices, e.g. plotter, rapid prototyping; storage, e.g. floppy disk, hard disk, memory stick, CD, network.

4 Be able to produce and interpret CAD drawings

CAD drawings: orthographic projections; circuit diagrams, e.g. hydraulic, pneumatic, electronic; exploded/ assembly drawing; standards, e.g. BS 8888, BS 3939, BS 2917.

Commands: absolute/relative/polar coordinates; features, e.g. linetypes, grids, snaps, circle, text, hatching, dimensioning, layers/levels, colour; viewing, e.g. zoom, pan; inserting other drawings, e.g. symbols, blocks; modifying, e.g. copy, rotate, move, erase, scale, chamfer, fillet.

Interpret: determine properties of drawn objects, e.g. list, distance, area, volume.

5 Be able to use CAD software to produce 3D drawings and views

3D environment: 3D views, e.g. top, front, side, isometric.

3D models: 3D techniques, e.g. addition and subtraction of material, extrude, revolve, sweep, 3D coordinate entry (x, y, z), wire frame drawing, 2D to 3D (thickness, extrusion); surface models; solid models.

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P1 describe the requirements of national and international standards and conventions relating to engineering drawing practice		
P2 explain which features of CAD drawings need to comply with national and international standards		
P3 explain the advantages, compared to other methods, of producing drawings electronically using a CAD package	M1 explain the relationship between CAD and other software/hardware used in manufacturing	D1 justify the use of CAD in a manufacturing company
P4 describe the software and hardware that are required to produce CAD drawings		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P5 produce 2D CAD detail drawings of five components that make up an assembly or sub-assembly to given standards, using appropriate commands	M2 explain how the range of commands used to produce CAD drawings can impact drawing production	
P6 produce a circuit diagram containing at least five components to appropriate standards, using appropriate commands		
P7 produce an assembly drawing and exploded view of an assembly or sub-assembly containing at least five parts, using appropriate commands		
P8 interpret the properties of an engineering component or circuit from a given CAD drawing		
P9 construct a 3D CAD drawing as a surface and solid model.	M3 explain how 3D CAD models can be used in the design process.	D2 evaluate the impact of the use of 2D and 3D CAD models on final design requirements.

Essential guidance for tutors

Assessment

An assignment could cover P1 and P2 and should be structured so that learners remain focused on the content of learning outcome 1. Learners are expected to use their own words when referring to the national and international standards and conventions. While much of their research will be done using the internet, it is important that what they present is not just a simple cut and paste exercise. Evidence to support knowledge of which features of CAD drawings comply with national and international conventions could be generated by giving learners drawings which highlight the details required for meeting National and International conventions.

The assessment evidence for P3 and P4 could be produced through a case study or through studying the company in which learners may be employed. Typically, it would take the form of a written report or presentation. To achieve P3, learners must demonstrate an understanding of how CAD is used in comparison with more traditional drawing methods, stating its advantages and explaining how CAD systems can be linked with other software. A description of basic hardware and software requirements to operate a CAD system will be required to achieve P4.

The remaining pass criteria could be evidenced through a series of competence-based practical activities. Evidence could be in the form of witness statements, tutor observation records or a portfolio, although it is likely that electronic files will be used for the majority of the assessment. Screen dumps can often be a good source of evidence to show the range of commands used during the development of the drawings. The process evidence for these remaining pass criteria (P5 to P9) could be obtained from further assignments. In the first of these, learners would be required to produce five separate CAD drawings of the components which make up an assembly or sub-assembly. The full range of commands must be used and the drawings should be dimensioned to an appropriate standard, enabling P5 to be achieved. These drawings could then be used to produce an assembly and exploded view drawing (P7).

A further assignment would require production of a circuit diagram to achieve P6. This might reflect learners' occupation or area of interest and should be assembled from symbols previously introduced by the tutor and/or externally sourced. This assignment could also ask learners to interpret and provide a summary of the information contained in a given detail drawing or circuit diagram (P8).

The final assignment would require production of a single 3D model using both surface and solid modelling techniques to enable achievement of P9. This might be a 3D version of one of the part drawings used as evidence for the assembly and exploded view drawing.

To achieve a merit grade, learners will need to look beyond how drawings are produced and evaluate their use and application. This will typically be through looking more closely at the relationship between CAD and other software.

Learners should explain how linking CAD to other software/hardware impacts on an organisation (for example improving production, reducing waste, reducing lead times). This will build on the evidence generated for P3 and enable the M1 merit criterion to be achieved.

An explanation of the range of commands for criterion M2 and how they impact on drawing production in terms of efficiency (for example speed, accuracy, repeatability) links with P5, P6 and P7. Similarly, knowledge for the M3 criterion of how 3D models can be used in the design process links with the 3D activity in P9.

To achieve distinction criterion D1, learners should justify the use of CAD and will need to analyse other factors (for example disadvantages, costs, training requirements). This links with P3 and P4 as well as the M1 and M2 criteria. Learners should evaluate the relative merits of using CAD software. This could be as part of the case study outlined as possible evidence for the P3 criterion.

To achieve the D2 criterion learners will need to evaluate 2D and 3D drawings from a customer perspective. This links directly with the P9 and M3 criteria. Learners will need to compare and contrast the impact on customers of producing drawings using 2D and 3D CAD and how customers might use the information produced.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1 and P2	National and International Standards Report	Learners to research national and international standards and relate to engineering CAD drawing practice.	A report describing national and international standards and an explanation of CAD features that need to comply with these standards.

Criteria covered	Assignment title	Scenario	Assessment method
P3, P4, M1 and D1	CAD Report	Learners to research and compare the use of CAD with other methods and determine the software and hardware required to produce CAD drawings; in addition an investigation of how CAD links to other software and hardware and a justification of the use of CAD in manufacturing.	<p>A report containing written responses about the use of CAD and alternative methods; in addition the software and hardware requirements of a CAD system should be listed and explained.</p> <p>An explanation of how CAD links with other software and hardware should support a justification of the use of CAD in a manufacturing context.</p>

Criteria covered	Assignment title	Scenario	Assessment method
P5, P7 and M2	CAD Portfolio	Learners to create an assembly drawing of at least five parts and detail CAD drawings of the five components; in completing the task learners should be able to explain how they used a range of commands in the CAD software to efficiently produce drawings.	A portfolio of five component drawings and an assembly drawing containing the five individual parts; in addition a short report containing written responses and/or screen dumps explaining how a range of CAD commands were used to efficiently produce the completed drawings.

Essential resources

Centres will need to have access to a suitably equipped IT facility with access to a printer/plotter. Access to software with 2D and 3D capabilities, such as AutoCAD and Inventor is also required. While general graphics packages would not be suitable, any CAD software capable of generating the evidence required for this unit would be acceptable.

Indicative reading for learners

Textbooks

Ambrosius L – *AutoCAD 2009 and AutoCAD LT 2009: All-in-one Desk Reference for Dummies* (John Wiley and Sons, 2008) ISBN 9780470243787

Cheng R – *Using Pro/Desktop 8* (Delmar, 2004) ISBN 9781401860240

Conforti F – *Inside Microstation* (Delmar, 2005) ISBN 9781418020842

Simmons C, Maguire D and Phelps N – *Manual of Engineering Drawing* (Butterworth-Heinemann, 2009) ISBN 9780750689854

Yarwood A – *Introduction to AutoCAD 2012* (Routledge, 2011)
ISBN 9780080969473

Unit 20: **Selecting and Using Programmable Controllers**

Level:	3
Unit type:	Additional
Guided learning hours:	60

Unit introduction

The automation of machines, process control and conveyor lines has resulted in the ever-increasing consistency of quality, speed and cost savings in complex processes. Consumers have come to expect high standards of quality in the manufactured goods they use, but to an engineer these are the challenges that make the profession interesting.

This unit will consider programmable logic controllers (PLCs), control devices which aid the automation of these processes. The capabilities of PLCs have developed over the years, with performance, reliability and operational resilience being key attributes to their continued success. In order to achieve automated monitoring and control, these devices can be used on their own or in conjunction with others through communication systems/links, which are themselves becoming more versatile.

The unit will introduce learners to the use and applications of PLCs, the hardware and software that makes up a PLC and the interaction needed between the component parts. Learners will develop their ability to use programming techniques to produce programs for modern PLCs. They will gain an understanding of the different types of communication media used to link larger numbers of PLCs together, the networking architecture used and the associated standards and protocols.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

- 1 Understand the selection, hardware and software requirements of a programmable controller
- 2 Be able to use programming techniques to produce a program for a modern programmable controller
- 3 Understand complex programmable controller applications
- 4 Understand data communications media and networks used with modern programmable controllers.

Unit content

1 Understand the selection, hardware and software requirements of a programmable controller

Programmable controller selection: types (unitary, modular, rack-mounted); criteria, e.g. cost, versatility and scanning time; internal architecture, e.g. central processing unit (CPU), arithmetic and logic unit (ALU), flags, registers, memory and types (volatile, non-volatile); scan cycle (self-test, input/logic/output scans).

System hardware and software requirements: manufacturers' specification of input/output (I/O) units (digital and analogue); power supply; use of operating system; configuration of inputs and outputs; number systems, e.g. binary, octal, hexadecimal, binary-coded decimal (BCD); input/output devices; mechanical switch relays (electromechanical and solid state); transducers, e.g. temperature, pressure, flow, smart sensors, simple motors and drives.

2 Be able to use programming techniques to produce a program for a modern programmable controller

Programming techniques: e.g. ladder and logic diagrams, statement listing, functional diagrams, graphical programming languages, mimic diagrams, sequential function charts (SFCs).

Produce, store and present program: human-computer interface (HCI), e.g. handheld input pad, personal computer, text, graphical touch screens; use of system software to write, edit, delete, save, restore, create reports, load/unload, search; use of fault diagnostic indicators; print copies of program; storage, e.g. scanning, memory organisation, continuous updating, back-up copies, supervisor control and data acquisition (SCADA).

Instruction types: production of program using relay, bit, branch, timer/counter, comparison, logical, arithmetic instructions; proportional integral derivative (PID) controller loops.

3 Understand complex programmable controller applications

Program documentation: hardware considerations (environmental, operational, maintainability); instruction types; documentation for testing, e.g. software debug instructions, diagnostic indicators, data monitors, search, force facilities; complex engineering applications, e.g. machine, process control, conveyor.

Health and safety with programmable controller: safe working practices for personnel and with equipment, e.g. tools and equipment risk assessment, job safety analysis (JSA), housekeeping practices for work areas, personal protective equipment (PPE), restriction of non-participants from areas; health and safety standards (local, national, international), e.g. local safety agreements between employees and employers, Health and Safety Executive (HSE), Health and Safety at Work etc. Act 1974, regulations for the use of display screens; avoiding haphazard operations, e.g. risk management, planning considerations, testing (usability, unit, component, acceptance), 'what if' scenarios, commissioning.

4 Understand data communications media and networks used with modern programmable controllers

Communication media: selection criteria, description of features, frequency ranges, technology, e.g. analogue, digital, wireless; cable, e.g. twisted pairs, coaxial, fibre-optic, shielded/unshielded, categories, operational lengths; connector, e.g. Bayonet-Neill-Concelman (BNC), registered jack (RJ-45), straight tip (ST), universal serial bus (USB) type A and type B; opto-isolator e.g. photodiode, phototransistor, thyristors, triacs.

Network: network architecture (fieldbus, distributed intelligence, 'open' communications networks); network standards/protocols, e.g. International Organisation for Standardisation (ISO), Institute of Electrical and Electronic Engineers (IEEE), Manufacturing Automation Protocol (MAP), Electronics Industry Association (EIA-485), Factory Instrumentation Protocol (FIP).

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P1 describe the selection criteria and a practical application for a unitary, a modular and a rack-mounted programmable controller	M1 explain the benefits and limitations of a programmable controller for a specific application	
P2 explain the system hardware and software requirements for a programmable controller application		
P3 use a programming technique to produce, store and present a program that demonstrates the full range of instruction types	M2 explain the programming technique used and list the instruction types	D1 justify the choice of a specific programming technique and the methods used to produce, store and present the program
P4 explain the program documentation that has been used for a complex engineering application		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P5 describe the importance of health and safety when working with programmable controlled equipment		
P6 explain how one example of each of the three types of communication media would be selected for a specific programmable controller application	M3 compare two different networks used for a modern programmable controller system.	D2 compare the current capabilities and limitations of a programmable controller and identify possible areas of future development.
P7 describe a network and relevant standards and protocols used for a modern programmable controller system.		

Essential guidance for tutors

Assessment

PLCs involve a complex mixture of computer technology, communication interfaces and software programming techniques.

The assessment strategy for this unit should consist of a mix of written technical reports and hands-on practical work. Annotated photographic evidence could also be a valuable tool to capture 'on-site' information and support learners' written work.

Where the grading criteria refer to an 'application', this is intended to mean a real-world situation wherever possible. Although a different application could be used for different criteria, it would be reasonable to use the same or closely related applications throughout.

P1 and P2 are closely linked. P1 requires learners to describe the selection criteria and a practical application for a unitary, a modular and a rack-mounted programmable controller. In doing so, learners need to demonstrate their ability to recognise the different approaches to PLC operational activities. In describing the selection criteria learners should consider things such as cost, versatility and scanning time, together with relevant descriptions of the internal architecture (for example central processing unit (CPU), arithmetic and logic unit (ALU) etc.) and a practical application of each.

For P2, a comprehensive range of hardware and software requirements should be considered. For example, the power supply available may have quite different consequences for an application involving a field monitoring system as opposed to an installation in a factory. The amount of coverage of content for this criterion will be determined by the actual programmable controller application considered, but it is expected that learners should have at least four or five system hardware and software requirements indicated and explained.

P3 requires learners to use a programming method to produce, store and present a program that demonstrates the full range of instruction types. Learners are not expected to be fully competent programmers but their programs should be printed out, annotated where appropriate and stored.

The explanation required for P4 needs to cover all the related unit content, including hardware considerations, instruction types and documentation for testing. A 'complex engineering application' in this context is intended to mean some form of machine, a manufacturing process control operation or a conveyor system based on a real-life situation. Learners will need to provide some details of the complex application and go on to explain the documentation, for example the program instructions, testing documentation and forced facilities etc. associated with it. Ideally this would be a work-based application, although learners could be provided with a case study of a complex application.

P5 requires learners to describe the importance of health and safety when working with programmable controlled equipment. A range of 'what if' scenarios for various applications could be used to cover the full requirements of the unit content.

P6 requires learners to explain how one example of each of the three types of communication media (cable, connector, opto-isolator) would be selected for a specific programmable controller application. The key point here is for learners to recognise the media, understand how each one is selected, describe the main features and consider aspects such as frequency ranges and the technology to which they are being applied.

For P7, there is a possibility that the description of a network and relevant standards and protocols could become overly complex and involve a wide range of issues. Therefore, learners need to be restricted to describing just the general network architecture of perhaps an Ethernet, and provide details of the associated standards and what they generally imply.

M1 builds on the work carried out for pass criteria P1 and P2, as learners need to consider a specific application and apply their understanding of the selection criteria already used. The important point is that they can demonstrate ability in selecting an appropriate PLC type and have knowledge as to why it is an appropriate choice.

M2 can be clearly linked to pass criteria P3 and P4. To achieve M2, learners need to reflect on their choice of programming methods. In their justification (D1), learners should identify why one programming method has been chosen and make it clear why the others have been rejected.

M3 builds on the work undertaken to achieve P6 and P7. It requires learners to compare two different networks used for a modern programmable controller system. This should include details of the networks, standards and key differences. Learners need to demonstrate that they realise the important differences between networks and how they may influence the associated PLC systems.

Finally, D2 requires learners to reflect on the unit as a whole. The comparison could include aspects such as memory capacity, the types of PLC available, the growing development in networking technologies (for example wireless implications), the use of smart sensors and how this may impair the programme and feedback loops, how processor power may influence the programming method etc. Satisfactory achievement of this criterion will require learners to have considered the range of issues covered by the unit content and undertaken some independent research of trends and potential benefits.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1	Selection and Applications of PLCs	A written assignment requiring learners to demonstrate an understanding of PLC selection and application	A series of three written tasks. Learners provide a description of the selection and application of PLCs and explain hardware and software requirements. Learners are then given an application for which they choose a suitable PLC.
P3, M2, D1	Using Programming Techniques	Learners are required by their employer to produce a program for a specific programmable controller to meet a customer's needs.	A practical programming task. Learners should produce a program, which should be printed out, annotated and stored.

Criteria covered	Assignment title	Scenario	Assessment method
P4, P5	Applications of Programmable Controllers	Learners investigate an industrial application of programmable controllers, and explain the documentation and health and safety considerations that relate to it.	A series of written descriptions/ explanations.
P6, P7, M3, D2	Data Communications Media and Networks	Learners investigate the different forms of media, their selection criteria and their applications.	A series of written descriptions/ explanations.

Essential resources

Centres will need access to a range of PLCs, communication media and interface devices. Software packages and tools should also be available to permit programming and implementation of device/applications for circuit performance and debugging. Learners will require access to a range of relevant manuals, reference data and manufacturers' information.

Indicative reading for learners

Textbooks

Bolton W – *Instrumentation and Control Systems* (Newnes, 2004)

ISBN 0750664320

Bolton W – *Programmable Logic Controllers* (Newnes, 2006) ISBN 0750681128

Hooper J – *Introduction to PLCs* (Carolina Academic Press, 2004) ISBN 0890893896

Unit 21: Principles and Applications of Electronic Devices and Circuits

Level:	3
Unit type:	Additional
Guided learning hours:	60

Unit introduction

Electronics and electronic devices are used in a huge variety of manufactured products. From everyday popular items such as cameras and thermometers to the robotic welding machines used in industry, the use of electronics is continually growing.

This unit provides a practical introduction to basic electronic devices along with analogue and digital electronic principles. It gives learners an opportunity to investigate the operation of diodes and transistors, two of the most important building blocks in electronic circuits. Learners will then go on to build and test circuits that make use of these devices and will consider the operation of integrated circuits such as the operational amplifier. Logic gates and flip-flops are also investigated both in practice and by using simple electronic principles, such as voltage gain or truth tables.

Finally, the unit will introduce learners to computer-based circuit design and simulation software packages that will allow them to build and test analogue and digital circuits. This will enable learners to recognise the importance of simulation software in the design of electronic circuits.

The overall aim of this unit is to build learners' confidence in their ability to construct and test simple electronic circuits. The emphasis is on prototyping, constructing and measuring. The unit treats systems in terms of their functionality and their input/output relationships.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

- 1 Understand the function and operation of diodes, transistors and logic gates
- 2 Be able to build and test operational amplifier-based analogue circuits
- 3 Be able to build and test combinational and sequential logic circuits
- 4 Be able to use computer-based simulation software packages to construct and test the operation of analogue and digital circuits.

Unit content

1 Understand the function and operation of diodes, transistors and logic gates

Diodes: types, e.g. Zener, light-emitting diode (LED), PN-junction; circuit applications, e.g. voltage stabiliser, indicator light, half-wave rectifier.

Transistors: types, e.g. NPN, PNP or field-effect transistor (FET); analogue circuit (single-stage amplifier); digital circuit, e.g. comparator, transistor as a switch (automatic vehicle head lights or night light); operation, e.g. analogue (voltage gain, phase inversion), digital (set-point of operation); function of components in circuits.

Logic gates: types of gates, e.g. AND, OR, NOT, NAND, NOR, XOR; gate symbols e.g. British Standards (BS), International Electrotechnical Commission (IEC), American National Standards Institute (ANSI); truth tables; Boolean expressions e.g. $A+B$, \bar{A} , $A \cdot B$.

2 Be able to build and test operational amplifier-based analogue circuits

Building analogue circuits: method of construction e.g. prototype/bread-board, printed circuit, strip-board; types of circuits, e.g. oscillator, filter circuit, comparator circuit, inverting and/or non-inverting amplifier.

Testing analogue circuits: performance against given design requirement; recording actual input and output voltages (tabulating data, plotting graph of results); circuit measurements, e.g. measurement of resonant frequency, cut-off frequency, switching point, gain at mid-frequency, bandwidth.

3 Be able to build and test combinational and sequential logic circuits

Building combinational and sequential logic circuits: types of combinational circuit, e.g. at least three gates and three input variables; types of sequential circuit, e.g. R-S bi-stables, JK bi-stable, 3-stage counter, 3-stage shift-register based on JK or D-type bi-stables; types of logic family, e.g. transistor-transistor logic (TTL) and complementary metal oxide semiconductor (CMOS); characteristics of chips, e.g. supply voltage, input and output operating voltages, input and output impedance, propagation delay, power.

Testing of logic circuits: records of performance against given design requirement; input and output states; use of truth tables; use of test equipment, e.g. logic probe, signature analyser.

Minimisation of logic circuits: e.g. use of De-Morgan's theorem; Karnaugh maps.

4 Be able to use computer-based simulation software packages to construct and test the operation of analogue and digital circuits

Simulation of analogue circuit: types of circuits, e.g. transistor amplifier, op-amp, active filter, rectifier; types of components, e.g. resistor, capacitor, transistor, diode; instrument simulation, e.g. voltmeter, ammeter, oscilloscope; records of performance against given design requirement, e.g. screen print, input/output waveforms (with scales), gain-frequency response.

Simulation of digital circuit: types of circuit, e.g. three input combinational circuit, counter, shift register; types of gates/sequential circuit, e.g. R-S bi-stables, JK bi-stable, 3-stage counter, 3-stage shift-register based on JK or D-type bi-stables; instrument simulation e.g. on/off indicator, logic probe, word generator, logic analyser; records of performance against given design requirement, e.g. screen print, digital input/output waveforms (with scales).

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P1 explain the function of different types of diodes, transistors and logic gates in different electronic circuit applications		
P2 explain the operation of two different types of transistor, one in an analogue and one in a digital circuit		
P3 build two different types of analogue circuit using operational amplifiers, testing appropriately	M1 modify an existing analogue circuit to achieve a given revised specification by selecting and changing the value of one of the components	
P4 explain the operation of three different logic gates with appropriate gate symbols, truth tables and Boolean expressions		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P5 build a combinational logic circuit that has three input variables, testing appropriately	M2 modify a digital circuit to achieve a given revised specification by selecting and changing up to two logic gates	D1 compare and contrast two different types of logic circuits, referencing five key characteristics
P6 build a sequential circuit using integrated circuit(s), testing its efficiency	M3 minimise a three input variables combinational logic circuit containing three gates	
P7 use a computer software package to simulate the construction and testing of an analogue circuit with three different types of components	M4 explain the benefits and limitations of a computer software package used to simulate the construction and testing of both analogue and digital circuits.	D2 analyse the effects of changing the values of circuit parameters on the performance of an analogue circuit containing transistors.
P8 use a computer software package to simulate the construction and testing of a digital logic circuit with three gates.		

Essential guidance for tutors

Assessment

The learning outcomes and related criteria can be assessed in any order. The criteria P1, P2 and P3 are related and it would make sense to build a practical assignment or project around them. The focus would be to build two different types of analogue circuit (P3) that would allow learners to explain the operation of two different types of diodes, transistors and logic gates (P1) and the operation of one of the two different types of transistor (P2). Learners would then need to work on another circuit or simply explain the operation of a transistor in a digital circuit.

A second assignment could be used to cover the practical work required for P5 and P6. This could be linked to the explanation of theory that is necessary to achieve P4.

The last two pass criteria, P7 and P8, could be covered by a third assignment, either before the build and test exercise to prove the circuits, or afterwards, to simulate the circuit performance and testing that learners have already experienced.

Opportunities for the achievement of the merit criteria can be set within the assignments suggested above. For example, a task could be set for M1 that requires learners to modify a circuit to produce a different voltage gain from the one used in P3, or for a different resonant frequency for an oscillator.

M2 could be obtained through a task additional to that used for P5, such as to modify the circuit given for P5. M3 simply requires a minimisation (for example using a Karnaugh map). M4 could then be completed as this requires an explanation of the benefits and limitations of a computer software package, essentially encompassing P7 and P8.

To achieve D1, learners need to compare and contrast two different types of logic family, with reference to at least five characteristics. The comparison, which can be partly but not wholly achieved using a table, should consider common logic families such as TTL and CMOS. Where a table is used for comparison, it is expected that the meaning of any terms used (for example sink current) should be clearly explained. The comparison as a whole (table, written explanations, diagrams etc.) must make it clear how one logic family can be differentiated from another.

D2 requires an analysis, using a simulation package, of the effects on the performance of an analogue circuit containing transistors of changing the values of circuit parameters (for example components or component values, input/output voltages or signals). To meet the criterion it would require at least one other parameter to be changed – possibly the supply voltage, or input voltage – and noting how ‘clipping’ can occur. Part of the analysis could be to use calculations to show how the theoretical results align with those actually obtained through simulation.

Again, careful selection of the circuits used for the pass/merit assignment could enable this final step to be a natural development from the work already carried out. Establishing firm links between the pass, merit and distinction criteria in this way will encourage learners to work towards higher levels of achievement and will improve the relevance and coherence of the assessment activities.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, M1	Construction and Operation of Analogue Circuits	Learners have been asked by their employer to build and test analogue circuits to meet a new design requirement.	<p>A practical assignment accompanied by written tasks/oral questioning in which learners construct and test two different analogue circuits, each circuit containing a diode and one containing a transistor. One of the circuits could then be modified to meet a revised specification.</p> <p>Additional tasks would then require the learner to explain the purpose/operation of the diodes and transistor, plus an additional transistor from a further digital circuit.</p>

Criteria covered	Assignment title	Scenario	Assessment method
P4, P5, P6, M2, M3, D1	Construction and Operation of Logic Circuits	Learners have been asked by their employer to build and test logic circuits to meet a new design requirement.	A practical assignment accompanied by written tasks/oral questioning, in which learners construct and test combinational and sequential circuits. Additional tasks would then require the learner to explain the operation of logic gates and compare and contrast different types of logic family.
P7, P8, M4, D2	Using Simulation Software to Construct and Test Circuits	Learners have been asked by their employer to use software to simulate the construction and testing of circuits to meet a new design requirement.	A practical assignment in which learners construct and test analogue and digital circuits using simulation software. They should also be given the opportunity to analyse the effect of changing circuit parameter values.

Essential resources

Centres will need to provide access to an appropriate electronics laboratory with a range of measuring and test equipment, as listed in the unit content. For example, facilities for circuit construction and prototyping, a range of components, logic-tutor boards, hardware and software to support computer-based analogue and digital schematic capture and circuit simulation will be needed. Learners will also need access to publications, reference data and manufacturers' product information to enable them to consider the different types of components listed within the unit.

Indicative reading for learners

Textbooks

Bell D – *Fundamentals of Electronic Devices and Circuits* (Oxford University Press, 2007)
ISBN 9780195425239

Tooley M – *Electronic Circuits: Fundamentals and Applications* (Routledge, 2006)
ISBN 9780750669238

Unit 22: Engineering Maintenance Procedures and Techniques

Level:	3
Unit type:	Additional
Guided learning hours:	60

Unit introduction

The correct maintenance of engineering systems results in improved efficiency and can save organisations time and money in relation to system downtime and stoppages in production. This unit introduces learners to a range of commonly used engineering maintenance procedures and monitoring techniques, which may be encountered in any manufacturing, plant or process environment. The unit will also help learners understand how the data gathered from monitoring engineering systems can be used.

Learners will examine the consequences of maintenance and maintenance planning in terms of cost, and the implications for production, personnel, the environment and safety. They will gain an understanding of engineering maintenance and process planning and develop the skills needed to plan scheduled and preventative maintenance activities on engineering systems.

The unit has been designed to reflect the multidisciplinary nature of maintaining manufacturing plant and process engineering systems, rather than being confined to specialist knowledge of a single discipline. Learners will need to produce a maintenance plan for an engineering system involving two or more interactive technologies from mechanical, electrical, fluid power, process control or environmental systems.

Learners will be required to know about the methods, procedures and documentation that must be completed before handing over maintained systems, and how to confirm that the system is ready to run in a safe and operable condition.

Finally, learners will gain an understanding of the basic techniques of condition monitoring and how computerised maintenance systems can be used to capture data and predict specific failure trends in plant, machinery, equipment and systems.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

- 1 Know about the types of maintenance associated with engineering plant, equipment and systems
- 2 Know about maintenance frequency, the cost of maintenance and its effects on production
- 3 Be able to produce a maintenance plan for a specific engineering system
- 4 Understand how data gathered from monitoring the performance and condition of engineering plant, equipment and systems can be used.

Unit content

1 Know about the types of maintenance associated with engineering plant, equipment and systems

Type of maintenance: types, e.g. planned, total preventative maintenance (TPM), breakdown, scheduled, corrective, emergency, post fault, scheduled servicing, modification to equipment, condition-based maintenance; maintenance activities, e.g. visual examination, monitoring, replacement, sensory, testing, checking alignment, making routine adjustments, removing excess dirt and grime, recording results and reporting defects.

Reasons for maintenance: issues relating to higher plant reliability and availability, e.g. longer equipment life, improved product quality, greater cost effectiveness, improved safety, legal requirements; issues relating to health and safety, e.g. statutory regulations and standards, company rules, codes of conduct, reduction in environmental damage.

Engineering systems, plant and equipment: systems, e.g. process monitoring and control, mechanical, fluid power, electrical, process control, environmental systems (such as fume extraction or air conditioning), medical; plant and equipment, e.g. gearboxes, pumps, engines, compressors, machine tools, lifting and handling equipment, process control valves, mechanical structures, company specific equipment, electrical plant, motors, starters, switchgear and distribution panels, cardiovascular equipment, medical imaging equipment.

2 Know about maintenance frequency, the cost of maintenance and its effects on production

Frequency of maintenance: time, e.g. daily/weekly/monthly/yearly; activities, e.g. data logging and checking, adjustments, tests, routine maintenance, fixed-interval overhaul, equipment replacement, use of computerised techniques; methods for determining frequency, e.g. calendar maintenance, hours run meter.

Costs: representative data of cost, e.g. maintenance as a proportion of total expenditure, utilisation of operator (frontline maintenance), maintenance labour, maintenance contracting, lost production, levels of spares and consumables in stores, equipment hire/replacement, safety and environmental effects.

Effects on production: e.g. downtime, effects on operating performance, product quality, customer service, financial penalties, effects on associated equipment or plant, higher energy costs, secondary damage.

3 Be able to produce a maintenance plan for a specific engineering system

Maintenance plan: maintenance planning, e.g. methods, sequence and timing, frequency, check lists, planned repairs, use of planning techniques, Gantt and Pert charts, team working, computerised methods; resources, e.g. personnel, supporting equipment, tools, manuals, materials, components, facilities, stores spares and consumables; procedures e.g. safety procedures, risk assessment, Control of Substances Hazardous to Health (COSHH) Regulations 2002 and other relevant safety regulations, safe access and working arrangements for the maintenance area, isolation requirements for plant/equipment, disposal of waste, handover procedures, liaison with other departments.

Engineering systems: process monitoring and control, e.g. mechanical, fluid power, electrical, process control, environmental systems (such as fume extraction or air conditioning), medical (such as cardiovascular, anaesthetic and ventilation, medical imaging).

Supporting documentation: manufacturers' drawings and maintenance documentation; maintenance logs, databases, records, results and defect reports; plans and schedules; production records; standing instructions; handover documentation.

4 Understand how data gathered from monitoring the performance and condition of engineering plant, equipment and systems can be used

Monitoring techniques: e.g. condition monitoring, scheduled overhauls, routine servicing, planning systems, hazard studies, failure mode and effect analysis (FMEA), teamwork, self-diagnostic and computerised systems.

Data collection: collected at identified points; data, e.g. types, operational characteristics, output quality, throughput, environmental operating conditions; interpreting data, e.g. electronic-based data, data recording and presentation.

Need for monitoring: physical aspects, e.g. improve safety, reduce environmental hazards, extend equipment life, ensure accurate equipment performance; cost-related aspects, e.g. improve product quality, reduce downtime, reduce costs; other aspects, e.g. produce comprehensive computer database, better communications.

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P1 describe two types of maintenance	M1 justify the suitability of particular types of maintenance for specific applications	
P2 describe the reasons for maintaining a specified engineering system		
P3 describe four maintenance activities for a specified engineering system		
P4 identify two items of plant and equipment for a specified engineering system that require maintenance, describing the frequency at which it should be carried out		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P5 describe the effects on production of carrying out maintenance on a specified engineering system	M2 from a given range of data, calculate the maintenance costs for a specified engineering system in relation to maintenance type, resources and production downtime	D1 discuss how the frequency of maintenance affects production and costs for a specified engineering system
P6 produce a basic maintenance plan for a specified engineering system containing supporting documentation with resource and procedure requirements	M3 justify planned maintenance for a specified engineered system in terms of system downtime, environmental and health and safety considerations	D2 produce a comprehensive plan for the maintenance of a specified engineered system containing all supporting documentation.
P7 describe an application of monitoring, the technique used and how the data is collected and interpreted	M4 analyse given condition monitoring and quality control data to predict specific machinery/plant failure.	
P8 explain the need to monitor the performance and condition of engineering systems.		

Essential guidance for tutors

Assessment

Evidence of achievement could be obtained from investigative assignments, reports of workshop activities or through learners building a portfolio from maintenance operations carried out in the in the workplace.

The unit could be assessed through a mixture of written assignments and practical tasks. Assuming that the learning outcomes are delivered in order, a first assignment with a series of written tasks could be used to cover the criteria associated with learning outcomes 1 and 2. The first task could ask learners to describe two types of maintenance (P1) and four maintenance activities (P3). Learners would then need to describe the need for maintaining a specific engineering system (P2). The system might be mechanical, fluid power, electrical, process control, or an environmental system. This could be extended to cover M1, for which learners must justify the suitability of particular types of maintenance for specific applications. The work produced for M1 should include total preventative maintenance (TPM), scheduled or condition-based maintenance.

A second assignment to cover P4 could ask learners to identify items of plant and equipment that require maintenance and the frequency at which maintenance should be carried out. They will also need to give reasons for carrying out maintenance, for example longer equipment life, improved product quality, greater cost effectiveness, improved safety or legal requirements. The task also needs to ensure that learners cover timing, activities carried out and methods of determining the frequency. It should also ensure that learners have opportunities to give reasons for the required maintenance covering plant reliability/availability and issues relating to health and safety.

A third assignment covering P5 and M2 and D1 could ask learners to calculate from given data the cost of maintenance and describe the effects on production. A further task requiring learners to explain how the frequency of maintenance can affect production and cost would enable M2 to be met.

A well-planned, investigative practical assignment could be used to cover criteria P6, M3 and D2. To achieve P6, learners need to produce a basic maintenance plan for a specified system with accompanying documentation with resource and procedure requirements.

This basic maintenance plan should include at least the following:

- identification of the plant/equipment/machinery to be maintained
- identification of the person with overall responsibility for the maintenance process
- the maintenance procedures to be adopted
- timescales for preparation and implementation of the maintenance activities

- a list of the physical resources required for the maintenance activities (for example lifting equipment, tools, test and measuring equipment)
- details of the administrative support that is to be provided for the maintenance work
- details of the maintenance documentation systems to be provided.

This then needs to be built on in order to achieve D2, where a comprehensive maintenance plan containing all supporting documentation needs to be produced for a specified engineering system. The comprehensive maintenance plan should contain the entire basic plan together with at least the following:

- health and safety procedures
- identification of appropriate types of maintenance compatible with production requirements
- identification of who is to carry out the maintenance (for example in-house labour, contractors, specialists)
- lists of sub-assemblies and spare parts to be held
- the quality control procedures that need to be followed during maintenance activities, together with maintenance tools/equipment control and test instrument calibration
- environmental considerations such as the procedures to be adopted for the disposal of all types of waste material arising from the maintenance activity including the safe disposal of toxic and/or hazardous materials if relevant
- handover documentation.

To achieve M3, the practical activity could be supported by written evidence, showing that learners are able to justify the maintenance plan in terms of system downtime, environmental and health and safety considerations.

The criteria associated with learning outcome 4 could be assessed through a written assignment. Learners need to explain the need for monitoring the performance and condition of engineering systems (P8). This should include the physical aspects, cost related aspects and other aspects as outlined in the unit content. Systems do not need to be given as the task should be tackled as a generic response outlining the need in systems in general. The task also needs to ask learners to describe an application of monitoring, the technique used and how data is collected and interpreted (P7).

To achieve M4, learners need to carry out an in-depth analysis of given condition monitoring and quality control data to predict specific machinery/plant failure. An example would be data produced by vibration analysis for a large motor bearing. The data could come from computer analysers, inspection and test, SPC (Statistical Process Control), or from general product quality control.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, M1	Types of Maintenance Activities	Learners need to report to their manager on types of maintenance and maintenance activities and justify particular reasons for maintenance.	A written report relating general maintenance types to specific examples.
P4	Maintenance Needs in a Complex Engineering System	Learners need to write a report on the maintenance of a complex engineering system.	A written report describing the practical needs for maintenance of plant and equipment that also discusses frequency that maintenance is carried out.
P5, M2, D1	Costing a Maintenance Schedule	Using plant data and a maintenance schedule, learners calculate the cost and effect of maintenance on system production.	A written assessment of the plant maintenance data to identify the costs of maintenance and its impact on production and cost.

Criteria covered	Assignment title	Scenario	Assessment method
P6, M3, D2	Maintenance Planning	Learners produce a maintenance plan and justify the maintenance programme.	<p>An investigative practical assignment. Evidence includes a written basic maintenance plan for the specified system with accompanying documentation, and resource and procedure requirements.</p> <p>A comprehensive maintenance plan containing all supporting documentation for the specified engineering system.</p> <p>Additional written evidence justifying the maintenance plan in terms of system downtime, environmental and health and safety considerations.</p>

Essential resources

In order to deliver this unit, centres will need to provide learners with access to complex engineered systems or test rigs, relevant data books, manufacturers' specifications, system manuals, functional flow charts and system diagrams. Learners will also need appropriate test equipment and tools and access to maintenance records/documentation from modern factories/plant. Computer software for data logging and self-diagnostics should also be provided.

Indicative reading for learners

Textbooks

Kelly A – *Maintenance Systems and Documentation* (Butterworth-Heinemann, 2006)
ISBN 0750669942

Kelly A – *Strategic Maintenance Planning* (Butterworth-Heinemann, 2006)
ISBN 0750669926

Mobley R K – *Maintenance Fundamentals* (Butterworth-Heinemann, 2004)
ISBN 0750677988

Snow D – *Plant Engineer's Reference Book* (Butterworth-Heinemann, 2001)
ISBN 0750644524

Unit 23: Monitoring and Fault Diagnosis of Engineering Systems

Level:	3
Unit type:	Additional
Guided learning hours:	60

Unit introduction

Condition monitoring and quality control techniques are used to detect potential failure symptoms in engineering systems. The methods used by engineering technicians range from fully automated monitoring down to the use of the human senses. This unit gives learners an understanding of the fundamentals of engineering system monitoring and fault diagnosis, and explains the basic concepts of condition monitoring. The unit examines the development of engineering system monitoring and fault diagnosis and how modern technology, quality control and environmental issues have affected current thinking.

The unit will give learners an understanding of the precautions required to protect themselves and others in the workplace, and focuses on the safety measures needed when carrying out monitoring activities, especially those for isolating equipment.

Learners will understand how to use a range of condition monitoring equipment and will develop the skills and knowledge required for the location and identification of faults in engineering systems. Learners will be required to select the appropriate monitoring technique and equipment based on the type of plant or equipment being monitored and the conditions checked.

The unit will enable learners to check and set up monitoring equipment before using it to carry out diagnostic condition monitoring on engineering systems, in accordance with approved procedures. Learners will be expected to use a variety of fault diagnosis methods and techniques, and use a number of diagnostic aids and equipment. From the evidence gained they will then identify the fault and its probable cause.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

- 1 Know the health and safety requirements relevant to monitoring and fault diagnosis of engineering systems
- 2 Know about system monitoring and reliability
- 3 Be able to use monitoring and test equipment
- 4 Be able to carry out fault diagnosis on engineering systems.

Unit content

1 Know the health and safety requirements relevant to monitoring and fault diagnosis of engineering systems

Legislation: appropriate statutory acts and regulations e.g. Health and Safety at Work etc. Act 1974, Management of Health and Safety Regulations 1999, Provision and Use of Work Equipment Regulations (PUWER) 1998, Control of Substances Hazardous to Health (COSHH) Regulations 2002, Reporting of Injuries, Diseases and Dangerous Occurrences Regulations (RIDDOR) 2013, Lifting Operations and Lifting Equipment Regulations (LOLER) 1998, Manual Handling Operations Regulations (MHOR) 1992, Personal Protective Equipment (PPE) at Work Regulations 1992, Confined Spaces Regulations 1997, Electricity at Work Regulations 1989, Control of Noise at Work Regulations 2005, Health and Safety (First-Aid) Regulations 1981; specific safety requirements, e.g. company rules, permit to work procedures, risk assessment, environmental issues; health and safety procedures e.g. response to alarms, use of safety equipment, reporting of accidents, reporting of hazardous items of plant or equipment; personal safety, e.g. appropriate dress, protective clothing, appropriate or protective headgear, protective gloves and footwear, eye protection, face masks and respirators, appropriate use of barrier creams, personal cleanliness, prompt attention to injuries.

Hazards and practices: workplace hazards, e.g. compressed air, hydraulic fluid, gases, hot surfaces, electrical equipment, unfenced machinery, toxic substances and fumes, falling objects, liquid spillage, untidy work area, badly maintained tools and test equipment; safe working practices, e.g. isolation procedures, methods of immobilising equipment, precautions to be observed when operating or working on live equipment, permit to work, use of danger tags, warning notices, safety barriers, cones and tapes.

Engineering systems: process monitoring and control; fault diagnosis; systems, e.g. mechanical, fluid power, electrical, process control, environmental systems (such as fume extraction or air conditioning), medical (such as cardiovascular, anaesthetic and ventilation, medical imaging).

2 Know about system monitoring and reliability

Monitoring terminology: condition monitoring methods, e.g. offline portable monitoring, sampled monitoring, continuous monitoring, protection monitoring, human sensory monitoring; monitoring techniques, e.g. vibration analysis, temperature analysis, flow analysis, particle analysis, crack detection, leak detection, pressure analysis, voltage/current analysis, thickness analysis, oil analysis, corrosion detection, environmental pollutant analysis.

Failure and reliability: calculations concerning failure, e.g. degrees and causes of failure, failure rate, failure modes, functional failure, primary and secondary functions, mean time between failures (MTBF), reliability; factors affecting reliability, e.g. design, operation, environment and manufacture, reduction in system/device failure, e.g. routine servicing, adjustments; data, e.g. defects examination, statistical process control (SPC), quality.

3 Be able to use monitoring and test equipment

Monitoring and test equipment: use of fixed and portable monitoring equipment for on and offline monitoring including continuous and semi-continuous data recording e.g. vibration monitoring of bearings, self-diagnostics (such as PLCs/smart sensors, computerised data acquisition, data logging, electrical data, gas analysis); use of handheld instruments, e.g. meters, thermal imaging; test equipment for taking measurements of parameters, e.g. temperature, pressure, viscosity, speed, flow, voltage, current, resistance, sound, vibration.

Procedures: practical methods, e.g. crack detection, leak detection, corrosion detection, flow analysis, vibration analysis, pressure analysis.

4 Be able to carry out fault diagnosis on engineering systems

Diagnostic terminology and techniques: terminology (definitions and explanations of symptoms, faults, fault location, fault diagnosis and cause); techniques, e.g. six point, half-split, input-output, emergent problem sequence, functional testing, injection and sampling, unit substitution.

Diagnostic aids: test and measuring equipment; other aids, e.g. plant personnel, manufacturers' manuals, system block diagrams, circuit and schematic diagrams, data sheets, flow charts, maintenance records/logs, self-diagnostics, software-based test and measurement, troubleshooting guides.

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P1 outline the aspects of health and safety legislation that apply to monitoring and fault diagnosis of an engineering system		
P2 describe workplace hazards and safe working practices relevant to specific monitoring and fault diagnosis situations		
P3 describe a condition monitoring method and technique related to a given engineering system	M1 explain four factors that influence either failure or reliability in a given engineering system	D1 analyse the environmental effects on reliability of temperature, humidity, vibration and pressure for a given engineering system
P4 use given data to calculate failure rates for a range of components and equipment	M2 explain the environmental conditions that affect the reliability of the components in given items of congruent equipment	
P5 describe the factors affecting reliability for a given engineering system		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P6 describe the monitoring and test equipment used for measuring given system condition parameters	M3 evaluate the quality of measurements made and the limitations of given items of condition monitoring equipment	
P7 use procedures to carry out system monitoring on two separate engineering systems		
P8 describe the terms and two different techniques related to fault diagnosis	M4 use diagnostic techniques, test and measuring equipment and aids to locate faults on two separate engineering systems where two malfunction symptoms are evident on each system.	D2 analyse monitoring/quality control data and information to predict/detect potential failures in given engineering systems.
P9 use diagnostic techniques, test and measuring equipment and aids to locate faults on two separate engineering systems where two malfunction symptoms are evident on each system.		

Essential guidance for tutors

Assessment

Evidence of achievement of the learning outcomes and grading criteria may be obtained from well-planned investigative assignments or reports of workshop activities. Alternatively, it may be accumulated by learners building a portfolio from investigations and monitoring and fault diagnosis operations in the workplace or through realistic exercises and tests. In either case, the opportunity should exist for merit and distinction grades to be achieved with relevant and sufficient evidence to justify the grade awarded.

Assuming that the unit is delivered in the same order as the learning outcomes, a first assignment could cover the criteria for learning outcome 1 (P1 and P2). This assignment could be a written or practical task requiring learners to identify appropriate health and safety procedures and personal safety requirements for an engineering system. Such a system might be mechanical, fluid power, electrical, process control or an environmental system (such as fume extraction or air conditioning).

Learning outcome 2 could be assessed through a written or time-constrained assignment requiring learners to calculate, from given data, failure rates for a range of components and equipment. These could be pumps, actuators, compressors, air receivers, accumulators, valves, generators, motors, transformers, switch gear, machine tools, engines or gearboxes (P4). The assignment could contain a task requiring learners to describe factors affecting reliability (P5) and monitoring methods and techniques (P3). A third task could be added to cover M1, requiring learners to identify and describe four factors that influence either failure or reliability in a given engineering system. A further task requiring learners to identify and describe environmental conditions affecting the reliability of components in items of equipment and analyse the effects of the environment on component/asset reliability could enable achievement of M2 and D1. The range of components and equipment should be sufficient to allow these higher grading criteria to be achieved. However, the range required for pass criterion P4 would need to be at least one mechanical type, one electrical type and one fluid type system. Therefore, a range of data for each is required to be given to learners.

Assessment of learning outcome 3 could be by a well-planned practical investigative assignment covering criteria P6, P7 and M3. This would require learners to carry out monitoring activities on two separate engineering systems, such as bearing vibration analysis, temperature, flow, particle, oil, pressure, voltage/current corrosion, environmental pollutant, crack and leak detection. Such systems may be mechanical, fluid power, electrical, process control or environmental systems. This could be supported by written evidence that shows learners are able to describe the use of monitoring and test equipment and evaluate the quality of measurements and the limitations of given items of monitoring equipment. Witness statements and annotated photographs would be suitable evidence to support the use of procedures to carry out system monitoring.

Learning outcome 4 is best suited to practical investigation. For P8, learners need to explain the terms and two different techniques from those in the unit content, such as six-point, half-split, input-output, emergent problem sequence, functional testing, injection and sampling and unit substitution. For P9, they need to use diagnostic techniques, test and measuring equipment (such as dial test indicators, torque instruments, logic probes, multimeters etc.) and aids to locate faults on two separate engineering systems, where two malfunction symptoms are evident on each system. The assignment to cover this could have a task requiring learners to carry out fault diagnosis on a given engineered system. This could be either in a simulated situation or in the workplace using evidence gathered in a logbook containing items such as equipment used, tests carried out and measurements taken. This should be supported by the inclusion of witness statements.

Learners must describe typical fault conditions and find faults independently on equipment, which exhibits symptoms of more than one function failure. For example, a pump can have two functions, one to pump water at a given rate, the other to be free of water leaks whilst pumping. To achieve M4, learners must demonstrate a logical approach to fault finding and be able to distinguish between symptoms, faults and causes. A second task supported by written evidence would enable learners to demonstrate that they are able to analyse data and use this information to predict/detect potential failures in given engineering systems for D2.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2	Health and Safety in System Monitoring and Fault-finding	An investigation of practical health and safety issues and legislation, relating to system monitoring and fault diagnosis.	A report and risk assessment, identifying and discussing relevant health and safety issues, including the methods used to address them.
P3, P4, P5, M1, M2, D1	System Condition Monitoring and Reliability	Practical and theoretical investigations into the factors affecting component and system reliability, including: failure rate calculations; factors affecting reliability and system and component monitoring techniques, in general and as applicable to a specified engineering system.	A written and/or time-constrained assignment containing learners': calculations of failure rates for specified components and equipment; discussions on reliability; and on system monitoring methods. Supported by learners' engineering sketches and diagrams.

Criteria covered	Assignment title	Scenario	Assessment method
P6, P7, M3	Performing System Monitoring and Measurements	A practical investigation into the monitoring and evaluation of two different engineering systems.	<p>A report or portfolio of evidence and data describing the monitoring techniques and equipment used, and interpreting the measurements made on the two systems.</p> <p>Supported by learners' engineering sketches and diagrams.</p> <p>Witness statements and annotated photographs.</p>
P8, P9, M4, D2	System Fault-Finding Techniques	A practical investigation into two different techniques across two separate systems (four tasks in total) using diagnostic techniques, test and measuring equipment and aids.	<p>A report containing an explanation and evidence of the investigations and tests performed, and the conclusions drawn.</p> <p>Supported by learners' engineering sketches and diagrams.</p> <p>Witness statements and annotated photographs.</p>

Essential resources

This unit is intended to provide learners with a practical introduction to monitoring and fault diagnosis methods and techniques. Therefore, it is essential that learners have access to:

- actual engineered systems or test rigs designed for monitoring/fault finding
- data books and manufacturers' specifications
- system manuals and functional flow charts and system diagrams
- computer software for data logging and self-diagnostics
- appropriate test equipment and tools
- maintenance records.

Indicative reading for learners

Textbooks

Yardley E – *Condition Monitoring: Engineering the Practice* (Wiley-Blackwell, 2002)
ISBN 9781860583612

Website

Health and Safety Executive

www.hse.gov.uk

Unit 24: Electrical Technology

Level:	3
Unit type:	Additional
Guided learning hours:	60

Unit introduction

Electricity is used in a wide range of applications, such as manufacturing, healthcare, transport and entertainment. All of these are reliant on electrical technology in one form or another. For example, for someone to be able to visit a holiday destination, go to a music festival or download the latest track by their favourite performer, numerous electrical activities and concepts must be coordinated.

Electrical technology provides the link between science and its application. It is underpinned by a range of enabling technologies and concepts such as materials science, energy efficiency, environmental impact, geological characteristics and design.

This unit provides an introduction to ways in which electricity is produced, the options we have about how and why we produce it, and the disposal of related by-products. The unit considers how the electricity that has been produced is then moved to where the customer (end-user) needs it. It also examines the materials used and whether alternatives exist or could be found.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

- 1 Know the methods used to produce electrical energy
- 2 Understand the properties and applications of conductors, insulators and magnetic materials
- 3 Understand the physical arrangements of supply, transmission and distribution equipment
- 4 Understand how electrical energy is used to support applications of electrical technology.

Unit content

1 Know the methods used to produce electrical energy

Electromagnetic generation: characteristics and principles of operation of alternating current (AC) and direct current (DC) generators, e.g. relative motion between conductors and magnetic fields, production and regulation of AC using field/slip-ring control, production of DC using commutators and brushgear; features of different types of electrical power generating stations and their energy sources, e.g. coal, gas, oil, nuclear, hydroelectric, pumped storage, wind farms, tidal, biomass.

Solar panels: developments in photoelectric cells, e.g. photo-electric effect, PN-junction for basic photocell, need for use of converters to convert to alternating current source; small and large scale applications of solar panels, e.g. roadside furniture such as school crossing warning signs, domestic/commercial roofing.

Electro-chemical cells and batteries: construction, applications and disposal; primary and secondary, e.g. lead/acid, alkaline, nickel-iron (NiFe), nickel-metal-hydride (NiMH), nickel-cadmium (NiCad), lithium.

2 Understand the properties and applications of conductors, insulators and magnetic materials

Conductors: properties, e.g. conductivity, resistivity, tensile strength, rigidity; electrical applications of solid conducting materials, e.g. copper, aluminium, steel, brass, carbon, soil (for Earth continuity); applications of liquids and gases e.g. electrolytes, fluorescent and discharge lighting.

Insulators: properties, e.g. resistivity, maximum voltage capability, operating temperatures, mechanical strength; applications of solid, liquid and gas insulating materials, e.g. polyvinyl chloride (PVC), butyl rubber, glass, paper, oil, air.

Magnetic materials: properties, e.g. retentivity, coercivity, B-H curve, hysteresis, iron losses; electromagnetic applications, e.g. permanent magnets, electromagnets, soft iron, silicon steel, mu-metal, ferrites for use at audio and high frequencies.

3 Understand the physical arrangements of supply, transmission and distribution equipment

Electrical generation: energy conversion methods, e.g. generating plant and equipment (coal, gas, oil, nuclear, hydroelectric, pumped storage, wind farms, tidal, biomass, photo voltaic, Gas turbine); by-products (useful and not so useful, CO₂ emissions, carbon neutral); speed governing and voltage regulation for supply standardisation.

Electrical transmission: use of transformers for feeding into and out of the grid network; construction and operation of power transformers, e.g. double-wound and autotransformers; construction and operation of switchgear and protection systems, e.g. air circuit breakers, oil circuit breakers, fuses, over current and over voltage devices; transmission voltages, e.g. 400 kV, 275 kV and 132 kV and the reasons for using them; cross-channel/intercontinental links for electricity supply.

Electrical distribution: ring and radial feeders; sub-stations; use of distribution voltages e.g. 33 kV, 11 kV; plant and equipment e.g. isolators, oil breakers, air breakers; three-phase and single-phase distribution systems and voltages (400V and 230V); earthing arrangements.

4 Understand how electrical energy is used to support applications of electrical technology

Applications of electrical technology: manufacturing, e.g. automated processes, robotics, control systems; healthcare, e.g. magnetic resonance imaging (MRI) scanners, operating theatre uninterruptible power supplies (UPS); entertainment, e.g. sound and video systems, theme parks, music festivals; transport, e.g. electric trains, inner-city trams, electric cars, solar-powered space travel.

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P1 describe the characteristics and principles of operation of a DC electromagnetic generator	M1 compare the features of three prime energy sources that are in general use for the production of electricity by mechanically driving an electromagnetic generator	D1 justify the use of different energy sources, including fuels and renewable sources, to provide a nation's electricity supply
P2 describe the characteristics and principles of operation of an AC electromagnetic generator		
P3 describe the operation and an application of a solar power source		
P4 describe the characteristic features of two different types of electro-chemical cells or batteries		
P5 explain the properties and a typical application of a solid and a liquid or gas electrical conductor		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P6 explain the properties and a typical application of a solid and a liquid or gas electrical insulator		
P7 explain the properties and an application of two different magnetic materials commonly used in electrical and electronic engineering		
P8 describe the arrangements and features of an electrical supply system from generation through to transmission and distribution to end users	M2 explain the reasons for the use of a range of voltages in an electricity supply system	D2 evaluate an electrical supply system suggesting possible improvements.
P9 explain two different applications of electrical technology and, for each of them, describe how electrical energy is used to enable them to function.	M3 explain how a practical application of electrical technology could be improved by making effective use of available technologies.	

Essential guidance for tutors

Assessment

Although this unit could be delivered completely in class, the learning and assessment experience is much more relevant if the learners make use of the outside world and visit real applications of electrical technologies.

The pass criteria could be achieved through the use of written assignments and/or illustrated posters with relevant text boxes to describe the concepts covered, for example the characteristics and principles of operation of a DC electromagnetic generator.

For P1 (DC generator) and P2 (AC generator), motor vehicle/motorcycle parts are cheap and are a relatively safe resource that could be investigated and described. The larger items in power stations are just scaled-up models (figuratively speaking) with somewhat larger brush gear and coils, etc. Hence, an assignment could require learners to use such an easily obtainable device to help them describe the principles and operation of electromagnetic generation.

Learners could then use this simple model to illustrate the similarities and differences between these and larger machines when they consider the characteristics of a power station and its energy sources (for example a coal, gas, oil, nuclear, hydro-electric, pumped storage, wind farm, tidal, biomass) used to generate power commercially.

Solar cells (P3) can be found on a range of items, including calculators and street signs, as well as small kits used by many college and school science departments. Learners' description of their operation should be limited to developments in photoelectric cells and a consideration of the action of the atoms in crystal lattice PN-junctions when subjected to illumination. An in-depth atomic theory explanation is not expected.

Cells and batteries take many forms and, although a wide range should be taught, learners only need to select two for P4. Liquid conductors and insulators (P5 and P6) could also be part of learners' response to P4 if a wet cell such as lead acid were to be described. Reference could also be made to the potential hazard of topping up the cell with tap water if living in a hard water, high mineral content region. This would short out the plates and ruin the cell(s), whereas distilled or de-ionised water would not.

There is a wide range of other examples that could be examined for P5 and P6. For example, oil is a good insulator and is used on oil circuit breakers to quench the spark and prevent conduction. Fluorescent lights contain a variety of conductive gases and vapours requiring different arcing voltages and producing a range of colours. Overhead lines are insulated by air and any simple electric switch uses air as an insulator when in the 'off' position.

To cover P7, learners could consider electrical relays, motors, generators or similar devices that rely on electromagnetism. For example the soft iron formers of transformers and motors or a radio tuner's use of ferrite core inductors. Some devices use permanent magnets, which could also be explained to address P7.

P8 requires learners to describe the arrangements and features of an electrical supply system to cover the key aspects of the content. This will include the generation method, transformer construction, types and operation, including single wound (autotransformers) and double wound voltages and distribution method. Learners might also include the finer details of distribution such as an electronics workshop having isolating transformers on bench supplies and reasons why they are used.

P9 provides an opportunity for learners to apply their knowledge by considering complete real-world applications. Examples could include lighting systems, sound systems or systems including motion (ranging from a model containing an electric motor to the electrification of the rail network). The Docklands Light Railway (DLR) and some airport transport systems have no driver and an investigation of these systems could allow learners to work on an area in which they may be interested and learn through the application of electrical technology. This should take learners into such aspects as electromagnetic effects and sensors for control, computer control, or the requirement for emergency or uninterrupted power supplies (UPS).

To achieve a merit, learners should differentiate between the mechanical prime movers of electromagnetic generators (M1), ranging from nuclear, coal and gas to wind and wave power and water storage such as that used at Dinorwic in Wales. Things to compare and contrast could include cost, response time, maximum demand, pollution, environmental issues, including appearance, hazards (and perceived hazards), locality of employees, life span of the project and post-service decommissioning.

While reporting on a supply system (P8), learners could address M2 by explaining why a range of voltages is used such as 15 to 25 kV at the generators and up to 400 kV for transmission, and the reasons for other voltages (for example 33 kV, 11 kV and 3.3 kV down to 400/230 volts) for light industrial and domestic end users.

To address D1, learners need to produce a thorough justification of why a nation might use a range of different energy sources. This could include (as a source and focus for the learner's own justifications) suitably referenced third-party comments from parliamentary reports, Greenpeace opinions, local opposition groups and the projected impacts on national and global economies. Other considerations could include the future of different methods and fuels, lifespan of equipment and the actual fuel, cost of fuel production, hazards and environmental impact assessments.

D2 provides an opportunity for learners to develop the ideas of P8 and M2, electrical supply systems. For D2, learners are expected to provide suggestions for improvements to many aspects of effectiveness and efficiency of a chosen system. The suggestions made, and their explanations and justifications, should be feasible and possible. This could include an evaluation of learners' ideas by a third party/engineer in that chosen industry. Learners could then make effective use of this through further reflection and subsequent development of their own work by following the professional feedback.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, P4, M1, D1	Electrical Energy Production	Learners produce an information poster for learners detailing the main forms of electrical energy production.	A written assignment with a series of tasks requiring learners to describe AC and DC generators, solar power and two different batteries.
P5, P6, P7	Conductors, Insulators and Magnetic Materials	Learners need to produce a report detailing the properties and applications of different conductors, insulators and magnetic materials to determine the best for a particular application.	A written assignment with a series of tasks requiring learners to explain conductors, insulators and magnetic materials.
P8, M2, D2	Electrical Supply, Transmission and Distribution Equipment	Learners produce a report on the electrical supply system.	A written assignment for which learners describe the electrical supply system and explain the reasons for a range of voltages.

Criteria covered	Assignment title	Scenario	Assessment method
P9, M3	Applications of Electrical Technology	Learners have been asked to investigate the use of electrical energy.	A written assignment requiring learners to explain the use of electrical energy in different applications.

Essential resources

Centres will need simple models or alternators/dynamos from motor vehicles to demonstrate AC and DC generation. Because cells and batteries can be hazardous, videos/DVDs or pictures are recommended to illustrate these along with manufacturers' data.

Indicative reading for learners

Textbooks

Hughes E – *Electrical and Electronic Technology* (Pearson Education, 2012)
ISBN 9780273755104

Kiameh P – *Power Generation Handbook* (McGraw-Hill, 2011) ISBN 9780071772273

Patrick D and Fardo S – *Electrical Power Systems Technology*
(Fairmont Press, 2008) ISBN 9781439800270

Unit 25: Business Operations in Engineering

Level:	3
Unit type:	Additional
Guided learning hours:	60

Unit introduction

Engineers are employed in a range of businesses in the primary, secondary and tertiary sectors. Their knowledge and skills are used to carry out a variety of specific functions that solve the needs of businesses and contribute to their commercial success. By making effective use of their engineers' expertise, organisations can secure competitive advantage, whether they be a small owner-managed company or a large limited company with many shareholders.

For anyone considering a career in engineering, it is important to have an understanding of how an engineering business operates and its position in society. This unit will develop learners' understanding of business, the engineering industry and the effect of engineering on the environment. It will help give learners a firm foundation for employment in the engineering sector and an understanding of the organisational, financial, legal, social and environmental constraints in which an engineering company operates.

The unit will enable learners to examine an engineering company in detail. This could be either the one in which they are employed or one in an engineering sector in which they may look for employment. Learners will understand how the company operates, the factors that impact on the business and the importance of a cost-effective output. This will include an examination of the engineering functions of the company and the importance of communication and information flow in the business. This is set within a study of how external factors and the economic environment impact on the company.

Learners will examine relevant legislation and how it can place considerable constraints on the way that a typical engineering company is required to operate. A company cannot survive if it is not profitable and the unit allows learners to consider the use and implication of costing techniques on the sustainability of a particular engineering activity.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

- 1 Understand how an engineering company operates
- 2 Understand how external factors and the economic environment can affect the operation of an engineering company
- 3 Know how legislation, regulation and other constraints impact on the operation of engineering businesses
- 4 Be able to apply costing techniques to determine the cost effectiveness of an engineering activity.

Unit content

1 Understand how an engineering company operates

Sectors: primary, e.g. oil, gas, agriculture; secondary, e.g. chemical, manufacturing, automotive, aerospace, marine, sports; tertiary, e.g. energy distribution, nuclear technologies, waste management, water services, building services, civil, construction, structural, health, telecommunications.

Engineering functions: e.g. research and development (R&D), design, manufacture, materials supply and control, production planning and control, installation, commissioning, maintenance, technical support, technical sales, project planning and management, quality assurance.

Organisational types: size, e.g. micro, small, medium, large; status, e.g. sole trader, partnership, public (plc), private (ltd), new, established, charitable, not for profit; structure, e.g. owner-manager, boards, committees, governors, hierarchical, flat, matrix.

Information flow: internal systems, e.g. lines of communication, working procedures, e-systems, integrated systems; people involved, e.g. supervisor, other employees, customers, suppliers; types of information, e.g. work instructions (such as operation sheets, engineering drawings, circuit diagrams), work in progress records, stock/orders/sales; work ethics of communication, e.g. confidentiality, integrity, respect.

2 Understand how external factors and the economic environment can affect the operation of an engineering company

External factors: factors to consider, e.g. markets, consumers, demographic and social trends, competitive products/services/organisations, customer/client relationships, innovation and technological change, availability of sustainable resources.

Economic environment: measures, e.g. gross national product (GNP), gross domestic product (GDP), balance of payments; location, e.g. local economy, regional and national economy (such as Regional Development Agency, local/regional skills targets); economic variables, e.g. interest rates, exchange rates.

3 Know how legislation, regulation and other constraints impact on the operation of engineering businesses

Legislation: legislation, e.g. Health and Safety at Work etc. Act 1974, Employment Act 2008, Factories Act 1961, Fire Precautions Act 1971, Data Protection Act 1998, Employment Equality (Age) Regulations 2006, Management of Health and Safety at Work Regulations 1999, Provision and Use of Work Equipment Regulations 1998, Control of Substances Hazardous to Health (COSHH) Regulations 2002, Lifting Operations and Lifting Equipment Regulations 1998, Manual Handling Operations Regulations 1992, Personal Protective Equipment at Work Regulations 1992, Confined Spaces Regulations 1997, Electricity at Work Regulations 1989, Control of Noise at Work Regulations 2005, Reporting of Injuries Diseases and Dangerous Occurrences Regulations 2013, Working Time Regulations 1998, Workplace (Health, Safety and Welfare) Regulations 1992, Health and Safety (First-Aid) Regulations 1981.

Environmental constraints: e.g. sustainability, environmental impact, use of renewable energy resources, carbon footprint, recycling, product end of life strategy.

Social constraints: e.g. employment levels, workforce skill levels and training requirements, opportunities for self-improvement and progression, motivation, impact of outsourcing.

4 Be able to apply costing techniques to determine the cost effectiveness of an engineering activity

Costing techniques: income; expenditure; profit/loss; cost control, e.g. direct cost, indirect cost, fixed cost, variable cost, contribution, marginal costing; assets, e.g. investment and value of fixed assets, depreciation of fixed assets.

Make-or-buy decisions: e.g. break-even point, investment appraisal, return on investment, pay-back time, financial risk, development costs.

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P1 explain the functions carried out by different engineering companies in the sectors in which they operate	M1 discuss how improvements in information flow could enhance the functional activities of an engineering company	D1 evaluate the information flow through an engineering company in relation to an engineering activity
P2 explain the organisational types of three given engineering companies		
P3 outline how information flows through an engineering company in relation to an engineering activity		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P4 explain how external factors and the economic environment affect the way in which an engineering company operates	M2 discuss the impact of relevant legislation on a specific operation in a typical engineering company in terms of benefits and limitations	D2 evaluate the importance and possible effect of the external factors that directly impact on an engineering company.
P5 describe the legislation and regulations that impact on the way an engineering business operates		
P6 describe the environmental and social constraints that impact on the way an engineering business operates		
P7 carry out costing techniques to determine the cost effectiveness of an engineering activity	M3 demonstrate how the cost effectiveness of an engineering activity could be improved.	
P8 carry out costing techniques to reach a make-or-buy decision for a given product.		

Essential guidance for tutors

Assessment

It is likely that the assessment evidence for pass criteria P1 and P2 could be produced through the study of three separate engineering companies. One of these could be the company in which the learner is employed, with the others through case study or relevant research of companies chosen either by the learner or the tutor. It is important to ensure an opportunity for activity in all three sectors is given collectively across the three companies studied. Evidence for criteria P3, P4, P5 and P6 could be produced through the study of a single engineering company, again likely to be one chosen by the learner. The remaining pass criteria (P7 and P8) lend themselves to a controlled and time-constrained activity. Although opportunities to carry out costing exercises in a real environment may be used, it may be that issues of business confidentiality will prevent this.

This unit could be assessed using three assignments. The first assignment could assess criteria P1, P2 and P3 together with M1 and D1. Information should be given about three separate engineering companies, real or fictitious, ideally one from each sector (primary, secondary and tertiary). The functions that the companies carry out can be simplified, such as designing a solution to an engineering problem or installing a machine. Other information should be given about the size and structure of the organisations.

Work-based learners may wish to use their own company to satisfy part of each criteria, although they will need data on a further two organisations to fulfil the criteria. Written tasks could be given and the evidence is also likely to be in written format.

For P2, sketches may also help to explain organisational structures. For P3, learners need to be able to explain how functions within a business are able to communicate effectively to support business strategies in relation to an engineering activity (for example the link between design and technical sales, manufacturing and material/component supply). This will link to the content section on information flow, where learners need to explain the internal systems, people involved, types of information and work ethics of communication relevant to a specific activity within an engineering company.

A second assignment should require learners to investigate how external factors and the economic environment (P4), legislation and regulations (P5), and environmental and social constraints (P6) impact on the overall operation of an engineering business. It is sensible to also include criteria M2 and D2 in this assignment.

The evidence for the last two pass criteria (P7 and P8) could be gathered through a third assignment involving a costing exercise based on the engineering activity considered in P3. For example, this could involve the use of costing techniques to

determine the cost effectiveness of the product/service and then looking at a make or buy decision for part of or the whole product/service. If this is not realistic or appropriate then separate tasks may be necessary. The engineering activity considered in the criteria P3 and P7 could, for example, be the manufacture of a product or the provision of a service. In either case, centres need to ensure that the relevant data is available to cover all aspects of the content, although the product or service itself does not need to be overly complex. A task could then be set to complete a make or buy decision (P8). Criterion M3 is also best linked to this assignment.

To achieve a merit grade, learners will need to apply evaluative skills to discuss how improvements in information flow could enhance the functional activities of an engineering company (M1). This could be a natural extension to work carried out for P1, P2 and P3. Learners should discuss the impact of legislation on a specific operation in a typical engineering company (M2). This has a link with the criterion P5, which considers legislation in a broader context for the company. For merit, learners need to analytically apply the understanding they have gained at pass level to consider the impact of legislation in terms of benefit (for example reduced risk to employees and therefore improved safety record) and limitations (for example increase in production cycle times and therefore increased costs) for the operation considered. Finally, to achieve the last merit criterion M3, learners should consider the costing exercise carried out for P7 and P8 and explain how the cost effectiveness of the engineering activity could be improved or the make-or-buy decision made more conclusive or even amended.

To achieve a distinction grade, learners should focus on a specific activity and evaluate the information flow through an engineering company in support of it (D1). This links to P2 and P3, where learners described organisational types and explained the information flow for an activity and with M1 their ability to consider improvements. The evaluation for D1 should consider the key aspects of the information flow, how it impacts on the specific activity and other functional activities of the company, plus any issues in terms of problems encountered or opportunities for improvement. As such this could be in the first assignment. To achieve D2, learners should evaluate the importance and possible effects of the external factors that directly impact on an engineering company. Learners will need to use their general understanding of external factors from P4 but at this level begin to take an analytical view of the relative importance and the direct effects on the business.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, M1, D1	Types and Operation of Engineering Businesses	An activity requiring learners to carry out research based on actual engineering companies. These companies will be involved in a range of business activities, and have different management structures and operating methods.	A portfolio containing written responses and flow diagrams based on primary and secondary research data. Carried out under controlled conditions. This activity could be supported by a PowerPoint presentation.
P4, P5, P6, M2, D2	External Factors and Legislation that Affect the Operation of an Engineering Company	An activity to investigate the external factors and pressures that can affect the profitability of businesses. It involves finding out about economic, legislative and environmental constraints in the context of a given engineering company.	A portfolio containing written responses to a number of defined activities. Carried out under controlled conditions. This activity could be supported by a PowerPoint presentation. This assessment could be delivered in two parts – small group research activity followed by a summative test.

Criteria covered	Assignment title	Scenario	Assessment method
P7, P8, M3	Assessing the Cost and Viability of an Engineering Activity	An investigative activity involving calculation and decision making supported by reflective writing and, where appropriate, verbal presentation.	A portfolio containing spreadsheets and written commentary carried out under controlled conditions. This activity could be supported by a PowerPoint presentation.

Essential resources

For this unit, learners require access to sufficient data on engineering companies. This can be in the form of case studies, industry visits or data available through learners' employers.

Indicative reading for learners

Textbooks

Boyce A, Cooke E, Jones R and Weatherill B – *Edexcel BTEC Level 3 National Engineering Student Book* (Pearson, 2010) ISBN 9781846907241

Boyce A, Cooke E, Jones R and Weatherill B – *Edexcel BTEC Level 3 National Engineering Teaching Resource Pack* (Pearson, 2010) ISBN 9781846907265

Chelsom J, Reavill L and Payne A – *Management for Engineers, Scientists and Technologists*, Second Edition (John Wiley and Sons Ltd, 2004)
ISBN 9780470021262

Nicholas J and Steyn M – *Project Management for Engineering, Business and Technology* (Routledge, 2011) ISBN 9780080967042

Tooley M and Dingle L – *BTEC National Engineering* (Routledge, 2010)
ISBN 9780123822024

Unit 26: Principles and Applications of Analogue Electronics

Level:	3
Unit type:	Additional
Guided learning hours:	60

Unit introduction

This unit will provide learners with an understanding of analogue electronics and the skills needed to design, test and build analogue circuits.

Although digital circuits have become predominant in electronics, most of the fundamental components in a digital system, particularly the transistor, are based on analogue devices. Advances in technology mean that, as transistors get smaller, it becomes more important when designing digital circuits to account for effects usually present in analogue circuits. This unit will give learners an understanding of the key principles and function of analogue electronics.

Analogue electronics are still widely used in radio and audio equipment and in many applications where signals are derived from analogue sensors and transducers prior to conversion to digital signals for subsequent storage and processing.

This unit will introduce learners to the basic analogue principles used in electronics, such as gain, loss and noise and the principles of a range of classes of amplifier. The unit will also cover the operation of analogue electronic circuit systems and their components, such as integrated circuits (ICs) and the sensors required in analogue (and some digital) circuits.

Learners will be able to apply their understanding of principles and operation in the design and testing of analogue electronic circuits for specified functions using electronic computer-based methods.

Finally, learners will build and test circuits such as a filter, amplifier, oscillator, transmitter/receiver, power control, or circuits/systems with telecommunication applications. This will include the use of circuit assembly and testing methods, such as circuit diagrams, interpreting/recording measurements, analysis of performance and the use of a range of test equipment.

Learning outcomes

On completion of this unit a learner should:

- 1 Understand the principles of gain and loss and the function of amplifiers in analogue circuits
- 2 Understand the operation of analogue electronic circuit systems and their components
- 3 Be able to use computer-based techniques to design and test analogue electronic circuits for specified functions
- 4 Be able to build and test an analogue electronic circuit.

Unit content

1 Understand the principles of gain and loss and the function of amplifiers in analogue circuits

Gain and loss: definition and use of the decibel (dB), benefits of using the logarithmic unit for voltage/ power gain; decibel reference to one milliwatt (dBm).

Noise: types of noise, e.g. thermal, cross-talk, shot; effects of noise on typical circuits/components; signal-to-noise ratio.

Transistor amplifier: classes of amplifier such as A, B, AB and C; feedback and its effects on gain, bandwidth, input and output impedance, noise and distortion.

2 Understand the operation of analogue electronic circuit systems and their components

Analogue integrated circuit (IC): use of and interpretation of manufacturers' data; IC operation, e.g. gain, frequency, power consumption; typical IC systems, e.g. 555 oscillators/timers, amplifiers (operational, power, instrumentation), voltage regulators (linear or switch mode), filters (switched capacitor), phase locked loop (PLL), power control (smart devices, MOSFET bridge driver), sensors (thermal, opto, magnetic), analogue switches.

3 Be able to use computer-based techniques to design and test analogue electronic circuits for specified functions

Propose design solutions: use of integrated circuits; use of simulation program with integrated circuit emphasis (SPICE)/electronic computer aided design (ECAD) techniques to analyse and develop circuits.

Circuits and systems: e.g. filters (anti-aliasing, mains, notch), amplifiers (specified gain/frequency response, power), oscillators (voltage controlled oscillator (VCO) for frequency shift keying (FSK) or frequency modulation (FM)), PLL for FSK or FM demodulator, opto-transmitter/receiver (fibre link, remote control), power supplies (DC/AC converter, non-interruptible), sensors (environmental), power control (stepper motor driver), circuits and systems with telecommunication applications.

Circuit simulation and testing: functional testing using a supplied test specification to determine circuit design inputs and outputs, e.g. test-point voltages, output signals.

4 Be able to build and test an analogue electronic circuit

Circuit assembly: use of prototyping methods, e.g. breadboard, stripboard, printed circuit board (PCB); typical circuits, e.g. filter, amplifier, oscillator, transmitter/receiver, power control, circuits/systems with telecommunication applications.

Circuit testing: use circuit diagrams; interpret/record measurements, e.g. voltage, frequency, noise, gain; analysis of performance; use of test equipment, e.g. oscilloscope, signal generator, digital multimeters, frequency meter/spectrum analyser, virtual (computer-based) instruments, data capture.

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P1 explain the decibel as a measure of gain and noise	M1 compare the practical performance of two different classes of amplifier	D1 analyse the results of a designed electronic circuit with reference to measured signals in terms of both voltage and frequency
P2 describe two different classes of amplifier	M2 justify the selection of specific analogue integrated circuit devices to meet a given design specification	D2 evaluate computer-based and practical methods used to analyse the behaviour of analogue circuits with respect to their effectiveness in the design process.
P3 explain four different effects of feedback on the function of an amplifier	M3 evaluate the performance of an analogue circuit by interpreting measured results.	
P4 explain the operation of three common analogue integrated circuit devices		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P5 describe two system applications for each of three common analogue integrated circuit devices		
P6 use computer-based simulation methods to produce a possible design solution for three different analogue circuit systems		
P7 use computer-based simulation methods to simulate and test the performance of a given analogue electronic circuit		
P8 build and test an electronic circuit to a given analogue circuit specification.		

Essential guidance for tutors

Assessment

This unit could be assessed through a carefully structured series of activities and assignments that link to each other and culminate in the building and testing of an electronic circuit to a given analogue circuit specification.

P1 could be assessed with a short assignment to determine the voltage gain of a transistor amplifier, expressing this first as a ratio and then converting the voltage gain (or loss) into decibels (dB). Learners could also measure the output noise power (in the absence of a signal) and use this to determine the signal to noise ratio for a given input signal voltage.

The assignment should ensure that it includes tasks to cover all the required aspects of content – definition and use of the decibel (dB), benefits of using the logarithmic unit for voltage/power gain and decibel reference to one milliwatt (dBm). The assignment must also provide an opportunity to consider the required aspects of noise – types of noise, effects of noise on typical circuits/components, signal-to-noise ratio. Setting this within the context of the amplifier investigated by each learner will provide scope for authentic evidence based on individual practical work. Ensuring that each learner is working with a slightly different amplifier could further reinforce this.

Assessment of P2 could build on the learner's work with transistor amplifiers by considering and describing two different classes of amplifier (e.g. class A and class B). The amplifiers described for P2 could then be used for P3, although the choice of amplifiers must ensure that between them, the learner is able to explain at least four different effects of feedback on the function of an amplifier (e.g. its effect on gain/bandwidth/input and output impedance/noise and distortion). This assignment could be designed to also provide learners with an opportunity to work towards M1 by comparing the practical performance of the two different classes of amplifier. An alternative to using two separate amplifiers (one of each class) is that of simply switching the bias of the output stage for operation in either class A or class B mode.

The third assignment, to cover P4 and P5, could require learners to explain the operation of three common analogue integrated circuit (IC) devices. One or more of these could then be used in their final circuit for P8. The explanation will need to address the learner's use and interpretation of manufacturers' data and the operation of each IC for typical IC systems. In addition, learners are required to describe two system applications of each IC. Again, one of these could be the focus of the build and test project for P8. A further task could be added to cover M2, requiring learners to justify the selection of specific IC devices to meet a given design specification. Note the use of 'devices' in the criterion. This implies that the system has more than one IC device operational.

Assessment of P6 and P7 could be through a fourth assignment requiring learners to use SPICE/ECAD to produce circuit designs, with annotated printouts of three different circuits, e.g. filters, amplifiers, oscillators. A more extensive range of examples is given within the unit content section for this criterion. Learners could then simulate and test the performance of one of these in detail (e.g. for DC levels/gain/frequency/bandwidth), which would give an opportunity to achieve P7. In addition, evidence of learners' ability to evaluate the performance of one of these analogue circuits by interpreting measured results, could lead to achievement of M3. If learners are also able to analyse the results of a designed electronic circuit with reference to measured signal in terms of both voltage and frequency then they could achieve D1. Note that another opportunity exists to achieve M3 and D1 during the build and test work for P8. However, M3 or D1 only needs to be achieved once and it is not important whether this is through simulated or real circuit evaluation and analysis.

Finally, P8 should bring together all of the learner's experience within one practical build and test of an actual circuit. This could be built using breadboard, stripboard or printed circuit board (PCB) techniques. The circuit could be one of the simulated circuits used for P6 or P7. Learners could reflect on the techniques carried out for P6, P7 and P8 and work towards achievement of D2. For example, the evaluation of the SPICE/ECAD approach (P6/P7) compared with the practical methods (P8) used to analyse the behaviour of an analogue circuit with respect to their effectiveness in the design process.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1	Principles of Gain and Loss	A technician has been asked to determine the voltage gain of a transistor amplifier.	A practical investigation evidenced through a written report.
P2, P3, M1	Amplifier Types and Functions	A technician needs to compare different types of amplifier to determine the best for an application in the workplace.	A practical investigation evidenced through a written report.
P4, P5, M2	Analogue Integrated Circuits	A technician needs to explain the operation of circuit devices to a new apprentice.	A written description of circuit devices including justification of choice of amplifiers for specific applications.
P6, P7, M3, D1	Design and Simulation of Analogue Circuits	A technician has been asked to design analogue electronic circuits for three different applications.	A practical activity evidenced through annotated printouts, observation records and a written report interpreting measured results.

Criteria covered	Assignment title	Scenario	Assessment method
P8, D2	Building and Testing Analogue Circuits	A technician needs to build and test an analogue electronic circuit.	A practical design and build activity evidenced through observation records and a written report.

Essential resources

Centres will need to provide access to an electronics workshop including facilities for circuit construction using breadboards/stripboard/PCB methods together with the relevant tools and equipment.

Centres will also need to provide the basic components and appropriate specialised integrated circuits together with relevant catalogues, application notes and data sheets. Access to SPICE/ECAD facilities that permit circuit simulation and testing is essential. Electronic test equipment will also need to be provided to meet the requirements of the unit content and assessment and grading criteria.

Indicative reading for learners

Textbooks

Storey N – *Electronics: A Systems Approach* (Prentice Hall, 2009)
ISBN 9780273719182

Tooley M – *Electronics Circuits: Fundamentals and Applications*, 4th edition
(Newnes, 2015) ISBN 9781138828926

Unit 27: Construction and Applications of Digital Systems

Level:	3
Unit type:	Additional
Guided learning hours:	60

Unit introduction

This unit aims to give learners an understanding of modern digital systems and technology and the skills needed to build and test a range of digital electronic circuits.

Digital electronics play an integral part in modern society. Their wide application, from washing machines and car management systems to street furniture devices (e.g. turning street lighting on and off), means that there is an increased need for safe, low maintenance, energy-efficient systems. These new systems also frequently use alternative energy sources and have their eventual disposal (e-waste) taken into account from their conception.

This unit will give learners an understanding of recent advances in digital electronics and the new technologies that often replace older electrical and electronic systems (legacy systems). Learners will also develop an understanding of how the components of an electronic system are connected together (interfaced) to enable analogue signals to be transmitted digitally. For example, interface circuit devices such as optocouplers can transfer an electrical signal from one circuit to another while electrically isolating the two.

Learners will also have the opportunity to build and test different digital systems, enabling them to understand circuit life cycles, circuit costs and build and test methods.

Learning outcomes

On completion of this unit a learner should:

- 1 Understand energy efficient use of modern digital electronics technology
- 2 Understand the transmission of analogue data in a digital system
- 3 Understand the selection and use of interface devices and logic devices for digital circuits
- 4 Be able to build and test digital systems.

Unit content

1 Understand energy efficient use of modern digital electronics technology

Small energy sources: source types, e.g. solar (photovoltaic), batteries (lead-acid, nickel-cadmium (NiCad), nickel-iron (NiFe)), alternative sources (small-scale wind/water turbines); maintenance, handling and care, e.g. recharging, testing, replacement techniques, disposal.

Extended system life: legacy systems and modern applications, e.g. historical technologies, impact of required energy levels, load evaluation and usage, alternative systems, consideration of e-waste, use of 'fuzzy logic' techniques; applications, e.g. street furniture, charge regulators, thermostats, load diverting controllers, calculators; lifetime costs, efficiencies, reliability, maintenance.

2 Understand the transmission of analogue data in a digital system

Data transmission: digital-to-analogue converters (DACs), e.g. digital-ramp, summing amplifier, current switches, R-2R ladder; analogue-to-digital converters (ADCs), e.g. counter, successive approximation, flash; integrated circuits, e.g. slope, dual slope; code converters and function generators (look-up tables); optoelectronic display devices, e.g. 7-segment, 14-segment (starburst), dot-matrix, liquid crystal display (LCD), light-emitting diode (LED), organic light-emitting diode (OLED), plasma, vacuum fluorescent display (VFD).

Tri-state devices: tri-state buffers and line drivers; control of data access to bus or transmission channel; random bus arbitration access; ordered time division multiplexed access.

3 Understand the selection and use of interface devices and logic devices for digital circuits

Standard data interface: industry standards, e.g. general applications (International Standards Organisation (ISO), American National Standards Institute (ANSI), British Standards Institute (BSI)), telecommunication applications (Telecommunications Industry Association (TIA), International Telecommunication Union (ITU), European Telecommunications Standards Institute (ETSI), Office of Communications (Ofcom)), electronic applications (Joint Electronic Device Engineering Council (JEDEC)); standard interfaces, e.g. RS232, RS422, RS562, V24, V28, V10, V11; electrical current sourcing and heat sinking requirements; voltage level adjusting; optocouplers/optoisolator; tri-state/bi-directional line driver device in a multiplexed data bus transmission system.

Logic devices families: characteristics, e.g. power consumption and interfacing (emitter-coupled logic (ECL), transistor-transistor logic (TTL), low-power Schottky transistor-transistor logic (LSTTL), complementary metal-oxide semiconductor (CMOS), high-speed CMOS (HCMOS)); levels of integration and benefits, e.g. small/medium/large/very large/ultra large scale integration (SSI/MSI/LSI/VLSI/ULSI), system-on-chip (SOC).

4 Be able to build and test digital systems

Circuits and systems: combinational circuit, e.g. logic encoder, decoder, multiplexer, demultiplexer, code converter, function generator; asynchronous/synchronous circuit, e.g. counter, frequency divider, ring counter, clock waveform generator, register, shift register, converters (serial-to-parallel, parallel-to-serial); systems, e.g. security (access control, intruder alarms, fire, nurse call), safety (weight levels, proximity, sensor technologies), monitoring (level indicators, flow rates, temperature), embedded (dedicated computers, RAM/Flash memory).

Circuit testing: aids, e.g. data sheets, test instruments, specialised tools; built-in self-tests, in-circuit emulators; glitches, e.g. electronic pulse of short duration cross-talk, amplitude noise margins; race conditions, e.g. input condition conflicts, floating inputs; hazards (static, timing); test patterns; precautions when testing components, datalines and systems.

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P1 explain how two different types of small energy sources are used to support two different digital electronic systems	M1 discuss the benefits of combining a small energy source with modern digital technologies	D1 evaluate a digital system to consider how a modern energy source and/or energy reducing components might improve the system's future life cycle
P2 explain how modern technologies can be used to extend the life of an existing electronic system	M2 compare the operation of two different types of data transmission device	D2 evaluate and suggest improvements to the circuit operation of a digital system with respect to the method of data acquisition and human interface employed.
P3 describe how analogue data is transmitted by a digital electronic circuit	M3 compare the operation of a combinational logic device and a sequential logic device.	
P4 explain the role and operation of a tri-state device in analogue data transmission		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P5 explain the selection and use of two different types of standard data interfaces within working systems		
P6 identify a logic device family, its current levels of integration and the benefits of using it		
P7 build two different digital electronic circuits to be used in different digital systems		
P8 carry out circuit testing of the two constructed circuits to check system performance against specification.		

Essential guidance for tutors

Assessment

Assessment evidence for this unit could be collected from a mixture of written technical reports and practical activities, supported by tutor observation records.

To achieve P1, learners need to consider two different given or chosen digital electronic systems, each with a different small energy source. Learners are expected to explain the type of energy source being used and the requirements of that system in terms of the source's maintenance, handling and care. When describing the type of small energy source being used learners should also consider the environment in which it operates and the expected energy levels required by the system to maintain effective operation.

For P2 learners must consider similar aspects to those required for P1 but from the perspective of a legacy system. Once again, the system can be chosen by the learner or be given by the tutor. Learners need to explain how current technologies might be used to enhance the efficiency of operation and maintenance of the existing system. This may draw from some or most of the examples given in the unit content such as historical technologies, impact of required energy levels, load evaluation and usage etc. Typical applications that may be considered are listed in the unit content although others may equally apply. The learner's explanation must cover aspects of lifetime costs, efficiencies, reliability and maintenance.

The work carried out for P1 and P2 will naturally prepare learners for achievement of M1, when they are required to explain the benefits of combining a small energy source together with modern digital technologies.

To achieve P3 and P4, learners need to consider the transmission aspects of data that many systems require in order to effectively process data. P3 requires learners to demonstrate their knowledge and understanding of how analogue and digital signals can be transposed. P4 requires them to show how the data transmitted around the system is controlled. Learners should consider at least one large complete circuit or a series of smaller ones. The written explanations/descriptions should use correct circuit/logic symbols that are based on an appropriate standard. Appropriate standards should be used at all times and learners should provide a key/suitable reference to indicate the standard to which they are working.

The work carried out for P3 and P4 can be extended to M2, when learners compare the operation of two different types of data transmission device.

P5 requires learners to explain the selection and use of two different types of standard data interfaces within working systems. They will need to look at two different and currently operational devices/systems and describe why they are the most appropriate for that situation.

P6 requires learners to identify a logic device family, the available levels of integration and the benefits of that family. This could be achieved by learners taking a digital image of a device/system and making a leaflet to identify the characteristics of the device family and relevant levels of integration that can be achieved.

P7 and P8 should be linked so that learners test the two circuits they have built. P7 requires learners to build two different digital electronic circuits that are to be used within different digital systems. It is expected that one of these would be a combinational circuit, e.g. logic encoder, decoder, multiplexer, de-multiplexer etc. The other digital electronic circuits should be either an asynchronous or synchronous circuit, e.g. counter, frequency divider, ring counter etc. These circuits may be given by the tutor or selected by the learner, with tutor guidance to ensure coverage of unit content. Typically, these circuits will be part of a digital electronic system such as a security system, a safety system, a monitoring system or an embedded system. It is not expected that the constructed circuit be used within the system but learners need to show they understand how it could be integrated within the working system.

The focus of this unit is not on circuit building or testing and it is assumed that learners have gained sufficient knowledge of these elsewhere. Assessment of P7 should therefore concentrate on learners' use of modern digital electronics, their understanding of analogue data transmission and the selection and use of interface devices and logic devices.

P8 requires learners to carry out circuit testing of the two constructed circuits to check system performance against specification. Between the two tests there should be sufficient evidence to meet all the requirements of the unit content. This must include a range of aids to testing, built-in self-tests, in-circuit emulators and identification of circuit glitches, race conditions, hazards, test patterns and precautions.

The need to fully meet the unit content requirements will inevitably influence the choice of suitable circuits for P7 and P8. Where centres wish to allow learner choice/employer involvement, it will be important to maintain sufficient tutor guidance on the circuits chosen to ensure full unit content coverage.

Assessment evidence for P7 and P8 is likely to be in the form of learner notes and records of circuit construction and testing plus tutor observation records of the build and test procedures. Annotated photographic records could also be used.

Achievement of M3 will build on the knowledge and understanding gained from P7 and P8. The two circuits to be compared could be the same as those built and tested for P7 and P8, although this is not essential. Centres may decide that learners would gain a wider understanding by comparing two different circuits provided by the tutor. The comparison should be based on the unit content as a whole, e.g. energy source used, consideration of extended system life, data transmission methods, data interfacing, application of a specific logic family, method of circuit/system construction and how circuits have been/could be tested.

For D1 and D2, learners will need to demonstrate a deeper understanding of working systems and the application of current and future technologies. For D1, learners should focus on small energy sources and energy-reducing aspects of a system. There is a natural link between this criterion and the work undertaken for P1, P2, M1 and M2. Learners should consider and review an existing digital system to establish how the system works and how energy reducing components could potentially improve the future life cycle of the system.

D2 is intended to allow learners to work in a way that may meet their own interests or local needs with either employer or centre guidance. Learners should be directed to consider the various aspects of circuit operation related to input and output for a system, including a good range of circuit level considerations.

Centres that do not wish to leave the delivery and assessment of the distinction criteria to the later part of the unit may wish to guide learners towards a suitable system at an early stage and build upon it as the unit progresses.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1, D1, D2	Efficient Use of Digital Electronics	Learners have been asked to investigate small energy sources and how current technologies might be used to enhance the efficiency of operation and maintenance of an electronic system.	A written report.

Criteria covered	Assignment title	Scenario	Assessment method
P3, P4, M2	Transmission of Analogue Data in a Digital System	Learners need to explain data transmission in electronic systems to a new apprentice.	A written report.
P5	Interface Devices	Learners have been asked to compare the selection and use of different types of data device for specific situations.	A written report.
P6	Logic Devices	Learners have been asked to produce an information leaflet detailing the levels of integration and the benefits of a logic device family.	A written report and/or information leaflet/poster.
P7, P8, M3	Building and Testing Digital Systems	Learners must build and test a variety of digital electronic circuits for a new customer.	A written report/portfolio based on practical activities supported by annotated photos and observation records.

Essential resources

Centres should have sufficient facilities to carry out practical investigations of legacy systems, working devices/systems and equipment and components for building and testing digital electronic circuits. Relevant software packages should also be available to permit simulation of device and circuit performance.

Indicative reading for learners

Textbooks

Agarwal A and Lang, J – *Foundations of Analogue and Digital Electronic Circuits* (Morgan Kaufmann, 2005) ISBN 9781558607354

Wakerly J – *Digital Design: Principles and Practices* (Prentice Hall, 2006)
ISBN 9780131733497

Unit 28: Electronic Fault Finding

Level:	3
Unit type:	Additional
Guided learning hours:	60

Unit introduction

This unit introduces learners to the principles of electronic fault-finding, including the procedures, techniques and skills required when carrying out fault-finding activities.

An understanding of the operation of electronic circuits is an important issue in the training of technicians and engineers. A complex electronic system is generally a number of individual circuits connected together to perform a specific function. However, to understand the overall circuit it is necessary to break it down into smaller, more easily understood circuits. This is particularly important when testing and fault-finding.

The unit will give learners an understanding of electronic components, circuits and systems and how to solve problems involving simple and complex faults to a professional standard.

Learners will develop their knowledge of the application of electronic components and how electrical signals are employed in a variety of analogue, digital and communications circuits. They will also develop the ability to select fault-finding instruments and apply the techniques used for the diagnosis of faults.

The unit will enable learners to read circuit, schematic and wiring diagrams and carry out fault-finding procedures by obtaining the necessary information, documentation, tools and equipment. They will also learn how to prepare accurate reports of all the steps that have been taken during the fault-finding processes.

The unit will ensure that learners have a firm understanding of safe working practices when carrying out fault-finding activities and that they are able to take the necessary safeguards to protect their own safety and that of others in the workplace.

Learning outcomes

On completion of this unit a learner should:

- 1 Be able to read and interpret a circuit diagram for an electronic system
- 2 Be able to plan and implement a fault-finding strategy
- 3 Be able to diagnose fault conditions using test equipment and record the results.

Unit content

1 Be able to read and interpret a circuit diagram for an electronic system

Circuit diagrams: analogue and digital circuit diagrams drawn to national standards, e.g. British Standards (BS) or American National Standards Institute (ANSI); types of circuit diagrams, e.g. block schematic, circuit, wiring, printed circuit board (PCB) layout diagram that each include a minimum of five components and should show input, output and power supply connections plus any external control connections.

Types of analogue circuits: e.g. audio/radio frequency amplifiers, oscillators, multiplexers, demultiplexers, function generators, power supplies.

Types of digital circuits: e.g. combinational/sequential logic circuits, flip flops, encoders, decoders, asynchronous/synchronous counters, frequency dividers, ring counters, waveform generators, registers, shift registers, serial-to-parallel and parallel-to-serial code converters.

Electronic components: passive components, e.g. resistors, capacitors, inductors, diodes; active devices, e.g. transistor and operational amplifiers – small (SSI), medium (MSI) and large scale integrated (LSI) devices for analogue circuits; logic devices for digital circuits, e.g. logic gates, multivibrators, timers.

Input/output signals: circuits working under normal/steady state operating conditions; signal values, e.g. voltage, current, gain, logic levels, alternating sinusoidal and pulse periodic signals at low (LF), medium (MF) and high frequencies (HF), direct current (DC) levels.

2 Be able to plan and implement a fault-finding strategy

Fault location strategy: planning, e.g. obtain relevant diagrams (block schematic, circuit wiring diagrams), establish component/circuit tolerances, specifications, restrictions or limitations of operation; predict circuit operation from diagrams, e.g. signal trace through schematic diagrams, produce a test schedule, identify key test nodes/input-output matrix/decision table, function tables; calculate expected signal conditions for analogue and digital circuits, e.g. operational amplifier (determine the expected output voltage level given the input signal voltage and the values of the input and feedback resistors), logic gates (determine the expected logic level of the output given the input level conditions).

Fault location and signal tracing techniques: input-to-output/output-to-input, half-split method, symptom to cause fault hierarchies, unit substitution, visual examination, top-down approach, module and component isolation; use of fault-finding aids, e.g. functional charts, diagrams, trouble-shooting charts, component data sheets, operation and maintenance manuals, software based records and data; fault/repair reporting, e.g. mean time between failure (MTBF) figures; path sensitisation; critical path and fault signal tracing node points.

3 Be able to diagnose fault conditions using test equipment and record the results

Test instruments: e.g. ammeter, voltmeter, multimeter, logic probe, cathode ray oscilloscope, signal analyser, frequency counter, digital test set, power meter, software simulation tools.

Fault conditions: normal (steady state) equipment operating conditions; component failures, e.g. total, partial; circuit faults, e.g. short circuit and open circuit connections, design and power supply faults; components out of specification; intermittent faults; fault and tolerance testing; digital faults, e.g. input side, output side, logic stuck-at faults.

Test data records: e.g. personal logbook, tabulated data, computer based records (tables, spreadsheet, database), referencing of data (indexed, cross-referenced, date), recorded details (description of systems/circuits, symptoms, operator details, equipment details, test conditions and methods, test results, statistics, comments).

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P1 read a circuit diagram for an electronic system and identify two different types of analogue circuit, the components that make up each circuit and the circuit input and output signals	M1 compare the circuit diagrams of two different approaches to the same type of circuit	D1 evaluate a circuit diagram for an electronic system and identify incorrect circuits/input-output signals
P2 read a circuit diagram for an electronic system and identify two different types of digital circuit, the components that make up each circuit and the circuit input and output signals	M2 evaluate a fault location strategy and make recommendations for improvement	D2 examine the fault conditions within an electronic system that presents a fault in more than one circuit.
P3 prepare a written fault location strategy for a given analogue electronic system and identify the fault-finding and signal tracing techniques to be applied	M3 justify the choice of test instruments selected to identify fault conditions within an electronic system.	

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P4 prepare a written fault location strategy for a given digital electronic system and identify the fault-finding and signal tracing techniques to be applied		
P5 use test instruments to identify fault conditions within an analogue electronic system that has at least one faulty circuit and one component fault		
P6 select and use test instruments to identify fault conditions within a digital electronic system that has at least one faulty circuit and one component fault		
P7 collect and record the test data from an analogue electronic system fault-finding test and prepare a test report		
P8 collect and record the test data from a digital electronic system fault-finding test and prepare a test report.		

Essential guidance for tutors

Assessment

Throughout assessment activities, learners must be made aware of the health and safety hazards applicable to electronic fault-finding operations.

It is likely that a system that has a fault only needs one component to be replaced. However, on some occasions more component failures may be found. Care needs to be taken here not to disadvantage learners if this is the case during their assessment. The criteria can be split into two sets, one for analogue circuits/ systems (P1, P3, P5 and P7) and the other digital (P2, P4, P6 and P8).

P1 and P2 relate to learning outcome 1. To meet P1, learners must be able to read a circuit diagram for an electronic system and identify two different types of analogue circuit within that system, the components that make up each circuit and the circuit input and output signals.

The circuit diagram should have been produced to a national standard, e.g. British Standards (BS) or American National Standards Institute (ANSI). The diagram can be a block schematic, circuit, wiring or printed circuit board (PCB) layout diagram. Each must include a minimum of five components and should show input, output and power supply connections plus any external control connections. The analogue circuits could be audio/radio frequency amplifiers, oscillators, multiplexers, demultiplexers, function generators or power supplies.

P2 requires a similar approach but for two different types of digital circuit, which could be any of those listed in the related section of unit content.

P3 and P4 cover learning outcome 2. Learners are expected to prepare a written fault location strategy for an analogue electronic system (P3) and a digital electronic system (P4) and identify the fault-finding and signal tracing techniques to be applied for each.

The fault location strategy for both P3 and P4 must provide details of the planning that is required for the task (e.g. obtaining relevant diagrams, establishing component/circuit tolerances, etc.), predicting the circuit operation from diagrams and calculating expected signal conditions for analogue and digital circuits respectively.

The signal tracing techniques applied will depend on the type of electronic circuit and the fault or faults present. However, learners should identify an appropriate strategy from the list provided in the unit content (e.g. input-to-output/output-to-input, half-split method, symptom to cause fault hierarchies, unit substitution, etc.). They are not expected to demonstrate them all for assessment purposes, but should have experienced them all during delivery to enable them to make the most appropriate choice.

Learners should also identify the most appropriate fault-finding aids to be used (e.g. functional charts, diagrams, trouble-shooting charts, etc.). The written strategy should also identify the required level of fault/repair reporting (e.g. MTBF figures and the use of path sensitisation, critical path and fault signal tracing node point techniques).

The remaining pass criteria relate to learning outcome 3 and all require proficiency in the practical techniques relating to fault-finding.

To satisfy P5 and P6, learners need to select and use the most appropriate test instruments for the circuits/systems under test.

For P7 and P8, learners must collect and record all the relevant test data and prepare relevant test reports. The data must be presented in a clear and legible form, for example use of a personal logbook, tabulated data that includes headings and relevant units (Voltage/mV, Resistance/Ohms, etc.), computer based records, etc.). It is expected that the report should reach a conclusion on the likely cause of the fault and include the learner's recommendation on how the circuit/system can be restored to full operational order.

When planning and designing assessment activities and assignments tutors should consider how best to incorporate opportunities for the achievement of the merit and distinction criteria. For example, M1 is a natural extension of the tasks carried out to satisfy P1 and P2, which assess learners' ability to read circuit diagrams for analogue/digital electronic systems.

For M1, learners should be able to apply this skill in a deeper way by comparing the circuit diagrams of two different approaches to the same type of circuit. The circuit diagrams could be of an analogue or digital circuit and are likely to be provided by the tutor, although they could come from the learner's workplace if available. The important aspect here is learners' ability to recognise that generally there is always more than one way to produce a given type of circuit.

M2 links with P3 and P4 – preparing written fault location strategies for given analogue/digital electronic systems. Learners should evaluate either a given fault location strategy (analogue or digital) or their own and make recommendations for improvement. This should demonstrate their ability to reflect upon their own work or that of others and apply their understanding to arrive at realistic and relevant improvements.

M3 links with P5 and P6 – the selection and use of test instruments to identify fault conditions in analogue/ digital electronic systems. Learners should justify the choice of test instruments selected to identify fault conditions within an electronic system (analogue or digital). The justification should not only indicate why the test instruments were used but also why others were not. This will show the depth of understanding of a greater range of instruments (e.g. ammeter, voltmeter, multimeter, logic probe, cathode ray oscilloscope, signal analyser, frequency counter, digital test set, power meter, software simulation tools) than will be possible in the work for P5 and P6.

D1 is an extension of the work undertaken for P1, P2, and M1. Again, the circuit diagram could be either analogue or digital and could be provided by the tutor or from the learner's workplace. It assumes that the circuit provided has errors with respect to either the circuit itself or the signals that have been indicated within the circuit. It is likely that such a circuit diagram will need to be produced by the tutor.

Alternatively, it may be possible for learners to produce work-based evidence of the detection of an error, for example through a quality assurance process in the design phase of an electronic product.

D2 is a natural extension of P5 and P6. It is intended to enable learners to demonstrate their ability to apply the skills gained at pass within a more complex context. This will mean that learners are not only able to appreciate that there is a fault in one of the circuits in a system, but that the symptoms indicate further external influence on the expected performance of the circuit as a whole.

For D2, the satisfactory response from learners will be to independently investigate beyond the original fault and identify the second problem. As this is unlikely to occur naturally, the circuit under investigation will need to be specially prepared for this particular task by the tutor.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1, D1	Reading and Interpreting Circuit Diagrams	Learners have been asked to look at circuit diagrams for electronic systems used by their employer, identify the components and signals, and suggest alternative circuits.	A written report based on the findings of an analysis of circuit diagrams.

Criteria covered	Assignment title	Scenario	Assessment method
P3, P4, M2	Fault-finding Strategies	Learners have been asked to prepare fault location strategies for analogue and digital electronic systems used by their employer.	A written report/fault-finding strategy identifying details of relevant planning, predicted circuit operation, fault location techniques and appropriate aids.
P5, P6, P7, P8, M3, D2	Diagnosing Electronic Faults	Learners must locate faults in electronic systems from their workplace, collect and record the test data and prepare a test report.	A written report based on the fault diagnostic techniques and instruments used and a test report based on relevant test data.

Essential resources

Centres must provide a range of analogue and digital electronic circuits and systems for practical investigation and suitable hardware and software for computer-based simulation.

Learners will require access to a range of manufacturers' literature for electronic components, devices and circuits/systems and a range of test equipment and their handbooks. The test equipment should be sufficient in number to allow learners to carry out fault-finding exercises on an individual basis.

A range of working and faulty electronic systems, circuits, devices and components should be made available for fault diagnosis purposes, together with the relevant manufacturer's service manuals, parts lists and circuit diagrams. The appropriate tools, safety equipment and a safe working environment must also be provided. In most cases, a typical electronics workshop or laboratory should prove adequate.

Indicative reading for learners

Textbooks

Gates E – *Introduction to Electronics*, 6th edition (Cengage, 2011)
ISBN 9781111128531

Loveday G C – *Electronic Testing and Fault Diagnosis*
(Longman Scientific and Technical, 1996) ISBN 9780582252424

Sinclair I and Dunton J – *Electronic and Electrical Servicing*, 2nd edition
(Routledge, 2007) ISBN 9780750669887

Unit 29: Railway Infrastructure Construction and Maintenance

Level:	3
Unit type:	Pathway 3 Mandatory
Guided learning hours:	60

Unit introduction

This unit focuses on the planning of a railway line, including the legal and financial frameworks that are applicable, the construction of earthworks and the approaches used to construct and maintain rail track infrastructure.

When designing the route for a new railway line, engineers need to consider a range of factors, including demand and suitability. Both natural and human factors can influence the route of a railway line, and in this unit learners will investigate how these factors can impact not only on the chosen route of a railway, but also on associated structures such as bridges and viaducts. Earthwork activities are associated with virtually all railway construction activities, and this unit addresses a range of aspects of earthworks, including excavations, the construction of embankments and the provision of subsoil drainage to reduce the risk of failure of embankments and earthworks.

Learners will gain an understanding of earthwork methods, including the plant and equipment used during earthwork, quality control measures to ensure that materials are suitable and sustainable, and methods of disposing of waste produced during any earthwork activities.

This unit enables learners to develop their knowledge of the construction methods for both light and heavy rail lines, considering track types, track geometries and the construction techniques used for each. Learners will also gain an understanding of the materials used, quality control measures and waste disposal. Finally, learners will investigate the need for maintenance of railway infrastructure, including the types of defects that can be present, how these are identified and methods used to rectify defects.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

- 1 Know the preparatory activities required for the construction of railway track infrastructure
- 2 Know the scope of earthwork activities that may be undertaken in association with railway track infrastructure
- 3 Understand the forms of construction and material specifications used in railway track infrastructure
- 4 Understand track maintenance processes used to identify and correct defects in railways.

Unit content

1 Know the preparatory activities required for the construction of railway track infrastructure

Legal and financial framework: primary legislation, e.g. Railways Act, regulations; funding of new railways, e.g. design, build, finance and operate (DBFO), private finance initiative (PFI); procedures to acquire land, e.g. compulsory, compensatory.

New build or renewal development process: route considerations, e.g. need for service, number of tracks required, impact on the environment (noise, vibration, aesthetic, pollution, sustainability), stability, infrastructure integrity, associated structures (bridges, tunnels and level crossings); public consultation, e.g. public enquiries, protests, environmental regulation, parliamentary approval; health, safety and welfare, e.g. workforce and public legislation/regulations (Health and Safety at Work Act 1974, Construction (Design and Maintenance) Regulations 2015), method statements and safe methods of work, railway safety systems, industry standards (Network Rail, Railway Safety and Standards Board); contract administration, e.g. legal process, selection of contract, contract conditions, methods of measurement.

2 Know the scope of earthwork activities that may be undertaken in association with railway track infrastructure

Earthworks project methodology: site preparation, e.g. advance fencing, geological survey, stripping topsoil, material disposal, haul road; cut and fill, e.g. site-specific problems and solutions, use of explosives, borrow pits.

Embankment construction: approaches to construction, e.g. suitable/unsuitable materials for fill, procedures and testing of soil properties as work proceeds; treatment of weak areas, e.g. stabilisation, replacement and drainage techniques; ground water control, e.g. methods of water table control (including vegetation), stability of slopes.

Drainage: forms of subsoil drainage, e.g. patterns used, types of drainage (collector/carrier, open channel, use of interceptors, typical cross-sections used); disposal of collected water, e.g. open channel, soakaways, watercourses and drains via catchpits, discharge legislation (Environment Agency).

3 Understand the forms of construction and material specifications used in railway track infrastructure

Design principles: forms of construction, e.g. light/heavy rail, specification selection (Network Rail (NR) Track Construction Standard SP/TRK 102); typical forms of track, e.g. cross-sections of track types, formation specifications, sand blanket, geotextile; tunnels; walkways; track design considerations, e.g. conventional passenger speed, enhanced passenger speed, transitions, curves, clearances, rolling stock; design standards, e.g. Technical Specification for Interoperability, Track Design Manual (NR/SP/TRK/049), Track Construction Standard (NR/SP/TRK/102).

Construction methods: renewal methods and plant utilisation, e.g. high output, conventional; methods of maintaining gauge clearance and track position (conventional and absolute track geometry); component fixity; stressing of rails; consideration of associated structures.

Materials and quality control: sampling and testing of materials and component parts; product specification and approval processes; sustainable sourcing; waste material disposal, e.g. ballast disposal, track recycling systems.

4 Understand track maintenance processes used to identify and correct defects in railways

Maintenance issues: fatigue defects, e.g. rail defects; seasonal/environmental, e.g. leaf fall, low/high temperature, snow, flooding; track component failure, e.g. rail, sleeper, fastening; instability of sub-grade or ballast.

Identification of rail infrastructure defects: inspection, e.g. visual, vehicles; high-speed testing/examination; review of outputs and application of maintenance standards; special inspections, e.g. bridges, tunnels; rail defect classification.

Remedial treatments: replacement of failed components; weld repair; grinding; leaf fall removal; remedial correction of defective ballast, e.g. manual/mechanical methods to stabilise weak sub-grade.

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P1 Describe the legal and financial framework applicable to a project for a new section of railway infrastructure	M1 Explain the key legal, financial and development stages that need to be followed when developing a new build or renewal within a railway environment	
P2 Describe the development process required for a new build or renewal within a railway environment		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
<p>P3 Describe the methodology used for site preparation when undertaking an earthwork project, including the plant and equipment required and site-specific problems and solutions that must be considered with the construction of a railway track infrastructure</p>	<p>M2 Explain how earthworks need to be constructed in order to provide a load-bearing formation for a standard track cross-section</p>	<p>D1 Evaluate methods taken to provide stable earthworks for track foundations for a standard track cross-section</p>
<p>P4 Explain the importance of embankment construction, including suitable drainage methods when carrying out earthwork activities for a railway track infrastructure</p>		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P5 Explain the essential design principles for track geometry and the importance of wheel rail interface	M3 Discuss the differences in design principles for track geometry for different forms of track construction	D2 Justify the selection of construction methods for a given form of track
P6 Describe the construction methods for initial placement and subsequent maintenance activities to ensure track position and geometry		
P7 Describe the materials and quality control processes required to ensure the provision of suitable and sustainable track construction material and waste material disposal		
P8 Describe the maintenance issues that need to be considered to determine rail infrastructure integrity	M4 Discuss the effectiveness of remedial actions for given rail infrastructure defects	
P9 Explain how rail infrastructure defects are identified and the prescribed remedial action for each		

Essential guidance for tutors

Assessment

Learners could be set an initial assignment that addresses P1, P2 and M1 through the consideration of either a new rail route or a renewal (the reinstatement of a previously closed line). For P1, learners will need to describe the primary legislation involved, how new railways are funded and the procedures that need to be followed when acquiring land. For P2, learners need to describe the development process for either a new build or reinstatement. Evidence will include consideration of the route, impact on the public, health and safety and the contractual processes associated with the development. For M1, learners will need to give details of examples of the key legal, financial and development stages that need to be followed during the building of a railway, such as public consultations regarding the location of a new line and its associated structures.

A second assignment could address P3, P4, M2 and D1. For P3, learners will need to describe the process of developing earthworks for a track formation. Learners will need to include descriptions of how a site is prepared, methods used for cut and fill and the approaches to constructing embankments and slopes, including drainage. Learners will need to include information about the plant and equipment that is used at each stage. This could be linked to evidence for P4, where learners will need to explain the importance of site preparation with reference to embankment construction and drainage to ensure tracks remain in the correct geometry and to prevent earthworks from subsiding or settling over time. Learners could expand on their evidence for these criteria to explain how earthworks are developed to provide a load-bearing formation (M2) and to evaluate alternative approaches to construction to reach a conclusion as to which is more appropriate for earthworks for a given situation (D1).

Learners could then complete a third assignment that addresses P5, P6, P7, M3 and D2 for a given scenario. P5 can be achieved through explanations of the design geometry of track, for example consideration of curves, transitions and clearances for a given location and type of construction. This could be linked with an activity for M3 that requires learners to discuss the differences in design principles for different forms of track construction, for example light and heavy rail; it is not necessary for all aspects to be discussed, however differences in approaches for transitions, for example, would be expected. Further development of the work could also address D2. with a justification of the construction methods used in a given situation, for example regarding line speed.

For P6, learners will need to describe the construction methods for the initial placement of a line and subsequent maintenance activities. This could include reference to approaches to construction of both running lines and associated structures. Finally, to achieve P7, learners will need to describe the processes that are used to test materials and carry out quality control processes. This will reference testing for strength and appropriate chemical composition (for example materials should not be contaminated) and testing against specifications. Learners will also need to consider sustainability, including the sourcing and disposal of materials, for example using a cut and fill balancing activity.

A final assignment could address P8, P9 and M4 through an investigation into the maintenance of railway infrastructure. Learners could be provided with a scenario from which to work that includes information about rail infrastructure defects, for example a cracked rail or the after-effects of flooding on ballast and sleepers. Learners will need to use this information to describe the maintenance issues that need to be considered in order to maintain the integrity of railway infrastructure, including information about fatigue defects, seasonal or environmental issues and component failures (P8). For P9, learners will need to explain the methods used to identify given defects, for example the use of visual inspections of fastenings, or the use of laser scanning within tunnels. For each of the defects, learners will need to identify an appropriate remedial treatment. For M4, learners will need to discuss how effective remedial actions are for each of the given defects.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1	Planning a railway	A mixed activity requiring learners to research and examine the factors that influence the construction or reinstatement of a rail line.	A written report that considers both the legal and financial aspects related to the construction of a rail line and the development process for a new or reinstated rail line.
P3, P4, M2, D1	Railway earthworks	An investigation into the design and construction of earthworks for railway lines, including a consideration of site preparation, construction and methods of drainage.	A series of short, illustrated reports that describe the preparation of a site for the construction of earthworks, the construction of embankments and slopes, and methods of providing drainage.

Criteria covered	Assignment title	Scenario	Assessment method
P5, P6, P7, M3, D2	Railway track infrastructure	An investigation of construction methods that are suitable for given rail projects, including track geometry, construction techniques and materials.	An illustrated, written report that investigates construction methods for rail track, including the use of plant and equipment, and the sustainable sourcing and disposal of materials. The report will continue to describe quality control methods to ensure the suitability of formations, with a third part to the report examining maintenance issues related to determine rail infrastructure integrity.
P8, P9, M4	Track maintenance	An investigation into the reasons why maintenance is needed and the issues related to maintenance. The investigation will consider maintenance issues, how defects are identified and appropriate remedial actions for given rail infrastructure defects.	A written report that will include reference to fatigue and environmental influences, and component failure. The report will also focus on methods of identifying defects in infrastructure and appropriate remedial actions for given defects.

Essential resources

Learners should be given a variety of technical documents and drawings for track layouts and related infrastructure.

Indicative reading for learners

Textbooks

Bonnett C – *Practical Railway Engineering*, (Imperial College Press, 2005)
ISBN 9781860945151

Glover J – *Principles of Railway Operation* (Ian Alan Publishing Limited, 2013)
ISBN 9780711036314

Li D et al – *Railway Geotechnics* (CRC Press, 2015) ISBN 9780415695015

Unit 30: Rail Surveying, Materials and Systems

Level:	3
Unit type:	Pathway 3 Mandatory
Guided learning hours:	60

Unit introduction

This unit introduces learners to some of the railway technologies required to construct and operate railway infrastructure and rolling stock. Learners will investigate how land surveying is used to measure railway features, materials used in rail engineering, mechanical systems in the rail environment and the interface between railway systems.

Correct track alignment is key to train performance and track must be constructed within millimetre tolerance of the engineering design. Land surveying is concerned with the measurement of railway features in the natural and built environment, such as track alignment. On completing this unit, learners will be familiar with basic linear and levelling surveying techniques, be able to carry out simple surveying tasks, and be able to present the data in a format that is suitable for engineers to use in the design and construction of a railway project.

It is essential that engineers understand the types of materials used in rail engineering and their properties, in order to predict their behaviour, calculate their strength and determine their performance for different applications. Engineering technicians working in the rail industry also need to understand the mechanical systems that enable trains to keep moving. From this unit, learners will gain a knowledge of lubricants and lubrication systems, the operation of seals, packing and bearings, and how motion is transmitted, converting from one form to another by means of different types of cam and follower, and different linkage mechanisms.

To give a train a good ride, appropriate railway infrastructure must be in place. In order to operate, a railway network requires an AC or DC electrical supply and signalling to direct railway traffic and to keep trains clear of each other at all times. A track is required to provide a dependable surface for the train wheels, with points to allow trains to change lines. This unit introduces learners to key requirements of railway infrastructure and the interface between different railway systems.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

- 1 Understand basic surveying techniques
- 2 Understand materials in the rail environment
- 3 Understand mechanical systems in the rail environment
- 4 Understand the interface between railway systems.

Unit content

1 Understand basic surveying techniques

Linear surveying terminology: framework; whole to part; well-conditioned; taping; horizontal and slope distances; chainage; running measurements; perpendicular offsets; tie lines; check lines.

Linear surveying equipment: tapes; bands; rules; handheld lasers; ancillary equipment.

Linear surveying calculations: basic arithmetical operations, e.g. trigonometric functions, Pythagoras' Theorem.

Linear surveying drawings: internal or external survey plotted to scale.

Levelling surveying terminology: back sight; intermediate sight; fore sight; reduced level; datums, e.g. Ordnance Survey Bench Mark; Temporary Bench Mark; height of collimation; rise and fall; fly levelling.

Levelling surveying equipment: automatic levels; tilting levels; water levels; rotating lasers; barcode instruments.

Levelling surveying calculations: basic arithmetical operations, simple trigonometry.

Levelling surveying drawings: spot heights on plans; sections.

Angular terminology and equipment: whole circle bearings; azimuth; horizontal angle; zenith angle; angles of inclination.

Angular equipment: optical square; theodolites.

2 Understand materials in the rail environment

Mechanical properties: strength (tensile, shear, compressive); hardness; toughness; ductility; malleability; elasticity; brittleness.

Physical properties: density; melting temperature.

Thermal properties: expansivity; conductivity.

Electrical and magnetic properties: conductivity; resistivity; permeability; permittivity.

Effects of processing metals: recrystallisation temperature; grain structure, e.g. hot working, cold working, grain growth; alloying elements in steel, e.g. manganese, phosphorous, silicon, sulphur, chromium, nickel.

Effects of processing thermoplastic polymers: polymer processing temperature; process parameters e.g. mould temperature, injection pressure, injection speed, mould clamping force, mould open and closed time.

Effects of processing thermosetting polymers: process parameters, e.g. moulding pressure and time, mould temperature, curing.

Effects of processing ceramics: e.g. water content of clay, sintering pressing force, firing temperature.

Effects of processing composites: fibres, e.g. alignment to the direction of stress, ply direction; delamination; matrix/reinforcement ratio on tensile strength; particle reinforcement on cermets.

Mode of failure: ductile and brittle fracture including: effects of gradual and impact loading (e.g. tensile, compressive, shear) effects of grain size, transition temperature, appearance of fracture surfaces; fatigue including: cyclic loading, effects of stress concentrations (e.g. internal, external), effects of surface finish, appearance of fracture surfaces; creep including: primary, secondary, tertiary, effects of temperature, strain versus time curve, creep limit, effect of grain size, effect of variations in the applied stress.

3 Understand mechanical systems in the rail environment

Purpose and application of lubricants: purpose, e.g. reduction of frictional resistance, reduction of wear, heat dissipation, prevention of corrosion, prevention of contamination; types, e.g. oils (mineral, synthetic, animal and vegetable), greases, copper compound, graphite; methods of application, e.g. total loss, re-circulatory, splash, grease guns and nipples; use in application, e.g. gear, traction motor bearing, switches, drives and chassis, bogies, rail head, coaches and connectors.

Operation and maintenance of lubrication systems: operation of lubrication systems, e.g. gravity feed, forced feed, splash lubrication, capillary action, grease cups and nipples, grease packing, compressed air/gas bearings; maintenance, e.g. replenishment and renewal of lubricants, safe storage and handling.

Operations of seals, packing and bearings: bearings, e.g. plain journal, plain thrust; system parameters, e.g. bearing dimensions, speed, viscosity of lubricant, viscous resistance, power loss; seals, e.g. seals in contact with stationary surfaces, seals in contact with sliding surfaces, non-contact seals, bellows and membranes; packing, e.g. rail pads, glands, gaskets, shims.

Cams and linkage mechanisms: cams and followers, e.g. radial plate cams, cylindrical cams, face cams, knife-edge followers, flat plate followers, roller followers; linkage mechanisms, e.g. slider-crank and inversions, four-bar linkage and inversions, slotted link quick return motion, Whitworth quick return motion.

4 Understand the interface between railway systems

Generation and distribution of electricity for the supply of traction: alternating current and direct current; AC and DC systems use in electrification; feeder points; earthing on AC systems.

Railway signalling: multi-aspect signals (e.g. two-, three- and four aspect), lineside equipment housing, lineside cables, under track crossings (UTX), operation of automatic warning systems or similar, operation of train protection warning systems or similar.

Operation of points and point detection systems: hand-operated points, mechanically operated points, power-operated points, detection of points, facing point locks, back drives.

Overhead line geometry and DC 3rd/4th rail traction supply geometry: overhead line geometry including: overhead catenary systems, e.g. contact wire, 'droppers', catenary wire cable, spacing of mast or portal frame support for catenary system, height of the contact wire; third-rail systems, location of rails, e.g. top contact, side contact or bottom contact, plough or collector shoes, DC substation; fourth-rail system, location of rails.

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P1 Identify linear and levelling together with angular surveying terminology and equipment		
P2 Carry out linear and levelling surveys, using appropriate equipment to produce drawings	M1 Carry out levelling calculations, using both height of collimation and rise and fall methods	D1 Analyse the methods used for level surveys in terms of accuracy
P3 Describe mechanical, physical, thermal, electrical and magnetic properties of materials used in rail engineering	M2 Explain how the properties of different given engineering materials affect their behaviour in given rail engineering applications	D2 Justify own selection of an engineering material for one given rail engineering application
P4 Describe the effects of processing on the properties and the modes of failure on materials used in rail engineering		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P5 Describe the purpose and application of lubricants and the operation and maintenance of lubrication systems	M3 Explain the use of a particular lubricant and lubrication system in a given rail engineering application	
P6 Describe the operation of seals, packing and bearings		
P7 Describe the operation of different types of cam and follower and linkage mechanisms		
P8 Describe the basic principles of electricity as applied to railway infrastructure		
P9 Describe the fundamental principles of railway signalling and the operation of points and point detection systems	M4 Explain the importance of clear signalling on a railway network	
P10 Describe the relationship between track geometry and overhead line geometry		

Essential guidance for tutors

Assessment

It is likely that at least four assessment instruments will be required for this unit. Evidence for this unit may be gathered from a variety of sources, including written reports and practical assignments. Some criteria can be assessed directly by the tutor during practical activities, with suitable evidence being observation records or witness statements. P1 and P2 lend themselves particularly to practical activities.

For P1 and P2, learners must identify linear surveying terminology and carry out linear surveys, using appropriate equipment to produce accurate site drawings. They must participate in this fieldwork, probably as part of a team, and produce at least two drawings to a reasonable standard of neatness and accuracy. These linear survey drawings must be produced using manual rather than computer-aided design (CAD) techniques, in order to demonstrate the achievable accuracies and to avoid the problems of dealing with inaccurate survey measurements in CAD. Also, learners need to identify levelling surveying terminology and carry out levelling surveys, using appropriate equipment to produce accurate drawings. They must carry out sufficient practical levelling to become reasonably proficient, then carry out a realistic task and produce at least two section drawings to a reasonable standard of neatness and accuracy. It is acceptable for these levelling survey drawings to be produced manually or by CAD. Learners must identify angular terminology and equipment. This could be achieved by learners setting up and using a theodolite to carry out a practical task requiring the measurement of angles and calculations involving degrees, minutes and seconds.

The evidence to satisfy pass criteria P3 and P4 could be generated by means of a written assignment, following a combination of tutor-led practical and theory sessions and individual research. P3 requires learners to describe the mechanical, physical, thermal, electrical and magnetic properties of a range of materials used in railway applications, given to include at least one ferrous, one non-ferrous, one non-ferrous alloy, one thermoplastic polymer, one thermosetting polymer, one ceramic, one composite, and one natural material. This criterion will involve learners observing or carrying out some experiments in a materials workshop/laboratory. Learners might, as an example, consider the toughness of mild steel by carrying out a Charpy impact test.

Achievement of P4 could involve learners in both practical and theoretical tasks in which they relate the effects of processing on the properties of materials to real rail engineering applications. As an example, the differing effects of hot and cold working on the properties of copper and carbon steel can be demonstrated by lightly hammering specimens of both metals. By comparing the effort required to bend the cold-worked and untreated specimens, learners will gain first-hand experience of the

effects of work hardening. Learners could be given the opportunity to research modes of failure and degradation processes reflected in rail engineering. Learners will need to consider fatigue, creep, ductile and brittle fracture. Learning must be contextualised to the rail industry, with learners considering these failures for a pertinent application such as the degradation of steel rails, rail vehicle wheels/axles or overhead line equipment.

Criterion P5 requires learners to describe the purpose and application of different types of lubricant and the operation and maintenance of different lubrication systems. This must be contextualised to a rail engineering application, and might include lubricants and lubricant systems for gears, traction motor bearing, switches, drives and chassis, bogies, rail head, coaches and connectors.

P6 requires learners to describe the operation and application of seals, packing and different types of bearing. This will be supported with an annotated sketch, and again must be contextualised to a rail engineering application. Learners might consider a traction motor bearing.

Criterion P7 requires learners to describe methods of transmitting/converting motion from one form to another by means of different types of cam and follower and different linkage mechanisms. Learners should be encouraged to illustrate the descriptions with diagrams and freehand sketches.

A single assessment activity could be used to link and capture evidence for P8, P9 and P10. The task might require learners to produce and then appropriately annotate a plan and cross-section for a length of rail network. The plan and cross-section would need to describe the principles of electricity as applied to railway infrastructure (P8), encompassing AC and DC supply systems. In addition, learners would describe the principles of railway signalling, for example multi-aspect signals (P9), track and overhead line geometry (P10) and point and point detection systems (P9). Learners would need to fully cover the material listed in the *Unit content*.

To achieve a merit grade, learners must meet all of the pass grade criteria and the merit grade criteria.

For M1, learners must carry out levelling calculations using both height of collimation and rise and fall methods. They must demonstrate proficiency in both methods of levelling calculation and know the standard checks for each method.

To achieve M2, learners need to explain how the properties of given materials will affect their behaviour in different rail applications. This is an extension task for P3 and P4, with learners considering the application of different materials for different uses in the rail sector. For example, learners might consider the application of thermoplastic polymers as rail pads.

To achieve M3, learners need to be able to explain the use of a particular lubricant and lubrication system in a given rail engineering application. This might be the lubrication system of a traction motor bearing or set of rail track switches.

To satisfy M4, learners need to explain the importance of clear signalling on a railway network. Learners might consider the use of signalling to direct railway traffic or to keep trains clear of each other at all times.

To achieve a distinction grade, learners must meet all of the pass and merit grade criteria and all the distinction grade criteria.

For D1, learners must analyse the methods used for levelling surveys in terms of accuracy. They could write a brief report showing an understanding of the methods used. They will recognise common errors and the relationship between the scale of the plan and measurement accuracy, and the availability and suitability of different equipment for performing levelling surveys.

To achieve D2, learners need to justify their selection of one of the materials for a particular railway application, giving reasons why the material was chosen and why other materials considered for the application were not selected. For example, learners might justify the selection of a particular grade of steel for use in rails.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1, D1	Surveying	Complete a linear and levelling survey of an accessible railway topographical feature, e.g. a disused railway embankment.	Portfolio of survey data, calculations and drawings.
P3, P4, M2, D2	Properties of Engineering Materials	A mixed activity requiring learners to research and conduct experiments to describe the properties, behaviour and modes of failure of engineering materials used in rail engineering.	A portfolio containing written evidence, laboratory results, and – where appropriate – tutor observation records.

Criteria covered	Assignment title	Scenario	Assessment method
P5, P6, P7, M3	Application of Engineering Components and Lubricants	A mixed activity in which learners complete three tasks. For Task 1, learners will describe lubricants and the operation of lubricant systems to a new apprentice. For Task 2, learners will describe the operation of seals, packing and bearings for a rail engineering application. For Task 3, learners must describe the use of cam, follower and linkage mechanisms.	A written report containing supporting sketches and diagrams.

Criteria covered	Assignment title	Scenario	Assessment method
P8, P9, P10, M4	Railway Infrastructure	An activity requiring learners to produce, and then appropriately annotate, a plan and cross-section for a length of rail network. This might be a junction for a branch line or track work on the approach to a station where additional running lines approach different platform faces. The plan and cross-section will describe the electrical supply, signalling, point and point detection systems, track and overhead line geometry for the length of rail network.	A plan and cross-section for a length of rail network, with supporting written annotation.

Essential resources

It is essential that learners have access to surveying equipment including dumpy levels, theodolites, chains, tapes, handheld lasers and ancillary equipment. Centres will also need to provide access to a well-equipped materials laboratory/workshop.

Indicative reading for learners

Textbooks

Bonnett C – *Practical Railway Engineering* (Imperial College Press, 2005)
ISBN 9781860945151

Boyce A, Cooke E, Jones R and Weatherill B – *BTEC Level 3 National Engineering Student Book* (Pearson, 2010) ISBN 9781846907241

Boyce A, Cooke E, Jones R and Weatherill B – *BTEC Level 3 National Engineering Teaching Resource Pack* (Pearson, 2010) ISBN 9781846907265

Glover J – *Principles of Railway Operation* (Ian Alan Publishing Limited, 2013)
ISBN 9780711036314

Tooley M and Dingle L – *BTEC National Engineering*, 3rd edition (Routledge, 2010)
ISBN 9780123822024

Uren J and Price B – *Surveying for Engineers* (Palgrave Macmillan, 2010)
ISBN 9780230221574

Unit 31: Overhead Line Infrastructure Construction and Maintenance

Level:	3
Unit type:	Pathway 4 Mandatory
Guided learning hours:	60

Unit introduction

This unit introduces learners to overhead line infrastructure construction and maintenance within the railway system as a whole.

Learners will explore preparatory activities for the construction of overhead line infrastructure, including primary legislation such as the Railways Act, financing by Private Finance Initiatives (PFI) and the process of acquiring land by compulsory purchase, in relation both to new build and renewals.

Learners will gain an understanding of construction techniques with particular reference to earthworks, including correct site preparation and the use of advance fencing, the use of geological surveys, the best way to ensure that material disposal is used effectively, and how and when to use explosives. Learners will also address ground water control.

Learners will investigate different forms of construction used in overhead line infrastructure, for example light and heavy rail, and different track designs for conventional and high-speed rolling stock, considering factors such as allowable curves and rolling stock. Construction methods and materials will also be addressed.

Finally, learners will find out how to identify and correct defects using maintenance techniques, addressing a range of problems such as broken and damaged rails, leaves on the line, snow on the line and the effects of high and low temperatures. Learners will also consider the different inspection methods used for bridges and vehicles, while maintaining the application of maintenance standards.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

- 1 Know the preparatory activities required for the construction of overhead line infrastructure
- 2 Know the scope of earthwork activities that may be undertaken in association with overhead line infrastructure
- 3 Understand the forms of construction and material specifications used in overhead line infrastructure
- 4 Understand overhead line maintenance processes used to identify and correct defects.

Unit content

1 Know the preparatory activities required for the construction of overhead line infrastructure

Legal and financial framework: primary legislation, e.g. Railways Act, regulations; funding of new railways, e.g. design, build, finance and operate (DBFO), private finance initiative (PFI); procedures to acquire land, e.g. compulsory, compensatory.

New build or renewal development process: route considerations, e.g. need for service, number of tracks required, impact on the environment (noise, vibration, aesthetic, pollution, sustainability), stability, infrastructure integrity, associated structures (bridges, tunnels and level crossings); public consultation, e.g. public enquiries, protests, environmental regulation, parliamentary approval; health, safety and welfare, e.g. workforce and public, legislation/regulations (Health and Safety at Work etc. Act 1974, Construction (Design and Maintenance) Regulations 2015), method statements and safe methods of work, railway safety systems, industry standards (Network Rail, Railway Safety and Standards Board); contract administration, e.g. legal process, selection of contract, contract conditions, methods of measurement.

2 Know the scope of earthwork activities that may be undertaken in association with overhead line infrastructure

Earthworks project methodology: site preparation, e.g. advance fencing, geological survey, stripping topsoil, material disposal, haul road; cut and fill, e.g. site-specific problems and solutions, use of explosives, borrow pits; embankment construction, e.g. suitable/unsuitable materials for fill, procedures and testing of soil properties as work proceeds; treatment of weak areas, e.g. stabilisation, replacement and drainage techniques; ground water control, e.g. methods of water table control (including vegetation), stability of slopes; forms of subsoil drainage, e.g. patterns used, types of drainage (collector/carrier, open channel, use of interceptors, typical cross-sections used); disposal of collected water, e.g. open channel, soakaways, watercourses and drains via catchpits, discharge legislation (Environment Agency).

3 Understand the forms of construction and material specifications used in overhead line infrastructure

Design principles: forms of construction, e.g. light/heavy rail, specification selection (Network Rail (NR) OHL Construction Standard), typical forms of track, e.g. cross-sections of track types, formation specifications, sand blanket, geotextile; tunnels; walkways; track design considerations, e.g. conventional passenger speed, enhanced passenger speed, transitions, curves, clearances, rolling stock; design standards e.g. Technical Specification for Interoperability, OHL Design Manual, OHL Construction Standards.

Construction methods: renewal methods and plant utilisation, e.g. high output, conventional; methods of maintaining gauge clearance and track position (conventional and absolute track geometry); component fixity; stressing of rails; consideration of associated structures.

Materials and quality control: sampling and testing of materials and component parts; product specification and approval processes; sustainable sourcing; waste material disposal, e.g. ballast disposal, track recycling systems.

4 Understand overhead line maintenance processes used to identify and correct defects

Maintenance issues: fatigue defects, e.g. rail defects; seasonal/environmental, e.g. leaf fall, low/high temperature, snow, flooding; track component failure, e.g. rail, sleeper, fastening; instability of sub-grade or ballast.

Identification of rail infrastructure defects: inspection, e.g. visual, vehicles; high speed testing/examination; review of outputs and application of maintenance standards; special inspections, e.g. bridges, tunnels; rail defect classification.

Remedial treatments: replacement of failed components; weld repair; grinding; leaf fall removal; remedial correction of defective ballast, e.g. manual/mechanical methods to stabilise weak sub-grade.

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P1 Describe the legal and financial framework applicable to a project for a new section of overhead line to the railway infrastructure	M1 Explain the financial framework and development process required for a new build or renewal of an overhead line within a railway environment	D1 Justify the legal and financial framework and development process required for a new build or renewal of an overhead line within a railway environment
P2 Describe the development process when an overhead line is required as a new build or renewal of an existing line within a railway environment		
P3 Describe the methodology used when planning an overhead line earthworks project, including the plant and equipment required for site preparation activities		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P4 Describe the factors to be considered when undertaking earthwork activities for the construction of an overhead line	M2 Explain the importance of applying construction standards for earthwork activities undertaken for the construction of overhead line structures	
P5 Explain the essential design principles for overhead line geometry		
P6 Describe the construction methods for initial placement and subsequent maintenance activities to ensure overhead line position and geometry		
P7 Describe the materials and processes required to ensure the provision of suitable and sustainable overhead line construction material and disposal of waste material	M3 Compare methods used for sampling and testing of materials and components used in the construction of an overhead line	D2 Evaluate the quality control processes used in overhead line construction

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P8 Describe the maintenance issues that need to be considered to determine rail infrastructure integrity		
P9 Explain how rail infrastructure defects are identified and the prescribed remedial action for each		

Essential guidance for tutors

Assessment

Much of the evidence for the unit can be generated through case studies, tutor-led sessions, and visits to real environments to study tracks and maintenance techniques. It is likely that at least three assessment instruments will be required for this unit.

For P1, P2, M1 and D1, learners need to describe the relationship between the legal and financial framework for overhead line infrastructure, using references to the Railways Act, and how funding can be achieved via the private sector. Learners are required to show an understanding of the use of contract administration, and selection of contractors, contract conditions and how this is linked to the design, build, finance and operate (DBFO). They must also be able to identify operating timescales for projects. Learners must show that they know the differences between the requirements for a new build and renewal process, the different route considerations and the effects on the environment. They must link the above factors to the public consultation process and a possibility of a public enquiry. Safety is also paramount within the rail industry, particularly with regard to overhead line infrastructure, and learners need to identify and reference the relevant Health and Safety Executive (HSE) requirements and the industry standards for overhead line infrastructure safety.

For M1, learners need to explain the financial and development process and why this process is used to support the development of a new build or a renewal process for overhead line infrastructure.

For D1, learners are required to justify the legal and financial frameworks, examining the development process required for successfully building a new overhead line, or renewal of an existing line.

For P3 and P4, learners need to show that they know the scope of earthwork activities and the relationships between site preparation to create a sound foundation and the creation of embankments, retaining structures and erosion control to prevent collapse. Learners need to show awareness of the underlying soil structure regarding moisture changes, how structures are affected by the height of the water table and how structures are affected by different drainage methods, and the disposal of collected water. For M2, learners need to explain, either following a visit to a local embankment or with reference to a case study, how the earthwork activities that have been undertaken with overhead line infrastructure interrelate to prevent collapse of the embankment.

For P5 and P6, learners will understand the construction and material specifications used in overhead line infrastructure, with reference to the underlying design principles – such as light and heavy rails and different construction standards – required for different organisations. This can be linked to the conventional passenger speed, and enhanced passenger speed, relating to the different curves, clearances, and types of rolling stock required. This must be supported by the design standards, using the Technical Specification for Interoperability, Overhead Line Design Manual and Overhead Line Construction Standards. The above related theory must be linked to the construction methods employed, such as renewal methods and how effectively plant can be utilised. Learners then can explore and report on methods of ensuring that gauge clearance is maintained and track position for both conventional and absolute track geometry, while considering associated structures.

For P7, learners need to describe the use of materials and processes to ensure the provision of suitable and sustainable overhead line construction material and waste material disposal. The description will cover methods of waste material disposal and recycling systems.

For P8, learners must describe three maintenance issues, including fatigue defects in rails, seasonal and environmental issues. Learners need to be able to describe two forms of track component failure and maintenance issues for items such as rails, sleepers, or the instability of ballast, that determine rail infrastructure integrity.

For P9, learners need to explain how at least six rail infrastructure defects are identified and state what remedial actions should be taken. As a minimum, these will include the replacement of failed components, weld repair for local wear, cracks in rails, or the renewal of complete rail tracks; the correct technique to remove leaf fall; and the remedial correction of defective ballast.

For M3, learners will compare material sampling and testing methods for the materials and components used in the construction of an overhead line and the infrastructure.

For D2, learners will evaluate the quality control processes used in overhead line construction, with reference to an actual series of components and materials and how they are sampled and the specification and approval process used.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, M1, D1	Preparatory activities needed when constructing overhead line infrastructure	Investigate the legal and financial framework in the workplace and the considerations required when building a new, or upgrading an existing, overhead line.	A report of the learner's evidence obtained from research into the legal and financial considerations of building a new, or upgrading an existing, line.
P3, P4, M2	Methodology, equipment and foundation systems for overhead line construction	Consider the earthworks methodology of a worksite through interconnecting activities.	A written report containing documentation, support sketches and diagrams.
P5, P6	Design, construction and maintenance of overhead line geometry	Explore the application of methods and principles of overhead line development, through interconnecting activities.	A portfolio containing written evidence, technical specifications for design principles, construction methods, materials and quality control for overhead line infrastructure.

Criteria covered	Assignment title	Scenario	Assessment method
P7, P8, P9, M3, D2	Sustainable overhead line construction, maintenance and disposal of waste	Consider the sustainability, maintenance and waste disposal from a workplace site for overhead line construction through interconnecting activities.	Engineering diagrams, sketches and test results, as well as documentation providing support for the learner's interpretation of appropriate maintenance and waste disposal of materials from active overhead line construction activities.

Essential resources

Learners should be given a variety of sample written materials (letters, memos, technical reports, data sheets, catalogues) and sketches. Centres will need to provide access to appropriate presentation and graphics software (for example Microsoft PowerPoint, Visio), spreadsheet/database software (for example Microsoft Excel/Access) and computer hardware (for example scanners, printers, optical character recognition and speech recognition software, barcode readers).

Indicative reading for learners

Textbooks

Bird J O – *Electrical and Electronic Principles and Technology*, 5th edition (Routledge, 2013) ISBN 9780415662857

Bird J O – *Electrical Circuit Theory and Technology*, 5th edition (Routledge, 2013) ISBN 9780415662864

Bonnett C – *Practical Railway Engineering*, 2nd edition (Imperial College Press, 2005) ISBN 9781860945151

Boyce A, Cooke E, Jones R and Weatherill B – *BTEC Level 3 National Engineering Student Book* (Pearson, 2010) ISBN 9781846907241

Darbyshire A – *Mechanical Engineering: BTEC National Engineering Specialist Units*, 2nd edition (Newnes, 2008) ISBN 9780750686570

Higgins R – *Materials for Engineers and Technicians*, 4th edition (Newnes, 2006) ISBN 9780750668507

Robertson C R – *Fundamental Electrical and Electronic Principles*, 3rd edition (Routledge, 2008) ISBN 9780750687379

Selig E and Waters J – *Track Geotechnology and Substructure Management* (Thomas Telford Ltd, 1994) ISBN 9780727720139

Timings R L – *Engineering Materials*, Volume 1, 2nd edition (Longman, 1998) ISBN 9780582319288

Timings R L – *Engineering Materials*, Volume 2, 2nd edition (Longman, 2000) ISBN 9780582404663

Unit 32: Rail Overhead Line Technologies (Construction)

Level:	3
Unit type:	Pathway 4 Mandatory
Guided learning hours:	60

Unit introduction

This unit is designed to give learners knowledge and understanding of the function and characteristics of rail overhead line technologies and their use within the railway system as a whole.

This will include an introduction to surveying techniques for linear and level surveying, covering both terminology and equipment. The unit will introduce the required calculations for both linear and level surveying and move on to angular terminology and the use of equipment.

Learners will then investigate the way materials are used in rail overhead line construction. They will develop an understanding of metallic, ceramics and polymers and their properties – including mechanical, physical and thermal properties – and the effects processes have on these.

Learners will move on to look at electrical systems in a rail environment, understanding fundamental electrical and electronic principles through analysis of simple direct current (DC) circuits. Learners then address the various properties and parameters associated with capacitance and inductance, before finally considering the application of single-phase alternating current (AC) theory.

The unit will encourage learners to take an investigative approach through practical construction, measurement and testing of circuits and, where applicable, the use of computer-based circuit analysis and simulation.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

- 1 Understand basic surveying techniques
- 2 Understand materials in the rail environment
- 3 Understand electrical systems in the rail environment.

Unit content

1 Understand basic surveying techniques

Linear surveying terminology: framework; whole to part; well-conditioned; taping; horizontal and slope distances; chainage; running measurements; perpendicular offsets; tie lines; check lines.

Linear surveying equipment: tapes; bands; rules; handheld lasers; ancillary equipment.

Linear surveying calculations: basic arithmetical operations.

Linear surveying drawings: internal or external survey plotted to scale.

Levelling surveying terminology: back sight; intermediate sight; fore sight; reduced level; datum; Ordnance Survey Bench Mark; Temporary Bench Mark; height of collimation; rise and fall; fly levelling.

Levelling surveying equipment: automatic levels; tilting levels; water levels; rotating lasers; barcode instruments.

Levelling surveying calculations: basic arithmetical operations, simple trigonometry.

Levelling surveying drawings: spot heights on plans; sections.

Angular terminology and equipment: whole circle bearings; azimuth; horizontal angle; zenith angle; angles of inclination.

Angular equipment: optical square; theodolites.

2 Understand materials in the rail environment

Mechanical properties: strength (tensile, shear, compressive); hardness; toughness; ductility; malleability; elasticity; brittleness.

Physical properties: density; melting temperature.

Thermal properties: expansivity; conductivity.

Electrical and magnetic properties: conductivity; resistivity; permeability; permittivity.

Effects of processing metals: recrystallisation temperature; grain structure, e.g. hot working, cold working, grain growth; alloying elements in steel, e.g. manganese, phosphorous, silicon, sulphur, chromium, nickel.

Effects of processing thermosetting polymers: process parameters, e.g. moulding pressure and time, mould temperature, curing.

Effects of processing ceramics: e.g. water content of clay, sintering pressing force, firing temperature.

Effects of processing composites: fibres, e.g. alignment to the direction of stress, ply direction; delamination; matrix/reinforcement ratio on tensile strength; particle reinforcement on cermets.

3 Understand electrical systems in the rail environment

Capacitors: types (electrolytic, mica, plastic, paper, ceramic, fixed and variable capacitors); typical capacitance values and construction (plates, dielectric materials and strength, flux density, permittivity); function, e.g. energy stored, circuits (series, parallel, combination); working voltage.

Charging and discharging of a capacitor: measurement of voltage, current and time; tabulation of data and graphical representation of results; time constants.

DC network that includes a capacitor: e.g. DC power source with two/three capacitors connected in series, DC power source.

Magnetic field: magnetic field patterns, e.g. flux, flux density (B), magnetomotive force (MMF) and field strength (H), permeability, B/H curves and loops; ferromagnetic materials; reluctance; magnetic screening; hysteresis.

Electromagnetic induction: principles, e.g. induced electromotive force (EMF), eddy currents, self and mutual inductance; applications (electric motor/generator, e.g. series and shunt motor/generator; transformer, e.g. primary and secondary current and voltage ratios); application of Faraday's and Lenz's laws.

Single phase AC circuit theory: waveform characteristics, e.g. sinusoidal and non-sinusoidal waveforms, amplitude, period time, frequency, instantaneous, peak/peak-to-peak, root mean square (RMS), average values, form factor; determination of values using phasor and algebraic representation of alternating quantities, e.g. graphical and phasor addition of two sinusoidal voltages, reactance and impedance of pure R, L and C components.

AC circuit measurements: safe use of an oscilloscope, e.g. setting, handling, health and safety; measurements (periodic time, frequency, amplitude, peak/peak-to-peak, RMS and average values); circuits, e.g. half and full wave rectifier.

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P1 Identify levelling and linear surveying terminology and equipment	M1 Explain the use of levelling and linear surveying equipment in the construction of one part of a rail system	
P2 Carry out linear and levelling surveys using appropriate equipment to produce drawings	M2 Explain a method used to carry out linear and levelling surveys using appropriate equipment to produce drawings	
P3 Identify angular terminology and equipment		
P4 Describe mechanical, physical, thermal, electrical and magnetic properties of materials used in rail engineering		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P5 Describe the effects of processing on the properties, and the modes of failure on materials used in rail engineering		
P6 Describe the types and function of capacitors and explain the relationship between the voltage and current for a charging and discharging capacitor	M3 Calculate capacitance, charge, voltage and energy in a network containing a series parallel combination of three capacitors	D1 Evaluate the results obtained for a network containing a series parallel combination of three capacitors with reference to capacitance, charge, voltage and energy
P7 Describe the principles and applications of electromagnetic induction and the characteristics of a magnetic field		
P8 Determine the characteristics of a sinusoidal AC waveform using single phase AC circuit theory	M4 Analyse the operation and the effects of varying component parameters of a power supply circuit that includes a transformer, diodes and capacitors	D2 Evaluate the performance of a motor and a generator by reference to electrical theory
P9 Use test equipment to test AC circuits		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P10 Compare the results of adding and subtracting two sinusoidal AC waveforms graphically and by phasor diagram		

Essential guidance for tutors

Assessment

Much of the evidence for the pass criteria can be achieved by practical experimentation with real levelling equipment, experiments on material and components, and the evaluation of circuits and computer-based software packages, where appropriate.

It is likely that at least three assessment instruments will be required for this unit, if practical work and tests are also used.

P1 and P3 require learners to identify surveying equipment. This could be achieved via annotated sketches or during the practical work for P2. The accurate and safe use of surveying equipment when carrying out surveys to produce drawings (P2) will require process evidence, supported by relevant learner calculations and drawings.

M1 and M2 require the learner to explain the use and appropriate methods of carrying out surveys and may be achieved following practical survey of a part of a rail system.

P4 could be achieved by means of a written assignment, following a combination of tutor-led practical exercises to explore the mechanical, thermal, electrical and magnetic properties of materials and to relate the theory of materials to the rail industry.

Achievement of P5 could involve learners in both practical and theoretical tasks in which they relate the effects of processing on the properties of materials with rail engineering applications, for example processes that alter the grain structure of steels due to hot or cold working. Learners could be given the opportunity to research the principles of failure and degradation processes reflected in local applications within a rail environment, rail defects, or defects in tracks, sleepers, or a comparison of fatigue, ductile and brittle failures in the rail industry. The appearance of these failures must be highlighted.

For P6, learners will need to describe the full range of types of capacitors (electrolytic, mica, plastic, paper, ceramic, fixed and variable), including typical capacitance values, construction (plates, dielectric materials and strength, flux density, permittivity), their function and working voltages. Learners are required to carry out laboratory experiments to investigate the charging and discharging of a capacitor through a resistor. A simple but effective way of doing this is to use a power supply unit, a 500 μ F electrolytic capacitor, a stopwatch or clock and an AVO type multimeter, using the internal resistance of the meter as the resistor. Learners could then be asked to plot the graph of the growth of capacitor voltage against time and evaluate the time constant by comparing the results with standard theory.

The characteristics of magnetic fields for P7 could be demonstrated by using magnets and iron filings. Learners could sketch the results and then make appropriate comparisons with expected theoretical results. Learners are required to describe the principles and applications of electromagnetic induction. A single application would be sufficient to describe electromagnetic induction in the rail industry.

P8 and P9 could link AC theory and practice, with learners observing and measuring some of the fundamental characteristics of a single wave AC circuit. This will require the use of a multimeter and an oscilloscope to make appropriate comparisons of frequency, maximum and root mean squared (RMS) values.

P10 is intended as an exercise in the graphical addition of two sinusoidal voltages or currents, checking the values theoretically by calculation and also by practical means. A spreadsheet can be used for this, or alternatively calculators and graphs could be used.

M3 involves the calculation of charge, voltage and energy values for DC networks that include a DC power source with two/three capacitors connected in series and a DC power source with two/three capacitors connected in parallel. Learners are required to evaluate their data to achieve D1.

For D1, learners need to evaluate results obtained from calculations with reference to capacitance, charge, voltage and energy for specific capacitors in a series parallel combination.

For M4, a basic power supply could be simulated to allow all the respective properties to be investigated without the hazards of high voltages or currents present. This could be achieved using a function generator as a source of sinusoidal alternating voltage, along with a small isolating transformer, diode rectifiers (half wave and bridge) smoothing capacitors and load resistors.

D2 requires learners to evaluate the performance of motors and generators by reference to electrical theory. This can be achieved practically by using appropriate experimental rigs or from given data that allow learners to compare their results with known characteristics for specific machines.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, M1, M2	Surveying terminology, equipment and techniques used in overhead line construction rail engineering	Within the railway environment, carry out linear and levelling surveys deploying the correct terminology and equipment, and identify angular terminology and equipment.	A portfolio including reference to subject-specific terminology, photographic evidence, calculations and accurate scaled drawings for each surveying technique.
P4, P5, P6	The properties, effects, behaviour and principles of materials used in overhead line construction rail engineering	To describe the properties, effects of processing and principles of materials.	A report or PowerPoint presentation with explanatory notes.
P7, P8, P9, P10, M3, M4, D1, D2	The characteristics of capacitors, magnetic fields and AC circuits used in rail engineering	To describe capacitors, explain charging and discharging of capacitors and the use and results of AC circuits.	A portfolio including reference to subject-specific terminology, photographic evidence, calculations and accurate scaled drawings.

Essential resources

Access to laboratories, mechanical and electrical/electronic and surveying equipment, is essential for the delivery of this unit. Centres will need to provide an appropriate practical environment, with access, if possible, to the rail industry.

In order to develop their skills in producing reports, PowerPoint presentations, drawings and sketches, learners will need suitable practice material prior to assessment and access to relevant computer software for graphics and presentations, spreadsheets and computer hardware (for example scanners, printers, optical character recognition and speech recognition software, barcode readers).

Indicative reading for learners

Textbooks

Bird J O – *Electrical and Electronic Principles and Technology*, 5th edition (Routledge, 2013) ISBN 9780415662857

Bird J O – *Electrical Circuit Theory and Technology*, 5th edition (Routledge, 2013) ISBN 9780415662864

Bonnett C – *Practical Railway Engineering*, 2nd edition (Imperial College Press, 2005) ISBN 9781860945151

Boyce A, Cooke E, Jones R and Weatherill B – *BTEC Level 3 National Engineering Student Book* (Pearson, 2010) ISBN 9781846907241

Darbyshire A – *Mechanical Engineering: BTEC National Engineering Specialist Units*, 2nd edition (Newnes, 2008) ISBN 9780750686570

Higgins R – *Materials for Engineers and Technicians*, 4th edition (Newnes, 2006) ISBN 9780750668507

Robertson C R – *Fundamental Electrical and Electronic Principles*, 3rd edition (Routledge, 2008) ISBN 9780750687379

Selig E and Waters J – *Track Geotechnology and Substructure Management* (Thomas Telford Ltd, 1994) ISBN 9780727720139

Timings R L – *Engineering Materials*, Volume 1, 2nd edition (Longman, 1998) ISBN 9780582319288

Timings R L – *Engineering Materials*, Volume 2, 2nd edition (Longman, 2000) ISBN 9780582404663

Unit 33: Rail Overhead Line Technologies (Maintenance)

Level:	3
Unit type:	Pathway 4 Mandatory
Guided learning hours:	60

Unit introduction

This unit is designed to give learners knowledge and understanding of overhead line infrastructure maintenance within the railway system as a whole.

This unit introduces learners to surveying techniques for linear and level surveying, covering both terminology and equipment. It also introduces the required calculations for both linear and level surveying, and moves on to angular terminology and use of equipment. Learners will have the opportunity to carry out practical linear and level surveying.

Learners will then investigate the way materials are used in the maintenance of rail overhead line technologies. They will develop an understanding of metallic, ceramics and polymers and their properties – including mechanical, physical and thermal properties – and the effects processes have on these.

Finally, learners will explore the application of mechanical principles in the rail environment. Science underpins all aspects of railway engineering and a sound understanding of its principles is essential for anyone seeking to become an engineer.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

- 1 Understand basic surveying techniques
- 2 Understand materials in the rail environment
- 3 Be able to apply mechanical principles in the rail environment.

Unit content

1 Understand basic surveying techniques

Linear surveying terminology: framework; whole to part; well-conditioned; taping; horizontal and slope distances; chainage; running measurements; perpendicular offsets; tie lines; check lines.

Linear surveying equipment: tapes; bands; rules; handheld lasers; ancillary equipment.

Linear surveying calculations: basic arithmetical operations.

Linear surveying drawings: internal or external survey plotted to scale.

Levelling surveying terminology: back sight; intermediate sight; fore sight; reduced level; datum; Ordnance Survey Bench Mark; Temporary Bench Mark; height of collimation; rise and fall; fly levelling.

Levelling surveying equipment: automatic levels; tilting levels; water levels; rotating lasers; barcode instruments.

Levelling surveying calculations: basic arithmetical operations, simple trigonometry.

Levelling surveying drawings: spot heights on plans; sections.

Angular terminology and equipment: whole circle bearings; azimuth; horizontal angle; zenith angle; angles of inclination.

Angular equipment: optical square; theodolites.

2 Understand materials in the rail environment

Mechanical properties: strength (tensile, shear, compressive); hardness; toughness; ductility; malleability; elasticity; brittleness.

Physical properties: density; melting temperature.

Thermal properties: expansivity; conductivity.

Electrical and magnetic properties: conductivity; resistivity; permeability; permittivity.

Effects of processing metals: recrystallisation temperature; grain structure, e.g. hot working, cold working, grain growth; alloying elements in steel, e.g. manganese, phosphorous, silicon, sulphur, chromium, nickel.

Effects of processing thermosetting polymers: process parameters, e.g. moulding pressure and time, mould temperature, curing.

Effects of processing ceramics: e.g. water content of clay, sintering pressing force, firing temperature.

Effects of processing composites: fibres, e.g. alignment to the direction of stress, ply direction; delamination; matrix/reinforcement ratio on tensile strength; particle reinforcement on cermets.

3 Be able to apply mechanical principles in the rail environment

Non-concurrent coplanar force systems: graphical representation, e.g. space and free body diagrams; resolution of forces in perpendicular directions, e.g. $F_x = F \cos\theta$, $F_y = F \sin\theta$; vector addition of forces, resultant, equilibrant, line of action; conditions for static equilibrium ($\Sigma F_x = 0$, $\Sigma F_y = 0$, $\Sigma M = 0$).

Simply supported beams: conditions for static equilibrium; loading (concentrated loads, uniformly distributed loads, support reactions).

Loaded components: elastic constants (modulus of elasticity, shear modulus); loading (uniaxial loading, shear loading); effects, e.g. direct stress and strain including dimensional change, shear stress and strain, factor of safety.

Kinetic parameters: e.g. displacement (s), initial velocity (u), final velocity (v), uniform linear acceleration (a).

Kinetic principles: equations for linear motion with uniform acceleration ($v = u + at$, $s = ut + \frac{1}{2}at^2$, $v^2 = u^2 + 2as$, $s = \frac{1}{2}(u + v)t$).

Dynamics parameters: e.g. tractive effort, braking force, inertia, frictional resistance, gravitational force, momentum, mechanical work ($W = Fs$), power dissipation (Average Power = W/t , Instantaneous Power = Fv), gravitational potential energy ($PE = mgh$), kinetic energy ($KE = \frac{1}{2}mv^2$).

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P1 Identify linear and levelling surveying terminology and equipment	M1 Explain the use of levelling surveying equipment and terminology	
P2 Carry out linear and levelling surveys using appropriate equipment to produce drawings	M2 Explain one method used to carry out linear and levelling surveys in the maintenance of overhead lines for a rail system	D1 Compare and contrast the methods used to carry out linear and levelling surveys using appropriate equipment and the production of drawings, in the maintenance of overhead lines for a rail system
P3 Identify angular terminology and equipment		
P4 Describe mechanical, physical, thermal, electrical and magnetic properties of materials used in rail engineering		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P5 Describe the effects of processing on the properties and the modes of failure of materials used in rail engineering		
P6 Calculate the magnitude, direction and position of the line of action of the resultant and equilibrant of a non-concurrent coplanar force system containing a minimum of four forces acting in different directions		
P7 Calculate the support reactions of a simply supported beam carrying at least two concentrated loads and a uniformly distributed load	M3 Explain the results obtained from calculations for support reactions of a simply supported beam carrying at least four concentrated loads, with one at 30 degrees and one at 45 degrees and two uniformly distributed loads	

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P8 Calculate the induced direct stress, strain and dimensional change in a component subjected to a direct uniaxial loading and the shear stress and strain in a component subjected to shear loading	M4 Analyse the results obtained for a component subjected to combined direct and shear loading for given criteria	D2 Evaluate the factor of safety in operation for a component subjected to combined direct and shear loading against given failure criteria
P9 Solve problems that require the application of kinetic and dynamic principles to determine unknown system parameters		

Essential guidance for tutors

Assessment

Much of the evidence for the pass criteria can be achieved by practical experimentation with real levelling equipment, experiments on material and components, and the evaluation of forces.

It is likely that at least three assessment instruments will be required for this unit, if practical work and tests are also used.

P1 and P3 require learners to identify surveying equipment. This could be achieved via annotated sketches or during the practical work for P2. The accurate and safe use of surveying equipment when carrying out surveys to produce drawings (P2) will require process evidence, supported by relevant learner calculations and drawings.

For M1, learners need to explain the use of levelling surveying equipment and terminology, so that it is easy to differentiate between the various items in each category. It may be useful for learners to include annotated diagrams to support their explanations.

For M2, learners need to select a section of the rail system that contains overhead line technologies and explain a method that would be used to carry out linear and levelling surveys in overhead line maintenance.

For D1, learners need to select a section of the rail system that contains overhead line technologies and compare and contrast the methods used to survey the site with linear and levelling surveys.

P4 could be achieved by means of a written assignment, following a combination of tutor-led practical sessions to explore the mechanical, thermal, electrical and magnetic properties of materials and to relate the theory of materials to the rail industry.

Achievement of P5 could involve learners in both practical and theoretical tasks in which they relate the effects of processing on the properties of materials with rail engineering applications, for example processes that alter the grain structure of steels due to hot or cold working. Learners could be given the opportunity to research the principles of failure and degradation processes reflected in local applications within a rail environment, rail defects, or defects in tracks, sleepers, or a comparison of fatigue, ductile and brittle failures in the rail industry. The appearance of these failures must be highlighted.

To achieve P6, learners are required to provide a solution for a single non-concurrent force system that contains a minimum of four active forces. Two of these forces will be set to act in directions other than the horizontal and vertical. This will necessitate the resolution of forces in perpendicular directions, e.g. the use of $F_x = F \cos\theta$ and $F_y = F \sin\theta$, as the first step in the solution to the problem.

A typical problem might be an engineering component under the action of at least four non-concurrent forces whose magnitudes and directions are given. One of the forces might be its own weight, but at least two of them should act in directions other than the horizontal and vertical. Learners would be expected to produce space and free body diagrams, resolve forces horizontally and vertically and take moments of the forces about some suitable reference point. The magnitude and direction of the resultant force and the position of its line of action could then be found through vector addition, application of Pythagoras' theorem and consideration of the resultant turning moment.

P7 requires the solution of a simply supported beam carrying two point loads, as a minimum, and a uniformly distributed load with the point loads perpendicular to the beam.

M3 requires the solution of a different simply supported beam from P7, carrying four point loads, with one at 30 degrees and one at 45 degrees and a uniformly distributed load.

P8 will require a task to calculate the direct stress, direct strain and the accompanying dimensional change in a directly loaded component. It will also require a task to calculate the shear stress and shear strain in a component or material subjected to shear loading.

M4 requires a separate problem to P8 to calculate for a component subjected to combined direct and shear loading against given criteria.

For D2, a separate component is required. This involves consideration of the factor of safety in operation for an angled joint that is bolted or riveted, such that the fastenings are subjected to both tensile and shearing forces.

P9 requires the setting of at least three dynamic system tasks to ensure that the range of kinetic and dynamic principles is applied to achieve this criterion. Centres should not fragment the application of kinetic and dynamic principles to the extent that they over-simplify the problems. It is the interrelationships between the kinetic and dynamic principles that are as important as the use of any single equation.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, M1, M2, D1	Surveying terminology, equipment and techniques used for overhead line maintenance within rail engineering	Within the railway environment carry out linear and levelling surveys deploying the correct terminology and equipment, and identify angular terminology and equipment.	A portfolio including reference to subject-specific terminology, photographic evidence, calculations, accurately scaled drawings for each surveying technique.
P4, P5	The properties, effects, behaviour and principles of materials used in rail engineering	To describe the properties, effects of processing and principles of materials.	A PowerPoint presentation with explanatory notes.
P6, P7, P8, P9, M3, M4, D2	The application of mechanical principles in the rail environment	To solve problems: non-concurrent coplanar force systems, simply supported beams, loaded beams, kinetic parameters and principles, dynamic parameters and principles.	A portfolio of problem solving calculations, to include formulae and diagrams.

Essential resources

Access to laboratories, mechanical and electrical/electronic equipment, workshops and surveying equipment is essential for the delivery of this unit.

Centres will need to provide an appropriate practical environment, with access, if possible, to the rail industry.

In order to develop their skills in producing reports, PowerPoint presentations, drawings and sketches, learners will need suitable practice material prior to assessment and access to relevant computer software for graphics and presentations, spreadsheets and computer hardware (for example scanners, printers, optical character recognition and speech recognition software, barcode readers).

Indicative reading for learners

Textbooks

Bird J O – *Electrical and Electronic Principles and Technology*, 5th edition (Routledge, 2013) ISBN 9780415662857

Bird J O – *Electrical Circuit Theory and Technology*, 5th edition (Routledge, 2013) ISBN 9780415662864

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Robertson C R – *Fundamental Electrical and Electronic Principles*, 3rd edition (Routledge, 2008) ISBN 9780750687379

Selig E and Waters J – *Track Geotechnology and Substructure Management* (Thomas Telford Ltd, 1994) ISBN 9780727720139

Timings R L – *Engineering Materials*, Volume 1, 2nd edition (Longman, 1998) ISBN 9780582319288

Timings R L – *Engineering Materials*, Volume 2, 2nd edition (Longman, 2000) ISBN 9780582404663

Unit 34: Functions and Characteristics of Railway Signalling Systems

Level:	3
Unit type:	Pathway 5 Mandatory
Guided learning hours:	60

Unit introduction

The rail system depends on the safety of the rail signalling system to ensure its safe running, by using line-side signals to control the movement of trains. Good signalling systems allow trains to run closer together and travel at optimum speeds while maintaining safe braking distances.

Learners will explore the historical background to signalling, moving on to the principles and scope of signalling, and will gain an understanding of the function and characteristics of the different line-side signalling elements. Finally, learners will move on to the related signalling notation and terminology.

This unit will encourage learners to take an investigative approach through practical activities that support theoretical learning, for example exploring hand control systems, examining case studies of accidents due to failure of signalling systems, developing miniature signalling systems, and safely examining real signalling systems. Learners will also develop an understanding of the function of government bodies and the licensing authorities involved with signalling.

For learners wishing to follow a rail signalling programme, this unit will provide the underpinning knowledge required for further study within this area.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

- 1 Understand the role of rail signalling within the railway system
- 2 Understand the principles of safety and high integrity systems as applied to a railway signalling system
- 3 Know the function and characteristics of line-side signalling elements
- 4 Know the major sources and categories of controlled documentation, signalling information, notation and terminology.

Unit content

1 Understand the role of rail signalling within the railway system

Historical landmarks for signalling: history of railway operations, e.g. hand control of movements, space interval, block systems; signals, e.g. fixed, colour light, multiple aspects; multiple train movement; impact of speed.

Purpose and scope of a signalling system: detection; separation of trains; use of points; route-setting; signal formation and permanent way, e.g. interface between ballast, track, traction systems (electrification – catenary, third rail), train braking systems; signalling and control methods, e.g. staff and competence, rules and regulations (control of train movements), capacity planning (headway, basis of timetable); signalling and external interfaces, e.g. level crossings, other infrastructure owners.

Man-machine interface: the driver and signaller interface; warning and advisory systems, e.g. advanced warning system (AWS), train protection warning system (TPWS), automatic train protection (ATP), accidents and preventive measures, automation.

Main line-side elements: e.g. control cabinets, signal posts/gantries, ground signals, route displays (feathers, theatre boxes), power systems, illumination systems/lamps.

2 Understand the principles of safety and high integrity systems as applied to a railway signalling system

Signalling system life cycles: design; construction; commissioning; lifespan of equipment; maintenance; repair; operation; decommissioning.

High-integrity systems: principles, e.g. fail-safe, wrong-side, right-side, failures, resilience, graceful degradation; components of signalling system, e.g. control circuitry (logic control and computing systems), lamps/bulbs, relays.

Application of principles throughout life cycle: reliability, availability, maintainability and safety (RAMS); concepts of redundancy; inherent safety characteristics; independent checks.

3 Know the functions and characteristics of line-side signalling elements

Function of elements: relationship between points, signals, train detection, communications and power; interfacing with signaller and driver.

Consequences of failure/incorrect commissioning: concepts of protected and unprotected failures; concept of as low as reasonably practicable (ALARP).

Risk and mitigation: design and construction features; testing and commissioning; preventive maintenance.

4 Know the major sources and categories of controlled documentation, signalling information, notation and terminology

Obtaining information: government sources, e.g. Her Majesty's Railway Inspectorate (HMRI), infrastructure controller (Network Rail National Records Group); contractors (manufacturers' operations manuals); professional bodies, e.g. Institution of Engineering and Technology (IET), Institution of Railway Signal Engineers (IRSE); role of IRSE licencing; Rail Safety and Standards Board (RSSB) Railway Group Standards (RGSs); company standards and instructions, e.g. specifications, drawings and records.

Document control: categories of documents, e.g. signalling plans, content identification; issue and distribution control, authorisations and signatures; correction systems; feedback from site after alterations; change control, e.g. asset registers, management of versions (especially software), compatibility and obsolescence effect.

Signalling abbreviations, symbols and definitions: abbreviations, e.g. Advanced Warning System (AWS), solid state Interlocking (SSI); symbols, e.g. semaphore signal, point machine, multiple aspect signal, ground signal; definitions, e.g. vital, non-vital.

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P1 Describe the historical development of signalling systems		
P2 Explain the purpose and scope of a signalling system within the rail system		
P3 Explain the man-machine interfaces, their problems and how they are addressed	M1 Compare and contrast the man-machine interfaces, including line-side elements, between the signaller and the driver	D1 Analyse a range of warning and advisory systems available for man-machine interfaces
P4 Describe a signalling system life cycle from design to decommissioning		
P5 Explain the principles of high integrity engineering with reference to the components of a signalling system	M2 Analyse the safety of high integrity signalling systems with reference to the systems' life cycle	

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P6 Describe the application of principles throughout the signalling life cycle	M3 Explain the consequences of failure or incorrect commissioning of signalling elements	D2 Analyse the effect of protected failures and unprotected failures in a signalling system
P7 Explain the function of elements, consequences of failure and risk mitigation for a given signalling application		
P8 Describe the main line-side elements of a typical railway signalling system		
P9 Describe how information is obtained and the importance of document control	M4 Explain the categories of documents in a document control system	D3 Analyse the use of government sources for obtaining information
P10 Describe signalling abbreviations, symbols and definitions		

Essential guidance for tutors

Assessment

This unit could be assessed using the four assignments outlined in the *Programme of suggested assignments* table. However, there are other valid ways of assessment and the *Programme of suggested assignments* is a suggestion only.

Although this unit could be delivered completely in class, the learning and assessment experience will be much more relevant if learners are able to access industrial links and visits that exemplify real applications of rail signalling.

For P1 (historical development) and P2 (purpose and scope of signalling system), learners could explore the introduction of signalling and the benefits of signalling, highlighting the purpose and scope of a signalling system. These could be investigated within an appropriate rail signalling situation, where this can be achieved safely. Learners could present their findings as a written report incorporating appropriate sketches, circuits and diagrams. For P3 (man-machine interfaces), learners could be presented with several scenarios and required to explain possible problems and how they could be addressed. For P4, learners need to describe the features of a signalling system life cycle from design to decommissioning. For M1, learners need to compare and contrast the man-machine interface, paying particular attention to the line-side elements that interface between the signaller and driver. For D1, learners need to analyse the best use of warning and advisory systems for man-machine interfaces, including AWS, TPWS and ATP.

For P5, learners need to be able to explain the principles of high-integrity engineering systems, referencing components of a signalling system, including the function of elements. For M2, learners must analyse the principles of high-integrity systems such as failsafe, right side, wrong side, with reference to the components of a signalling system and life cycle stages from design and commissioning through to decommissioning.

A range of applications of principles must be described through the course of a signalling life cycle (P6), and learners need to be able to explain the function of elements, the consequences of failure and risk mitigation for a given signalling application (P7). For M3, learners need to explain the consequences of failure or incorrect commissioning of signalling elements, such as protected and unprotected failure, or the concept of as low as reasonably practicable (ALARP). For D2, learners will analyse the effect of protected failures and unprotected failures in a signalling system. Learners could research a rail signalling communication problem and then use the information obtained to develop a solution. By giving a description of main line-side elements of a typical railway signalling system for P8, learners will show their understanding of the methods used in the rail industry to determine the interface between signaller and driver.

For P9, exploration of case studies showing commercial uses could enable learners to consider the nature of document control and the various sources of information, across various rail regulatory bodies. For P10, learners could investigate effective system requirements that are linked with signalling, such as identifying where AWS and SSI is used, describing examples of the correct use of symbols, such as semaphore signals and ground signals, and developing these to define vital and non-vital signals. Learners could move on to explain the document control requirements that are necessary and the categories of documents (M4) and then analyse the use of government sources for obtaining information (D3).

In all areas, the suggestions made by learners – together with their explanations and justifications – should be feasible and possible.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, P4, M1, D1	Role of rail signalling	Explore the purpose and scope of a signalling system. Research effects of historical landmarks and interpret findings to prepare appropriate engineering sketches, circuits and diagrams within a written report.	A written report providing the learner's interpretation of the information and features found.

Criteria covered	Assignment title	Scenario	Assessment method
P5, M2	Components of a signalling system	Explore the main line-side elements and the features of a signalling life cycle with respect to safety.	Learners will be required to complete tutor-prepared worksheets with recorded data and make required responses together with a brief conclusion. Carried out under controlled conditions.
P6, P7, P8, M3, D2	Line-side signalling	Solving a rail signalling system problem through use of research and using the information obtained.	Observation records for identified problem with use of witness statements and production of a report together with a project presentation.
P9, P10, M4, D3	Document control and signalling information	Presenting engineering information using ICT to present finding relating to document control.	A written report on the selection of system requirements for use and control of documentation.

Essential resources

It is essential that learners have access to case studies, simulation and (if possible and safe to examine) real-life systems. They could also benefit from virtual reality, by using simulators or multimedia tools to gain experience before handling signalling issues.

With the increased use of computer-based methods for rail signalling and simulation, centres are strongly advised to consider the provision of suitable models, hardware and software.

Indicative reading for learners

Textbooks

Hall C – *Modern Signalling Handbook*, 5th edition (Ian Allan Publishing, 2016)
ISBN 9780711038394

Yu F – *Advances in Communications-Based Train Control Systems*
(Routledge, 2018) ISBN 9781138894501

Websites

orr.gov.uk

Office of Rail and Road: Common Safety Method for Risk Evaluation and Assessment; guidance on the CSM RA

uic.org

Worldwide Railway Organisation: information and articles on ERTMS

www.ertms.net

European Rail Traffic Management System: updates and general reference

www.irse.org

Institute of Railway Signal Engineers: technology updates and general reference

Unit 35: Electronic Circuits for Rail Signalling

Level:	3
Unit type:	Pathway 5 Mandatory
Guided learning hours:	60

Unit introduction

Electronic analogue and digital devices and circuits are at the heart of familiar household products and complex operations in industrial applications and products, including rail signalling technologies. They are also fundamental to the operation of television remote control units and to the control of processes in nuclear power generation.

This unit will cover the simulation, construction, testing and evaluation of analogue electronic circuits based on diodes and transistors, together with combinational and sequential logic digital circuits. As part of the unit, learners may use software to simulate circuits and use typical bench instruments to test them, since electronic circuit designers make use of software to simulate design ideas before building prototype circuits.

Finally, learners will cover the areas of condition monitoring methods, failure modes and rates and the reduction of system/device failure in a circuit.

A wide range of industries, including rail, aerospace and automotive, employ electronic engineers. This unit helps learners to prepare for employment or development within industry and allows progression to higher education.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

- 1 Understand the function and operation of diodes, transistors and logic gates
- 2 Be able to build and test operational amplifier-based analogue circuits
- 3 Be able to build and test combinational and sequential logic circuits
- 4 Know about system monitoring and reliability.

Unit content

1 Understand the function and operation of diodes, transistors and logic gates

Diodes: types, e.g. Zener, light-emitting diode (LED), PN-junction; circuit applications, e.g. voltage stabiliser, indicator light, half-wave rectifier.

Transistors: types, e.g. NPN, PNP or field-effect transistor (FET); analogue circuit (single-stage amplifier); digital circuit, e.g. comparator, transistor as a switch (automatic night light); operation, e.g. analogue (voltage gain, phase inversion), digital (set-point of operation); function of components in circuits.

Logic gates: types of gates, e.g. AND, OR, NAND, NOR, XOR; gate symbols, e.g. British standards (BS), International Electrotechnical Commission (IEC), American National Standards Institute (ANSI); truth tables; Boolean expressions, e.g. $A+B$, A , $A*B$.

2 Be able to build and test operational amplifier-based analogue circuits

Building analogue circuits: method of construction, e.g. prototype/bread board, printed circuit, strip board; types of circuits, e.g. oscillator, filter circuit, comparator circuit, inverting and/or non-inverting amplifier.

Testing analogue circuits: performance against given requirements; recording actual input and output voltages (tabulating data, plotting graph of results); circuit measurements, e.g. measurement of resonant frequency, cut-off frequency, switching point, gain at mid-frequency, bandwidth.

3 Be able to build and test combinational and sequential logic circuits

Building combinational and sequential logic circuits: types of combinational circuit, e.g. at least three gates and three input variables; types of sequential circuit, e.g. R-S bi-stables, JK bi-stable, 3-stage counter, 3-stage shift register based on JK or D-type bi-stables; types of logic family, e.g. transistor-transistor logic (TTL) and complementary metal oxide semiconductor (CMOS); characteristics of chips, e.g. supply voltage, input and output operating voltages, input and output impedance, propagation delay, power.

Testing of logic circuits: records of performance against given design requirements; input and output states; use of truth tables; use of test equipment, e.g. logic probe, signature analyser.

Minimisation of logic circuits: e.g. use of De-Morgan's theorem; Karnaugh maps.

4 Know about system monitoring and reliability

Monitoring terminology: condition monitoring methods, e.g. offline portable monitoring, sampled monitoring, continuous monitoring, protection monitoring, human sensory monitoring; monitoring techniques, e.g. vibration analysis, temperature analysis, flow analysis, particle analysis, crack detection, leak detection, pressure analysis, voltage/current analysis, thickness analysis, oil analysis, corrosion detection, environment pollutant analysis.

Failure and reliability: calculations concerning failure, e.g. degrees and causes of failure, failure rate, failure modes, functional failure, primary and secondary functions, mean time between failures (MTBF), reliability; factors affecting reliability, e.g. design, operation, environment and manufacture, reduction in system/device failure, e.g. routine servicing, adjustments; data, e.g. defects examination, statistical process control (SPC), quality.

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P1 Explain the purpose of two different types of diode, each in a different electronic circuit application		
P2 Explain the operation of two different types of transistor, one in analogue and one in digital circuit	M1 Justify the application of two different types of transistor in an analogue and a digital circuit	D1 Analyse the use of transistors as comparators and a switch in given circuits
P3 Explain the operation of three different logic gates with appropriate gate symbols, truth tables and Boolean expressions		
P4 Build and test two different types of analogue circuit using operational amplifiers	M2 Justify the results obtained from the practical tests carried out on a circuit using operational amplifiers	
P5 Build and test a combinational logic circuit that has three input variables		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P6 Build and test a sequential circuit using integrated circuit(s)	M3 Explain the operation of a 3-stage shift register, using flip flops	D2 Compare and contrast the effectiveness in use of TTL and CMOS types of transistors
P7 Describe a condition monitoring method and technique related to a given engineering system		
P8 Using given data, calculate failure rates for a range of components and equipment	M4 Explain the factors affecting component failure rate	D3 Analyse the use of a range of truth tables within the testing of logic circuits
P9 Describe the factors affecting reliability for a given engineering system		

Essential guidance for tutors

Assessment

This unit could be assessed using the four assignments outlined in the *Programme of suggested assignments* table. However, there are other valid ways of assessment and the *Programme of suggested assignments* is a suggestion only.

Although this unit could be delivered completely in class, the learning and assessment experience will be much more relevant if learners are able to access industrial links and visits that exemplify real applications of rail signalling technologies.

For P1 (diodes), P2 (transistors) and P3 (logic gates), learners could investigate the function and operation of these devices and the areas identified could be examined theoretically and practically within a typical circuit. Learners need to consider the application of these components and their use in a typical situation. Learners could present their findings in a written report incorporating appropriate sketches, circuits and diagrams. Learners could then justify the application of two different types of transistor, one in an analogue and one in a digital circuit (M1), analyse the use of transistors as a switch (D1), and present the findings as a report that includes circuits, sketches and test results.

For P4 (operational amplifiers) and P5 (combinational logic circuit), learners could be presented with a number of components and required to build and test circuits, working from circuit diagrams provided by the tutor. A combinational logic circuit with three inputs (P5) could be built and tested. A justification of the results (M2) could then be presented to a selected audience. This could be followed by the building and testing of a sequential circuit (P6). Learners could then explain the operation of all stages of a 3-stage shift register based on flip flops (JK or D-type bi-stables) (M3) and compare and contrast the effectiveness in use of TTL and CMOS transistors (D2). This evidence could be presented in a written report.

For a given engineering system presented to them, the learner will be required to describe a conditional monitoring method and technique (P7).

Stem monitoring and reliability is a major factor to be considered in an electronic circuit and learners will need to calculate failure rates for components and equipment from a set of given data (P8). The learner will then need to analyse the use of truth tables within logic circuit testing (D3), explain factors that affect the failure rate of components (M4), and describe factors affecting reliability for a given engineering system (P9).

In all areas, the suggestions made by learners – together with their explanations and justifications – should be feasible and possible.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, M1, D1	Component operation	Explain the operation of selected electronic components. Review and analyse the findings to prepare appropriate engineering sketches, circuits and diagrams within a written report.	A written report providing the learner's interpretation of the information and features found.
P4, P5, M2	Build and test circuits	Build and test circuits and from the results obtained present findings.	Learners will be required to build and test circuits, recorded data and make required responses together with a brief conclusion. Carried out under controlled conditions.
P6, P7, M3, D2	Using integrated circuits	Solving an engineering problem through research and use of information.	Observation records with witness statement and report with presentation.

Criteria covered	Assignment title	Scenario	Assessment method
P8, P9, M4, D3	Failure rates and reliability	Presenting engineering information using ICT.	A written report on the calculation of failure rates and system reliability.

Essential resources

It is essential that learners have access to a well-equipped laboratory with up-to-date electrical/electronic instruments such as digital and analogue multimeters, function generators and oscilloscopes. They could also benefit from using simulators or multimedia tools to gain experience before handling live resources. Centres will also need to provide appropriate circuit components, as required for the *Unit content*, together with the means to physically construct circuits.

With the increased use of computer-based methods for circuit design and simulation, centres are strongly advised to consider the provision of suitable hardware and software.

Indicative reading for learners

Textbooks

Bird J O – *Electrical and Electronic Principles and Technology*, 5th edition (Routledge, 2013) ISBN 9780415662857

Bird J O – *Electrical Circuit Theory and Technology*, 5th edition (Routledge, 2013) ISBN 9780415662864

Hall C – *Modern Signalling Handbook*, 5th edition (Ian Allan Publishing, 2016) ISBN 9780711038394

Robertson C R – *Fundamental Electrical and Electronic Principles*, 3rd edition (Routledge, 2008) ISBN 9780750687379

Yu F – *Advances in Communications-Based Train Control Systems* (Routledge, 2018) ISBN 9781138894501

Websites

orr.gov.uk

Office of Rail and Road: Common Safety Method for Risk Evaluation and Assessment; guidance on the CSM RA

uic.org

Worldwide Railway Organisation: information and articles on ERTMS

www.ertms.net

European Rail Traffic Management System: updates and general reference

www.irse.org

Institute of Railway Signal Engineers: technology updates and general reference

Unit 36: Telecommunication Technologies

Level:	3
Unit type:	Pathway 6 Mandatory
Guided learning hours:	60

Unit introduction

The modern world relies on telecommunications – from email and video conferencing to the internet, telecommunications have an enormous impact on the way we live today. New and developing communication technologies are used in the business world to maximise productivity and access information, and in the rail industry, telecommunication is used to improve rail efficiency. Through communication devices, signal theory, transmission media and methods of electronic communication, engineering requirements may be identified while a journey is in progress and an engineer put on board at a convenient station to work on the problem.

This unit starts by developing and extending learners' understanding of the main elements of data communication within rail industry systems. Learners then address communication principles within the rail industry, covering computer networks and looking at various features of networks including LAN, WAN, ISDN and network operating systems through the network components and interconnection devices of hubs, routers and wireless devices.

Learners will also study transmission protocols and models (i.e. open system interconnections (OSI) model) and wireless security protocols, for example WEP TCP/IP model.

Finally, learners will have the opportunity to develop their understanding of internet communications and their system requirements, including email, internet and video conferencing. Internet communications developed within the rail industry may be used to ease the number of breakdowns and allow preventative maintenance to be identified and carried out during a journey. Direct communications will also be included in the unit. Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

- 1 Know the main elements of data communications systems
- 2 Understand the communication principles of computer networks
- 3 Understand transmission protocols and models
- 4 Understand internet communications.

Unit content

1 Know the main elements of data communications systems

Communication devices: wired devices, e.g. data terminal equipment (DTE), data circuit-terminating equipment (DCE); wireless devices, e.g. third generation (3G) cellular phone, wireless personal data assistant (PDA), wireless laptop.

Signal theory: digital signalling methods; representing data electronically (bits, bytes, packet structures); synchronous and asynchronous transmissions; error correction and detection; effects of bandwidth limitation and noise; channel types, e.g. telephone, high frequency (HF) radio, microwave, satellite; other issues, e.g. bandwidth, data compression.

Data elements: checksum, e.g. cyclic redundancy check (CRC); frames; packets; datagrams; addresses; sequence numbers.

Methods of electronic communication: simplex, duplex and half duplex communication; parallel, e.g. universal serial bus (USB); serial, e.g. RS-232; other, e.g. infrared, Bluetooth[®], Wi-Fi.

Transmission media: coaxial; optical fibre; unshielded twisted pair (UTP); shielded twisted pair (STP); other, e.g. infrared, radio, microwave, satellite; features and benefits.

2 Understand the communication principles of computer networks

Features of networks: types, e.g. LAN, WAN, wireless; network topologies, e.g. star; mesh; bus; tree (or hierarchical); ring; network services, e.g. packet switched, ISDN, multiplexed, ATM, WAP, broadband; network software, e.g. network operating system; network connections software; access methods, e.g. CSMA/CD, CSMA/CA, token passing.

Network components: servers; workstation; network cards, e.g. Ethernet, wireless, token ring.

Interconnection devices: e.g. hubs; switches; routers; repeaters; bridges; gateways, wireless devices.

3 Understand transmission protocols and models

Model: e.g. open system interconnection (OSI) model; levels and relationship with connection devices.

Protocols: e.g. Bluetooth[®], Wi-Fi, IrDa, cellular radio; examples, e.g. GSM/UMTS, WAP, WML; 802.11x standards, TCP/IP model: levels and relationship with connection devices.

4 Understand internet communications

Internet communication: terminology, e.g. HTTP, HTTPS, FTP, SMTP; uniform resource locator; worldwide web; other, e.g. blogs, wikis, video conferencing, vlogs.

System requirements: hardware and software system requirements, e.g. for wired or mobile systems; communication services, e.g. email, video, internet; software; configuration.

Direct communication: e.g. chat, video communication, email, web phone.

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P1 Identify and explain types of communication devices		
P2 Explain the principles of signal theory		
P3 Identify and describe the roles of network components and how they are interconnected		
P4 Describe the features of networks and the communication services they offer	M1 Explain a range of communication services offered by different network types, their services and topologies	D1 Analyse the effectiveness of the communication services offered by different network types, their services and topologies
P5 Describe communication protocols used and explain why they are important		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P6 Describe different methods of electronic communication and transmission media used	M2 Explain why particular transmission methods are chosen in particular situations	D2 Compare and contrast the effectiveness of different transmission methods
P7 Describe the nature of internet communication and the associated system requirements	M3 Justify the system requirements for effective internet communications	

Essential guidance for tutors

Assessment

This unit could be assessed through specific rail industry themes, based around the four assignments outlined in the *Programme of suggested assignments* table. However, there are other valid ways of assessment and the *Programme of suggested assignments* is a suggestion only.

Although this unit could be delivered completely in class, the learning and assessment experience will be much more relevant if learners are able to access industrial links and visits that exemplify real applications of telecommunication technologies.

For P1 (communication devices) and P2 (principles of signal theory), the exploration of data communication device element areas within the rail industry could be investigated and the areas identified could be seen in an industrial situation. Learners could include results and knowledge gained from their studies for this unit in a written report incorporating appropriate sketches, circuits and diagrams.

For P3 (network components), learners could be presented with a number of components and required to build a network. The features of a network will need to be explored, along with the communication services that are offered with these features. For P4, learners need to be able to describe the features of networks and the range of communication services they offer. For P5, this can be extended to describe the communication protocols and their importance. For M1, learners need to be able to explain this wide range of services offered by the communication networks with relevance to industrial services. For D1, learners also need to carry out an analysis of the effectiveness of the communication networks in industrial situations.

P6, M2 and D2 could be covered by an exploration of an engineering communication problem or a technological development that would impact the rail industry. Learners could research the problem and then use the information obtained to develop a solution. Production and presentation of a technical report would require learners to describe different methods of electronic communication and appropriate transmission media used within the rail industry (P6). For M2, learners will need to explain why particular transmission methods are chosen in particular situations in a selection of industrial applications. For D2, learners are required to compare and contrast the effectiveness of different transmission methods.

For P7, exploration of commercial uses could enable learners to consider the nature of internet communication and the associated system requirements. In order to meet M3, learners could then justify the system requirements needed for effective internet communication. This justification must be in a form that is easily understood by a peer or third party engineer within the railway industry.

In all areas, the suggestions made by learners – together with their explanations and justifications – should be feasible and possible.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2	Data communication systems	Explore data communication device elements, including transmission media, and interpret findings to prepare appropriate engineering sketches, circuits and diagrams in a written report.	A written report providing the learner's interpretation of the information and features found.
P3, P4, P5, M1, D1	Principles of computer networks	Explore the features of a network and the communication services offered with these features.	Learners will complete tutor-prepared worksheets regarding network communication in the rail industry, recording appropriate responses together with a brief conclusion. Carried out under controlled conditions.

Criteria covered	Assignment title	Scenario	Assessment method
P6, M2, D2	Transmission protocols	Solving an engineering problem through research and use of information.	Observation records with witness statement and report with presentation.
P7, M3	Internet communications	Presenting engineering information using ICT.	A written report on the selection of system requirements for use of internet communication.

Essential resources

It is essential that learners have access to a well-equipped laboratory with up-to-date telecommunication facilities, and electrical/electronic instruments such as digital and analogue multimeters, function generators and oscilloscopes. They could also benefit from using simulators or multimedia tools to gain experience before handling live resources. Centres will also need to provide appropriate components, as required for the *Unit content*, together with the means to physically construct networks.

With the increased use of computer-based methods for network design and simulation, centres are strongly advised to consider the provision of suitable hardware and software.

Indicative reading for learners

Textbooks

Bird J O – *Electrical and Electronic Principles and Technology*, 5th edition
(Routledge, 2013) ISBN 9780415662857

Bird J O – *Electrical Circuit Theory and Technology*, 5th edition (Routledge, 2013)
ISBN 9780415662864

Dodd A – *The Essential Guide to Telecommunications*, 4th edition
(Prentice Hall, 2005) ISBN 9780131487253

Goleniewski L – *Telecommunications Essentials*, 2nd edition
(Addison Wesley, 2006) ISBN 9780321427618

Plevyak T, Sahin V – *Next Generation Telecommunications Networks, Services, and Management* (IEEE Press Series on Network Management) (WileyBlackwell, 2010)
ISBN 9780470575284

Robertson C R – *Fundamental Electrical and Electronic Principles*, 3rd edition
(Routledge, 2008) ISBN 9780750687379

Unit 37: Telecommunication Principles

Level:	3
Unit type:	Pathway 6 Mandatory
Guided learning hours:	60

Unit introduction

The modern world relies on telecommunications and the transmission of data along transmission lines, which has an enormous impact on the way we live today. New and developing communication technologies are used within the rail industry to maximise productivity and provide quick access to information.

This unit will concentrate on telecommunications in the rail industry. It starts by developing and extending learners' understanding of the properties of circuits, the characteristics of digital signals and transmission lines, together with the relationship between these telecommunication circuits and transmission lines, before considering their effect on a digital signal.

Learners are then taken through the theory of frequency modulation and multiplexing principles and characteristics, looking at the reasons for modulation of electrical circuits, analogue to digital conversion and frequency and time division multiplexing.

Learners will also carry out testing on telecommunication electrical circuits, including analogue and binary systems, obtaining appropriate data and presenting the findings in a suitable format. Practical work should be used to reinforce learners' understanding of concepts and theory.

Finally, the unit will address electromagnetic theory with regard to applications within telecommunications.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the depth and breadth of the topic area. As such, not all content that follows an 'e.g.' needs to be taught.

Learning outcomes

On completion of this unit a learner should:

- 1 Understand the relationship between telecommunication circuits and transmission lines and their effect on a digital signal
- 2 Understand the principles and characteristics of frequency modulation and multiplexing
- 3 Be able to carry out tests on telecommunications electrical circuits and present the results
- 4 Understand the applications of electromagnetic theory as applied to telecommunications.

Unit content

1 Understand the relationship between telecommunication circuits and transmission lines and their effect on a digital signal

Circuit properties: behaviour of inductance, capacitance and resistance in alternating current (AC) circuits; concept of resistance; concept of impedance in terms of resistive and reactive components; characteristics of parallel and series resonant circuits; statement of the formula for determining resonant frequency in terms of resistance, capacitance and inductance.

Characteristics of transmission lines: equivalent circuit model of a transmission line in terms of resistance, capacitance and inductance; concept of characteristic impedance; conditions for maximum power transfer between a source and a load; typical values of characteristic impedance for various types of cable, e.g. coaxial cable; twisted pairs; definition of bandwidth of a line in terms of a frequency range between half power points.

Digital signals: representation of binary information using non-return to zero (NRZ) and return to zero (RZ) waveforms; advantage of RZ in terms of extracting clocking information; digital signal impairments (delay, jitter, binary errors); effects of delays; limited bandwidth and jitter on the extraction of binary information from a digital signal; definition of bit rate and bit error rate (BER).

2 Understand the principles and characteristics of frequency modulation and multiplexing

Modulation techniques: reasons for modulation of electrical signals; concepts of modulating signal and carrier; principles of amplitude modulation (AM), frequency modulation (FM) and phase modulation (PM) in terms of the effect of the modulation signal on the properties of the carrier, e.g. phase, amplitude, frequency; properties of AM, FM and PM signals, e.g. bandwidth requirement, relative noise immunity; transmission of binary code using on-off keying.

Analogue to digital conversion: principles of pulse amplitude modulation (PAM) with reference to sampling amplitude levels; principles of pulse code modulation (PCM) in terms of converting sampled levels into binary code; function of an encoder/decoder combination (codec) for transmission of speech, transmission of video; benefits, e.g. higher noise immunity, enabling of bandwidth compression techniques.

Frequency and time division multiplexing: principles, e.g. transmitting traffic from various sources at different frequencies, reference to transmission timeslots; benefits of multiplexing, e.g. reduction in number of links in a network, reduction in operating and equipment costs.

3 Be able to carry out tests on telecommunications electrical circuits and present the results

Measurements on electrical circuits: use of test equipment, e.g. oscilloscope, function generator, frequency meter, power meter; measurements (resonant frequency, signal phase shift, bandwidth, pulse shape, signal power); recording and presenting test results, e.g. tabulation of data, graphical representation (line chart, bar chart, pie chart, column chart), paper or computer-based methods.

4 Understand the applications of electromagnetic theory as applied to telecommunications

Electromagnetic spectrum frequency bands: applications from near infrared (NIR) band to low frequency (LF) band, e.g. mobile telephony, optical fibre transmission, satellite communications, broadcast radio and television, microwave radio links; propagation characteristics, e.g. line of sight, groundwave, ionospheric refraction, reflection.

Application of electromagnetism: principles of operation, e.g. role of electromagnetism, main components; relevance of turns ratio; efficiency of a transformer in terms of relationship between input power, output power and losses (eddy currents, hysteresis); other telecommunications applications, e.g. microphone, loudspeaker.

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P1 Describe the properties of a circuit with reactive and resistive components		
P2 Describe the characteristics of a transmission line with reference to an equivalent circuit model		
P3 Describe the properties of a digital signal and the impairments that could affect it	M1 Explain the representation of binary information, non-return to zero (NRZ) and return to zero (RZ) waveforms of a digital signal	D1 Analyse the effects of delay, limited bandwidth and jitter on the extraction of binary information from a digital signal
P4 Describe signal modulation techniques and the properties of a modulated signal	M2 Justify modulation techniques on a range of signals used by railway applications that operate in different frequency bands of the electromagnetic spectrum	

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P5 Describe the principles and benefits of analogue to digital conversion		
P6 Describe the principles and benefits of frequency and time division multiplexing	M3 Explain the benefits of transmitting traffic at different frequencies transmitted from a range of different devices	D2 Analyse the benefits of multiplexing and the reduction of network links, in relation to operating and equipment costs
P7 Make measurements on telecommunication electrical circuits		
P8 Describe the characteristics and application of frequency bands in the electromagnetic spectrum	M4 Justify the efficiency of a transformer in terms of the relationship between input and output power	D3 Compare the effectiveness of electromagnetic spectrum frequency bands
P9 Explain how transformers and other communication devices make use of the principles of electromagnetism		

Essential guidance for tutors

Assessment

This unit could be assessed using the four assignments outlined in the *Programme of suggested assignments* table, using appropriate references to the rail industry. However, there are other valid ways of assessment and the *Programme of suggested assignments* is a suggestion only.

Although this unit could be delivered completely in class, the learning and assessment experience will be much more relevant if learners are able to build practical circuits, experiment with different devices, access industrial links, and visits that exemplify real applications of telecommunication technologies.

For P1 (properties of a circuit) and P2 (transmission line), the circuit transmission line areas could be investigated, together with the properties and potential impairments of a digital signal (P3). The representation of binary information must be explained for non-return to zero (NRZ) digital encoding from given values and return to zero (RTZ) digital encoding from given values for M1; then for D1, learners will need to analyse the effects of impairments, including delay, limited bandwidth and jitter on the extraction of binary information from a digital signal, within a rail industry situation selected by the tutor.

Learners could include their findings in a written report, which must incorporate appropriate sketches and circuits, and could also include diagrams covering P4 (signal modulation). Learners could then be presented with a selection of tutor-prepared given applications and required to justify the effects of signal modulation on a range of signals and the effect these have on the carrier, for M2. For P5, the principles and benefits of analogue to digital conversion will need to be described. P6 requires a description of the principles and benefits of frequency and time division multiplexing, including reasons for modulation of electrical signals, concepts of modulating signal and carrier, principles of amplitude modulation (AM), frequency modulation (FM) and phase modulation (PM). Learners will also need to explain the benefits of differences in transmitted frequency from different devices (M3) and analyse the benefits of multiplexing data and the reduction of network links in relationship to operating and equipment costs for D2.

For P7, learners will need to take appropriate practical measurements of electrical/telecommunication circuits, using various instruments, and record and present test data and results, in a tabulated or graphical form (VR or simulation can be used for teaching and learning, but assessment needs to be completed on actual circuits).

Learners must be able to describe the characteristics and application of frequency (P8), make appropriate measurements in order to justify the efficiency of a transformer (M4), and compare the effectiveness of frequency bands (D3). Learners also need to explain how communication devices make use of the principles of electromagnetism (P9).

In all areas, the suggestions made by learners – together with their explanations and justifications – should be feasible and possible.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, M1, D1	Telecommunication circuits and transmission lines	Explore circuit components of a circuit, the properties of a digital signal and an analysis of the effects on a digital signal.	A written report providing the learner's interpretation of the information and features found.
P4, P5, M2	Signal modulation and analogue to digital conversion	Explore modulation and analogue to digital conversion and the effect on a signal.	Learners will be required to complete tutor-prepared worksheets recording data and providing suitable responses, together with a brief conclusion. Carried out under controlled conditions.

Criteria covered	Assignment title	Scenario	Assessment method
P6, P7, M3, D2	Electrical circuits and time division multiplexing	Solve a rail telecommunication engineering problem obtaining circuit data through measurement, research and use the information within the solution.	Observation records with witness statement and report with presentation.
P8, P9, M4, D3	Make use of electromagnetism	Determine efficiency and effectiveness of electromagnetism	A written report on the selection of system requirements for use of internet communication.

Essential resources

It is essential that learners have access to a well-equipped laboratory with up-to-date electrical/electronic instruments such as digital and analogue multimeters, function generators and oscilloscopes. They could also benefit from using simulators or multimedia tools to gain experience before handling live resources. Centres will also need to provide appropriate circuit components, as required for the *Unit content*, together with the means to physically construct circuits.

With the increased use of computer-based methods for circuit design and simulation, centres are strongly advised to consider the provision of suitable hardware and software.

Indicative reading for learners

Textbooks

Bird J O – *Electrical and Electronic Principles and Technology*, 5th edition (Routledge, 2013) ISBN 9780415662857

Bird J O – *Electrical Circuit Theory and Technology*, 5th edition (Routledge, 2013) ISBN 9780415662864

Hall C – *Modern Signalling Handbook*, 5th edition (Ian Allan Publishing, 2016) ISBN 9780711038394

Robertson C R – *Fundamental Electrical and Electronic Principles*, 3rd edition (Routledge, 2008) ISBN 9780750687379

Yu F – *Advances in Communications-Based Train Control Systems* (Routledge, 2018) ISBN 9781138894501

Websites

orr.gov.uk	Office of Rail and Road: Common Safety Method for Risk Evaluation and Assessment; guidance on the CSM RA
uic.org	Worldwide Railway Organisation: information and articles on ERTMS
www.ertms.net	European Rail Traffic Management System: updates and general reference
www.irse.org	Institute of Railway Signal Engineers: technology updates and general reference

Unit 38: **Underground Rail Vehicle Traction and Associated Systems**

Level:	3
Unit type:	Pathway 1 Mandatory
Guided learning hours:	60

Unit introduction

The provision of a safe, reliable and resilient transport network is essential for travel around a modern city. Key conurbations across the world, including Hong Kong, Singapore, New York and London, benefit from underground rail networks. Ensuring that underground rail vehicles' traction and rolling stock operates safely and efficiently is key to guaranteeing that passengers on underground systems are transported to their destinations without disruption.

Underground rail networks use traction and rolling stock that are powered by AC or DC electricity. Rail vehicles must have braking systems that ensure the safety of the train and must be mounted on suspension that is suitable and appropriate. This unit enables learners to develop their knowledge of the types of suspension that are used for underground rail vehicles, including different types of bogie and wheelset. It introduces the features that ensure braking systems operate safely and the factors that influence the efficiency of braking systems. The unit also develops learners' understanding of AC and DC electrical traction, considering both infrastructure and on-train equipment.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

- 1 Understand traction and rolling stock suspension systems
- 2 Understand the fundamentals of traction and rolling stock braking systems
- 3 Understand the fundamentals of traction and rolling stock axles, wheels and bearings
- 4 Understand AC electric power collection and transmission
- 5 Understand the fundamentals of DC electric power collection and transmission.

Unit content

1 Understand traction and rolling stock suspension systems

Design factors: weight, e.g. axle loads (light rail, high speed, multiple units, locomotives); purpose, e.g. passenger, freight, light rail, high speed; passenger; wheelset arrangements, e.g. inboard axle boxes, outboard axle boxes, axle bridges, independent wheels.

Suspension systems: dampers, e.g. active dampers, hydraulic dampers, mechanical dampers; levelling valves; over heights; springs, e.g. primary springs, secondary springs, spring types (leaf springs, parabolic leaf spring, cylindrical spring, flexi-coil), rubber springs.

Bogie styles: styles, e.g. 2-axle, Jacobs, powered, steerable; assemblies; shoe gear mountings, swing hanger, bolster, e.g. suspended, spring-loaded.

Bogie mountings: pivots; fixed; suspension.

2 Understand the fundamentals of traction and rolling stock braking systems

Braking systems: friction, dynamic, pulse width modulation (PWM), brake safety systems, blending.

Operation of braking systems: air/electric brake systems; round train circuits; variable load valves.

Friction pads: cast iron; high temperature; organic; sintered.

Wheel slide prevention system: system, dump valves, interaction with dynamic brake.

Sanding de-icing systems: increase adhesion and grip, triggers for use.

Implications of fault: implications being unable to release brakes while on the line; implications of failure of round train circuits.

3 Understand the fundamentals of traction and rolling stock axles, wheels and bearings

Components of a wheelset: axle; wheel; bearings.

Wheel types: styles, e.g. conical, tapered; size and use, e.g. multiple units/passenger coaches/high-speed vehicles, locomotives, freight cars; profiles; flanges.

Bearing types: cylindrical roller; ball, e.g. angular contact, four-point contact, deep groove; tapered; tapered roller.

Maintenance: process of changing out wheelsets, e.g. processes, routine maintenance, risk assessments; faults, e.g. flats, tread run-out, cracks, tread cavities, tread rollover; inspections, e.g. in-situ tests, inspection methods; frequency (time/distance); implications of 'flats'; methods of extending life of wheelsets.

4 Understand AC electric power collection and transmission

Features of AC traction supply: voltages, e.g. 25kV; relationships between voltage, current and frequency; transformers (voltage outputs); earth return and bonding, e.g. earthing through wheels, bonding; systems in place to offload and prevent arc dragging at neutral sections, e.g. APC magnets, vacuum circuit breakers.

Traction unit types and system/components: use of AC traction motors; motor converter module, 3-phase inverter, charging circuits.

Maintenance of traction units: types and periods of maintenance regimes used, performance, reliability characteristics and maintenance implications of AC and DC traction motors.

Braking: principles of rheostatic/regenerative braking; brake resistors.

5 Understand the fundamentals of DC electric power collection and transmission

Features of DC traction supply: supply voltages, e.g. 630V, 750V, 1.5kV; relationships between voltage, current and frequency; 630V and 750V DC collection equipment, e.g. third/fourth rail and collector shoe gear (top contact, side contact, bottom contact), OHLE and pantographs; earth return and bonding.

Traction motors: use of AC traction motors; speed control for DC traction motors.

Factors impacting on performance of DC electrification: sub-zero temperatures, snowfall; equipment to reduce effects of snowfall, e.g. sleet brushes, third rail scrapers or heated liquid.

Traction unit types and system/components: thyristor control; filter circuits, e.g. RFI suppression; static converter; traction inverters.

Maintenance of traction units: types and periods of maintenance regimes used.

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P1 Describe the design, construction, maintenance and operation of train suspension and the purpose of systems fitted to trains		
P2 Compare conventional body/bogie mountings		
P3 Explain how failed suspension increases damage to both track and vehicles, the importance of a regular maintenance programme for traction and the implications of a delay in this	M1 Compare how two different suspension systems might fail in operation and how maintenance could reduce damage to track and vehicles	D1 Evaluate how design, construction and maintenance of suspension systems affect failure rates

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P4 Describe the operation of a typical air/electric brake system and the safety systems that can take over the operation of a train braking system in the event of an operator error	M2 Explain the operation of an air or electric brake system and how the choice of friction pad contributes to its safe operation	
P5 Describe the various types of friction pad in use on traction and rolling stock		
P6 Explain the implications for the Train Operating Company (TOC) of a unit in service being unable to release brakes while on the line		
P7 Describe how a variable load valve works and what symptoms would become apparent in the event of failure		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P8 Describe the operation of a wheel slide prevention system and why automatic sanding is necessary		
P9 Explain the use of round train circuits and the implications of their failure		
P10 Describe a typical wheelset, identifying all components and different types of wheel profile and ways in which wheelset life may be extended	M3 Explain the relationship between wheel profiles and their specific use	
P11 Describe in situ test and inspection methods for traction and rolling stock wheelsets, including the implications of a 'flat' on a wheelset and the risks associated with changing out a wheelset		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P12 Describe the relationship between the design, construction and operation of an AC electrical power unit and how an AC vehicle's main transformer works and the need for different voltage outputs		
P13 Compare the performance, reliability characteristics and maintenance implications of AC and DC traction motors		
P14 Explain the principles of rheostatic/ regenerative braking		
P15 Describe DC traction supply in terms of the relationship between voltage, current and frequency and a typical 630/750V DC collection equipment		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P16 Describe the systems that are in place to offload and prevent arc dragging at both section gaps and neutral sections	M4 Explain how different systems prevent arc dragging	
P17 Describe how the speed of DC traction motors is controlled and how a traction unit operating on a DC electrified railway may utilise AC traction motors		
P18 Describe the main performance issues resulting from sub-zero temperatures and snowfall	M5 Explain methods used to minimise performance issues resulting from sub-zero temperatures and snowfall	D2 Evaluate one method for minimising performance issues resulting from sub-zero temperatures or snowfall

Essential guidance for tutors

Assessment

This unit is suitable to be delivered in conjunction with *Unit 39: Underground Rail Passenger Comfort, Safety and Security*.

Learners will need to provide descriptions of the design, construction, maintenance and operation of at least one type of train suspension (P1) and then provide a description of the purpose of at least two suspension systems fitted to different types of train vehicle. P2 requires a comparison between two types of conventional body/bogie mountings, for example swinger hanger or lateral stiffness bolster spring bogie. Learners will need to explain the implications of suspension failures in terms of damage to both track and rail vehicles (P3). Learners need to compare the ways in which two different suspension systems fitted to different types of rail vehicle might fail, for example comparing a system with active damping to one with mechanical damping, explaining how maintenance can reduce the effects of failure on both track and vehicles (M1). Then learners must evaluate how different designs, construction types and use of maintenance affect the failure rates of suspensions (D1), using reliability data to support judgements.

Learners could be set a single assessment task that links together P4, P5, P7, P9 and M2. The activity could be based on a given air/electrical brake system that would allow learners to describe the operation of the system (P4) and then consider the different types of friction pads that could be used with the system (P5) and the function of the variable load valve in the system (P7). Learners could then explain how the safe operation of an air or electric brake system may be influenced by the choice of friction pad. Learners also need to explain how round train circuits are used to ensure safe operation of trains and the implications of failures of these circuits (P9).

A further task could consider the safety systems that are present in the braking system, such as the systems that take over operation of the braking system if there is operator error (P4), the systems that prevent wheel slide, and the reasons why underground railway stock needs to have automatic sanding systems (P8). Finally, learners need to explain the consequences of the failure of systems in a unit to release the brakes when on the line, and the various implications of this to a Train Operating Company, including financial penalties and the need to potentially withdraw a unit from service (P6).

Evidence for learning outcome 3 is likely to be in the form of an illustrated technical report that consists of three sections. The first part would address P10, along with M3. Learners will need to produce an illustrated report that describes a typical example of a wheelset, with all components identified (P10). This could consist of exploded drawings or other technical diagrams. Learners must also include illustrations of the different wheel profiles that can be used on railway vehicles, explaining the link between each wheel profile and its use, for example tapered profile wheels are used on passenger vehicles in order to assist with stability and for travelling around curves.

The second part of the report could address P11 through an explanation of the risks associated when changing out wheelsets before describing the tests and inspection methods that can be used for wheelsets – for example, visual inspections for tread run-out or wheel ‘flats’ – and then explaining the importance of carrying out regular maintenance on wheelsets and the implications of maintenance for rolling stock.

The final part of the report could consider the implications of a ‘flat’ on a wheelset (P11), for example removal of a vehicle from service or reduced running speeds. The report must include a discussion of ways in which the life of a wheelset could be extended.

For learning outcome 4, learners are likely to produce an illustrated report that firstly examines the AC traction supply, then examines on-train equipment and systems before finally moving on to consider rheostatic or regenerative braking systems.

The first part of the report could describe the relationship between the design, construction and operation of an AC electrical power unit (P12) and the electrical traction supply, with appropriate calculations, to describe the relationship between voltage, current and power, before considering methods used to offload and prevent arc dragging at neutral sections (P16) – for example the use of trackside magnets – with explanations of at least two alternative approaches being required for M4.

The second part of the report could consider on-train equipment, including illustrated diagrams that explain operation of a typical AC traction power control system that shows variations to allow for the control of both AC and DC traction motors (P12). Learners must then describe, using illustrations and sketches as appropriate, how the main transformer works, giving reasons for the need for a range of different voltage outputs. Learners then need to continue to compare AC and DC traction motors by considering performance, reliability and maintenance (P13). Finally, learners are required to explain the principles of rheostatic or regenerative braking systems (P14).

A similar approach could be used for learning outcome 5, where learners investigate similar systems for DC traction.

The first part of the report could describe the DC electrical traction supply, with appropriate calculations, to describe the relationship between voltage, current and power (P15), before considering methods used to offload and prevent arc dragging at neutral and section gaps (P16) for third rail systems and overhead systems.

The second part of the report could consider on-train equipment, including illustrated diagrams that explain the construction and function of shoe gear for 630V fourth rail systems (P15), for example London Underground trains. Learners must then describe, using illustrations and sketches as appropriate, how the speed of DC traction motors is controlled (P17), and how AC traction motors can be used for DC railways. The final part of the report could address the linked criteria of P18, M5 and D2 through an activity that describes performance issues associated with snowfall and sub-zero temperatures, before explaining two methods used to minimise performance issues (M5) and evaluating one method, such as the use of sleet brushes (D2).

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, M1, D1	Suspension systems	An activity that examines the suspension systems used for different types of underground rail vehicles that are used on contrasting types of underground rail system, e.g. London Underground or Newcastle Metro.	A written report that considers two different types of suspension used in railway vehicles.
P4, P5, P6, P7, P8, P9, M2	Underground railway braking systems	An investigation into the braking systems used on underground rail vehicles.	A series of short illustrated reports that consider the characteristics, operations and safety features of railway braking systems. The report will include technical illustrations and diagrams to help describe concepts.

Criteria covered	Assignment title	Scenario	Assessment method
P10, P11, M3	Wheelsets	Investigation of wheelsets and their maintenance.	An illustrated written report, in three parts, that investigates the parts of a wheelset and examines inspection for faults and maintenance requirements.
P12, P13, P14, M4	AC Traction	Investigation of infrastructure and on-train AC traction systems.	A written report on AC traction systems that considers infrastructure and on-train equipment.
P15, P16, P17, P18, M5, D2	DC Traction	Investigation of infrastructure and on-train DC traction systems.	A written report on DC traction systems that considers infrastructure, on-train equipment and the effects of weather on the performance of systems.

Essential resources

Learners should be given a variety of technical documents and drawings of parts of traction systems.

Indicative reading for learners

Textbooks

Bonnett C – *Practical Railway Engineering*, 2nd edition
(Imperial College Press, 2005) ISBN 9781860945151

Glover J – *Principles of Railway Operation* (Ian Alan Publishing Limited, 2013)
ISBN 9780711036314

Steimel A – *Electric Traction – Motive Power and Energy Supply: Basics and Practical Experience* (Oldenbourg, 2008) ISBN 9783835631328

Unit 39:

Underground Rail Passenger Comfort, Safety and Security

Level:	3
Unit type:	Pathway 1 Mandatory
Guided learning hours:	60

Unit introduction

When underground rail networks are successfully operated they bring many benefits to a city, including helping to reduce traffic congestion in the streets, promoting commerce and benefiting the environment, for example by assisting in reducing vehicle exhaust fumes. Successful operation includes ensuring that underground rail networks are comfortable, safe and secure, which encourages their continued use by passengers. Passengers must receive clear information on their approach to stations and on disruptions to rail services and must receive instructions in the event of an emergency while travelling. Underground rail carriages must be ventilated and maintained at a suitable temperature for users.

As customers progress through an underground rail facility, they board and alight from rail carriages speedily using automatic doors, and are monitored from a central control room using closed-circuit television to ensure their safety.

This unit enables learners to develop their knowledge of the purpose, installation, use and maintenance of different types of passenger comfort, safety and security systems. It introduces the engineering principles for heat transfer and also electrical and pneumatic control systems used on underground rail vehicles. The unit develops learners' understanding of key components and the methods used for fault finding on essential systems. These systems include railway doors and vehicle trim used in rail underground vehicles.

Note that the use of 'e.g.' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'e.g.' needs to be taught or assessed.

Learning outcomes

On completion of this unit a learner should:

- 1 Understand closed-circuit television systems
- 2 Understand heating, ventilation and air conditioning systems
- 3 Understand passenger information systems
- 4 Understand train door systems
- 5 Understand train vehicle trim.

Unit content

1 Understand closed-circuit television systems

Purpose of closed-circuit television systems: protecting the health and safety of rail employees, customers and members of the public, e.g. enabling the driver or central control room to confirm people are clear of an underground vehicle's doors; preventing and detecting crime and antisocial behaviour; monitoring rail traffic and passenger numbers in real time.

Components, function and technical requirements of a closed-circuit television system: different types of cameras, their characteristics, capabilities and positioning, e.g. analogue and IP cameras; different lens types, e.g. fixed, automatic iris, zoom, adjustable fixed, infrared; moveable camera mounts and controllers; monitors and displays including switcher unit; wireless and fixed cable systems.

Types and function of closed-circuit television system recording media: different types of recording media including: video content analysis, e.g. automatic smoke detection; facial recognition systems, e.g. identifying undesirable entrants at turnstiles; people counter systems, e.g. counting people passing pre-defined areas; digital video recorder (DVR) and network video recorder (NVR).

Failure of closed-circuit television systems: implications of failure including: the importance to health and safety of passengers, rail operators and the public of being able to speedily and easily pass on information and intelligence concerning people and vehicles in crime/non-crime events on an underground system; methods used for fault finding including: diagnostic software, ohm meter and system schematics.

Appropriate use of closed-circuit television systems to respect privacy: Data Protection Act 1988; Human Rights Act 1988 (articles 6, 8, 10, 11 and 14); Freedom of Information Act 2000; The Information Commissioner's Code of Practice; impact of these on the operation of closed-circuit television systems; the requirements of 'privacy' zones; responsibilities and actions to be taken if a request for information is received.

2 Understand heating, ventilation and air conditioning systems

The principles of heat transfer: conduction including: Fourier's law, thermal conductivity, thermal resistance, temperature gradient; convection including: forced and natural convection, convective heat transfer, film and overall coefficient; radiation including: natural radiation, Stefan-Boltzmann law, black and grey body radiation, emissivity, absorptivity, correction for overall heat coefficient; relationship of pressure to temperature in a sealed HVAC system, e.g. suction and discharge pressure, enthalpy.

Components and function of HVAC systems: components including: compressor, evaporator, condenser, capillary tubes, thermostatic expansion vessel, reversing valve, exhaust ducts and fans, air diffusers and intakes; function of system including: heating, ventilation, air conditioning, emergency ventilation; the refrigeration vapour and compression cycle.

Operation and control of HVAC systems: two-stage heating and cooling; operating conditions, e.g. operating in all environments and climatic conditions, maintaining and restoring interior temperature with loading/unloading of carriage and recovering heat losses due to the train's motion; power supply; freeze protection circuits and thermostats; methods to stagger start refrigerant compressor motors; temperature sensor types and location, e.g. automatic microprocessor temperature controls within passenger seating area and an evaporator coil to detect ice build-up; manual temperature control adjustment device and location; zone heating and cooling demand; use of pressure transducers.

HVAC maintenance and safe working procedures: fault finding, e.g. use of laptop computer and HVAC diagnostic firmware, operational tests, maintenance frequency, unit replacement, e.g. use of lifting equipment to remove/install HVAC units, spill trays, electrical isolation and static discharge, fire and gas detection; noise protection; avoiding contact with hot/cold surfaces, purging system, anti-microbial treatment.

Environmental considerations: depletion of ozone layer and contribution to global warming, hydrofluorocarbons, European Fluorinated (F) Gas Regulations and Ozone Depleting System Regulations.

3 Understand passenger information systems

Key components of a passenger information system and their operation and function: public address system; passenger emergency call system and talkback, e.g. to alert the driver to a problem with the train and/or apply the emergency brakes to the vehicle; LED information panels, e.g. to provide information on the next station or stop; driver's audio system.

Automatic announcements: provided by onboard computer, pre-recorded speech segments transmitted to the public address system; use of LED displays, ability for software to enable communication with only a selected part of the train, e.g. first class passengers or where the train is due to split at a particular station.

Importance to safety and comfort of a functioning passenger information system: managing congestion in rail facilities, informing passengers about changes to timetable and disruptions, method to communicate instructions in response to an emergency situation, e.g. displaying information on means of emergency exit, providing passengers with useful information, e.g. information on routes or fares.

Fault finding: using downloads, diagnostic software, system schematics and MVB analysis if applicable.

4 Understand train door systems

Components, function and operation of door systems: pneumatic systems that use compressed air to control train doors and components including: pneumatic actuators, compressor, filter, pressure regulator, lubricator, cylinder pistons, directional control valve; electrical door systems and components including: electric actuators, locking mechanisms, encoder, relays, motors and electric circuits; Selective Door Operation, e.g. controlled by Global Positioning System (GPS), Driver Only Operation; materials including aluminium casting and aluminium honeycomb composites.

Design of door safety systems: central locking systems which ensure trains do not start until doors are locked and passengers cannot open them while the vehicle is moving, warning alarm and light systems to inform passengers to 'stand clear' when doors are closing, drag detection systems, obstacle detection systems.

Fault finding: train management systems, using downloads, door diagnostic unit software, system schematics and MV analysis if applicable; wrong side failure and implication to exterior saloon door system, e.g. door opens at the wrong time.

Correct saloon door set up: advantages and disadvantages of head mounted door or floor mounted activators; types of door locking mechanism; impact on the serviceability of door components, e.g. noise, dust, unit life in high traffic areas; safety implications including: speed of opening, obstruction sensors and force applied upon opening.

5 Understand train vehicle trim

Passenger counting systems: types, e.g. thermal counters, video counters, infrared beam counters, pressure pads; use of counters, including: carriage occupancy monitoring, detection and analysis of passenger flow, link to ventilation and heating systems.

Passenger train glazing systems: impact resistance specification for windscreens; laminated glass; glass spall.

Emergency lighting: power supply, e.g. independent battery; colour of lighting, e.g. white; minimum requirements for period of lighting after the loss of main supply; location of lighting, e.g. egress points, 750 mm above the floor in the saloon, escape routes and adjacent to emergency equipment.

Train housekeeping: preparing trains for service, e.g. exterior wash, interior sweeping, dusting and vacuuming; manpower and equipment; requirements for night shift work to prepare vehicles for morning operation at peak demand.

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P1 Explain the components used, technical requirements and their function within a typical closed-circuit television system		
P2 State the purposes of a closed-circuit television system in terms of passenger security and comfort and the implications for passengers of a closed-circuit television system failing, indicating the methods used for fault finding on the system		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P3 Explain the implications of using a closed-circuit television system with respect to the privacy of passengers and the reasons for different types of recording media being used in typical closed-circuit television systems	M1 Compare and contrast the types of recording media used with different camera systems	
P4 Explain the principles of heat transfer in terms of conduction, convection and radiation and the relationship between temperature and pressure and how this relationship is used in an HVAC system, and the stages and operation of a typical rolling stock HVAC system		
P5 Describe the operation of an air conditioning refrigeration system in a typical rolling stock HVAC system and the function of the components used		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P6 Describe a typical control unit for an HVAC used within rolling stock and outline any associated maintenance requirements, identifying the environmental and legal implications of a release of refrigerant into the atmosphere	M2 Explain the importance of maintaining an HVAC unit in serviceable condition	D1 Evaluate the potential impact on passengers and a train operator of the failure to maintain an HVAC unit in serviceable condition
P7 Describe a typical passenger information system, showing all the key components including controllers, displays, passenger alarms and on-train audio		
P8 Demonstrate an understanding of the relationship between passenger alarms and emergency brakes	M3 Compare the operation of different types of passenger alarm system available to activate the emergency brakes	

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P9 Describe the function and operation of each of the passenger information system components and explain how automatic announcements are controlled on a typical passenger information system, and the importance of a functioning passenger information system in terms of passenger safety and comfort		
P10 Demonstrate the ability to fault find on passenger information system using downloads, system schematics and MVB analysis if applicable		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P11 Explain the operating principles of electrical/electronic and pneumatic door systems and the components, materials used and operational requirements of exterior door systems	M4 Compare and contrast the safety implications of selecting a pneumatic or electrical door operating system	D2 Evaluate the limitations of pneumatic and electrical door operating systems.
P12 Identify the safety devices fitted to exterior saloon doors and describe the operation of these devices		
P13 Explain the term 'wrong side failure' and any implications that such a failure would have on the exterior saloon door system		
P14 Demonstrate the ability to fault find on the cab and door systems using downloads, diagnostic software, system schematics and MVB analysis if applicable		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P15 Explain the importance of a correct mechanical saloon door set up with regard to normal operation, safety implications and impact on the serviceability of door components		
P16 Describe a typical passenger counting or load system and explain the reasons why a TOC would choose to install or use such a system		
P17 Describe the required properties of the glazing used on passenger trains		
P18 Explain the minimum lighting requirements of a passenger train if it were to lose its main source of electrical power		

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P19 Describe the logistics of maintaining a clean and tidy service for passengers from the perspective of train down time and manpower requirements	M5 Explain the importance of maintaining a clean and tidy service for passengers	

Essential guidance for tutors

Assessment

This unit is suitable to be delivered in conjunction with *Unit 38: Underground Rail Vehicle Traction and Associated Systems*. By completing both units, learners will gain a more complete knowledge of underground rail vehicles, combining learning about vehicle traction power units with carriage comfort and security systems.

Four assessment instruments will be required for this unit. If practical work and tests are also used, the total number of pieces of assessed work could be even more than this. This should be carefully considered so that it does not place an unduly high assessment burden on learners or the tutor.

Wherever possible, practical work should lead to a final outcome that can be handed in for assessment at the end of the session without further need for report writing. This will help control authenticity of evidence and also keep the assessment activities short, sharp and relevant.

An activity for P1 and P2 would require learners to consider a scenario where a rail operator for a new model of underground rail vehicle requires a closed-circuit television system. To achieve P1, learners could prepare a sales letter to the rail operator providing an explanation of how their closed-circuit television system would assist passenger safety and security, covering the key purposes in the *Unit content*, i.e. crime prevention and monitoring passenger numbers. To accompany the letter, learners could draw a diagram of the layout of a typical closed-circuit television system, including all components detailed in the *Unit content* and their interconnection. Learners will need to annotate the diagram clearly, identifying the function of each component and its technical requirements – for example for a CCTV camera component this would include details of the mounting, possible positions, lighting requirements and the types of lens. For P2, learners could prepare a fault-finding guide for a rail vehicle closed-circuit television system. The activity should be structured so that learners include as an introduction an overview of the implications of a system failing (e.g. of intelligence on people movement or an inability for the train driver to confirm that the carriage doors are free from obstruction and can be closed), followed by methods employed for fault finding, including the use of diagnostic software or an ohm meter to test the proper resistance and termination of coaxial cables.

An activity could be used to capture evidence for P3, extending the scenario adopted for P1 and P2. Learners could be required to prepare a guidance document on the use of the closed-circuit television system, for the new model of underground vehicle proposed for the train operator. As part of the activity, learners would be required to explain the reasons for the different types of recording media used in closed-circuit television systems covering fully the *Unit content*, such as video content analysis that can automatically detect smoke in an underground vehicle. In addition, learners would also be required to provide guidance on the implications of the use of closed-

circuit television system in terms of privacy, covering both legislation and the use of 'privacy zones'.

For P4, learners need to explain the principles by which heat transfers from one place to another, including conduction, convection and radiation. Learners will need to consider Fourier's law of heat conduction and might carry out a laboratory experiment recording the heat conducted from a metal bar or surface. A similar laboratory experiment could be completed to study convection; learners might observe the movement of water in a tray over a heat source by injecting food colouring. Additionally, for radiation, learners will need to consider the Stefan-Boltzmann law and could complete basic calculations for the radiance and emissivity of black and grey bodies.

Learners could achieve P5 through an appropriately structured practical involving dismantling or assembling an HVAC training rig. Tutors could capture evidence by using an appropriate record of observation and oral questioning of each learner during the practical activities used for delivery. Alternatively, learners could achieve P5 using a paper-based assessment such as preparing a systems diagram or by means of an HVAC system computer-based simulation training software package. Whichever method is used, centres need to ensure that sufficient evidence is available to satisfy the pass criteria as outlined in the *Unit content*. Learners need to explain the relationship between pressure and temperature in a sealed HVAC system covering suction and discharge pressures, and enthalpy. Learners will need to describe the full range of components of an HVAC and air conditioning refrigeration system (compressor, evaporators, condenser, capillary tubes, thermostatic expansion vessel, reversing valve, exhaust ducts, fans, air intakes and diffusers), and explain their function and stages of operation. Learners must describe safety controls required when working on or around HVAC systems; these include when lifting equipment and procedures for the removal/installation of an HVAC unit, use of drip pans for spills, measures for avoiding contact with extreme hot/cold surfaces, fire and gas detection and electrical unit isolation. Learners could prepare a risk assessment as evidence to satisfy this criterion.

P6 involves learners describing a typical control unit for an HVAC unit, including the use of sensors within the passenger cabin to monitor temperature and within the evaporator coil to detect ice build-up; use of pressure transducers; and the attributes, location and manual override features of the main HVAC control board. Learners are required to describe how laptop computers installed with HVAC diagnostic software are used for period maintenance of the control unit, including maintenance frequency, checking that the correct version of HVAC firmware is installed and the completion of operational test to verify control modes. Learners will need to explain the impact on the ozone layer, and the contribution to climate change, arising from a release of refrigerant. Learners could achieve this by preparing a chemical safety data sheet for a typical hydrofluorocarbon refrigerant. Learners will need to demonstrate an understanding of the environmental legislation governing the use of refrigerant in air conditioning units, covering the requirements of the regulations in the *Unit content*.

For P7, learners could draw a diagram of a typical passenger information system showing all the key components that are listed in the *Unit content*. Learners would need to annotate the diagram, describing the function and operation of each of the components, for example the use of LED display panels to provide information on the next station or stop, and their manual or automatic operation from the control centre of an underground rail facility.

P8 requires that learners demonstrate an understanding that the passenger alarm located in a carriage can either directly stop the train or send an alarm to the driver so that they can stop the train. Learners need to describe the mechanism by which both alternatives stop the train, for example the alarm may directly cause a break in the continuity of the brake pipes (whether vacuum or air brakes) resulting in an immediate loss of brake pressure (or vacuum), causing the brakes to be applied and the train to halt. Annotation of the diagram for P7 could be an appropriate way to achieve this criterion.

To satisfy P9, learners must explain the control of pre-recorded audio and automatic LED announcements generated by a rail vehicle's onboard computer, including the ability to zone messages. Again, this evidence might be annotated on a diagram of a typical passenger information system.

For P10, learners need to demonstrate ability to fault find on a passenger information system. This criterion lends itself to a practical activity using simulated diagnostic software to find typical faults such as distorted images on a monitor display or loss of audio. Tutors could use printouts from the software or an observation record as evidence of achievement. Learners are required to describe the importance of having a functioning passenger information system. Learners will need to cover the *Unit content*. Written evidence would be suitable for this criterion.

A second practical assessment could be used for P11, P12, P14 and P15, involving dismantling or assembling parts of a door opening system for a pneumatic and electrical train door. Tutors could capture evidence by using an appropriate record of observation and oral questioning of each learner during the activity. Alternatively, a video could be taken of each learner. The practical activity would require each learner to clearly satisfy the criteria for P11, P12, P14 and P15. For P11, learners would need to explain the principles of how a pneumatic door operates (for example use of compressed air or inert gas under pressure to produce a force in a cylinder to move a piston) and an electrical door (for example conversion of electrical energy to a force using encoder, activators, relays and motors). Learners must describe key door components, materials used, and their operation as given in the *Unit content*, including the electrical/electronic methods of control, including Selective Door Operation and Driver Only Operation. For P12, learners need to describe the operation of safety devices fitted to exterior saloon doors, including central locking, closure, drag-detection and obstacle detection systems. As part of the practical activity, learners could use door diagnostic software to find standard faults, for example failure of a

door's audio closure warning signal or light (P14). Finally, they need to explain the correct mechanical set-up of a saloon door, addressing operation, serviceability and safety implications covered in the *Unit content* (P15).

To satisfy P13, learners will explain that a 'wrong side failure' is a failure condition in a piece of railway signalling equipment that results in an unsafe state, and discuss the implications for an exterior saloon door system, for example a train leaving a station with the door open. Evidence for this could be oral with an observation record, a video, or a written explanation.

Evidence for P16 is descriptive; learners will need to provide details of typical passenger count systems (for example thermal, video and infrared beam counters) and why these are used by train operating companies, including managing congestion, controlling the operation of train doors, and managing the frequency of services. Written evidence would be suitable for this criterion.

The evidence for P17 is again descriptive. Learners will need to cover the properties of laminated glass (including impact resistance and spall criteria) and the material's selection for use in the glazing of carriage windows and a train engine unit's windscreen. As evidence for this criterion, learners might produce a PowerPoint presentation to train other technicians on glazing rail vehicles.

For P18, learners are required to explain the emergency lighting requirements for a passenger train. This criterion could be achieved by learners producing a wiring diagram for an auxiliary lighting system. Learners need to explain the requirements for an independent power supply, lux levels, the position of lighting and, where appropriate, the colour to be specified to avoid potential confusion with signals.

For P19, learners are required to describe how rail vehicles are cleaned at the end of a journey. Learners need to describe typical cleaning activities (including exterior wash, interior sweeping, dusting, vacuuming and litter collection), resource requirements (including staffing and equipment) and the timing of cleaning activities. Learners must cover the implications of having a train out of operation. Learners might achieve this criterion by preparing a cleaning programme for a case study train service, perhaps leaving or arriving at a local station.

To achieve a merit, for M1 learners could complete an extension task to P3, comparing and contrasting the recording media used with analogue and IP camera systems. For example, learners might cover when digital video recorders or network video recorders are to be used with the camera systems.

M2 is an extension of P6, requiring an explanation of the importance of maintaining an HVAC system in serviceable condition. Learners will need to consider the importance of appropriate maintenance on the performance and safety of key HVAC components.

To satisfy M3, learners must compare the operation of different types of passenger alarm system available to activate the emergency brakes of a train (P8).

M4 is an extension of P11. Learners must compare and contrast the safety implications of selecting a pneumatic or electrical door operating system, for example electric actuators do not suffer from air pressure leaks and tend to be quieter than pneumatic actuators.

To achieve M5, learners must explain the importance of maintaining a clean and tidy service for passengers, for example ensuring repeat travel by passengers on a service and thereby maintaining income for a train operating company from train fares. Learners will need to consider in their response the impact on the train operating company and the comfort of passengers. The evidence for this criterion is likely to be written.

To achieve a distinction, for D1 learners will need to evaluate the impact on both passengers and rail operators of the failure of an HVAC system. Learners might consider the impact on passenger comfort and safety, operation of train services, passenger patronage and a rail operators' financial bottom line. The evidence for this is likely to be a written evaluation.

For D2, learners must evaluate the limitations of pneumatic and electrical door operating systems, considering space requirements for installation, noise, potential for leaks, maintenance requirements and the length of the in-service life span of each system before replacement is required.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2, P3, M1	Rail vehicle surveillance systems	For a new model of underground rail vehicle, learners explore the requirements for a closed-circuit television system, interpret and prepare a guidance document for the train operator company, including a network diagram.	A written report providing the learner's interpretation of the components, features, technical requirements and appropriate operation of the system.
P4, P5, P6, M2, D1	Heating, ventilation and air conditioning systems	An activity requiring learners to dismantle or assemble an HVAC training rig, preparing beforehand a written risk assessment and a chemical data sheet for a refrigerant.	A portfolio of evidence containing tutor observation record, written risk assessment and chemical data sheet.

Criteria covered	Assignment title	Scenario	Assessment method
P7, P8, P9, P10, M3	Passenger information systems	A mixed activity in which learners prepare an annotated diagram for a new passenger information system required for a scenario rail vehicle and use simulated diagnostic software to find typical faults.	An annotated engineering diagram of a passenger information system, with supporting written report. Output from diagnostic software and/or tutor observation record.
P11, P12, P13, P14, P15, P16, P17, P18, P19, M4, M5, D2	Pneumatic and electrical train door systems including train vehicle trim	A mixed activity comprising five tasks. The first task requires learners to describe typical passenger counting systems. For the second task learners prepare a training presentation for other technicians explaining the properties of glazing for rail vehicles. The third task requires learners to prepare an annotated emergency lighting diagram for a carriage. The fourth task requires learners to prepare a programme for cleaning a rail vehicle. In a final practical activity, learners are required to dismantle or assemble a train door system, and use door diagnostic software to find faults.	A video recorded under controlled conditions or an observation record, with supporting output from diagnostic software. A portfolio of evidence containing a written report, presentation slides, engineering diagrams and a cleaning programme.

Essential resources

Learners should be given access to diagnostic software for train door systems and passenger information systems. It is desirable that centres also provide access to an HVAC and train door training rig.

Indicative reading for learners

Textbooks

Bonnett C – *Practical Railway Engineering*, 2nd edition
(Imperial College Press, 2005) ISBN 9781860945151

Boyce A, Cooke E, Jones R and Weatherill B – *BTEC Level 3 National Engineering Student Book* (Pearson, 2010) ISBN 9781846907241

Boyce A, Cooke E, Jones R and Weatherill B – *BTEC Level 3 National Engineering Teaching Resource Pack* (Pearson, 2010) ISBN 9781846907265

Kruegle H – *CCTV Surveillance: Video Practices and Technology*
(Butterworth-Heinemann, 2006) ISBN 9780750677684

Tooley M and Dingle L – *BTEC National Engineering*, 3rd edition (Routledge, 2010)
ISBN 9780123822024

Unit 40: Engineering Design

Level:	3
Unit type:	Additional
Guided learning hours:	60

Unit introduction

An understanding of how the design process operates within an engineering business is important for anyone considering a career in the design and manufacture of products. This unit provides learners with the opportunity to consider design in a holistic way. It combines study of the technical aspects of engineering design with wider issues such as the environment, sustainability and legislation.

The unit introduces and develops the concept of design for manufacture. It is crucial that the design process be effective. Success in the marketplace can be achieved only if products are fit for purpose, marketable and meet customer requirements. The importance of market research, generation of new ideas and the consequences of poor design are investigated.

Learners will also investigate the issues which influence whether a design proposal should be developed into a final solution suitable for manufacture. These issues include the impact of legislation and standards, the need to conform to environmental and sustainability requirements, materials selection and the types of manufacturing process available. On completion of the unit learners will understand the wider implications of engineering design and the reasons why it cannot be carried out in isolation from the rest of the manufacturing/production process.

The unit content is linked together through a practical task which starts with learners interpreting the requirements of a customer and producing a product design specification (PDS). This is followed by an investigation into the legislation, standards and reference sources that are used by designers who work in manufacturing engineering. This knowledge is then used to influence the production of their own design proposals. These proposals are refined and developed into a final design solution which meets the requirements of the customer. Design ideas will have been communicated using a number of techniques including sketching and formal engineering drawing, design calculations and written commentary.

Learning outcomes

On completion of this unit a learner should:

- 1 Know how the design process operates when dealing with customers
- 2 Know the impact of legislation, standards and environmental and manufacturing constraints can have on the design function
- 3 Be able to prepare design proposals that meet the requirements of a product design specification
- 4 Be able to produce and present a final design solution.

Unit content

1 Know how the design process operates when dealing with customers

The design process: triggers e.g. market pull, demand, profitability, technology push, innovation, market research; process of design for manufacture; decision making; use of new technologies e.g. computer aided design (CAD), simulation, rapid prototyping, computer integrated manufacture (CIM); lines of communication

Customer: customer/client relationship; types of customer e.g. external, internal; requirements of customer e.g. performance specifications (physical dimensions, mass), compliance to operating standards, reliability and product support, end of life disposal, production quantities (custom built, modification to an existing product, small batch, large volume)

Product design specification (PDS): analysis of customer requirements; production of an agreed PDS; documentation e.g. physical dimensions, materials, mass, operation and performance

2 Know the impact of legislation, standards and environmental and manufacturing constraints on the design function

Legislation and standards: relevant and current legislation, standards and codes of practice e.g. British Standards (BS), International Standards (ISO), electromagnetic compatibility (EMC) directive, European legislation (European Conformity (CE marking))

Environmental and sustainable constraints: energy efficiency; environmental impact; constraints e.g. Environmental Protection Act, Waste Electronic and Electrical Equipment Directive; end-of-life disposal e.g. refurbishment, recycling, disassembly, material recovery, non-recyclable components

Manufacturing constraints: availability of resources e.g. labour, material, equipment; influence of physical and mechanical properties of a material in relation to manufacturing methods; cost effective manufacture e.g. set up cost (jigs, tools), production quantities; health and safety in the workplace e.g. Health and Safety at Work Act, Control of Substances Hazardous to Health (COSHH) Regulations

3 Be able to prepare design proposals that meet the requirements of a product design specification

Requirements of a PDS: interpretation of technical requirements e.g. operating performance, physical dimensions; interpret economic requirements e.g. production quantities, product life, market place positioning

Prepare design proposals: ideas generation e.g. research into existing products, freehand sketching, simulation, flow charts; realistic design proposals e.g. fitness for purpose, manufacturability, aesthetics, ergonomics

Design reference material: manufacturers' catalogues e.g. screw fixings, bearings, seals, electrical connectors, drive belts, gear drives; materials databases e.g. mechanical properties, physical properties; design databases e.g. structural beam sections, corrosion protection, anthropometric data

4 Be able to produce and present a final design solution

Final design solution: evaluation of proposals and selection of most appropriate for further development e.g. suitability for available manufacturing processes, cost effectiveness, contribution to profits, visual appearance; development of design proposal into a feasible solution suitable for prototype manufacture e.g. specify materials, appropriate manufacturing processes, estimation of manufacturing cost, quality; conformity to relevant legislation and design standards

Presentation techniques: 2D engineering drawings e.g. general arrangement drawing, assembly drawing, detail drawings, circuit diagrams, flow diagrams, schematic diagrams; drawing conventions and relevant British Standards e.g. BS308, BS8888, BS7307, BS3939, BS2197; documentation e.g. design diary, logbook, product specification; design calculations e.g. sizes of materials to meet strength requirements, electric motor power, electronic circuit performance, battery life

Assessment and grading criteria

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all the learning outcomes for the unit. The assessment criteria for a pass grade describe the level of achievement required to pass this unit.

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P1 describe the operation of the design process in an engineering company	M1 explain the possible impact of a poor customer design process on customer relationships and requirements	D1 evaluate the impact of legislation and standards on the design process in relation to the profitability of the business
P2 interpret the requirements of a given customer and produce a product design specification	M2 explain the importance of using a range of accurate design reference materials when developing design proposals	D2 evaluate a final design solution against customer requirements and a PDS, and suggest improvements.
P3 describe the appropriate legislation and standards which apply to the design of two different products	M3 explain the issues which influence whether a design proposal should be developed into a final solution suitable for manufacture.	

Assessment and grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
P4 describe the environmental, sustainability and manufacturing constraints which influence the design of a given product		
P5 produce design proposals which meet the requirements of a given PDS		
P6 extract reference information from component manufacturers' catalogues and materials and design databases		
P7 use a range of techniques to present a final design solution which meets the requirements of a given PDS and relevant legislation and design standards.		

Essential guidance for tutors

Assessment

Assessment of this unit could be covered through three assignments. To achieve a pass grade learners are expected to describe how the design process operates in an engineering company and its links to other aspects of the business. It is suggested that during the first assignment the evidence for P1 could be gained by learners visiting the design department of an engineering company, carrying out an interview with an engineering designer and preparing a short report. It is important that learners understand that design cannot be carried out in isolation and that it is an income-generating function with the customer having the final say.

After the visit or similar activity, a written task for P2 should be given that asks learners to produce a PDS from the requirements of a given customer.

A second assignment could involve a research activity. Two different products need to be given to each learner and research carried out to allow them to describe the legislation and standards that apply to each product (P3) and the environmental, sustainability and manufacturing constraints that influenced the design of one of these products (P4).

Learners will need to demonstrate a basic mastery of design and drawing skills and they should be producing sketches and drawings which are broadly in line with British Standards and which use simple drawing conventions. There should be some evidence of design calculations when presenting evidence for P5, P6 and P7.

For assessment of these criteria a third assignment could be set where a PDS should be given and learners asked to produce a range of design proposals (P5). Three proposals would generally be sufficient although, if the solutions are complex, two would be enough. In doing this, it is important that learners use design reference material (P6) and a range of techniques to present the final solution (P7). The techniques used are dependent on the solution (for example if it involves an electronic system then circuit diagrams will be needed as well as perhaps general arrangement drawings).

Learners will demonstrate a basic understanding of the use of information sources such as books, technical reports, data sheets, catalogues, CD ROM and online databases. They should be selecting, interpreting and applying data extracted from a limited range of sources and will have been given guidance on what to look for.

Design work must show good evidence of knowledge gained from the linked units so that learners can be critical about their evolving designs and adapt them, rather than pursue a single idea. Grading criteria P5 and P6 link the extraction of reference information about materials and components to the design proposals being put forward by the learner. This will give more focus when gathering resource material. It is intended that the assessment evidence for criterion P6 is based on development ideas generated in P5.

To achieve a merit grade, learners will need to apply evaluative skills and explain the impact of poor design. To achieve M1 the manufacturer/client relationship should be explored in some depth with evidence supported by examples taken from case studies based on real products. These could be discussed during the visit in the first assignment.

M1 builds on knowledge used to achieve P1 and P2 and may be best attempted in the first assignment.

To achieve M2 learners should support their reasons for having accurate reference material by using examples taken from documented sources of products which are mission critical (for example correct specification of dimensions and material for a load bearing structure such as a roof beam). As such, a further written task could be set in assignment three to facilitate M2.

M3 builds on P5 and P7 and a further written could be set task in assignment 3. There should be evidence of thought being given to economic issues and the pressure on a designer to design to a price in order to be competitive. Explanations should be supported by examples relating to real products that learners are familiar with.

To achieve a distinction grade, learners should be able to focus on specific legislation and standards when working towards D1. There are strong links here to learning outcome 3 from *Unit 25: Business Operations in Engineering*. Learners should support their evaluation of the impact of legislation and standards on the design process with examples drawn from documented sources (for example businesses that have either lost market share by being caught out by changes in legislation or others that have benefited through anticipating changes and beating competitors in the market). As such, a task targeting D1 could be set as part of assignment 2.

To achieve the criterion D2, evaluation could relate to a design solution provided by the tutor but it may be better to link with P7 so that learners evaluate their own work. A written task in assignment 3 may be appropriate for this.

Programme of suggested assignments

The table below shows a programme of suggested assignments that cover the pass, merit and distinction criteria in the assessment and grading grid. This is for guidance and it is recommended that centres either write their own assignments or adapt any Pearson assignments to meet local needs and resources.

Criteria covered	Assignment title	Scenario	Assessment method
P1, P2 and M1	Design Report	An activity requiring learners to research and/or visit a design department and investigate the relationship between designer and customer.	A report containing written responses about the design process and its impact on customer relationships. In addition a PDS should be generated from a given customer specification.

Criteria covered	Assignment title	Scenario	Assessment method
P3, P4 and D1	Product Evaluation	An activity requiring learners to research legislation and standards that apply to two different products as well as the manufacturing, environmental and sustainability constraints for one of them.	A report containing written responses outlining legislation and standards that apply to two different products and an evaluation of the manufacturing, environmental and sustainability constraints for one of them in terms of profitability for the business.
P5, P6, P7, M2, M3 and D2	Design Proposals	An activity requiring learners to interpret a given PDS and, by using appropriate research techniques, present a final design solution from a selection of design proposals.	A portfolio of design solutions and a written report explaining how a final design solution has been selected. In addition explanations of the importance of accurate design reference materials and an evaluation of the chosen design solution with reference to the given PDS.

Essential resources

To meet the needs of this unit it is essential that learners have, or have access to, some if not all of the following:

- a range of customer design requirements
- a range of products to investigate design requirement features
- manual drawing equipment
- 2D commercial CAD software
- extracts and illustrations from appropriate drawing standards and conventions
- access to reference material which provides information about the physical and mechanical properties of materials
- access to legislation and design standards
- component and material suppliers' catalogues.

Indicative reading for learners

Textbooks

Dieter G and Schmidt L – *Engineering Design* (McGraw-Hill, 2013, 5th Edition)
ISBN 9780073398143

Simmons C, Maguire D and Phelps N – *Manual of Engineering Drawing*
(Butterworth-Heinemann, 2012) ISBN 9780080966526

Tooley M and Dingle L – *BTEC National Engineering 3rd Edition* (Newnes, 2010)
ISBN 9780123822024

13 Appeals

Centres must have a policy for dealing with appeals from learners. Appeals may relate to assessment decisions being incorrect or assessment not being conducted fairly. The first step in such a policy is a consideration of the evidence by a Lead Internal Verifier or other member of the programme team. The assessment plan should allow time for potential appeals after learners have been given assessment decisions.

Centres must document all learners' appeals and their resolutions. Further information on the appeals process can be found in the document *Internal assessment in vocational qualifications: Reviews and appeals policy*, available on our website.

14 Malpractice

Dealing with malpractice in assessment

Malpractice means acts that undermine the integrity and validity of assessment, the certification of qualifications and/or may damage the authority of those responsible for delivering the assessment and certification.

Pearson does not tolerate actual or attempted actions of malpractice by learners, centre staff or centres in connection with Pearson qualifications. Pearson may impose penalties and/or sanctions on learners, centre staff or centres where malpractice or attempted malpractice has been proven.

Malpractice may occur or be suspected in relation to any unit or type of assessment within a qualification. For further details on malpractice and advice on preventing malpractice by learners, please see Pearson's *Centre guidance: Dealing with malpractice* available on our website.

The procedures we ask you to adopt vary between units that are internally assessed and those that are externally assessed.

Centres are required to take steps to prevent malpractice and to investigate instances of suspected malpractice. Learners must be given information that explains what malpractice is for internal assessment and how suspected incidents will be dealt with by the centre. The *Centre guidance: Dealing with malpractice* document gives full information on the actions we expect you to take.

Pearson may conduct investigations if we believe a centre is failing to conduct internal assessment according to our policies. The above document gives further information and examples, and details the penalties and sanctions that may be imposed.

In the interests of learners and centre staff, centres need to respond effectively and openly to all requests relating to an investigation into an incident of suspected malpractice.

Learner malpractice

The head of centre is required to report incidents of suspected learner malpractice that occur during Pearson qualifications. We ask centres to complete Joint Council for Qualifications (JCQ) *Form M1* (www.jcq.org.uk/exams-office/malpractice) and email it with any accompanying documents (signed statements from the learner, invigilator, copies of evidence, etc.) to the Investigations Processing team at candidatemalpractice@pearson.com. The responsibility for determining appropriate sanctions or penalties to be imposed on learners lies with Pearson.

Learners must be informed at the earliest opportunity of the specific allegation and the centre's malpractice policy, including the right of appeal. Learners found guilty of malpractice may be disqualified from the qualification for which they have been entered with Pearson.

Failure to report malpractice constitutes staff or centre malpractice.

Teacher/centre malpractice

The head of centre is required to inform Pearson's Investigations team of any incident of suspected malpractice (which includes maladministration) by centre staff, before any investigation is undertaken. The head of centre is requested to inform the Investigations team by submitting a *JCQ M2 Form* (www.jcq.org.uk/exams-office/malpractice) with supporting documentation to pqsmalpractice@pearson.com. Where Pearson receives allegations of malpractice from other sources (for example Pearson staff, anonymous informants), the Investigations team will conduct the investigation directly or may ask the head of centre to assist.

Pearson reserves the right in cases of suspected malpractice to withhold the issuing of results/certificates while an investigation is in progress. Depending on the outcome of the investigation, results and/or certificates may not be released or they may be withheld.

We reserve the right to withhold certification when undertaking investigations, audits and quality assurance processes. You will be notified within a reasonable period of time if this occurs.

Sanctions and appeals

Where malpractice is proven, we may impose sanctions or penalties, such as:

- mark reduction for affected external assessments
- disqualification from the qualification
- debarment from registration for Pearson qualifications for a period of time.

If we are concerned about your centre's quality procedures, we may impose sanctions such as:

- working with centres to create an improvement action plan
- requiring staff members to receive further training
- temporarily withholding certification of learners
- placing temporary blocks on registration of learners
- debarring staff members or the centre from delivering Pearson qualifications
- suspending or withdrawing centre approval status.

The centre will be notified if any of these apply.

Pearson has established procedures for centres that are considering appeals against penalties and sanctions arising from malpractice. Appeals against a decision made by Pearson will normally be accepted only from the head of centre (on behalf of learners and/or members or staff) and from individual members (in respect of a decision taken against them personally). Further information on appeals can be found in the JCQ appeals booklet: *A guide to the awarding bodies' appeals process*.

15 Further information and publications

- Edexcel, BTEC and Pearson Work Based Learning contact details: qualifications.pearson.com/en/support/contact-us.html.
- Books, software and online resources for UK schools and colleges: www.pearsonschoolsandfecolleges.co.uk.
- Our publications catalogue lists all the material available to support our qualifications. To access the catalogue and order publications, please visit our website.

All centres offering external assessments must comply with the Joint Council for Qualifications (JCQ) document *Instructions for conducting examinations*.

Further documents that support the information in this specification:

- *Access arrangements and reasonable adjustments* (JCQ)
- *A guide to the special consideration process* (JCQ)
- *Collaborative and consortium arrangements for the delivery of vocational qualifications policy* (Pearson)
- *UK information manual* (updated annually and available in hard copy) **or** *Entries and information manual* (available online) (Pearson).
- Distance learning and assessment policy (Pearson)

Publisher information

Any publisher can seek endorsement for their resources and, if they are successful, we will list their BTEC resources on our website.

16 Glossary

Part A – General terminology used in specification

Level	Units and qualifications have a level assigned to them. The level assigned is informed by the level descriptors defined by Ofqual, the qualifications regulator.
Guided learning hours (GLH)	This indicates the number of hours of activities that directly or immediately involve tutors and assessors in teaching, supervising, and invigilating learners, for example lectures, tutorials, online instruction and supervised study. Units may vary in size.
Total qualification time (TQT)	This indicates the total number of hours that a typical learner will take to complete the qualification. This is in terms of both guided learning hours but also unguided learning, for example private study, time spent in the workplace to master skills.
Learning outcomes	The learning outcomes of a unit set out what a learner knows, understands or is able to do as the result of a process of learning.
Assessment criteria	The assessment criteria specify the standard the learner is required to meet to achieve a learning outcome.
Unit content	This section sets out the required teaching content of the unit and specifies the knowledge, skills and understanding required for achievement of the unit. It enables centres to design and deliver a programme of learning that will enable learners to achieve each learning outcome and to meet the standard determined by the assessment criteria.
Summative assessment	Assessment that takes place after the programme of learning has taken place.
Valid assessment	The assessment assesses the skills or knowledge/understanding in the most sensible, direct way to measure what it is intended to measure.
Reliable assessment	The assessment is consistent and the agreed approach delivers the correct results on different days for the same learners and different cohorts of learners.

Part B – Terms used in knowledge and understanding criteria

Analyse	Examine methodically and in detail, typically in order to interpret.
Assess	Consideration of all factors or events that apply, to identify those which are the most important or relevant and make a judgement.
Compare	Identify the main factors relating to two or more items/situations, explaining the similarities and differences or advantages and disadvantages, and in some cases say which is best and why.
Describe	Give a clear account in their own words, including all the relevant information (e.g. qualities, characteristics or events, etc.). Description shows recall and in some cases application.
Detailed	Having additional facts or information beyond a simple response.
Evaluate	Bring together all information and review it to form a supported conclusion, drawing on evidence, including strengths, weaknesses, alternative actions, relevant data or information.
Explain	Provide details and give reasons and/or evidence to support an opinion, view or argument. OR Provide details and give relevant examples to clarify and extend a point. This would usually be in the context of learners showing their understanding of a technical concept or principle.
Identify	Shows the main features or purpose of something. Can recognise it and/or name characteristics or facts that relate to it.
Outline	Provide a summary or overview or brief description.
State	Express information in clear and precise terms.

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