



Institution of Mechanical Engineers

Railway Challenge

Technical Specification

1 Requirements

1.1 General

1.1.1 Design

Detail drawings. Full performance calculations. Structural calculations. Parts lists

1.1.2 Safety / Failure Analysis

Top down analysis. Bottom up analysis (Clauses 3.1, 3.2 refer)

1.1.3 Manufacture

Procurement. Manufacture. Assembly

1.1.4 Testing

Recorded on-site validation of all performance calculations / statements (Clause 11.2.3 refers). Off-site comparative demonstration (Clause 10 refers), as defined under separate cover, of specified performance characteristics

1.1.5 As-Constructed Drawings

Detailed drawings updated to reflect post-assembly modifications with full demonstrable version control

1.1.6 Spares / Tools / Test Equipment

Procurement, design, manufacture, assembly of spares, tools and test equipment

1.2 Cost Benefit Analysis

1.2.1 Production

Production cost estimate against the selected design and method of manufacture (on the basis that the initial locomotive is a prototype for a production run) of 50 units

1.2.2 Testing

Cost of any testing, identified as required and above and beyond the selection testing of the prototype as referred to in Clause 10 of this document

1.2.3 Maintenance

Maintenance cost estimate, including cost of all spares / consumables (Clauses 11.2.6, 9.1 refer)

2 System Description

2.1 Configuration

The wheel arrangement and general configuration of the locomotive will be at the Team's discretion, subject to the conditions herein

2.2 Operation

The locomotive will operate remotely via radio-based or cable-based transmission. All functions will be operable via the remote system. Specified functions will be operable only via the remote system

Such remote systems shall be designed on the basis that the operator will be located within the trailing load as described in Clause 10.1 (supplied by a separate party)

2.3 Design

It is not intended that the locomotive be a scale representation of a larger vehicle

The aesthetics of the locomotive with respect to proportion, shape and colour will be assessed as part of the selection process

3 Systems Assurance

3.1 Top Down Analysis - Safety

The Team will produce and provide comprehensive top down safety analysis, the exact nature of which will be as selected by the Team. The analysis will include a text comprising conclusions with appropriate justification for acceptability

The analysis will identify all potential safety related failures and via appropriate statistical analysis demonstrate that the probability pre and post mitigation is understood, and that post-mitigation levels are As Low As Reasonably Practical (ALARP). The analysis will include a text comprising conclusions with appropriate justification for acceptability

3.2 Bottom Up Analysis – Safety

The Team will produce and provide comprehensive bottom up safety analysis, the exact nature of which will be as selected by the Team

The analysis will identify all safety related consequences of single component failure, for all components and, via appropriate statistical analysis, demonstrate that the probability pre and post mitigation is understood, and that post-mitigation levels are ALARP

3.3 Maintainability

The Team will demonstrate that all components replaced as part of a planned preventative maintenance programme (Clause 11.2.6 refers) can be replaced without disruption to any other component other than designated access facilities and the

immediate connection to interfacing components

The design will consider hazards associated with maintenance and repair activity when undertaking the production of the analysis specified in Clauses 3.1 and 3.2. These should include, but not be limited to, electric shock, hazardous substances, entrapment, sharp edges and burns

3.4 Reliability

The Team will demonstrate that the completed prototype locomotive is adequately reliable for the purposes of undertaking the selection testing of the prototype as referred to in Clause 10 of this document by undertaking test-running. This shall comprise no fewer than four hours of operation, during which all functions detailed in the selection testing shall be exercised

In all cases the final hour shall be of near continuous operation without any failure inhibiting movement

The completion of reliability testing as described in this clause must be verified by a Chartered Engineer and evidenced by provision of a video showing the locomotive in normal operation during the testing specified in this clause

The video will be made available to the Railway Challenge team committee via any selected method at least two weeks before the Railway Challenge competition weekend. Failure to do so will incur a penalty

4 Technical Requirements – General

4.1 General

The locomotive shall provide self-contained motive power and be able to operate for 3 hours without refuelling, on the basis that operation comprises continuous travel at 5km/h on a 2% gradient with a 400 kg trailing load of negligible friction¹². All functionality shall remain available for repeated use throughout this period without any further input. The locomotive shall be able to haul and start a trailing load of up to 1800 kg on a 2% gradient

The type of motive power utilised will be entirely at the discretion of the team, subject to the other requirements of this specification

Refuelling from zero to 100% capacity shall take no longer than 120 seconds. If refuelling comprises the replacement of energy storage assets, no individual such asset shall have a mass greater than 25 kg³

¹ Note that these figures define energy capacity only and not maximum performance / environment

² Note the requirements of Clause 11.4 (compliance matrix). For this requirement, the compliance statement should comprise operation endurance calculations

³ If refueling comprises the replacement of energy storage assets then the specified maximum

4.2 Materials

4.2.1 Inventory

The Team will provide a full inventory of materials (or BOM: Bill of Materials) used in the construction of the locomotive, for all materials making up more than 5% of the total mass

4.2.2 Safety

The Team will demonstrate (as part of the delivery of the requirements specified in Clauses 3.1 and 3.2) that the selection of materials takes safety implications, including fire, duly into account

4.2.3 Environmental

The Team will demonstrate that 95% of components by mass can be disposed of in such a way that facilitates recycling

No hardwood components will be used for which Forest Stewardship Council (FSC) certification cannot be demonstrated

4.3 Loading Gauge

The locomotive shall be designed to operate within a dynamic loading gauge as described in Drawing RC02

Gauge infringement resulting from component failure (including inadvertent opening of access panels) or movement during operation must be included with the top down and bottom up analyses (Clauses 3.1 and 3.2 refer)⁴

4.4 Mass

4.4.1 Total

The total mass of the locomotive will not exceed 2000 kg. Due consideration shall be taken of all traction and braking requirements

4.4.2 Axle Load

The maximum axle load of the locomotive will be 500 kg

4.5 Operating Conditions

With respect to cooling systems and motor rating, the locomotive will be designed for continuous operation in all environmental conditions specified

refueling time will be demonstrated during scrutineering

⁴ Due attention should be paid at an early design stage to guarding, with respect to protection against injury / entrapment by moving parts, chains and belts. Out of gauge, insecure or flexible guarding will prohibit locomotive operation in the Railway Challenge

4.6 Environmental Conditions

The locomotive shall be designed to operate in direct sunlight, and under all forms of precipitation

The locomotive shall be designed to operate at shade temperatures between -10 and +40 degrees centigrade and between 0 and 90% humidity levels

4.7 Track Characteristics

The locomotive shall be designed to operate on track with the following characteristics:

- Gauge: 10 ¼ inches (between rail inner faces). May widen to up to 10 ½ inches on curves
- Minimum horizontal curvature radius: 20m
- Maximum track twist gradient: 6mm over 0.25m
- Maximum gradient: [1:84]
- Wheelsets shall comply with all characteristics detailed in Drawing RC04
- Minimum wheel diameter: 200mm

The Team will demonstrate that all the above clauses have been duly considered in the design, when operated as described in this document

4.8 Markings

The locomotive shall be painted or otherwise protected against all specified environmental factors as specified in Clause 4.6 in a manner to be selected by the Team, but not in a manner resulting in non-compliance with any other Clause of this document

The Team will ensure that markings included in any scheme, where feasible, highlight the presence of any hazards and warn of the presence of the locomotive itself

5 Technical Requirements – Performance / Control

5.1 Operating Speed

The locomotive will be limited to a maximum speed, unless being towed, of 15 km/h
The locomotive will incorporate speed limiter systems to inhibit operation above this limit

The locomotive shall be designed so that it may be towed, when on track with characteristics as described in Clause 4.7, at a speed of 15 km/h

5.2 Energy Recovery

The locomotive will incorporate an energy recovery system for use in retarding the locomotive and trailing load. Energy so recovered will be stored separately from that supplying the primary traction system. The retardation rate delivered by the energy recovery system shall be limited to a maximum deceleration rate of 1.3 m/s/s on level track (assuming no trailing load)

The locomotive will utilise recovered energy only, if selected by the operator, to deliver tractive effort

The performance of the locomotive with respect to the energy recovery will form a major part of the test specification referred to in Clause 10.1

Particular attention shall be paid to the requirements of Clauses 3.1 and 3.2 with respect to stored energy systems

5.3 Braking Systems

In addition to the energy recovery system, the locomotive will incorporate the following exclusive braking systems:

- A service brake
- An emergency mechanical brake, which shall operate indefinitely even in the event no power is available

Both above services may be provided by a common actuator

5.4 Braking Performance⁵

- All brake systems will limited to a maximum deceleration rate of 1.3 m/s/s (+0/-0.15) on level track (assuming no trailing load)
- The emergency brake shall provide a deceleration rate of 1.3 m/s/s (+0/-0.15) on level track (assuming no trailing load)
- The emergency brake will operate whenever communication with the remote control unit is lost, regardless of current locomotive operating state, within 0.5 seconds of disconnection
- The emergency brake will operate in the event that service brakes are released but the presence of an operator in contact with the remote control unit is not detected for a period longer than 0.5 seconds
- The locomotive (or remote control unit if wired to the locomotive) will be fitted with a tether point and tether plug linked (via a cord of 2m length if wired to the locomotive, 0.5m if wired to the remote control unit) to a wrist band, so that separation of the operator and locomotive is detected. The emergency

⁵ Note the requirements of Clause 11.2.1 (compliance matrix). For this requirement, the compliance statement should comprise schematics and full functional description

brake will operate in the event of such separation within 0.5 seconds. The wrist band must be worn by the operator at all times that the locomotive is powered. This function shall be directly electrically or mechanically facilitated and not dependent on software

- The remote control unit will incorporate an emergency stop button which shall operate the emergency brake, regardless of current locomotive operating state, within 0.25 seconds
- An emergency brake button, clearly marked and safely accessible, shall be provided on both sides of the locomotive which shall operate the emergency brake, regardless of current locomotive operating state, within 0.25 seconds. This function shall be directly electrically or mechanically facilitated and not dependent on software
- The emergency brake system shall feature a manual brake release to enable movement of the locomotive by external means when it is safe to do so. The emergency brake release system must be such that inadvertent operation is impossible, and emergency brake isolation is inherently visible to all parties. Release shall be, preferably, via continuous attended operation. Manual re-application of the brakes following release shall also be possible
- The brake systems on the locomotive shall be so designed that no single fault shall reduce the available brake effort by more than 50%.
- Operation of the emergency brake by any means shall set the traction rate to zero. Release of the emergency brake button shall have no effect unless full service braking is selected on the locomotive controller

5.5 Braking Control – Automatic

The locomotive braking system will incorporate an automatic braking mode which will, if selected, bring the locomotive and trailing load to a standstill, exactly 25m after passing a lineside distance marker⁶. No tractive effort will be applied in this mode and the brakes will remain activated, each being indicated (clause 5.7 refers). All braking systems will remain normally operative also when this mode is selected

5.6 Traction Control

Traction control will be via the remote control unit only. Traction control will provide continuously variable or multi-stepped tractive effort, at the Team's discretion

5.7 Indications

Clearly continuously visible indications will be provided to:

- a) the locomotive operator and

⁶ Teams will be expected to provide and temporarily fix a detectable location device of their choice at the location of this marker. This device will be designed such that it is entirely outside the structure gauge limits (Drawing RC02 refers). Such devices may be located between the running rails provided gauge compliance is met

b) the Challenge judge,

via the same or separate means, to be selected by the Team, of the locomotive's functional status. These will include, but are not limited to:

- Fire
- Braking system fault
- Tractive effort applied
- Brakes applied
- Status of recovered energy storage (continuous)
- Locomotive speed
- Locomotive running on recovered energy only (Clause 5.2 refers)
- Automatic braking mode selected

The design of all such indication will allow for the stated environmental conditions (Clause 4.6 refers)⁷

5.8 Audible Warning

A horn or whistle shall be fitted to the locomotive which shall be operable from the remote control unit. The maximum C weighted sound pressure level ($L_{pCeq,T}$) at 1m distance (between 0.5m and 1.5m above ground level) shall be no less than 93dB and no greater than 112dB. The principal frequency of the audible warning device shall be between 800Hz and 3570Hz

6 Technical Requirements - Locomotive Structure

6.1 Structure

6.1.1 Calculations

The Team shall provide analysis and calculations to demonstrate the adequacy of structure which shall include / allow for the following (on all track conditions detailed in Clause 4.7):

- A 30% dynamic loading factor (factor to be applied to all loads in structural analysis to allow for sudden application)

⁷ Note that visibility will be assessed as part of scrutinising, which will be undertaken on a moving vehicle, possibly in bright sunlight. The scrutinising team may recommend disqualification from one or more challenges should visibility be deemed inadequate

- Tensile and compressive loads applied to coupler bars and fixings (Clause 6.2 refers) at both ends, demonstrated by the Team to be appropriate
- Loads resulting from use of jacking / lifting loads at the jacking / lifting points provided by the Team (bogies and / or wheelsets to remain attached)

6.2 Coupler

On each headstock of the locomotive a coupling shall be provided as follows:

- A 'U' bracket with centreline 10" above rail head supporting a vertical shaft or pin of $\frac{3}{4}$ " diameter with suitable retention

A single coupler bar shall be provided, with one end suitable for the shaft as referred to above, and a hole to clear a coupler pin of $\frac{3}{4}$ " diameter at the other

The coupler bar design (including length) shall be assessed against the track characteristics, haulage and braking loads as specified in this document, taking into due account the end-throw of the locomotive and all limits of dynamic displacement. In the event the design proves impractical, the general arrangement of the locomotive shall be changed

Drawing RC05 shows a typical design for a coupler bar (subject to the assessments above)

6.3 Jacking and Lifting

6.3.1 Jacking wheels for transverse movement

A set of swivel type jacking castors will be provided to allow the lifting and transverse movement across hardstanding (level with the railhead) for recovery and routine transportation to and from the track. The wheels will be rubber tyred (solid or pneumatic) and have a minimum diameter of 150mm (+50/-0).

Locomotives will be provided with fitment points for the supplied number of such wheels, and will be designed so that all components (such as bogies and wheelsets) are retained during their use.

Fitment and removal of all castors, by two competent persons, shall take no longer than five minutes in total.

Jacking wheels and any accessories or tooling required for jacking shall be stowed on the locomotive when they are not in use in such a way that provides compliance with Clause 4.3.

With jacking wheels fitted, the requirements of Clause 4.3 do not apply.

6.3.2 Jacking or lifting for maintenance

A system for jacking or lifting all or part of the locomotive for the purpose of removing a power wheelset shall be provided.

The system shall be designed and assessed to ensure its safe operation and

stability⁸ at all times such that manual maintenance activities can be performed without unacceptable risk. The system and process shall be subject to a method statement and risk assessment (Section A17 of the Rules refers). The jacks shall be of a design that allows a controlled rate of descent⁹.

The jacking wheels (Clause 6.3.1 refers) may also be used as part of the system of jacking or lifting for maintenance subject to also complying with the requirements of this clause.

6.3.3 Jacking Point Marking

The points at which jacks should be attached to the locomotive should be clearly indicated by clear inverted-triangle signs

7 Running Gear

7.1 Vehicle Suspension

7.1.1 General

The vehicle suspension shall provide for safe operation of the vehicle at all specified speeds and avoid the generation of excessive wheel flange forces (esp. forces causing flange climb) during curving. The Team shall provide detailed calculations to confirm that this criterion has been satisfied. Coefficients of friction varying between 0.15 and 0.6 between wheels and rails shall be used.

7.1.2 Wheel Unloading

The Team shall ensure that, when the locomotives operate on track with specified characteristics, the maximum wheel unloading under this condition shall not exceed 60% of the nominal wheel load. The latter is defined as the measured wheel load with the locomotive stationary on straight and level track. The Team shall provide detailed calculations to confirm that this criterion has been satisfied. Coefficients of friction varying between 0.15 and 0.6 between wheels and rails shall be used.

7.1.3 Axlebox Longitudinal Movement

To as great a degree as possible, the Team shall seek to allow, or achieve on an active basis, longitudinal movement of axleboxes so as to achieve stable alignment of wheels tangential with respect to the alignment of the rails

7.1.4 Unsprung Mass

The team will provide a breakdown of locomotive mass with respect to the proportion unsprung, supported by primary suspension only and supported by primary and

⁸ The assessment of stability will include the method by which the jacking or lifting device is prevented from moving from the jacking point during operation

⁹ Whilst no form of jack is prohibited, teams should note that the pressure release screw on simple bottle jacks cannot be considered to provide controlled descent

secondary suspension

7.2 Earth Bonds

The design of the locomotive will demonstrate protection against electric shock. In the event any such risk exists, earth bonds shall be provided between one axlebox on each axle and the locomotive underframe and/or all normally accessible metallic structures and enclosures

Designs will demonstrate due consideration of the following:

- containment of electrical components in suitable cabinets
- bonding paths from all metallic cabinets and other conducting components.
- specification of bonding cables and fasteners

7.3 Transmission

The form of power transmission employed by the locomotive shall be entirely at the discretion of the team. However, due attention should be paid at an early design stage to guarding, with respect to protection against injury / entrapment by moving parts, chains and belts. Out of gauge, insecure or flexible guarding will prohibit locomotive operation in the Railway Challenge

8 Technical Requirements - Fire Protection

8.1 General

The locomotive shall be fitted with heat detection systems which in the event of operation, shall:

- Cause the emergency brake to be operated
- Sound an alarm, as to be selected by the Team
- Activate indication to the operator (Clause 5.6 refers)

9 Spares, Special Tools and Test Equipment

9.1 Tools / Test Equipment

The Team will manufacture, or otherwise provide, all tools and test equipment necessary to repair and maintain, as specified, the locomotive and to ascertain correct operation of all specified functions.

9.2 Test Points

9.2.1 Ride

The locomotive shall include a nominated accelerometer mounting point. This mounting point must be directly on the sprung body structure of the locomotive and must not be dynamically isolated any further.

The mounting point must provide a horizontal surface (with respect to the track) of ferrous (magnetic) construction on which clearance must be provided for a 25mm x 25mm x 100mm (in longitudinal direction) device, with clearances.

The mounting point must be within the main body structure but readily accessible and such that the fitting and removal of an accelerometer does not require the removal of any locomotive component or fixed / bolted bodywork.

The mounting point must be such there is a route for a cable to the exterior of the locomotive at high level

10 Performance Demonstration

10.1 General

The Team shall demonstrate the performance of the locomotive relative to others produced against the same specification via a number of tests.

Full details of the competition are set out in the Railway Challenge Rules.

Performance demonstration will incorporate the haulage of a trailing load of up to 1200kg (note that the ratio of un-braked trailing load mass to locomotive mass will be taken into account during brake rate assessment).

11 Technical Documentation

11.1 Design Report

The Team will supply a short written report to outline the design philosophy of the produced vehicle

The design report should be of short length, fifteen pages maximum¹⁰ excluding title pages, contents pages / index), consisting of text and figures etc. to explain the concept of the vehicle. Analysis and calculation evidence will be provided in the Appendices to this report (Clause 11.2 refers).

The document should contain a brief description of the vehicle with a discussion of any important design features and vehicle concepts. Include a list of different analysis and testing techniques (FEA, dynamometer testing, etc.). Evidence of the

¹⁰ Including Executive Summary if provided

analysis and back-up data should be brought to the competition and be available, on request, for review by the judges.

11.2 Design Report – Appendices

The team will provide appendices, comprising no more than 100 sheets, to the design report as follows:

11.2.1 Compliance Matrix

The Team will produce a clause by clause compliance matrix providing evidence that all technical requirements within this specification (Sections 1 – 10) have been met on a clause by clause basis. This will include a verified statement with respect to reliability testing (Clause 3.4 refers). Teams are advised to use the compliance matrix provided by the Railway Challenge Committee for this purpose. For each requirement, the matrix should briefly state how compliance is achieved in the design and refer to any relevant drawings (Clause 1.1.5 refers) (which may be additional to the Design Report). If full compliance with any requirement is not achieved, details of why shall be provided.

11.2.2 General Assembly Drawing

In addition to drawings supporting the compliance matrix, the Team will include within its submission:

- A General Assembly drawing showing the configuration of the locomotive
- A parts list / bill of materials (Clauses 1.1.1, 4.2.1 refer)

The Team will demonstrate appropriate levels of version control has been applied to the production of all drawings and other design documents

11.2.2 Calculations

The Team will provide evidence of compliance with this specification in the form of calculations, and / or test results to the performance demonstration. These will include:

- Track characteristic compatibility calculations / drawings (Clauses 4.7, 7.1 refer)
- Performance Calculations (Clause 5 refers)¹¹
- Structural calculations (Clause 6.1 refers)
- Wheel unloading calculations (Clause 7.1.2 refers)

¹¹ Including how the energy recovery system will respond to the energy challenge in terms of clearly and unambiguously demonstrating to the riding judge that only energy recovered in the braking phase is reused for propulsion

11.2.3 Control Systems

The Team will provide a block diagram illustrating how subsystems within the locomotive are connected (Control signals between subsystems shall be included on the diagram)

Teams may be required to submit their control system software before / during the competition for scrutineering purposes. The decision to do this will be at discretion of the railway challenge organising committee

11.2.4 Manufacturing and Production

The Team will provide evidence of compliance with this specification by submitting information relating to the procurement, manufacture and assembly of their locomotive (Clause 1.1.3 refers).

The team will provide a full cost benefit analysis (Clause 1.2 refers).

11.2.5 Testing and Safety

The Team will provide a full safety case for their locomotives. This will include:

- Top down analysis (Clauses 1.1.2, 3.1, 4.2.2, 4.3 refer)
- Bottom up analysis (Clauses 1.1.2, 3.2, 4.2.2, 4.3 refer)

11.2.6 Operation and Maintenance

The team will provide a short manual / data sheet which will cover the following (Clauses 3.4, 10 refer):

- Operation with respect to safety
- Operation with respect to reliability / longevity
- Operation with respect to performance

The manual / data sheet will be made available to the driver during operation via printing or provision of a dedicated tablet device

The team will provide a short manual / data sheet which will cover the following (Clauses 1.1.6, 3.3, 9.1, 11.2.6 refer):

- Planned preventative maintenance (with frequency data)
- Routine inspection (with frequency data)

11.3 Design – Technical Poster

The Team will produce a summary of the locomotive system architecture and of the functional principles of the locomotive in poster form. Assessment of the clarity of the technical poster will form part of the selection process

11.3.1 The technical poster shall be A0 in size (841 x 1189 mm), landscape in orientation,

and presented on a rigid board. The poster may be printed directly on the board or on one or several sheets of paper mounted on a rigid backing. The poster will be displayed to attendees during the competition weekend.

11.3.2 The technical poster will be in addition to that described in the Railway Challenge Rules for the purposes of marketing

11.3.3 The poster shall provide information to enable an understanding of the principles adopted on the function and control of all major systems of the locomotive including, but not necessarily limited to, the following:

- Traction and power system
- Braking
- Energy storage and re-use
- Fuel storage
- Running gear, dynamics and suspension
- Train control and operation
- Fire protection

11.4 Innovation

The Team will supply a short written journal article or conference style paper to outline a novel and innovative aspect of the produced vehicle.

- The paper should be of short length, four pages maximum, consisting of text and figures, tables, etc. to explain the innovative aspect of the vehicle.
- The paper should focus on one innovation of the locomotive and how it can contribute to the industry's Railway Technical Strategy, specifically one or more of the four Cs (increasing customer satisfaction and capacity, reducing carbon and cost). The paper should detail the innovation, provide an indication of how it improves on a conventional approach, and how it may be adopted by the national railway.
- The paper should be written in an academic style and include citation of references in the Harvard style.

Appendix 1 - Table of Revisions

General

The following table describes any significant changes made relative to Version 1 of the Railway Challenge 2020 Technical Specification

Typos and format changes will not be listed

Revisions

Table 1 - Table of Revisions

Clause	Change Date	Change