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RAIL INDUSTRY SAFETY AND STANDARDS BOARD

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Distributed Power Freight Trains

CODE OF PRACTICE

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1 Introduction

1.1 Introduction

In freight rail operations, the term 'distributed power' refers to the practice of placing locomotives at more than one location within the train. Such practice is differentiated from conventional freight train practice where all the locomotives are marshalled at the front of the train, a configuration known as 'head end power'. Distributed power trains may take many different configurations to suit various purposes including the following examples:

- Push-pull arrangement with one or more locomotives at each end
- 'Banker' arrangement with temporary locomotives pushing from the rear to assist in ascending ruling grades
- Long trains with locomotives distributed at several locations along the train, often in groups known as 'consists'.

Each configuration may suit a different purpose. For example, a push-pull configuration enables the direction to be easily reversed for operational convenience and the use of banker locomotives is convenient where extra tractive effort is required at one location only. Distributed power enables an increased in train length which would otherwise be limited by the traction force developed by using head end power only. Distributed power therefore has the advantage of reducing in-train forces by distributing traction and braking forces along the train.

1.2 Purpose

The purpose of this document is to establish a code of good practice for stakeholder activities related to the operation of distributed power freight trains.

1.3 Scope

This Code of Practice covers activities related to the operation of distributed power freight trains. It is intended as a guidance document and contains high level functional recommendations rather than prescriptive requirements.

This Code of Practice is intended to cover all types of distributed power trains and considers manual distributed power, as well as wired and radio frequency type distributed power systems (WDP, RFDP) and does not exclude other types where it can be demonstrated that safety and network interface requirements can be met to the satisfaction of the Network Manager

Users of this Code of Practice should not rely solely on this document and are required to satisfy themselves that all relevant risks have been identified and risk controls adopted are satisfactory for their specific distributed power train operations.

This code of practice makes reference to established WDP and ECP standards and practices developed under the Association of American Railroads (AAR) Manual of Standards and Recommended Practices (MSRP) including commercial WDP and ECP systems developed to comply with the AAR standards. However, this Code of Practice does not exclude the adoption of alternative WDP and ECP systems which may not comply with the AAR standards, on condition that suitable assurance is provided that an equivalent or superior level of safety is achieved in operations. It should be noted that at the time of writing, the AAR did not have published standards for radio-frequency distributed power.

2 References Documents

2.1 Normative References

The following referenced documents are indispensable for the application of this Standard:

(a) AS 7722 EMC Management.

(b) RISSB Code of Practice ECP Braking.

(c) AAR Manual of Standards and Recommended Practices.

(d) EN 50126 Railway applications- The specification and demonstration of reliability, availability, maintainability and safety (RAMS)- Part 1 Basic requirements and generic processes.

2.2 Informative References

The following referenced documents are cited in this Standard for information only:

(a) Design and Simulation of Heavy Haul Locomotives and trains. Ground Engineering Series 2017.

(b) International Benchmarking of Longitudinal Train Dynamic Simulators: Results. Vehicle System Dynamics 2017

(c) International Benchmarking of Longitudinal Train Dynamic Simulators: Results: Benchmarking Questions. Vehicle System Dynamics 2017

(d) Modelling, simulations and applications of longitudinal train dynamics, Vehicle System Dynamics, Vol 55. Issue 10. 2017

(e) S-4200 Electronically Controlled Pneumatic (ECP) Cable Based Brake System- Performance Requirements

(f) TS TOC.1 Train Operating Conditions (TOC) Manual- General Instructions

2.3 Definitions

Distributed Power: The practice of placing locomotives at several locations within a train as distinct from placing all locomotives at the front of the train.

DP train operations: all stakeholder activities associated with the operation of distributed power trains including train safety assessment, risk management, network requirements, train operations, rolling stock and DP system equipment design, manufacture, testing and maintenance.

Banking Loco: a loco used to provide buff load (pushing) to assist a train to transit a ruling grade.

Loco: Locomotive

Manual Distributed Power: a distributed power train using crew in more than one locomotive to control locomotives as directed by the driver in the lead locomotive, usually using radio communication.

Push-Pull: a train with at least one locomotive at each end and capable of operating in either direction.

Front-Middle-Back: a distributed power train with locomotives at the front, middle and rear.

Good Practice: Practice entailing safety, reliability, dependability, economic efficiency and sustainability.

DP: Distributed Power.

WDP: Wired distributed power.

RFDP: Radio frequency distributed power

ECP Brakes: Electronically controlled pneumatic brakes.

RSNL: Rail Safety National Law

RTO: Rail transport operator, as defined in RSNL

RSO: Rolling stock operator as defined in RSNL

RIM: Rail Infrastructure manager as defined in RSNL

Network Manager: the authority in charge of the rail network on which the distributed power train is operating. Usually the rail infrastructure manager (RIM) responsible for managing the Network Rules applying to rollingstock on the network.

TMP: Technical Maintenance Plan

RACI: Matrix for assignment of Responsible, Accountable, Consulted and Informed personnel

3 Risk Management

Hazards associated with banking locomotives, amalgamated trains and push-pull trains operating in manual distributed power have been previously identified and are covered by the network rules managed by the relevant network manager. An example of network rules is given by Section 2 of the TOC Manual Volume 1 managed by ASA for the Sydney metropolitan heavy rail network. Other rail network managers have similar rules with minor variations applicable to the local network.

For the introduction of technology for automated distributed power into freight operations, such as wired and wireless distributed power, it is necessary to review the potential changes in risk profile. While the focus is generally on negative risks, it should be noted that there are also significant positive risk benefits including the following:

- Reduced in-train forces due to the distribution of tractive effort along the train.
- Reduced wear rates for many components in rolling stock, track and other infrastructure.
- Potential energy saving.
- Amalgamation of two or more trains into a single longer train:
  - Reduced number of trains.
  - Reduced operating costs.

Hazards associated with operating automated distributed power freight trains have been identified and summarised in a Hazard Table provided in Appendix A. The table includes hazards which are either specific to distributed power trains or pre-existing hazards applying to non-DP freight trains, but which may be more significant or with greater risk profile with distributed power trains.

The distributed power train operator and associated stakeholders should develop a train-specific risk register to suit their operations. The train specific risk register should be reviewed and updated regularly incorporating the lessons learnt from distributed power freight train operations.

4 Stakeholders

This Code of Practice is intended to provide a reference document for stakeholders which may include some or all of the following:

- Rolling stock operator (RSO).
- Rail Infrastructure manager (RIM).
- Rolling stock suppliers, designers, manufacturers, maintainers and consultants.
- Rolling stock sub-system suppliers, designers, manufacturers, maintainers, and consultants.
- Train Forces.

4.1 General

In many cases distributing tractive effort along the train will result in lower in-train forces. However, with long trains which can span varying track geometry such as crests, dips, lateral curves and track twist, it is also possible to generate train forces exceeding safe limits. The use of asynchronous control can be used to reduce in-train forces, however mastering its application in different situations is difficult and its application in some situations can result in the opposite effect to that intended. For this reason, it is essential that train forces are correctly analysed and managed in DP operations.

4.2 Analysis

Train forces should be analysed for each train configuration and operating regime, including any modified and recovery configurations. Figure 1 in Appendix B provides a logic diagram to capture the various combinations of parameters. The logic requires all relevant combinations of variables to be analysed. Train force analysis should be conducted by one of the organisations that have specialist expertise in train dynamics.

Some examples of train and track parameters that affect train forces include the following:

- Loco / wagon axle load and spacing.
- Loco / wagon length between couplers.
- Loco traction and braking characteristics.
- Coupler / draw-bar / draft gear characteristics.
- Wagon loading.
- Train configuration of locos and wagons.
- Track horizontal and vertical curvatures and gradients.
- Crest and dips.
- Adhesion conditions.
- Use of synchronous and asynchronous control of DP locomotives.
- Recovery train configurations.

Modelling of longitudinal train dynamics is discussed in detail in various source documents and guidance by authors from the Central Queensland University is provided in Appendix C.

It should be noted that for small changes in train configuration or operating parameters, it may not be necessary to repeat the full analysis, but instead apply a reduced analysis and/or engineering judgement to assess the likely effect on operations.

4.3 Driver Training and Competency

Whilst analysis of train forces can be used to eliminate potentially unsafe train configurations, control of train forces during operations depends on the driving ability of the train crew. The operator should ensure that adequate DP operations training is provided to the train crew and associated operations staff and a high level of competency is maintained. Ideally this should include training using DP train simulators. Driver training programs should cover the use of synchronous and asynchronous control as applicable to the specific DP train operation.

4.4 Synchronous and Asynchronous Control

In synchronous control of DP locomotives, the control systems forces all locomotives in the train to apply the same engine power and dynamic brake (DB) settings as commanded by the driver in the lead locomotive. In asynchronous control mode, the driver can select different engine power and DB settings for each loco consist in the train. These control modes have significantly different effects on the in-train forces developed. The analysis of the proposed DP train operations should take account of the use of the control methodology to be employed including the use of synchronous and asynchronous control at all locations on the train path

4.5 Distributed Power Train Operations Management

Train operations managers should have a high level of understanding of the requirements for safe operation of distributed power trains. The operator should ensure that a high level of DP operations management training and competency assessment is provided to the operations staff. Ideally this should include training using DP train simulators and cover the use of synchronous and asynchronous control.

4.6 Environmental Conditions

Train forces can be affected by environmental conditions which may have a significant effect on traction and braking performance. For this reason, all operational staff should understand environmental effects and the ability to make appropriate adjustments or changes to DP operations in response to changes in the environment.

4.7 Network Conditions

Train forces can be affected by changes to the network (track condition, curvature, gradient, speed limit etc). For this reason, rail infrastructure managers should notify all DP train operators of changes to the network. The relevant DP train operational staff, should have an understanding and ability to make appropriate adjustments or changes to DP operations in response.

4.8 Risk Assessment

In developing the DP risk register, stakeholders should conduct the following activities:

- Verification of the train force model by measurement of in-train forces by strain gauging or other suitable methods.

- Modelling of in-train forces for loaded and unloaded trains on relevant routes using the analysis from section 4.2 above.
- Review the safe limits for in-train forces, traction effort and dynamic breaking.
- Review of safe limits for in train forces, traction effort and dynamic breaking.
- Review of limits for partly loaded wagons in loaded trains and loaded wagons and idle or "dead" locomotives in unloaded trains.
- The continued functionality of the vehicle-vehicle and bogie-vehicle connections should be monitored, particularly in respect of buff and draft load carrying capability and should involve through-life condition monitoring of critical components.

4.9 Continual Improvement

DP train operators should continue to monitor risks associated with DP trains on an 'ongoing basis' and participate in the continual improvement actions listed in Section 9.

5 Network Interface Requirements

5.1 Network Rules

The network manager (RIM) is responsible for controlling requirements on rolling stock using the network and has network rules that must be complied with as a pre-condition of network access. Prior to accepting distributed power trains onto the network, the network manager should consider the following issues and amend and apply the network rules as appropriate

5.2 Long Trains

The introduction of automated DP train technology (such as WDP and RFDP) enables the operation of longer trains. The network manager should consider the following long train issues and where necessary, apply new or updated network rules as applicable-

- train pathing and impact on timetabling;
- longer running times through network sections;
- occupation of two or more sequential signalling sections;
- train recovery in the event of a failed train;
- longer network disruption than for typical shorter trains;
- environmental issues associated with remote locomotives idling at new locations;
- hazards associated with long trains in tunnels;
- emergency response and operational readiness for long trains;
- staff training and awareness for long train operations;
- changes to the network that may affect DP train operations.

5.3 Train Forces

The Network Manager should be aware of the following issues and manage the associated risks in accordance with their network management policies and procedures:

- Train forces developed by the designated DP train and load configurations in operation on the designated routes as determined by train force analysis.
- Wheel-rail interface and forces on the rails and track.
- Loading effects of DP trains on bridges and structures.
- Traction and Braking performance.
- Braking characteristics including use or non-use of ECP brakes.
- Limits on application of dynamic brake.
- The use of synchronous and asynchronous control of lead and remote locomotives.
- Positioning of empty or lightly loaded wagons in a loaded train.
- Positioning and load of loaded wagons or non-powering locomotives in an unloaded train.
- The competency level of the train crew and the extent of dependency on the train crew for controlling train forces.

5.4 Requirements on the RSO for network access for long DP trains

The network manager should be aware of the following issues and manage the associated risks in accordance with their network management policies and procedures:

- Network access requirements for individual rolling stock (locos and wagons) including RS Type testing and registration requirements.
- The RSO's training and competency in DP train operations.
- The RSO's train force analysis and Risk Register.
- The RSO's DP Operations Plan including train recovery plan.
- The RSO's DP Train loading plan (empty or part loaded wagons in the train).
- DP train pre-operations functional test requirements such as traction and brake performance.

5.5 Continual Improvement

Network Managers should maintain awareness of risks associated with DP trains on an 'ongoing basis' and participate in the continual improvement actions listed in Section 9 below.

6 Distributed Power Systems

6.1 Common Requirements for all Distributed Power Operations

- The operator shall notify the network manager of all trains operating in DP mode.
- The operator shall ensure that all DP trains meet the network access requirements administered by the network manager.

6.2 Banking Locomotive Distributed Power

Banking loco operations should incorporate the following:

- Provide communication between the driver in the lead loco of the train and the Driver of the banking locos.
- The driver in the lead locomotive shall direct the driver of the banking loco when to apply and reduce power.
- The driver in the lead locomotive shall have full control of the automatic brake for all rolling stock in the train but excluding the banker locos if not draft-load coupled to the train.
- The maximum tractive effort applied by the banking loco shall not exceed the network limit based on the axle weight of the wagons of the rear 1/3 of the train
- In banking loco operations, the banking locos may not be coupled to the assisted train.

6.3 Manual Distributed Power

Manual Distributed Power train operations should incorporate the following:

- Provide communication between the train Driver in the lead loco and the Driver of the trailing loco.
- The Driver in the lead locomotive shall direct the Driver of the trailing loco when to apply and reduce power.
- The Driver in the lead locomotive shall have full control of the automatic brake for all rolling stock in the train including the trailing loco.
- The maximum tractive effort applied by the trailing loco shall not exceed the network limit based on the axle weight of the wagons of the rear 1/3 of the train.

6.4 Common Requirements for Automated Distributed Power

Automated Distributed Power systems should have the following common requirements:

- Provide full traction and braking control for all rolling stock in the train to the Driver in the lead locomotive.
- Provide appropriate train system monitoring and warning capability for all powering locomotives in the train to the Driver in the lead locomotive.
- Provide means for synchronous and asynchronous control of remote locomotives, including dynamic braking, to the Driver in the lead locomotive.
- Only be used when traction control and anti-wheel slip/slide is provided for all locomotives in the train.
- Provide fail-safe intervention for critical faults by applying penalty brake and traction cut-out.
- Protect the DP system integrity including vehicle and train identification.
- Prevent interference between different trains or rolling stock.
- Fail-safe by cutting locomotive power and applying emergency brakes in the event of a critical system failure.
- All equipment and systems used on DP trains should meet electro-magnetic compatibility (EMC) requirements and prevent interference between systems on

the same or nearby rolling stock. Guidance can be found in AS 7722 EMC Management.

6.5 Wired Distributed Power System (WDP)

Wired distributed power systems (WDP) are used with electronically controlled pneumatic braking (ECP) systems. The WDP-ECP system has a trainline wire to provide control and monitoring of every vehicle (wagon and loco) in the train. This ensures that the functional status of the brakes on every vehicle is monitored.

Where degraded mode brake systems rely on batteries, the battery health and charge-life should be considered in the train operations planning.

To ensure train reliability, the functional integrity of the WDP-ECP trainline cable should be maintained, including the cable and connectors between vehicles.

6.6 Radio Frequency Distributed Power Systems (RFDP)

Radio frequency distributed power systems (RFDP) use the multiple-unit cable connection between locomotives within each consist and radio frequency communication between the train lead locomotive and the lead locomotive of each remote consist.

RFDP can be used with trains that are not fitted with ECP brake systems (note that trains fitted with ECP brake systems usually have a WDP capability). For this reason, the braking performance and time-dependent nature of conventional automatic air brake systems should be taken into account when analysing the train forces and assessing each train configuration proposed.

Driver and operation staff training, and competency requirements should include consideration of the time-dependent characteristics of conventional automatic brake systems.

Radio frequency communications between DP locomotives can sometimes be impaired by infrastructure and geographical features. For this reason, the operator should work with the Network Manager to identify areas where DP communications are interrupted or degraded such as in tunnels. Repeaters and other system enhancements can then be implemented effectively.

Rolling stock and track based RF equipment should be functionally compatible with all RFDP systems to achieve commonality of systems, equipment and components.

6.7 Alternative Systems

Alternative systems for distributed power trains may be acceptable if adequate assurance of train safety and network compatibility can be demonstrated to the local Network Manager.

The alternative DP system should meet the common system requirements listed above and provide compatibility and interoperability with other rolling stock on the network, including train recovery operations.

7 DP Train Planning

Before operating new distributed power trains, the following planning tasks should be undertaken:

- The DP train operator and network manager should liaise and agree the requirements to be met to permit DP train operation on the network. These should include a requirement that the Operator notify the Network Manager of all trains operating in DP mode and the method of notification is to be agreed between the parties.

- The proposed DP train configuration and route should be analysed for train forces and assessed for overall safety and network compatibility – refer to Figure 1 in Appendix B and the guidance notes in Appendix D. Note that minor changes may not require a full repeat of the analysis.
- A train specific risk analysis and risk register should be generated or updated and reviewed by the relevant stakeholders.
- Suitable risk mitigation actions should be implemented.
- Planning of train marshalling, shunting and locomotive provisioning.
- The train recovery plan should be prepared by the operator, reviewed and agreed to by the relevant stakeholders.
- Train operation staff / crew should be provided with appropriate training and competency assessment.
- Network management staff should be briefed, and RACI allocated.

DP train operations planning should include the following:

- Checking that all rolling stock, including sub-systems, has been type tested and meets the Network acceptance requirements of the network manager.
- All rolling stock sub-systems have been routine tested since the last maintenance activity.
- Pre-run checks including inspections and tests for the following:
  - Train integrity.
  - Brake system functionality.
  - DP system functionality.

8 Maintenance

Train maintenance should include the following:

- Application of reliability centred maintenance techniques.
- Updating of TMP to cover DP train systems and lessons learnt.
- Post maintenance routine testing to ensure DP and related systems integrity (Brake, Traction, Control, Distributed Power, Wheel Slip Protection systems etc).

9 Continual Improvement

For continuing DP train operations, the stakeholders should collaborate on safety matters and implement the continual improvement actions listed below-

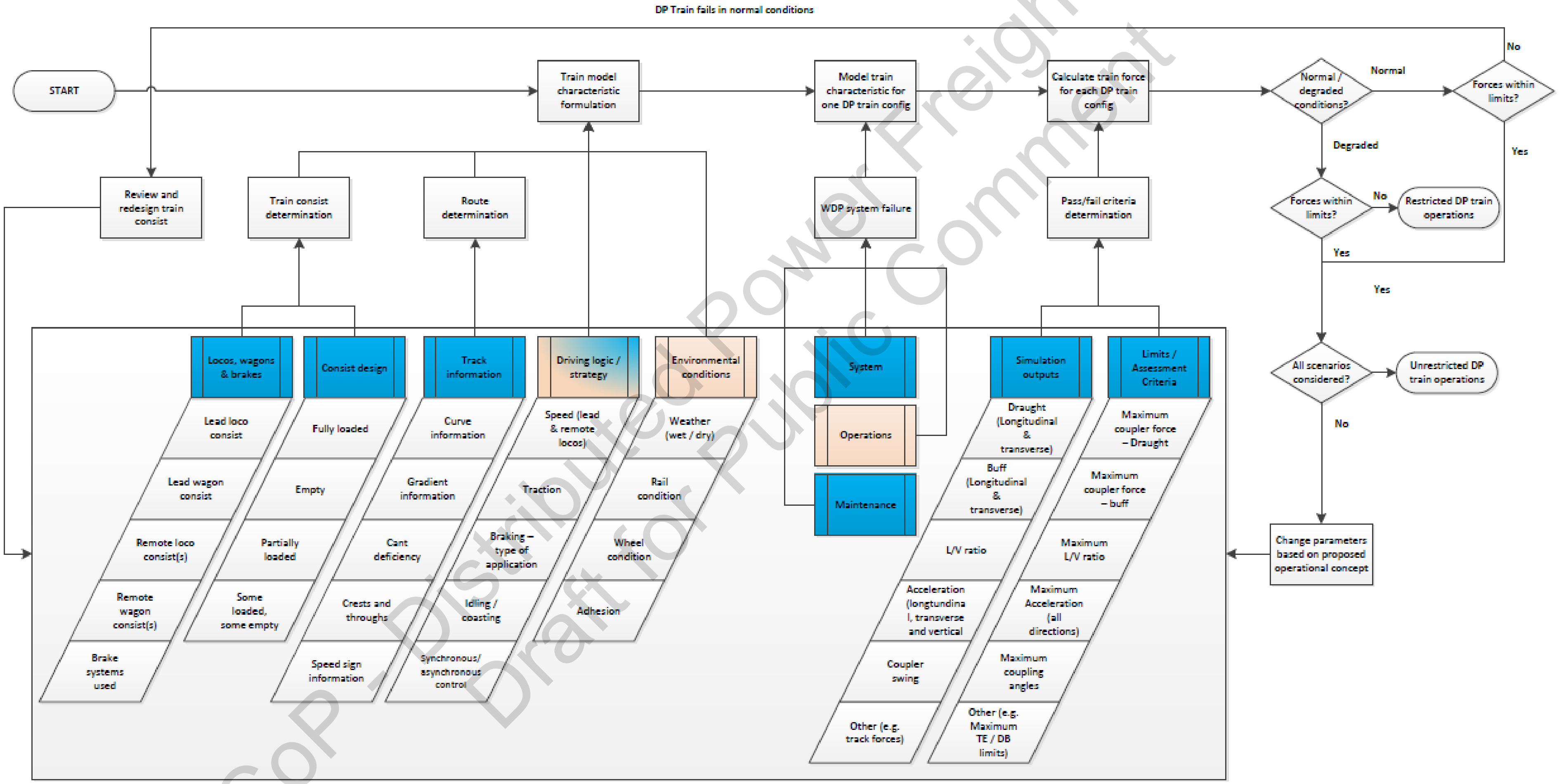
- Sharing of safety knowledge between stakeholders.
- The risk analysis and risk mitigations should be reviewed and updated on a regular basis.
- Measurement of in-train forces by strain gauging or other suitable methods to verify the accuracy of the analytical modelling.
- Simulation or modelling of in-train forces for loaded and unloaded trains on relevant routes.

- Review of safe limits for in train forces, tractive effort and dynamic braking.
- Review of limits for partly loaded wagons in loaded trains and loaded wagons and idle or 'dead' locos in unloaded trains.
- Review of synchronous and asynchronous control.
- Review and implementation of new technology options for improved monitoring, control and automation.
- Updating of training and knowledge of operations staff with lessons learnt and new technology where available.
- DP Train simulators should be evaluated for potential benefits in training and risk assessment. Note that 'DP Train simulators' can take several different forms and are not necessarily in the form of a 'Driver hands on controls' operating environment. DP train simulators may need extensive development before they reach a commercially viable standard.
- Lessons learnt should be documented and disseminated to the stakeholders.
- Updating and briefing to stakeholders of train recovery plans if altered.

Appendix A Distributed Power Hazard Identification

Hazard Reference	Hazard	Section Addressing
5.1	Harm to the environment	2.3.5.7
5.3	Harm to persons	2,3,5,7,
5.5	Harm to Rolling Stock Related Processes	2,3,5,7
5.6	Out of Control Trains	2,3,4,5,7
5.8	Collision	2,3,6,7
5.9	Signal Passed at Danger	2,3,7
5.10	Brakes being Inadequate when Moving	2,3,7
5.19	Derailment	2,3,4,5,7
5.28	Vehicles overturning	2,3,4,5,7
5.30	Excessive dynamic longitudinal forces	2,3,4,5,7
5.35	Trains parting	2,3,4,5,6,7
5.38	Hazardous substance contact	2,3,5,7
7.1	Derailment and or Collision	2,3,4,5,7
7.3	Damage to Rolling Stock and or Infrastructure	2,3,4,5,7
7.4	Harm to the Environment	2,3,5,7
8.2	Damage to Rolling stock and Infrastructure	2,3,5,7
10.3	"Authority "execution error	2,3,5,7
10.14	Incompetent workers	2,3,4,5,7

Appendix B Train Force Analysis Logic Diagram



Appendix C Guideline Notes for Long Train Dynamic Analysis

The following levels of analyses should be undertaken to satisfy risk assessment criteria:

(a) Simple analysis: this analysis is limited to a quasi-static case and does not allow calculating dynamic coupler forces through the train. The analysis should be performed in risk assessment cases when the train and track operational parameters are known but the train operational parameters are subject to insignificant changes in values.

(b) Full analysis: his analysis considers the longitudinal behaviour of the train as a function of train control inputs from the locomotive, train brake inputs, track design characteristics and vehicle connection characteristics. In this analysis, the lateral and vertical movements of the vehicles are not considered. The analysis should be performed in major risk assessment cases and allows determining in-train forces and energy usage.

(c) Advanced analysis: this type of analysis presents additional extensions to the full analysis that focus on the interaction of longitudinal train dynamics and lateral/vertical rail vehicle dynamics and it can be performed in longitudinal train dynamics simulators or multibody software packages. The longitudinal train dynamics and multibody simulation approaches can be combined to deliver comprehensive simulation results. This analysis should be performed for the following risk assessment scenarios:

   i. Wheel unloading, wheel climb and rollover on curves due to lateral components of coupler forces;

   ii. Rail vehicle body and bogie pitch due to coupler impact forces;

   iii. Rail vehicle lift-off due to vertical components of coupler forces;

   iv. Infrastructure damage.

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