

Ref: R00673

**Report on the findings of:
Current practice and
effectiveness of derailment
containment provisions on high
speed lines**

Issue 1

Zoetermeer, Netherlands
30 September 2004



HSL-Zuid

Submitted by:

Booz | Allen | Hamilton
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information of the company to whom it is addressed.*

Executive Summary

Overview of Current Practice

The findings indicate that there is a general acknowledgment that Derailment Containment Provision (DCP) is a positive approach to minimising derailments although there was:

- No single current practice to derailment containment provision,
- No substantive reasons for the provision of DCP,
- No standard used in applying DCP,
- No definite opinion on the effectiveness of DCP,
- No DCP is 100% effective.

The majority of projects and organisations looked to use DCP Type 1 or DCP Type 3 at high risk locations and there was widespread agreement that DCPs are not used as a matter of course throughout the system.

Estimation of Effectiveness of DCP

There is insufficient information to make a quantified decision on the effectiveness of DCPs to confidently predict how a train will behave in a derailment at speeds above 200 km/h. Furthermore, determining effectiveness is problematical, due to the complex variable factors to be considered when trying to evaluate the effectiveness of DCP and every accident is unique.

After a high level qualitative assessment, DCP Type 3 is the most effective form of DCP on high speed lines based on high level causal events. This high level assessment is supported by organisations which operate high speed lines such as CTRL and Skinkansen who implement DCP Type 3.

The effectiveness of DCP can be enhanced through mixing DCP Types, with DCP Type 3 at switches in conjunction with DCP Type 1 to be potentially effective. The least effective form of DCP was Type 2.

The most effective approach to managing the risk of derailments is to focus on “Step Zero”, the prevention of the causal events. Many of the causal factors associated with derailment could be mitigated to some degree by the detection / prevention of faults on the vehicle or the infrastructure.

This attention to managing derailment risk includes the system design phase, where there needs to be a realistic expectation regarding the maintainability of the equipment. The designer should be careful about making design assumptions which can have long term consequences.

Furthermore, through the lifecycle of the project and its operational lifecycle, when a change to the system is proposed, the relevant custodian of the system should evaluate the effect of the change across the whole system environment.

Adverse Effects of DCP

It can be stated that under certain conditions, DCP could contribute to the escalation of a derailment, or to the derailment in the first place. These being:

- The overall continuity of the DCP,
- Adverse effects related mainly to the maintenance elements,
- Debris between the running rail and the DCP rail causes or escalates derailment,
- Deutsche Bahn indicated that they limit the use of DCP Type 1 because of the difference in passenger carriage bogie and axle designs,
- Under coach arrangement of brake rigging and traction equipment may also interfere with the guide rails and cause a more dangerous situation after a derailment,
- An increase in escalation with DCP Type 3, since the barrier could cut through the passenger areas on a double-decker train.

HSL-Zuid Application

On the HSL-Zuid line there is a combination of ballasted track and Rheda slab form track. In the instance of a derailment on Rheda slab form track there is no ballast to act as resistance to slow the train down. Furthermore the structure of the Rheda track, such as the concrete boots for the base plates could accelerate the escalation of the derailment and derailment escalation since the wheel set could “fall off” the Rheda track bed slab.

Infraspeed's proposed concrete upstand between the rails would appear to be a sensible provision, though it should be designed so as to ensure the outside derailed wheel remains securely upon the track slab. There is a concern with the interface design on HSL-Zuid between the vehicle and the DCP, since the brake disc may ride on top of the concrete plinth DCP and cause potentially serious consequences.

Recommendations

1. Undertake a critical evaluation of the design assumptions and inputs for the civil design and system design (especially with regards to the Rheda Slab Form Track) in and validation of the design within the boundary of the HSL-Zuid Transportation System.
2. Independently review the HSL-Zuid Transportation System safety management system to ensure it is effective, as far as reasonably practicable, in eliminating derailments since this is the most effective solution to reduce escalation. This would include for example:
 - Ensuring that appropriate risks are being adequately managed i.e. fires in tunnel systems;
 - Ensuring that a consistent approach (whilst understanding where this is not applicable) to derailment issues are taken into account in operations, training and procedure definition as appropriate;
 - Appropriate assurance regimes in place in order to ensure that installation, inspection and maintenance are undertaken.

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Section

1

Introduction

This report forms the Booz Allen deliverable in response to the letter from the HSL-Zuid organisation (ref HAVL/517575 [AD1]) requesting a study into the current practice and effectiveness of derailment provisions on high speed lines.

1.1 Background to the Assignment

The HSL-Zuid organisation, are responsible for the delivery of the HSL-Zuid Transportation System with the requisite level of safety. Derailment risk is one of the main issues in the safety management of the project. The high traffic density, large number of overpasses/structures/transitions and extensive use of elevated track significantly increase the consequences of a derailment on HSL-Zuid.

A key element of the HSL-Zuid derailment risk limitation strategy is limiting the consequences of a derailment. This approach provides a second line of defense in managing derailment risk, (the first line of defense being the prevention of the derailment occurring in the first place, the last being emergency response). In the event that a train has derailed, the measures introduced as a result of this element of the derailment risk limitation strategy, aim to reduce the loss of life, injury, property damage and economic damage of that derailment.

Whilst a train might be derailed, the consequences of that derailment may be limited provided the train does not collide with another object (e.g. civil structure or another train) nor fall from a structure (e.g. elevated viaduct, bridge or embankment) nor roll over. This principle is most graphically demonstrated by comparison of the derailments of TGVs at Haute Picardie station in 1993 and the ICE at Eschede in 1998. In the case of the TGV, the train remained upright and did not encounter any obstructions. There were no deaths and few injuries. In the case of the ICE, the derailed train collided with an overbridge, resulting in many deaths and extensive damage. Whilst there are a number of variables involved with these two significantly different results, it is clear that in the case of the ICE, escalation of the derailment was a major factor as the train encountered a rigid object due to travel beyond the planned track alignment.

The goal of Derailment Containment Provisions (DCP) is to reduce the probability of a derailment escalating by increasing the probability that a derailed train will:

- Follow the track;
- Not enter the free space profile of an adjacent track;
- Remain upright;
- Not encounter a rigid object.

Provision of DCP falls within the scope of the Infrastructure Provider to the extent that it is required to achieve the Safety Case and specific targets detailed in the Implementation Agreement.

Recent reports commissioned by the Infrastructure Provider have cast doubts on the viability of some of these targets. The Infrastructure Provider has presented a position where targets are not achievable. A major part of the Infrastructure Providers argument is founded on the degree to which DCP can reduce the probability that a derailment will escalate. It has also been stated that DCP could increase the probability of escalation.

1.2 The Assignment

In managing the delivery of the HSL-Zuid Transportation System and the Infrastructure Provider contract in particular, the HSL-Zuid organisation wishes to act as the informed client and reach a better understanding of current practice and effectiveness of DCP on high speed lines. To achieve this and to allow a fair appraisal of the case presented by the Infrastructure Provider, the HSL-Zuid organisation has, in part, commissioned this assignment. Three separate parts of the assignment were identified. These were:

- Part A An Overview of current practice and existing knowledge. Requiring discussions with railway organisations and a search of existing knowledge on DCP effectiveness;
- Part B An estimation of effectiveness of whether DCP will work for trains running 200-300 kph. Three configurations were identified for the purpose of this assessment, these being:
- | | |
|------------|---|
| DCP Type 1 | provisions mounted between the running rails, intended to guide the derailed train at wheel level; |
| DCP Type 2 | provisions mounted outside of the running rails, intended to guide the derailed train at wheel level; |
| DCP Type 3 | provisions mounted outside the running rails intended to guide the train at bogie level; |
- Part C An Assessment of the adverse effect of DCP.

The full Terms of Reference for this assignment are contained in [AD2]. This report provides a discussion of derailments and how and why they escalate. It also reviews several significant derailments that have occurred in Germany, United Kingdom, Australia, and the United States to determine what may be learned from these real world occurrences. This report also provides our findings on each of the three parts of the assignment and draws conclusions and recommendations, based on our findings and analysis.

1.3 Methodology and Approach

The methodology adopted to approach this assignment was founded on the three separate parts of the assignment. It was considered both prudent and practical to address Part C of the assignment (detrimental effects) as an integral part in the execution of Parts A and B.

During Part A of the assignment it became apparent that organisations and projects were unwilling or unable to discuss the sensitive issue of derailments and DCP due to a variety of reasons, e.g. lack of data collection processes, commercial exposure. In addition, the numbers of derailments above 200 km/h are thankfully small. As a result the lack of data throughout the world, the original quantified approach which included estimating the probability of escalation, given initial derailment for the determination of DCP effectiveness as detailed in the assignment Terms of Reference [AD2] was un-achievable.

The approach to the assignment was modified in agreement with the client (AD3) to a qualitative approach. The revised methodology and approach relied heavily on interpretation by an expert panel, which had a wide range of expertise, covering technical, operational, research, design, construction, maintenance and investigation skills. The revised approach and methodology is detailed below in Table 1 to Table 4 and is illustrated in Figure1.

Part A	Overview of current practice and existing knowledge
Task	Activity performed
A1.	Compiled a list of projects and organisations to be interviewed. The list was agreed with the HSL-Zuid organisation. The list identified projects and organisations worldwide but concentrated on European countries. The basis for selection was relevant experience associated with derailment and / or high-speed line operation.
A2.	Developed a standard questionnaire which ensured a consistent approach to the interviews and focused the interviewer on gaining appropriate and relevant data for Parts B & C of the assignment. The questionnaire was agreed with the HSL-Zuid organisation and is included as Appendix A to this report. The questionnaire was distributed to selected organisations.
A3.	Conducted face to face interviews with associated organisations and projects which had similarities with HSL-Zuid, to ensure a full understanding of the issues and implications.
A4.	Conducted telephone interviews where face-to-face interviews were not possible.
A5.	Undertook a worldwide overview of existing knowledge about effectiveness and possible adverse effects of DCP. This overview covered academic sources as well as sources from within the railway industry and involved: <ul style="list-style-type: none"> • Literary review; • Internet search; • Contacting organisations for data; • Internal sources within Booz Allen.
A6.	Collation and tabulation of the captured data to enable the information to be analysed. Any discrepancies in the captured data or white spots were identified and supplementary interviews, investigations were conducted. The results of this tabulation are included as Appendix B to this report.

Table 1: Activities for Part A

Part B		Assessment whether DCP will work for trains running 200-300 kph
Task		Activity performed
Pre Expert Panel Session	B1.	The expert panel: a) Analysed the common trends, operational similarities and key characteristics of the information gathered in Part A. b) Reviewed the Questionnaires obtained from High Speed Operators. c) Identified and justified accidents for the Expert Panel review.
	B2.	Reviewed the accident synopsis, which provided factual information on each derailment under review.
	B3.	Identified a comprehensive list of the causal factors based on the synopsis from the selected accidents.

Table 2: Activities for Part B prior to Expert Panel Session

Part B		Assessment whether DCP will work for trains running 200-300 kph
Task		Activity performed
<p><i>The expert panel meeting was a discussion of a number of accidents and expert opinion on how the outcome of the accident would vary based on the application of Derailment Containment Provisions (DCPs). The expert panel reviewed each accident and attempted to draw conclusions about DCPs. Steps B4 to B7 were executed for each of the accidents. Drawing on the results of this analysis, activities B8 to B 10 were concluded.</i></p>		
During the Expert Panel Session	B4.	Discussed escalation of the Accidents covering: a) Did Escalation Occur? b) When did Escalation Occur? <ul style="list-style-type: none"> • At the time of the Derailment • Some time after the derailment c) What caused the derailment Escalation to Occur?
	B5	Reviewed if DCPs were in place at the derailment site? Yes – DCPs were in place in the area of the derailment <ul style="list-style-type: none"> • What type of DCPs? • What was the effectiveness of the DCP? No – DCPs were not in place in the area of the derailment <ul style="list-style-type: none"> • How would application of DCP Type 1, DCP Type 2, DCP Type 3 have affected the accident including speeds at 200-300 Km/h?
	B6.	Identified steps that could have been taken to prevent escalation of the derailment: a) Infrastructure b) Vehicles c) Operation d) Human factors e) Others

Table 3: Activities for Part B during the Expert Panel Session

Part B		Assessment whether DCP will work for trains running 200-300 kph
Task		Activity performed
		Identified steps that could have been taken to prevent the derailment: a) Infrastructure b) Vehicles c) Operation d) Human factors e) Others
	B8.	Expert panel identified derailment causal factors
	B9.	Identified additional risks that may be associated with each type of DCPs.
	B10.	Expert panel key findings

Table 3 Continued: Activities for Part B during the Expert Panel Session

Part C		Assessment of potential adverse effects of DCP
Task		Activity performed
General		Determined and assessed the adverse effects of DCP in parallel with Part A and Part B of the assignment. Whilst undertaking the Part A and Part B of the assignment, the data collected and analysis performed addressed the potential for any extra risk that could be introduced as a result of installing DCP. The assessment considered direct impacts, such as dragging train equipment, interaction with derailment provisions that may not be continuous, but also indirect impacts, such as issues with maintainability, cost or system availability.
Interaction in Part A.		Interaction with Part A included: <ul style="list-style-type: none"> • Inclusion of specific questions relating to adverse effects in the data collection questionnaire; • Addressing adverse effects explicitly in the interviews; • Searching on adverse effects during the worldwide overview of existing knowledge; Identification and isolation of adverse effects in the collation and tabulation of the available data.
Interaction in Part B		Interaction with Part B included: <ul style="list-style-type: none"> • Evaluation of negative effects of DCP on test derailment examples, • Determination of negative influences on overall effectiveness, • Identification of additional risks associated with DCP, • Consideration of negative effects in determination of the way forward.

Table 4: Activities for Part C

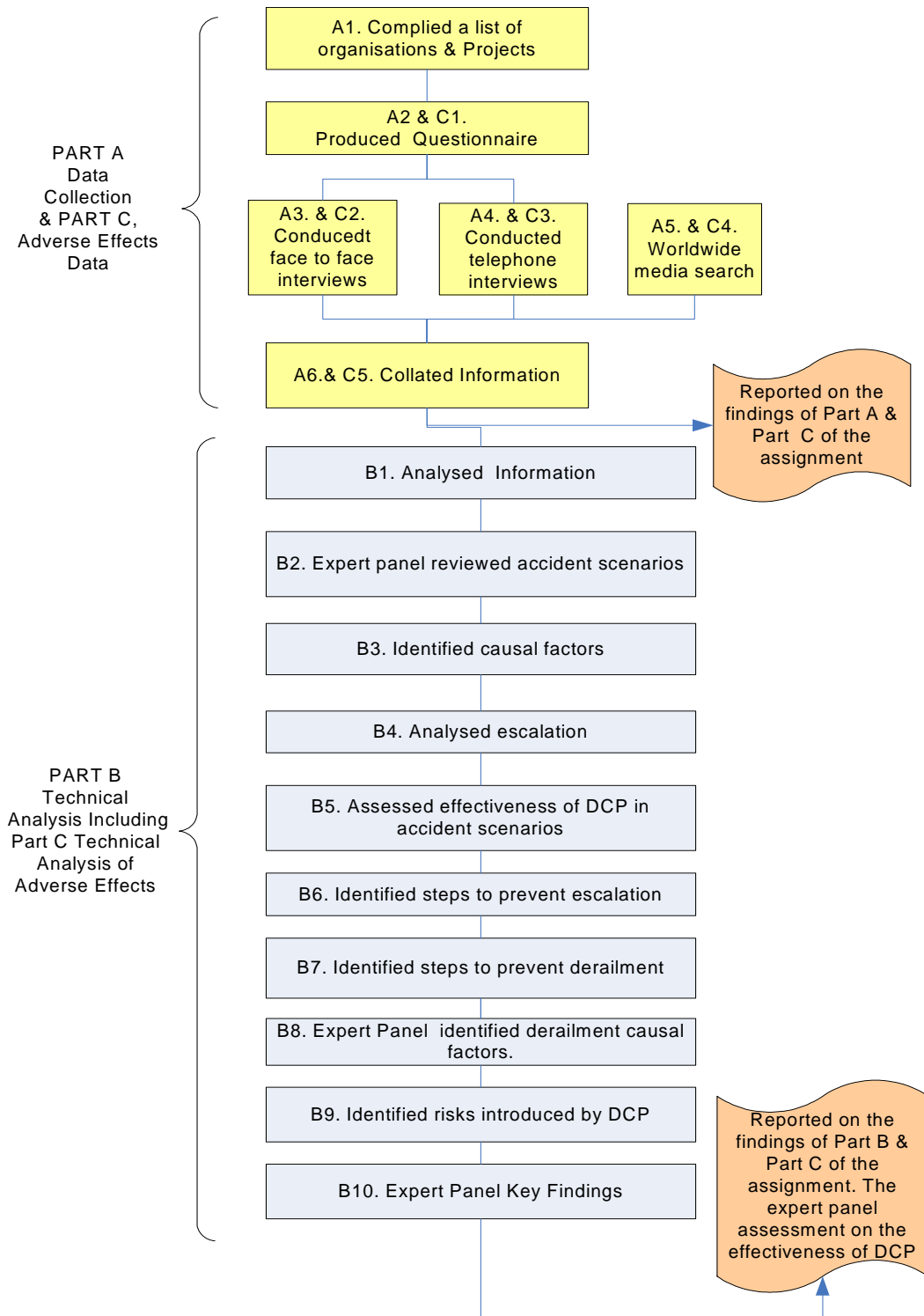


Figure 1 - Methodology Flow Chart

1.4 Report Structure

This report is structured as follows:

- | | |
|-----------|---|
| Section 1 | Introduction
Provides a background to the assignment, details of the assignment itself and the methodology used for the execution of the assignment. |
| Section 2 | Results
Provides the results of the interviews and process's of the expert panel activities. These results are then tabulated and inferences drawn from them |
| Section 3 | Conclusions
Details the conclusions drawn from the analysis. |
| Section 4 | Recommendations
Provides recommendations coming from the assignment with cross reference to the appropriate section of the report with the substantiating data. |

The base data from the interviews and the expert panel is provided in the appendices and references.

Section 2 Technical

2.1 Part A: Overview of Current practices and existing knowledge

Part A of the assignment consisted of gathering information in order to achieve an overview of current practices and existing knowledge in DCP. This was achieved using a series of interviews and a media search. The results for these activities are detailed below.

2.1.1 Interviews

The investigation included interviews with projects and organisations in Europe, North America, the Far East and Australia and involved face-to-face interviews and telephone interviews. The projects and organisations that were contacted are listed in the following tables. Those organisations with which were conducted face to face interviews are shown in Table 5 whilst those with whom telephone interviews were conducted are shown in Table 6. The interviewees were motivated by supporting the open exchange of information to benefit the rail industry though out the world. An in this culture, HSL-Zuid offered to share the final report with each of the projects or organisations providing input information.

Railway / Organisation	Contact
Deutsche Bahn AG, Germany	Dr. Gunnar Baumann Director of track techniques
Société Nationale des Chemins de Fer Belges, Belgium	Mr. Johan Verschaeve, Safety Manager (R+D), B-Rail (SNCB)
Øresund Link, Denmark/Sweden	Johnny Restrup-Sørensen Director of Infrastructure
Central Japan Railway Company	Takeshi Inagawa, manager, representing Central Japan Railway Company
Société Nationale des Chemins de Fer Français, France	No response
High Speed Lines France	R Dayez, French Ministry of Transport
Channel Tunnel Rail Link, UK	Lorna Small Rail Safety Manager & Ken Harvey Risk Manager

Table 5: Railways/Organisations for Face- to-Face Interviews

Railway / Organisation	Contact
Taiwan High Speed Rail Corporation	Mike Baxter, Head of Track Design
U.S. Department of Transportation	Robert M. Dorer Acting Deputy Director, Office of Safety and Security Volpe National Transportation Systems Center, Chief of the High-Speed, Ground Transportation Division Research and Special Programs Administration Chairman of a TRB committee (High Speed Ground Transportation technical topics)
Massachusetts Institute of Technology Center for Transportation Studies Information on Japan	Professor Joseph M. Sussman Professor of Civil and Environmental Engineering and Engineering Systems
Great Belt (Storebælt) Railway Link Denmark	Jørgen Kampmann Senior Engineer, Risk Analysis COWI A/S
LTF (Lyon Turin high speed link), France/Italy	Lorenzo Brino, Assistant Director Technical Studies, Lyon Turin FerroViaire & Eddi Verbesselt, Risk Analyst
Italy	Ing. Natoni, Chief Engineer permanent way at Italferr up to last year, a renowned expert in Italy

Table 6: Railways/Organisations for Telephone Interviews

Results

Whilst undertaking the interviews, some organisations were willing to provide an overview of DCP, however they would not complete the questionnaire. The completed questionnaires are summarised in Appendix B and the original completed questionnaires are contained in [RD1]. The major findings of the interviews are listed below:

DEUTSCHE BAHN

The Eschede accident is a major incident in German rail history and is covered in detail in Part B of the report.

Track standards require that guard rails are needed only on lines with mixed traffic under certain conditions. They are not used on the Cologne – Frankfurt/Main route.

There have been two instances where DCP Type 1 has been successful. In 1992 a train involved in a collision on a bridge was prevented from falling off of the bridge by guard rails, and in 1996, impact to an abutment of a road bridge was prevented by guard rails. In addition to guard rails, passive protection systems along roads and on road bridges are used to prevent the deflection of vehicles onto the track.

SNCB

DCP Type 1 protection is used especially on high embankments and on bridges. In specific areas where there is a possibility of subsidence, then DCP Type 3 is used, i.e. concrete platforms.

SNCB are proactive in trying to prevent derailments and undertake various preventative measures. These include:

- Hot axle box detectors used as a preventative measure.
- Each morning the lines are declared secure for operation after a ride of an opening train (train balai according to the French practice). This opening train can be a commercial or non-commercial ride of any train at 160 km/h maximum. These opening rides are very helpful to avoid unexpected obstacles when the rides at 300 km/h start. SNCB stated that with regards to the opening train, *"It is considered as a major contribution to our DCP-strategy"*.
- On high speed lines, the escalation of the derailment can be reduced by the use of a special rolling stock (high speed trains with bogies between the cars which assist in keeping the train as one).
- The formation of a specific multi-disciplinary team for maintaining the DCP on the high speed line.

GREAT BELT (STOREBÆLT) RAILWAY LINK

DCP Type 1 is used on the west bridge and within tunnels DCP Type 3 is used in the form of concrete walkways. Furthermore, there are derailment preventative measures employed. These include hot axle box detectors and gauge control facilities at the entrance to the crossing.

It is noted that in Denmark there has been one derailment on a bridge. In this case DCP Type 1 served its purpose. In 1978 there was a derailment on the Storstrøms Bridge which carries a single track railway and a two lane highway between Zealand (Sjælland) and the island of Falster, south of Zealand. A lamp post fell across the track which was subsequently hit by a locomotive. The locomotive derailed and was caught by the DCP.

ØRESUND LINK, DENMARK/SWEDEN

DCP Type 3 in the form of concrete and steel "side walls" or guiding devices are used. These were part of the bridge/tunnel construction, so their instalment did not trigger additional investments. The concrete option is used in the tunnel and on the approach bridges, where as steel is used on the span bridge due to constructional reasons (weight). Prior to the entrances to tunnels and the crossing there are dragging equipment detectors and on the trains there are rail break detectors.

JAPAN

DCP Type 1 is used at bridges, in other specific high risk areas DCP Type 3 is used. It is of significance to note the response from Japan Eastern:

“In the case of the SHINKANSEN, a derailment accident in a high-speed run has not occurred for 40 years since we started service in 1964. We have confidence that the SHINKANSEN will not be derailed in a high-speed run by internal factors in JR East, because we have done strict maintenance of wheels and rails, and we have past results which never have been occurred. The SHINKANSEN basically runs through a exclusive track which is surrounded with soundproofing walls, consequently the possibility of collision with other structures after a train was derailed to the truck outside such as the accident in Eschede will be extremely low. We think that it is important to detect accident as early as possible and to limit speed of trains when we have some troubles in the track and an earthquake occurs in Japan.”

The cultural perspective of the Shinkansen is interesting. Drivers and maintainers etc. comply with the rules and regulations rigorously. The level of training is extremely high and is, of course, based on the foundation of an extremely disciplined society.

In addition to this, the management of the infrastructure is such that passenger services are complete by midnight and do not commence till 6am the following morning. This allows a regularly available window in which maintenance work can be carried out. Within this maintenance regime a special train (Dr Yellow) checks all aspects of the lines and overhead power cables at normal Shinkansen operating speeds.

This response demonstrates alternatives available an in operation that can allow railways to operate at high safety levels with limited DCP. We consider this to be an important indication when making informed decision concerning DCP.

HIGH SPEED LINES, FRANCE

DCP Type 1 is applied on bridges i.e. the bridge over the river Rhone and at transition curves where the alignment changes. Mr R Dayez from the French Ministry of Transport stated:

“In the few derailments that have occurred, as on HS lines as on conventional lines the TGV has followed the track and stayed upright. This is mainly thanks to the characteristics of the fixed train set heavy locomotive (motor coach) bogies situated at the connections between the coaches (jacobsdraaistellen) which leads to stiff connections between coaches.”

At over passes, columns supporting the road or rail that cross the line are situated at some distance from the rail track. The running rail normally limits the lateral displacement of a derailed train and therefore the train does not hit the columns. And on elevated sections of track, the embankment is made wide enough to support a derailed train caught by the running rail.

Therefore in France a combination of DCP Type 1 and construction design is used to reduce derailment escalation. This is also supported by concentrating on the causal events and they believe the main risk is motor vehicles falling from overpasses. In order to mitigate this causal event, detection devices are attached to viaducts. Therefore when a motor vehicle is detected as a potential derailment obstacle, trains within the relevant area are stopped automatically through the signalling system.

CTRL

CTRL produced a Derailment Containment Strategy (ALARP Risk assessment) which recognised that no DCP is 100% effective and that the attention should be focused on preventing the causes of derailments and rather than managing the consequence of a derailment.

The approach to DCP was based on their Train Accident Model which is an averaging model in the sense that it takes an average embankment etc.

There was no justification for the provision of DCP if CTRL was to have been a passenger only line. The additional risk introduced by mixed traffic required DCP to be installed at strategic and high risk locations.

Due to the absence of derailment data and evidence of DCP effectiveness, the risk analysis used assumptions and estimated ranges and considered common derailments. The report identified that check rails (DCP Type 1) and guard rails (DCP Type 2) were not effective at high speed.

CTRL - CONTINUED

CTRL undertook an approach which was a variation on UIC Leaflet 777-2 'Structures built over Railway lines- Construction requirements in the track zone' [RD5]. In addition the positioning of the DCP Type 3 is designed so that during a derailment the concrete kerb acts and the running rail act as a barrier to the laterally displaced wheelset.

A key lesson from CTRL is that the theoretical approach to DCP as a result of analysis has to be technically feasible and practicable and compatible with the track bed design.

TAIWAN, THSRC

On the THSRC there are a significant number of tunnels, viaducts and bridges. THSRC has a walkway/cable duct that serves the purpose of the DCP, which runs through the tunnels, viaducts and bridges and is almost continuous. The implementation of this type of DCP was not based on an analytical study but on expert judgment.



THSRC Construction showing walkway extreme left

LYON TURIN HIGH SPEED LINK

This project is at the Functional Specification stage. The approach to DCP is based on the approach taken on Channel Tunnel, and will adopt DCP Type 3 in the form of sidewalks on each side as was the case in Channel Tunnel. It is worth noting that LTF carries freight and passengers.

ITALY

The approach taken on Italian high-speed lines compared to their traditional lines is significantly different to other countries. The distance of the axes of parallel lines is increased to lower the probability that a derailed train enters the free space of an adjacent track, and the width of the ballast at each side of the line is increased, doubling the effect of containing the wheels of the derailed train and of dampening the impact of the wheels on the ground. This approach to DCP is noticeably different to other countries in one particular aspect. Worldwide, DCP Types 1,2 and 3 are generally only used at areas of high risk, i.e. elevated lines and tunnels and switches, where as the Italian approach to DCP which, although not one of the defined types in this study, is used almost continuously along their high speed lines.

2.1.2 Media Search

The approach to the media was to undertake an extensive search of the internet to ensure that we covered the breadth of the subject area. However this approach did not provide substantial detailed information. In order to capture detailed information, we utilised individual experience and contacts within the rail industry worldwide to identify and obtain detailed information. We also approached a non-railway academic body to broaden the search.

Results

The worldwide media search data successfully identified additional material to that provided in the interviews and questionnaire. A summary of the media search information is shown in Appendix C.

The media search demonstrated that throughout the world derailment is a major risk for transport systems. This risk is extended further than the safety implications, for example the recent derailment in Sakarya, Turkey where 38 people were killed. The State Railways Authority (TCDD) was found to be at fault in addition to the chief machine operator and his deputy. This derailment during has resulted in significant political changes.

In undertaking the media study the results indicate that the derailment provision was not designed specifically for high speed lines, and generally there has been no robust analysis to demonstrate the effectiveness of DCP on high speed lines.

In support of the change of methodology and approach to this assignment, the only statistics we found on derailments were published by the Independent Transport Safety & Reliability Regulator New South Wales in Australia (RD2). The statistics confirmed that data is only available for low speed, or depot derailments.

Examining events in the Netherlands, the recommendations from the Baarn derailment [RD3] look towards management actions in preventing derailments rather than the provision of additional infrastructure as an effective way forward. This is of significant relevance to HSL-Zuid who will be required to support this recommendation.

The TTAC 'The review of Derailment Risk for the HSL-Zuid Railway' [RD15] identified that only three high-speed derailments have occurred involving trains operating between 200 to 300 km/h. All three occurred in France and involved TGV or Eurostar Services. The TTAC report determined the effectiveness of DCP in a manner which included several caveats and limitations.

In the UK there is no common practice for DCP. The risk of derailments is assessed on a case by case basis [RD4]. For example, the Health and Safety Executive required the Heathrow Express Airport Tunnel project to incorporate derailment containment throughout the lengths of the tunnels, to ensure that any injuries or losses caused by train derailment would be minimised. The project implemented a central concrete

up-stand in the four-foot area, which is stopped when equipment is required in the four foot area. [RD6]

There is considerable work generally being led by the European Commission on derailments. The media search has identified some of these initiatives below:

TRAINS SAFE

European Commission is supporting various activities in response to the following issues:

- the move towards separation of infrastructure management activities from those of train operation, and the opening up of the network to new entrants;
- the increase target increases in capacity whilst simultaneously delivering safety improvements;
- interoperability, intermodality and the harmonisation of standards.

The TRAINSAFE thematic network provides a mechanism for addressing the passive safety aspects of the above issues. Their review into DCP concluded that in high risk areas, (i.e. switch and crossing layouts, on bridges and during construction work), check rails can be installed. More importantly, the review identified the adverse effects of using long sections of checkrail is that if the rail vehicle did become derailed, the presence of the checkrail can impair deceleration compared to running on ballast, [RD7].

Standards

The European Commission commissioned a study of the obstacles to the completion of the internal market for rail mass transit systems. The report identifies standards in Member states that relate to derailment. The report demonstrates that across the member states there is no uniform approach to derailment. The report concluded that standards aimed at reducing derailments would be highly beneficial for the railway industry and was given a medium priority [RD8].

Safety In Tunnels

Economic Commission for Europe Inland Transport Committee invited a group of experts throughout Europe to consider safety in tunnels, their recommendation to the Inland Transport Committee was that derailment containment measures should be provided in all tunnels, [RD9].

In Australia the approach is to use guard rails on bridges and, more significantly, under many bridges and other structures to prevent a derailed vehicle straying too far and into the bridge columns/supports. Other preventative measures used are hot axle box detectors used trackside in order to prevent bearing failures that can lead to derailment, and devices such as catch points and 'derailment devices' blocks to stop runaways from entering mainlines.

The information from the United States of America brought a different view towards DCP. Amtrak has not implemented DCP and considers there to be adverse affects with its implementation and its associated maintenance [RD14].

In terms of the information available from the academic world, the Federal Railroad Administration has undertaken various studies. These include “Shared Right-of-Way Safety Issues” [RD10] which look at protecting operating envelopes through the means of ditches and barriers etc. Of more significance is the “Intrusion Barrier Design Study” [RD11], which modelled intrusion barrier methods of DCP. Their conclusion was that with an intrusion barrier on both sides of the running lines, the consequences of the derailment were more severe due to trains getting wedged between the two barriers. In instances where the intrusion barrier was on only one side of the running rails, the lower speed trains stayed in contact with the barrier longer and came to rest in a more severe zig-zag, which could result in more severe consequences.

Within the United Kingdom there have been several accidents involving derailments. As a result the Rail Safety & Standards Board has initiated several research assignments. (Although RSSB is not an academic organisation, it does sponsor research topics undertaken by academic and research organisations etc).

These papers, Rail Safety & Standards Board Report “Engineering Overhead line structure design to cater for collision” [RD12] and Rail Safety & Standards Board Report “Engineering Derailment mitigation – categorisation of past derailments” [RD13], conclude that:

- When there is an impact with overhead line side structure, there may be a significant amount of damage to the train. The severity is dependent on which part of the train absorbs the impact, however line side structures can have a beneficial containment effect.
- Statistics show that most derailments do not affect passenger services and just under half of the derailments occurred when the train was travelling at less than 16km/h.

2.1.3 Part A Summary

DCP is a sensitive topic amongst rail organisations and there is concern that information provided could expose them to commercial issues.

The questionnaires and interview responses indicate that there is a general (although not universal) acknowledgment that DCP is a positive approach to minimising. Although there is:

- No single current practice to derailment containment provision,
- No substantive reasons for the provision of DCP,
- No standard used in applying DCP and consequently
- No definite opinion on the effectiveness of DCP
- No DCP is 100% effective.

In the majority of cases, it was provided because it was considered to be a ‘good idea’ e.g. Taiwan, or due to an earlier accident. The exception was CRTL where their approach was based on a quantified risk assessment. Due to the lack of data

concerning derailments this risk assessment was used assumptions and ranges of values and only considered 'common' derailments. The risk analysis concluded that check rails (DCP Type 1) and guard rails (DCP Type 2) were not effective at high speed. A key lesson from CTRL is that the theoretical approach to DCP has to be feasible and practicable and the design of the DCP Type 3 took into considered the track layout to improve DCP effectiveness.

The widespread findings are that most authorities looked to use DCP Type 1 or DCP Type 3 at high risk locations. These being where there are potential obstructions (over bridges), escalating track geometry (curves) or structure transitions (into tunnels). However, DCPs are not used as a matter of course throughout the system. Most agreed that the discontinuity of the DCP could in itself contribute to the derailment escalation but offered no solution or analysis to support this concern.

The safety record of some high-speed lines has been remarkable. The Japanese Shinkansen has never experienced a passenger fatality or had a high-speed derailment during 40 years of operation. This is a tribute to the design, inspection, and maintenance of both track and vehicle and includes the inspection of the Shinkansen track every day.

Other high-speed operations have not maintained as good a safety record as the Shinkansen. Several derailments of the French TGV and the fatal German ICE accident at Eschede Germany mar an otherwise enviable high-speed rail safety record. It is important to acknowledge these accidents to better understand the issues involved in high-speed rail safety.

From the interviews and media search, the greatest contributory factors associated with escalation are:

- A derailed train hitting a second train where one or more are passenger trains as demonstrated by several accidents in the UK (Great Heck derailment caused by errant motor vehicle causing the initial derailment which escalated when a second train was hit),
- The impact of a derailed train with lineside infrastructure (e.g. Hatfield, UK and Eschede, Germany),
- Trains overturning.

The information collected through the media study supported the trends identified in the interview and questionnaire responses.

Adverse effects of DCP include cost, maintenance and potential to escalate derailments in certain circumstances, however these do not appear to have been quantitatively demonstrated. The media research provided some information on the adverse effects of DCP as discussed in the Intrusion Barrier Design Study by the US Federal Railroad Administration and from the approach taken by Amtrak in the US.

The media research identified several European Commission initiatives, which are looking to the future and promoting a standardisation of the approach to controlling derailment. However, they did highlight the current fragmented approach to

derailment across Europe. It is of interest that interviewees did not discuss the initiatives being led by the European Commission.

Although we have been able to find examples of train derailments, we have found that high-speed derailments above 200 km/h are not common. More frequent are derailments that occur when trains are operating at slow speed, often in storage yards and staging areas. The track in these slow speed areas usually contains specialised track work – crossovers, turnouts, switches etc. Since the yards are low speed operation, derailments are usually minor in nature with minimal damage to equipment or long-term implications.

Mainline derailments are less frequent than low speed yard derailments, however, trains travelling at higher speeds have greater kinetic energy. The kinetic energy increases with the square of the train speed so a small increase in train speed can have significant effect on the severity of the accident or the damage to the rolling stock, track and infrastructure.

The low number of high-speed derailments is possibly due to the close attention paid to inspecting and maintaining track and equipment and the less challenging track structure used on high speed lines. High-speed lines typically have fewer curves, long straight-aways, and fewer turnouts or special track work. A high level summary of the findings of the interviews and questionnaires is contained in Appendix C.

2.2 Part B: Effectiveness & Part C Adverse Effects

Valid data on the effectiveness of DCPs is as rare as data on high-speed derailments. There is little information and no real world statistics on DCP effectiveness. An appropriate methodology to assess DCPs in this situation is for an expert panel consisting of rolling stock, permanent way, derailment investigators and risk experts from around the world to review the characteristics of individual derailments and provide guidance on how effective DCP may be.

In determining the causal factors, the expert panel considered it prudent to extend the scope of the analysis beyond the information determined in Part A media search and interviews. The panel considered it necessary to not only examine the forensics of general concept of derailments, but also to review the generic relationship between derailment casual and escalation behaviour. Finally, prior to the commencement of the expert panel, a review of the DCP Type definition and summary of implementation was conducted. This was designed to ensure all parties would be thoroughly conversant with the framework of the assignment.

2.2.1 Causes of Derailments

A comprehension of the different types of derailments helps in understanding how factors may contribute to high-speed derailments, since the effectiveness of DCP is linked to the causal event of the derailment.

When design, inspection, and maintenance activities fail to fully address a defect or hazard, derailments and other accidents can occur. Specifically, there are many conditions of track and vehicles that can affect the safety critical wheel rail interface. Derailments can result from failures of the track, track structure, special track work, bridges, or other static structures. Derailments can also result from failures of mechanical components related to the vehicle wheels and suspension, or from human error or operations related problems. The causes of derailments are described in more detail in Appendix D.

2.2.2 Relationship of Derailment Cause and Escalation

Understanding Derailment Escalation

Some types of derailments may escalate quickly (e.g. Potters Bar, UK accident). These most usually result from derailments involving the following:

- Track Buckle
- Defective Switch
- Washout
- Overspeed
- Collision
- Elevated Track or Track on an embankment
- Structures i.e. Over Head Wire
- Geometry of curved track
- Location of curves
- Signalling/turnouts/conflicting movements

Other types of derailments may not escalate immediately (e.g. Eschede, Germany accident). These may involve the following:

- Broken wheel
- Wheel lift
- Wheel climb
- Wheel tread defects
- Bogie defects

The dynamics of each derailment is different. Some derailments immediately become major derailments at the point of initial derailment. The derailments that escalate immediately often involve a collision or the catastrophic failure of critical vehicle component or catastrophic failure and damage to the track structure. In these cases the location of the initial point of derailment and the location of the general derailment are in close proximity. The over speed derailment that occurred at Waterfall Australia is an accident that escalated at the initial point of derailment.

Other derailments may not escalate until the train has travelled kilometres from the initial point of derailment. These types of derailments involve problems with wheels, track, or bogies but are not so catastrophic as to result in an immediate pile up of equipment. In these types of derailments, the initial point of derailment and the location of the general derailment are far removed. The general derailment may be triggered by track curves, elevated tracks with steep embankments, stationary object close to the right of way, grade crossings, or special track work. Special track work in the form of turnouts is especially efficient at locating a derailed wheel and causing and contributing to derailment escalation.

Several of the general derailments took place at turnouts and accident records contain numerous examples of derailed trains that have travelled for km before escalating into a general derailment. For example, the Eschede ICE train travelled 5.6 km between the initial derailment and the point of escalation.

Some derailments never escalate. The derailment is discovered and the train is brought to a stop with minimal damage. Once the train stops, the train is inspected and the derailed wheel(s) is discovered. These incidents are not widely publicised so we do not hear about many of the non-escalating accidents as the damage and disruption is minimal. The Laval, France TGV accident is one such accident where the train was brought to a stop with no escalation and no injuries to passengers.

2.2.3 Review of Derailment Containment Provisions

The types of DCPs considered within this assignment are:

- **DCP 1**

The first type of DCP mentioned consists of check rails installed between the running rails within the track gauge. The check rails can help keep the rolling stock in line with the roadbed. This is especially important on elevated structures where keeping the carriage in line with the guideway is critical to prevent the carriage from overturning or falling down an embankment.

Current practice is to apply check rails only in areas where there is a risk of the carriage falling or overturning. They are not installed continuously because the check rail can interfere with special track work such as turnouts. The curve rail of the turnout occupies the same space as that needed by the check rail.

Note: An alternative type of DCP I being proposed by Infrasppeed for the HSL-Zuid project is a tapered concrete plinth situated between the running rails which restricts the lateral movement of the wheelset in the situation where the wheels set has lost contact with the running rail. The configuration of this DCP Type 1 is detailed in Appendix E.

- **DCP 2**

The second type of DCP consists of guide rails installed outside of the running rail. Outside guide rails can also help maintain a carriage upright and in line on the right of way. Outside guide rails are not as common as inside check rails and are applied in areas where inside check rails cannot be used – such as in the area of special track work. However, outside guide rails will still have application issues with turnouts and cannot be applied continually.

- **DCP 3**

The third type of DCP is the use of a structure that contacts the sides of the bogies in the event of a derailment and holds the bogies and car in alignment with the roadbed and right of way. The third type of DCP can be effective if it is designed to work with the expected forces generated by a train travelling at 200 to 300 km/h. A structure this strong can exert significant forces on the bogie and car body and may contribute to the severity of the accident.

There is no doubt that a strong enough structure could be designed to keep a derailment from escalating. The question is how much would such a structure cost and would it be cost effective to apply to the entire system. Other than short barriers at the entrances to tunnels and bridges, we know of no application of DCP Type 3 barriers exclusively designed to restrain the movement of a derailed train. Research and testing in this area would be required to confirm that the structure selected was strong enough for the application.

2.2.4 Expert Panel Assessment

The expert panel was held on the in Amsterdam and was attended by:







Gerard Nakken	DCP Project Manager, HSL-Zuid
Rob Houben	Hoofd Integrale Safety Case + VG ontwerp, HSL-Zuid
Marten Brascamp	Safety Manager, HSL-Zuid
Rene van der Vooren	Manager Technical Compliance Department, HSL-Zuid
Harry Killaars	Fire and Safety Department, Dutch Ministry
Robert Bos	Manager Contracts, Infrasppeed
Hans Risseeuw	Manager of Derailment Risk Management and Mitigation Safety Case, Infrasppeed
Andy Espley	Project Manager, Booz Allen Hamilton
Nicholas Bahr	Safety & Risk Technical Expert, Booz Allen Hamilton
Fred Mau	Track and Derailment Technical Expert, Booz Allen Hamilton
John Boss	HSL-Zuid / Booz Allen Hamilton.

The expert panel was presented with derailment accidents for which they were to assess the effectiveness of the three different types of DCP if it had been installed at the time of the accident.

The expert panel undertook a review of the selected accidents in Table 7 against the effectiveness of DCP in line with the assignment methodology. Details of these accidents have been included in Appendix F. Appendix G contains further reading on derailment accidents.

The results of the qualitative assessment of the effectiveness of DCP was indicated by "Harvey balls" which provide a quick visual indicator as to how well an item being evaluated meets the evaluation criteria.

For the expert panel evaluation in Table 10, the following nomenclature was used:

DCP Effectiveness	Harvey Ball
Stops/prevents escalation	
Significantly stops escalation	
Somewhat affects escalation	
Marginal/minor effect on escalation	
No effect on escalation	
Negative effect on escalation	

The results of the expert panel methodology Steps B1 and B3 - B10 are detailed in Tables 7- 13.

Accident	Justification
1. Eschede, Germany	<ul style="list-style-type: none"> • Severity • First accident and the only accident in the history of high-speed rail that resulted in a passenger fatality • Vehicle failure cause event • Combination of several causal events • Similarity with HSL-Zuid infrastructure for example the Flyover Den Hoek
2. Waterfall, Australia	<ul style="list-style-type: none"> • Operations causal event • Expert panel familiarity
3. Hatfield UK	<ul style="list-style-type: none"> • Infrastructure causal event • Relative high speed
4. Mobile, Alabama, USA	<ul style="list-style-type: none"> • Human factors causal event and involved a bridge crossing water which is relevant to the HSL-Zuid geography i.e. Holland's Diep bridge.

Table 7: Methodology Step B1, Accidents Identified For Expert Panel Investigation

Expert Panel Methodology Step

B3. Identified Generic Causal Events

The causal factors are common reasons for derailments that have occurred in the past on all types of trains - not just high-speed trains. A review of these high-speed derailments provides little insight into preventing other high-speed derailments beyond the concept of design, inspection and maintenance discussed previously.

1. Track and Track Components including:

- Track buckle/Twist of Continuous Welded Rail (CWR)
- Broken rail
- Collapsed rail bed (i.e. WWI event France)
- Soft road bed (inadequate drainage, poor track geometry)
- Inadequate lateral stability (ties/fasteners)
- Track tolerances (rail wear)
- Rail geometry (cross level, gauge spread, etc.)
- Defective switch (numerous failure initiating events can occur)

2. Vehicle (locomotive and coach) Wheel and Bogie Components including:

- Broken wheels
- Worn / broken suspension
- Wheel lift
- Wheel climb
- Wheel tread defects (sharp flange, hollow tread, etc.)
- Wheel profile condition

3. Special Track Work related including:

- Switch or turnout defects

4. Bridges, Structures, Signals, and other Infrastructure including:

- Errant vehicles on level crossings
- Structural failure of lineside equipment (lamp post, signal falling onto the running rails)

5. Operational Issues (Operating Rules and Methods) including:

- Over speed roll over
- Collision
 - Train to train
 - Train to highway vehicle
- Train handling

6. Human Factors

- Human error
- Training

7. Other Causal Factors

- Washout
- Maintenance tools, branches, landslip
- Flooding

Table 8: Methodology Step B3, Expert Panel Findings

Expert Panel Methodology Step	
Accident	B4. Did escalation occur and if so when?
1. Eschede, Germany	Escalation did occur at the points. It seems probable that a derailed wheel was running on the outside of the right-hand rail and on reaching the turnout it was diverted towards the slow line and onto a collision course with the bridge supports. There was lateral movement of the wheels set which escalated to the eventual impact with the bridge support. Although facing points are essential to the smooth flow of traffic, there will be a tendency to guide a derailed wheel, running outside of the rail, in the direction of the turnout. The guard rail (function of point design) contributed to the escalation of the derailment. The number and location of points is an important consideration in the design stage of a project in order to minimise the consequences of derailments.
2. Hatfield, United Kingdom	The escalation occurred quickly after the derailment due to the rail break and the curvature of the track.
3. Waterfall, Australia	The escalation was immediate.
4. Mobile, Alabama, USA	The escalation was immediate.

Table 9 Methodology Step B4, Expert Panel Findings

B5. Was DCP in place at the derailment site and estimates the effectiveness of each type of DCPs					
	Yes, what type and what was there effectiveness?	No			
		How would application of DCP Type 1, DCP Type 2, DCP Type 3 have affected the accident including speeds at 200-300 Km/h.			
		Accident Stage	DCP Type 1	DCP Type 2	DCP Type 3
Accident 1. Eschede, Germany		Initial derailment	○	○	○
		Continued travel after initial derailment	1	⊗	4
		Escalation derailment	○	○	2 or ○ ¹
Accident 2. Hatfield, United Kingdom		Accident Stage	DCP Type 1	DCP Type 2	DCP Type 3
		Initial derailment	○	○	○
		Continued travel after initial derailment	3	3	3
		Escalation derailment	4	3 or ○ ¹	2
Accident 3. Waterfall, Australia		Accident Stage	DCP Type 1	DCP Type 2	DCP Type 3
		Initial derailment	○	○	○
		Continued travel after initial derailment	3	3	3
		Escalation derailment	4	3 or ○ ¹	2
Accident 4. Mobile, Alabama, USA	Yes DCP Type 1 but was not effective 0	Accident Stage	DCP Type 1	DCP Type 2	DCP Type 3
		Initial derailment	○	○	○
		Continued travel after initial derailment	○	○	○
		Escalation derailment	○	○	○

Table 10 Methodology Step B5, Expert Panel Findings

¹ Note: Effectiveness of the DCP is directly related to which side of the track the DCP is fitted relative to which side of the track the wheel set derails.

Expert Panel Methodology Step	
Accident	B6. Expert Panel identifies steps that could have been taken to prevent <u>escalation</u> of the derailment
1. Eschede, Germany	<p>The importance of detecting a derailment (broken wheel) before escalation takes place significantly affects the escalation consequences. The consequences of Eschede could have been minimised if the derailment was detected immediately. In the case of this accident the identification of derailment was detected by the cutting of the LZB cable and the vehicle floor penetration. The identification of the derailment was delayed because the power car was already located on the next LZB loop when the previous LZB loop was cut and the lack of action of the Eschede conductor who did not stop the train after receiving reports that debris had penetrated the floor of the first passenger coach.</p> <p><i>Infrastructure</i></p> <ul style="list-style-type: none"> a) The location of a turnout immediately before a bridge is a significant escalation factor that should be avoided. They should not be placed near highway bridges, train bridges, elevated track, tunnel entrances, or other locations that are considered excessively hazardous if a derailment were to take place. A safety based hazard analysis should have been used to identify these high-risk areas. b) The lack of crash walls or other protection for the bridge support should have been identified as an issue. The use of crash walls in the vicinity of the bridge may have been a method of reducing the hazard of having the turnouts in such close proximity to the bridge. Again, a good hazard analysis would have identified the hazard. c) Installation of Dragging Equipment Detectors (DED) which automatically stop the train. These detectors could be placed specifically prior to turnouts at sufficient distances to allow the train to stop before the turn out. For example, DEDs are commonly used by Amtrak in the US and by New South Wales in Australia. These devices are of relatively low cost and there is no known evidence of adverse reliability. <p><i>Vehicles</i></p> <ul style="list-style-type: none"> d) The design of the wheel may not have been appropriate for a high-speed application. Components designed for a safety critical function such as the wheel rail interface must be able to be adequately inspected for defects. The resilient material interfered with the ultrasonic testing and may have masked a defect. In any case, a thorough inspection of the wheel would have indicated that the wheel tread was below the condemning limit and should be changed out. Again, inspection and maintenance practices are a primary method of controlling hazards of safety critical systems. e) On board DED f) Detectors mounted on the bogies to detect excessive movement in the horizontal plane which would, in approximately 90% of instances, identify a derailment. (These are currently being installed on the Thalys trains which will be operated on the HSL-Zuid).

Table 11: Methodology Step B6, Expert Panel Findings

Expert Panel Methodology Step	
Accident	B6. Expert Panel identifies steps that could have been taken to prevent <u>escalation</u> of the derailment
<p>1. Eschede, Germany (cont)</p>	<p><i>Operations</i></p> <ul style="list-style-type: none"> g) It is true that the brake application may have escalated the accident before reaching Eschede but the results would have certainly been more forgiving than running into a concrete bridge structure at 180 km/h. h) If the installation location on the infrastructure of the DED is restricted then it may have to be moved closer to the risk area. In such instances, a Permanent Speed restriction may be necessary to allow the train to be brought to a halt before the turnout. i) Loop 9 of the LZB system was ruptured. If this information could have been communicated to the controlling power car, then the train could have been stopped before it reached the bridge at Eschede. The power car finally received the information and applied emergency brakes after loop 11 was ruptured by the general derailment. j) Operational rules that instruct the driver to slow down to 80kph if he receives a warning signal that the train is not operating in an acceptable manner (This rule is being proposed on the HSL-Zuid line). k) Several trains may traverse the cause of a derailment as in the case of the TGV derailment at Lille in France, where it was the 3rd train to pass the site which derailed. Therefore train drivers and train crew should be trained in responding to abnormal instances and have the means of communicating information to the relevant persons (i.e., signallers). <p><i>Human Factors</i></p> <ul style="list-style-type: none"> l) Driver and crew training to recognise and respond to abnormal events. <p><i>Others</i></p> <ul style="list-style-type: none"> m) Trip wire at free space envelope as used on the Washington Metro and similar to the installation used on high speed lines in France as identified during the interviews in Part A of this assignment which detects the presence of automobiles etc.

Table 11 Continued: Methodology Step B6, Expert Panel Findings

Accident	B6. Expert Panel identifies steps that could have been taken to prevent escalation of the derailment
<p>2. Hatfield United Kingdom.</p>	<p><i>Infrastructure</i></p> <p>a) Installation of DCP Type 3 would have had a positive effect on the escalation of the derailment. In terms of DCP Type 3 the accident occurred along a curved section of route in which there were multiple running lines. The derailed train was operating on one of the inner lines. For DCP Type 3 to have been effective, it would require installation along side all the lines on the curves section of route. In order for this to take place, the original track scheme would need to have considered this requirement and made sufficient space provision. To install DCP Type 3 on routes containing multiple lines may be difficult due to space limitations. Furthermore, as identified in the media study, the effect of having DCP Type 3 on both sides of a line may have an adverse effect, with the derailed train experiencing becoming wedged between the DCP barriers, while following coaches continue to impact into the jammed train.</p> <p>The effectiveness of DCP Type 3 is difficult to quantify, however modelling work undertaken by Infrasppeed has indicated that at instances where there is greater than 450Kn of force on the bogie it will separate from the coach body. The Greenhout tunnel will be installed with DCP Type 3 in the form of walkways which have been designed to act as DCP.</p> <p>b) The cant deficiency on the track should be minimised as far as possible to reduce the track forces. c) The design and location of line side structures should be such that they minimise the affect of escalation d) Cross section of the track design to maintain the derailed train upright. e) DCP Type 1 would have had some effect as it would have not been subject to effects of track forces and so would not have broken when the rail break occurred. It then would have guided the derailed wheelset. f) Detection of the broken rail</p> <p><i>Vehicles</i></p> <p>g) Detection devices attached to Bogies to detect derailment h) The use of articulated bogies</p> <p><i>Operations</i></p> <p>i) Adequate inspection, testing and maintenance regimes</p> <p><i>Human factors</i></p> <p>j) No significant steps identified</p> <p><i>Others</i></p> <p>k) No significant steps identified</p>

Table 11: Methodology Step B6, Expert Panel Findings

Accident	B6. Expert Panel identifies steps that could have been taken to prevent escalation of the derailment
3. Waterfall, Australia	In addition to steps identified in the previous accident, the following steps were identified: <ul style="list-style-type: none"><li data-bbox="443 284 1503 312">• Detection of overspeed and the application of automatic braking as appropriate (ATP)<li data-bbox="443 316 1648 344">• Design of deadmans handle to ensure that fatalities will not continue to operate deadmans handle.
4. Mobile, Alabama, United States America.	None of the 3 different types of DCP would have prevented the escalation of the accident. Items identified in this case related to operation of the river barge transport and infrastructure elements on and around the bridge, including bridge impact detectors.

Table 11 Continued: Methodology Step B6, Expert Panel Findings

Accident	B7. Expert Panel identifies steps that could have been taken to prevent the <u>derailment</u>
1. Eschede, Germany	<p>Preventing the wheel departing the rail.</p> <p><u>Infrastructure</u></p> <p>a) Installation of dynamic wheel impact load detectors, although this equipment is considered costly.</p> <p><u>Vehicles</u></p> <p>b) Maintenance and Inspection c) Component Integrity (design, constraints) d) Quality (control assurance, suppliers)</p> <p><u>Operations</u></p> <p>e) Detection f) Communication g) Failsafe h) Train handling</p> <p><u>Human Factors</u></p> <p>i) No significant steps identified</p> <p><u>Others</u></p> <p>j) No significant steps identified</p> <p>The panel noted that the DCP does not affect the cause of the broken wheel.</p>
2. Hatfield, United Kingdom	<p>It is very difficult to ensure there are no rail breaks. The use of suppliers with high standards of Quality Assurance and Quality control will minimise rail breaks. Regular maintenance and inspection of the running rails can identify some potential failures. It was noted that ultrasonic testing would not identify all instances of potential failure.</p> <p>On the Shinkansen railway in Japan in addition to the maintenance and inspection regime, the running rails are replaced at regular frequencies.</p>
3. Waterfall, Australia	<p>Fencing to prevent obstacles on the track. Prevent overspeeding by the use of ATP.</p>
4. Mobile, Alabama, USA	<p>No significant steps identified</p>

Table 12: Methodology Step B7, Expert Panel Findings

Accident	B8. Expert Panel identified derailment causal factors.
1. Eschede, Germany	<ul style="list-style-type: none"> a) Broken wheel b) Warning signal not received from LZB system c) The guard rail² used in the configuration of the points may have contributed to the escalation. d) Speed at turnout e) Deflection of wheel set f) Train struck bridge support g) Bridge collapse (consequences)
2. Hatfield, United Kingdom	<ul style="list-style-type: none"> a) Rail break (increased probability due to high cant deficiency) Note: on HSL-Zuid cant deficiency is 180mm. b) Track geometry (curvature of the track) c) Hits catenary
3. Waterfall, Australia	<ul style="list-style-type: none"> a) Over speed. b) Curvature of the track. c) Hitting fallen rocks as a result of the initial derailment d) Human Factors, the design of the deadmans handle was deficient and required a constantly maintained pressure to ensure the brakes were not automatically applied. e) The guard on the train did not recognise he was in danger. f) The culture was that guards did not stop trains since this was the responsibility of the drivers. The divers also had a different culture to maintainers.
4. Mobile, Alabama, USA	Bogies were derailed as a result of running rail bridge and running rail displacement.

Table 13: Methodology Step B8, Expert Panel Findings

² Guard Rails are generally used in as part of the basic design of points. These guard rails are designed to guide the wheelset, as opposed to the Guide rails described in DCP Type 1, which are more robust and designed to prevent Derailment. Guard rails are found in two locations within points: a) guard rail (turnout) A rail or other device laid parallel to the running rail opposite a frog, b) guard rail (switch) A rail or other device laid parallel to the running rail ahead of a split switch

Expert Panel Methodology Step

B9. Expert Panel identified any additional risk that may be associated with each type of DCP

General

The transition along a line from no DCP to DCP presents an additional opportunity to escalate the derailed train. Furthermore there is also additional risk to maintenance workers due to additional equipment on track which may require more workers on the track and the possibility of a more complicated working environment.

DCP Type 1:

Debris between the check rail and the running rail could cause wheel climb. Debris can be from a variety of sources i.e. maintenance tools left behind after works, fragmentation of a running rail, ballast or foreign object on the track.

Deutsche Bahn have indicated that they limit the use of Type I DCPs because of the difference in passenger carriage bogie and axle designs. For example, the axle design for passenger carriages include a brake disc that can contact and ride along the guide rail causing damage to both the guide rail and the brake disc that could escalate a simple derailment. Another consideration is that the under car arrangement of brake rigging and traction equipment may also interfere with the guide rails and cause a more dangerous situation after a derailment.

Guide rails were originally designed for freight cars, which are not equipped with the axle or bogie mounted equipment mentioned above. The concern at DB was sufficient to limit the use of guide rails to only the most significant areas.

DCP Type 2:

Again debris between the guard rail and the running rail may result in DCP being ineffective. Under some circumstances, outside guardrails may contribute to the overturning of the carriage.

DCP Type 3:

The height of DCP Type 3 in relation to double decker trains could significantly cause an increase in the escalation derailment risk, since the DCP Type 3 barrier could cut through the passenger areas on a double decker train. Therefore the effectiveness of DCP is influenced by the fleets of trains which may be expected to operate on HSL Zuid?

The implementation on DCP Type 3 near switches and points can act as a physical barrier to the maintenance activities which are so critical to preventing the causal factors.

Table 14: Methodology Step B9, Expert Panel Findings

2.2.5 Expert Panel Commentary & Methodology Step 10

The expert panel provided a solid judgement of DCP effectiveness based on the combination of the experience of individuals and the latest state of the art knowledge. The panel reviewed the effectiveness of DCP on four accidents and in accordance with the Methodology defined in Section 1 the results of which are detailed in tables 9-13.

It became apparent that there are complex variable factors to be considered when trying to evaluate the effectiveness of DCP, and each application of DCP is specific to the operational environment. Therefore the effectiveness of DCP cannot be quantified, **[Key Finding 1]**.

Step Zero

The expert panel identified that the most effective approach to DCP is actually at “Step Zero” in the design and implementation phase and subsequent maintenance stage. The early detection of abnormal events can reduce escalation, **[Key Finding 2]**.

During system design there needs to be a realistic expectation regarding the maintainability of the equipment. The designer should be careful about making design assumptions which can have long-term consequences.

When a change to the system is proposed, the custodian of the system should evaluate the effect of the change across the whole system, **[Key Finding 3]**.

During the life of the system, specifically the infrastructure, there may be an increase in track forces due to an increase in:

- Density of rolling stock,
- Heavier rolling stock (longer trains, more auxiliary systems),
- Faster rolling stock (accelerate faster and therefore have a higher average speed which means there is an increase in track forces around switches and crossings in close proximity to stations).

This increase in track forces may result in an acceleration in the degradation of the track quality and an increase in serious faults.

For example, a change in the area of operations such as increased train paths in the timetable can result in accelerated rolling contact fatigue (RCF). Therefore the maintenance and inspection aspects of the system would require evaluation. This was discussed as part of the Hatfield accident where high cant deficient track and track geometry were important contributors to the risk of derailment and its escalation. High cant deficient tracks with head hardened rails should be subject to regular inspection and maintenance (rail grinding) to identify any potential RCF which could result in gauge corner cracking and ultimately a rail break, the cause of the Hatfield accident.

For example, in the case of the Eschede accident, to minimise the escalation of derailment, the bridge structure should have been constructed to withstand an impact from the train. However, this may have been the part of the original design requirements, but changes to the system may have taken place without evaluating the effect of the proposed change, i.e. linespeed may have increased.

Mitigating Escalation

Operations

In the case of Eschede, the passengers heard noise and felt vibration for approximately two minutes prior to the impact with the bridge structure. During this time, actions could have been taken to reduce the consequence of the derailment. A further example of this is the Central Line underground train in the UK. It did not respond to the abnormal noise of the motor shearing away from securing bolts, hitting the track and bouncing along the track hitting the underside of the train and subsequently derailing the train as it entered Chancery Lane station.

It was suggested that detection of a derailment needs to be identified as quickly as possible and this facility should be incorporated into the Railway System, **[Key Finding 4]**.

This can be achieved either through a technical or operational approach, i.e. training drivers and train crew to recognise the derailment.

The risk of derailing or minimising escalation can be achieved by stopping rail traffic as quickly as possible after an appropriate safety critical event, **[Key Finding 5]**.

The Great Heck accident (as detailed in Appendix G) would have been less severe if both a passenger and freight train had not interacted so disastrously when the automobile landed on the line.

As the mitigation of derailment is placed on the maintenance and inspection of the vehicle and the infrastructure, an increase in the maintenance and inspection periods is required, irrespective of the pressure to maximise operations.

Infrastructure

As identified in the interviews, high-speed lines in France use ballast to slow down a derailed train and provide sufficient free space on bridges to allow this to occur. However, on the HSL-Zuid line there is a combination of ballasted track and Rheda slab from track. In the instance of a derailment on Rheda track there is no ballast to act as resistance to slow the train down. Furthermore the structure of the Rheda track, such as the concrete supports to the rails, could accelerate the lateral movement of a wheelset and subsequently escalate the derailment.

In addition, the Rheda track is being backfilled with ballast to a level such that the distance between the rail and the ballast is 240mm. This may increase the probability of derailment escalation since the wheel set could “fall off” the Rheda track bed slab.

Infraspeed's proposed concrete upstand between the rails would appear to be a sensible provision, though it should be designed so as to ensure the outside derailed wheel remains securely upon the track slab. In Part A of the assignment, DB reported that the interference between the brake disc and the Type 1 DCP was a main concern for limiting the use of DCPs. Therefore the expert panel was concerned with the interface design on HSL-Zuid between the vehicle and the DCP, where the axle mounted brake disc may ride on top of the concrete plinth DCP and cause potentially serious consequences, **[Key Finding 6]**.

The effectiveness for track systems with proposed derailment provisions verses scenarios / causes has already been subject to an earlier expert panel. This report does not seek to duplicate work, therefore further information is detailed in ‘ Expert Panel Meeting on Effectiveness of different derailment provisions ’ [RD.14].

One of the mitigation actions to reduce escalation would be to add deflector plates, to lineside structures to assist in reducing escalation dynamics during derailment. The installation deflector plates could be fitted retrospectively to lineside infrastructure and would not incur a significant cost. This approach would require further investigation and an appropriate cost benefit analysis.

Management Systems

A deficiency in the competence of staff (experience, knowledge, training) may result in the failure to identify the fault during inspection and maintenance. There may be insufficient staff to rectify the fault in an acceptable timeframe, and there may be insufficient competent staff to supervise the work undertaken, **[Key Finding 7]**.

Japan's remarkable safety record is due to strong in-depth inspection (100% every 24hrs) and maintenance accompanied by reduced wartime of the system components. In order to support this approach, asset management plans are a contributory factor to ensuring a coordinated approach, **[Key Finding 8]**.

DCP Effectiveness

There are complex variable factors to be considered when trying to evaluate the effectiveness of DCP. Every accident is unique and even where it is possible to break down the accident into phases (initial derailment, continued travel, escalation derailment), as in the case of Eschede, it was difficult to establish consistent causal factors which could be utilised in other derailment accident analysis. Therefore the effectiveness of DCP cannot be quantified, **[Key Finding 9]**.

The expert panel agreed that the greater the lateral movement generally the greater escalation of the derailment. In all the accidents it was considered that no form of DCP could have prevented the derailment. The mechanism causing the derailment was independent to the control mitigating DCP, **[Key Finding 10]**.

DCP Types

DCP Type 1 is effective at mitigating escalation in certain scenarios, although it cannot be used in points and crossings and, as shown by the approach by DB, there are adverse effects to its implementation, **[Key Finding 11]**.

During the expert panel, the meeting concluded that the effectiveness of DCP Type 2 is less than DCP Type 1, since DCP Type 2 would have to be applied at the end of the structure or the ends of the sleeper where the track structure has less strength, **[Key Finding 12]**. This supports the trends observed in Part A of the assignment, where worldwide DCP Type 1 and DCP Type 3 are more commonly used.

The panel discussed that at points and crossings DCP Type 3 could be installed which would reduce the escalation of the derailments. The vertical profile of this would be ramped reaching a maximum height at switches and crossings, **[Key Finding 13]**.

When examining the implementation of DCP Type 3, it is not always clear if the structure is initially designed as DCP or for another function, such as a walkway. If designed as DCP, then the structure should have performance standards or specifications that relate the design to controlling train derailments. There is a possibility that because a structure is located either side of the right-of-way, it will be assumed to be an effective DCP. This is not necessarily true especially at high speeds, **[Key Finding 14]**.

DCP Application

Through switches and points, the ability to implement effective DCP is minimal.

The effectiveness of DCP can be enhanced through mixing types. The expert panel identified the mix of Type 3 DCP at switches in conjunction with Type 1 to be potentially effective for a derailment in the trailing direction with the bogie off set away from the direction of the approaching turnout, **[Key Finding 15]**.

Implement DCP Type 1 on open track at high risk areas (i.e. urban) and elevated sections subject to cost benefit analysis and DCP type 3 in tunnels and around turnouts, **[Key Finding 16]**.

Since each potential application of DCP is unique, there is a danger that the organisations or projects may adopt what is seen as best practice. This approach should be used with caution since it is critical each organisation should understand the failure modes of their system before implementing DCP, **[Key Finding 17]**.

Adverse effects of DCP

The installation of a DCP Type 3 barrier in close proximity to switches and crossings may act as a physical barrier to inspection and maintenance regimes which are designed to mitigate the causal factors of derailment. Therefore although DCP Type 3 may mitigate escalation, it may be contributing to the causal event in the first instance, **Key Finding 18**].

The height of DCP Type 3 in relation to double decker trains could significantly cause an increases in the escalation derailment risk, **Key Finding 19**].

There may be adverse effects of installing DCP Type 1 where foreign objects such as previously sucked up ballast or fragmented rail as a result of an infrastructure fault could act as a ramp to derail the wheel set, **Key Finding 20**]. This ramp principle is very effective and is used in certain locations i.e. in sidings to protect main lines from runaway rolling stock.

Under some circumstances, DCP Type 2 may contribute to the overturning of the carriage. Again debris between the guard rail and the running rail may result in DCP Type 2 being ineffective.

Additional Analysis

At the conclusion of the expert panel meeting a high level qualitative assessment (Table 15.) of the effectiveness of DCP Types 1,2 and 3 against the causal factors identified in Table 8. was undertaken using the following nomenclature:

DCP Effectiveness	Harvey Ball
Stops/prevents escalation	●
Significantly stops escalation	◐
Somewhat affects escalation	◑
Marginal/minor effect on escalation	◒
No effect on escalation	○
Negative effect on escalation	⊗

However, whilst undertaking the qualitative analysis, it quickly became apparent that balanced and comparative qualitative assessment was not achievable since the causal factors were generic in some instances (i.e. human factors) and, as identified in the expert panel meeting, there are complex relationships between factors in derailments and many of these are variable. Therefore the results of the qualitative assessment in Table 16 can only be regarded as an initial high level judgement at a generic level.

They are not supported by robust justifications and therefore should be viewed as an interpretation rather than based on robust arguments.

From Table 16 it can be seen that at a generic level DCP Type 3 is the most effective form of DCP on high speed lines a range of high level causal events. This is supported by Part A of the assignment, where organisations which operate high speed lines such as CTRL and Skinkansen implement DCP Type 3.

Derailment Causal Event	DCP Type 1	DCP Type 2	DCP Type 3
Track and Track Components including:			
Track Buckle of Continuous Welded Rail (CWR)			
Broken rail			
Collapsed rail bed			
Soft road bed (inadequate drainage) / poor track geometry			
Inadequate lateral stability (ties/fasteners)			
Track tolerances (rail wear)			
Rail Geometry (cross level, gauge, etc.)			
Defective switch (failure dependent)			
Vehicle Wheel and Bogie Components including:			
Worn / broken suspension			
Wheel lift			
Wheel tread defects (sharp flange, hollow tread, etc.)			
Special Track Work related including:			
Switch or turnout defects			
Bridges, Structures, Signals, and other Infrastructure			
Errant vehicles at level crossings			
Structural failure of line side equipment (Lamp post, signal) fall onto track			
Train handling			
Human Factors			
Human error and training (too generic to assess)	Not possible to assess		
Other Causal Factors			
Washout			
Maintenance tools, branches, landslip			
Flooding			

Table 15 Continued: Qualitative Assessment of DCP's

Section
3

Summary

In managing the delivery of the HSL-Zuid Transportation System, the HSL-Zuid organisation wishes to act as the informed client with regards to current practice and effectiveness of DCP on high speed lines. To achieve this HSL-Zuid organisation has, in part, commissioned this assignment which consists of three parts, which are as follows:

3.1 Overview of Current Practice

DCP is a sensitive topic amongst rail organisations and there is concern that information provided could expose them to commercial issues.

The questionnaires and interview responses indicate that there is a general (although not universal) acknowledgment that DCP is a positive approach to minimising derailments. In spite of this there is:

- No single current practice to derailment containment provision,
- No substantive reasons for the provision of DCP,
- No standard used in applying DCP and consequently
- No definite opinion on the effectiveness of DCP,
- No DCP is 100% effective,
- Widespread agreement that DCPs are not used as a matter of course throughout the system.

The findings indicate that DCP has been provided because of it was considered to be a 'good idea' and the approach to installation of DCP has been based on other railway projects. The assignment identified that most projects and organisations looked to use DCP Type 1 or DCP Type 3 at high risk locations.

The media research identified several European Commission initiatives, which are looking to the future and promoting a standardisation of the approach to controlling derailment.

3.2 Estimation of Effectiveness of DCP

During the assignment it became apparent that organisations and projects were unwilling or unable to discuss the sensitive issue of derailments and DCP due to a variety of reasons. In addition, the numbers of derailments above 200 km/h are small. As a result the lack of data made, the original quantified approach for the determination of DCP effectiveness un-achievable.

Therefore the approach to the assignment was modified in agreement with the client to a qualitative approach. The revised methodology and approach relied heavily on interpretation by an expert panel

There is a general acknowledgment that DCP is a positive approach to minimising derailment escalation under certain circumstances. However, there is insufficient knowledge to make a quantified decision on the effectiveness of DCPs to confidently predict how a train will behave in a derailment at speeds above 200 km/h. There are complex variable factors to be considered when trying to evaluate the effectiveness of DCP. Every accident is unique, and even where it is possible to break down the accident into phases (initial derailment, continued travel, escalation derailment), is difficult to establish consistent causal factors which could be utilised in other derailment accident analysis. Therefore the effectiveness of DCP cannot be quantified.

The effectiveness of DCPs is strongly dependant on the cause and configuration of the initial derailment. Effectiveness is very limited when derailments escalate immediately. When escalation is not immediate, DCPs may help keep some trains upright and in line but a derailment escalation may still occur if the derailment is not detected quickly and appropriate emergency systems come into effect, e.g. emergency stop.

At a generic level DCP Type 3 is the most effective form of DCP on high speed lines based on high level causal events. This is supported by organisations which operate high speed lines such as CTRL and Skinkansen who implement DCP Type 3.

The effectiveness of DCP can be enhanced through mixing types. The expert panel identified the mix of Type 3 DCP at switches in conjunction with Type 1 to be potentially effective for a derailment in the trailing direction with the bogie off set away from the direction of the approaching turnout.

One of the key outputs from the expert panel was the identification of “Step Zero”, where the prevention of the causal events was the area on which to focus attention. Many of the causal factors associated with derailment could be mitigated to some degree by detection or prevention of the faults on the vehicle or the infrastructure. The longer these faults remain undetected the greater the potential risk of derailment. An increase in the frequency of inspection would reduce the time that track, or train faults exist, and therefore reduce some of the causal factors in derailments by proactively controlling derailment risk.

During system design there needs to be a realistic expectation regarding the maintainability of the equipment. The designer should be careful about making design assumptions which can have long term consequences. When a change to the system is proposed, the custodian of the system should evaluate the effect of the change across the whole system environment.

A logical approach to addressing the derailment hazard would be to:

1. Prevent as many derailments as possible through superior design, inspection and maintenance practices.
2. Conduct regular risk assessments to detect and correct hazardous conditions.
3. Reduce the number of turnouts and special track work along the right of way.
4. Use technology to detect derailments.
5. Only install the appropriate type of DCP or mixture of DCP's in the relevant areas.

3.3 Adverse Effects of DCP

The overall continuity of the DCP has been identified by most projects and organisations as a factor in the effectiveness of the DCP provision. Discontinuity of DCP can be the cause of escalation and is considered to be a significant adverse effect of DCP. Other adverse effects relate mainly to the additional capital costs and maintenance elements involved (Amtrak does not use DCP due to maintenance issues).

Specifically DB indicated that they limit the use of Type 1 DCP because of the difference in passenger carriage bogie and axle designs. Another consideration is that the under coach arrangement of brake rigging and traction equipment may also interfere with the guide rails and cause a more dangerous situation after a derailment.

Under some circumstances, DCP Type 2 may contribute to the overturning of the carriage.

The installation of a DCP Type 3 barrier in close proximity to switches and crossings may act as a physical barrier to inspection and maintenance regimes which are designed to mitigate the causal factors of derailment. The expert panel identified a potential increase in escalation with DCP Type 3, since the barrier could cut through the passenger areas on a double-decker train.

3.4 HSL-Zuid

On the HSL-Zuid line of route there are certain locations i.e. Hollandsch Diep bridge, Flyover Van Hoek and Viaduct Bleiswijk, which could be considered as high risk, where as a result of a derailment the consequences could be severe.

The expert panel discussed the derailment escalation in relationship to the presence of structural discontinuities in the near vicinity of the rails and to the track bed constructions on the HSL-Zuid line, where there is a combination of ballasted track and Rheda slab form track.

In the instance of a derailment on Rheda slab form track there is no ballast to act as resistance to slow the train down. Furthermore the structure of the Rheda slab form

track, such as the concrete boots for the base plates could accelerate the escalation of the derailment. In addition, the Rheda slab form track is being backfilled with ballast to a level such that the distance between the rail and the ballast is 240mm. This may increase the probability of derailment escalation since the wheel set could “fall off” the Rheda track bed slab.

Infraspeed's proposed concrete upstand between the rails would appear to be a sensible provision, though it should be designed so as to ensure the outside derailed wheel remains securely upon the track slab. In Part A of the assignment, DB reported that the interference between the brake disc and the Type 1 DCP was a main concern for limiting the use of DCPs. Therefore the expert panel was concerned with the interface design on HSL-Zuid between the vehicle and the DCP, since the brake disc may ride on top of the concrete plinth DCP and cause potentially serious consequences.

3.5 Recommendations

1. Review the applicability of design inputs that have taken the “best practice” on DCP from other railways. Differences in operations, geometry, track speed and track bed profile could invalidate the original reasoning behind the application and continue to review during changes in the operation of the HSL-Zuid or the surrounding environment.
2. Review the rolling stock design input into the design of the HSL-Zuid DCP to ensure the risks associated with brake discs and other train characteristics on the Thalys trains were addressed throughout the design process.
3. Ensure the risk analysis for the determination of the high risk areas has addressed the characteristics of the Rheda track with respect to derailment escalation in the absence of any DCP.
4. Establish a management process to prioritise the rectification of faults which could lead to derailments.
5. Ensure the management system accurately captures the reporting of derailment incidents on HSL-Zuid. This will improve the understanding of derailment incidents and their associated causes and will result in the appropriate modification of derailment containment provision strategies, assisting in mitigating new issues as they develop. Note that the project should monitor derailment mechanism from around the world to ensure that any potential issues are managed.
6. Ensure there are appropriate assurance regimes in place in order to ensure that installation, inspection and maintenance are undertaken as prescribed in the relevant documentation over time (rolling stock and infrastructure).

7. Review the safety management system to ensure it is effective, as far as reasonably practicable, in eliminating derailments since this is the most effective solution to reduce escalation. The safety management system should demonstrate the following steps:
 - a) Identify and understand derailment causal factors
 - b) Determine individual risk of each causal factor
 - c) Rank and prioritise:
 - Design
 - Operations
 - Maintenance
 - d) Determine controls for each risk
 - e) Re-evaluate risk
 - f) Develop robust verifiable monitoring systems
 - g) Determine lagging and leading indicators
 - h) Adjust strategy as necessary
8. Assess the derailment resistance of vehicles operating on HSL-Zuid and the track forces they generate on a periodic basis.
9. Review the possibilities for the application of a mix of different DCP types to minimise the escalation of derailments.
10. Review the possibilities for other (non DCP) infrastructure equipment to assist in reducing escalation of derailment, or derailments occurring in the first place, e.g. dragging equipment detectors, Hot box detectors, wheel condition monitors, bridge movement detectors.
11. Review the rail change out policy against the risk of undetected rail flaws.
12. Ensure derailment issues are taken into account in operations, training and procedure definition. This requires specific attention to all steps along the derailment event to ensure appropriate behaviour to limit escalation.
13. Develop a culture of active intervention upon recognition of “abnormal events “ which could escalate with serious consequences.

4 References

Applicable Documents

The following documents identify dependencies, interfaces and/or other requirements with which this document or activities described therein must comply:

- AD1 HSL-Zuid Remit letter ref HAVL/517575.
- AD2 HSL-Zuid Terms of Reference 16th April 2004.
- AD3 Email from HSL-Zuid confirming revised Methodology and Approach.

Reference Documents

The following documents provide supporting information:

- RD1. Original Interview Data
- RD2. Independent Transport Safety & Reliability Regulator New South Wales in Australia Rail Derailments Statistics
<http://www.transportregulator.nsw.gov.au/stats/rail-derailments.html>
- RD3. Council For transport safety Netherlands, Baarn derailment.
<http://www.rvtv.nl/english/data/985865498.pdf>
- RD4. Principles of Railway Derailment Management R-0014-00-HSL-J2.
- RD5. UIC Leaflet 777-2 'Structures built over Railway lines- Construction requirements in the track zone'.
- RD6. Pandrol Case Study Heathrow Airport Rail link.
http://www.pandrol.com/cstudies/c05_bdy.htm
- RD7. TRAINSAFE Thematic Network Passive Safety in the Railways: A State of the Art Review December 2003.
http://www.arrc.ac.uk/docs/trainsafe_state_of_the_art_report.pdf
- RD8. Obstacles to Internal Market in Rail Mass Transit.
http://europa.eu.int/comm/enterprise/rail_guided_transport/rail_mass_transit.pdf
- RD9. Economic commission for Europe Trans/ac.9/91 December 2003
Recommendations of the Multidisciplinary group of experts on safety in tunnels (rail).
<http://www.unece.org/trans/doc/2003/ac9/TRANS-AC9-09e.pdf>
- RD10. Federal Railroad Administration, Safety of High Speed Guided Ground Transportation Systems Shared Right-of-Way Safety Issues.
- RD11. Federal Railroad Administration, Safety of High Speed Guided Ground Transportation Systems, Intrusion barrier Design Study.

- RD12. Rail Safety & Standards Board Report “Engineering Overhead line structure design to cater for collision.”
[http://www.rssb.co.uk/pdf/reports/research/Overhead_line_structure_design_to_cater_for_collision_\(T177\).pdf](http://www.rssb.co.uk/pdf/reports/research/Overhead_line_structure_design_to_cater_for_collision_(T177).pdf)
- RD13. Rail Safety & Standards Board Report “Engineering Derailment mitigation – categorisation of past derailments.”
[www.rssb.co.uk/pdf/reports/Research/Overhead%20line%20structure%20design%20to%20cater%20for%20collision%20\(T177\).pdf](http://www.rssb.co.uk/pdf/reports/Research/Overhead%20line%20structure%20design%20to%20cater%20for%20collision%20(T177).pdf)
- RD14. Infraspeed Expert Panel meeting on Derailment Provisions IDE(TRK+T&CDD # 000006) Revision A November 2003.
- RD15. Review of Derailment Risk for the HSL-Zuid Railway February 2004, Issue 1.

5 Glossary & Abbreviations

Check Rail	A guiding rail, located between the two running rails, and set close to one of the running rails to make contact with the back of a flange. Normally used to prevent the opposite flange from making hard contact with the running rail on a sharp curve; or to prevent the opposite flange from taking the wrong route at a rail crossing.
DB	Deutsche Bahn
DCP	Derailment Containment Provision
DED	Derailment Equipment Detection
Derailment	Generic Term: “A derailment is the action of one or more flanged railway wheels departing from the rail” HSL-Zuid RIA – Restated Implementation Agreement (contract with Infraspeed) Term: "A derailment on the HSL assets occurs when one or more wheels lose contact with the rail"
Derailment Escalation	The situation where the consequences of the accident are severely aggravated, because the derailed train leaves the track, enters an adjacent track, turns over, falls to a lower level, or jack-knives, etc.
Guard Rail	A longitudinal rail running alongside a railway track and raised in height above the running rails. Guard rails are sometimes found on bridges and are intended to restrain the lateral movement of vehicles which may become derailed.
HSL-Zuid	High Speed Line - South

R+D	Research + Development
RCF	Rolling Contact Fatigue
Robust Kerb	Generally a reinforced concrete up-stand located adjacent to the track at varying heights usually to restrain lateral movement following a derailment on a rail bridge or to protect bridge piers.
SNCB	Société Nationale des Chemins de Fer Belges
SNCF	Société Nationale des Chemins de fer Français
TGV	Train à Grande Vitesse

Appendices

Appendices

- A** Standard Questionnaire
- B** Detailed Questionnaire Results Table
- C** Summary of Questionnaires, Interviews & Media Search
- D** Causes of Derailments
- E** Infrasppeed Concrete Plinth Illustrations
- F** Accidents for Expert Panel Assessment
- G** Derailment Accidents - Further Reading

Appendix
A

Standard Questionnaire

**DERAILMENT CONTAINMENT
PROVISION QUESTIONNAIRE**



HSL-Zuid

Location _____

Date _____

*This report is confidential and intended solely for the use and
information of the company to whom it is addressed.*

Booz | Allen | Hamilton

Interviewee Name		Date of Interview	
Project / Organisation discussed		Role on the Project or in the organisation	

1.0	High Speed Rail (HSR) Service	
1.1	Where does the HSR line run?	
1.2	How many miles/km of HSR service is provided?	
1.3	What is the maximum line speed?	
1.4	What is the average train speed?	
1.5	How is the train powered? (3 rd rail, diesel engine, overhead catenary)	
1.6	If electric, what is the operating voltage?	
1.7	Is the HSR service on exclusive right of way?	
1.8	Is the HSR service for passenger service or for both freight and passenger service?	
1.9	How often do HSR trains operate in each direction?	
1.10	What are the minimum headways?	
1.11	What is the total length (miles/km) of single track?	
1.12	What is the total length (miles/km) of double track?	
1.13a	What is the minimum vertical curvature of the track?	
1.13b	What is the percentage of track in a curve?	
1.14	What is the minimum horizontal curvature of the track?	
1.15	What is the maximum track cant?	
1.16a	What are the typical intervals between mainline turnouts?	
1.16b	What are the typical intervals between switches?	
1.17	What provisions are made to keep road vehicles, people and animals away from the right of way (fencing)?	
1.18	How is broken rail detected?	
1.19	What types of rail fasteners are used?	
1.20	What types of pads are used under tie plates?	
2	Rolling Stock	
2.1	What type of rolling stock is used?	
2.2	What is the length of a standard HSR train?	
2.3	How many train sets support the HSR service?	
2.4	Are they tilting train sets?	
2.5	How many passenger cars?	
2.6	How many power cars (or other cars)?	
2.7	How many passengers can a train set carry?	
2.8	What is the annual ridership and the distance operated?	
3	Infrastructure	

3.1	How much track (by percentage or mile/km) is installed: <ul style="list-style-type: none"> • in tunnels? • on viaducts? • on filled embankments? • at grade? 	
3.2	How many highway rail grade crossings are included in the HSR network? (Typical intervals 1 or 2 or 3 km)	
3.3	How many highway overpasses are included in the HSR network? (Typical intervals 1 or 2 or 3 km)	
3.4	How many bridges are included in the system?	
3.5	How many tunnels are included in the system?	
3.6	How many mainline turnouts are installed in the track?	
3.7	How is the track structure supported (sleepers on ballast, concrete sleepers, concrete slab, etc.)?	
3.8	Are train speeds reduced over certain types of track or infrastructure features?	
3.9	Who takes responsibility for maintaining the DCP?	
4	Track Standards	
4.1	What track standards are applied to the HSR line?	
4.2	Do the track standards include any derailment containment strategies (for example, do you require guard rails on bridges)?	
4.3	If so, what types of derailment containment strategies are used? <ul style="list-style-type: none"> • DCP Type 1 – Guide Rails inside the gauge • DCP Type 2 – Guide Rails outside the gauge • DCP Type 3 – Guide mechanisms that work on the bogie frame 	
4.4	How did you make the decision to use a specific derailment containment strategy?	
4.5	What type of information was available to help you make a derailment containment strategy decision?	
4.6	Have you considered and rejected other derailment containment strategies? Why?	
4.7	What are/ were the expectations of Derailment Containment Provision?	
4.8	If you use derailment containment strategies, have the results been positive? What if any were the adverse effects?	
5	Derailments	
5.1	Have you experienced any derailments on your HSR operation?	
5.2	If so, under what circumstances did they occur?	
5.3	What was the cause of each derailment?	
5.4	Do you use any specific technology to detect a derailment (dragging equipment detectors, impact sensors, etc.)?	
5.5	Do you consider preventive measures in the rolling stock (Hot Boxes etc.)?	

5.6	Did the derailment escalate (per HSL definitions)? <ul style="list-style-type: none"> • Train failed to follow track • Train failed to remain upright • Train entered into the clearance envelope for a train potentially travelling in the opposite direction • Other 	
5.7	Did derailment containment strategies adopted for your operation play a role in controlling the derailment?	
5.8	Could the application of a derailment containment strategy have reduced the consequences of the derailment?	
6.0	Other questions	
6.1	What derailment scenarios do you worry about most when considering derailments on your HSR system?	
6.2	Are there specific facilities or structures located along the right of way that could escalate a derailment?	
6.3	Are there natural factors or considerations that could cause or escalate a derailment (earthquakes, floods, brush fires, etc.)?	
6.4	Do you have any experience with derailments being caused or escalated due to one of these natural phenomena?	
6.5	In your opinion, what differentiators between a low-speed derailment and a high-speed derailment should be considered?	
6.6	In your experience, what are the most important factors that cause a simple derailment to escalate to a more serious accident?	
6.7	What do you think can be done to control these escalation factors?	
6.8	What would you like to see from the DCP in the future?	
6.9	Which specific prevention measures are taken (i.e. gates, (more) maintenance, nets near viaducts) and how effective are these measures?	
7	Any Further Information?	

Appendix B Detailed Questionnaire Results Table

Note 1 The information provided by Japan Central Railway was for the sole use of the Client and Booz Allen. Since this report may be released to other parties, the information regarding Japan Central Railway has been filtered.

		DB	SNCB	Great Belt (Storebælt) railway link Denmark	Oresund Link Sweden	Japan See note 1.
1.0	High Speed Rail (HSR) Service					
1.1	Where does the HSR line run?	1 Hannover – Würzburg 2 Mannheim – Stuttgart 3 Oebisfelde – Berlin 4 Cologne – Frankfurt/Main	In Belgium, in 2004, the HSR lines run: - Between Bruxelles and the French border towards Paris (line 1) and - Between Bruxelles and Liège towards the German border and Köln (line 2). Two other HSR lines are under construction: - line 3 between Liège and the German border and - line 4 between Antwerpen Centraal and the Dutch border	Between the Danish islands of Funen (Fyn) and Zealand (Sjælland) across the Great Belt (Storebælt) From Funen to the small island of Sprogø in the middle of the Great Belt, the railway is on the 6.6 km long West Bridge, which carries both road and railway. From Sprogø to Zealand the railway passes through the 8 km long East Tunnel.	On the tunnel and bridge between Denmark and Sweden (fixed Oeresund link)	Tokyo - Shin-Osaka, Japan
1.2	How many miles/km of HSR service is provided?	1 327 km 2 99 km 3 159 km 4 164 km	Line 1 : Bruxelles to the French border : 91 km with a section of 71 km (Lembeek to the French border) up to 300 km/h (design speed 320 km/h) Line 2 : Bruxelles to Liège: 100 km with a section of 64 km (Leuven - Ans) up to 300 km/h.	The part of the project covered by the requirements for risk management and risk acceptance criteria includes 19.4 km of double track railway.	16 km	515.4km
1.3	What is the maximum line speed?	1 280 km/h 2 280 km/h 3 280 km/h 4 330 km/h	The maximum line speed is 300 km/h. Line 1 has been tested for a future maximum speed up to 320 km/h	180 km/hr (in some design aspects 200 km/hr has been used)	200 km/h (120 km/h for freight trains)	270km/h
1.4	What is the average train speed?	1 250 km/h 2 250 km/h 3 250 km/h 4 300 km/h	Line 1 : 245 km/h Line 2 : 211 km/h	In the update of the risk analyses just completed the following average speeds for passenger trains were assumed: - West Bridge and Sprogø: 180 km/hr. East Tunnel: 131 km/hr.	~ 180 km/h	Information not for Public domain
1.5	How is the train powered? (3 rd rail, diesel engine, overhead catenary)	all overhead catenary	The trains are powered by overhead catenary	Diesel and overhead catenary	Overhead catenary	Overhead catenary
1.6	If electric, what is the operating voltage?	15.000 V/ 16,7 Hz	25.000 Volts 50 Hz		25 KV AC	25kV AC
1.7	Is the HSR service on exclusive right of way?	1 no 2 no 3 no 4 yes	On line 1, the HSR service is exclusive right of way (High speed trains PBKA and Eurostar only for passengers up to 300 km/h) On line 2, the HSR service is exclusive right of way for passengers: - up to 300 km/h for high speed trains PBKA - up to 200 km/h for intercity trains (Ostende - Eupen) push-pull formation		yes	Exclusive
1.8	Is the HSR service for passenger service or for both freight and passenger service?	1, 2, 3 for both passenger and freight service 4 only for passenger service	The HSR services are only for passenger services (see above)	In 2015 (basis year for the risk analysis update) it is expected that there will be 51.650 passenger trains (31% electric and 69% diesel) and 18.168 goods trains.	Both	Passenger only
1.9	How often do HSR trains operate in each direction?	1 4 trains/per hour 3 3 trains/per hour 4 3 trains/per hour	L1: 533 trains per week in both directions L2: 7 trains per day and per direction	With very few exceptions, all passenger trains are able to run 180 km/hr, such that the number of HSR trains per hour can be estimated on the basis of the above 51.650 passenger trains in 2015.	Four trains per hour and direction (160 trains/day thereof 20 freight trains)	Information not for Public domain

		DB	SNCB	Great Belt (Storebælt) railway link Denmark	Oresund Link Sweden	Japan See note 1.	
1.10	What are the minimum headways?	At operation with the LZB (line-type inductive train control system) it depends on the braking capacity of both successive trains	Minimal distance between "signals" = 1500 m Minimal distance between trains = 9000 m (typical)		1.5 min	Information not for Public domain	
1.11	What is the total length (miles/km) of single track?	none	Line 1 : - One single track of 1.610 m with a maximum speed of 160 km/h for the junction at Antoing between an intern Belgium railway line (L78) and the line 1, for the service "high speed train" from Namur to Paris. - One single track of 1.372 m with a maximum speed of 160 km/h for the junction at Silly between an intern Belgium railway line (line 94) and the line 1. - Line 2 : no single track	None	0 km		
1.12	What is the total length (miles/km) of double track?	327 + 99 + 159 + 164 = 749 km	Line 1 : 71 km of double track (300 km/h) Line 2 : 64 km of double track (300 km/h)	19.4 km as explained in 1.2	16 km		
1.13 a	What is the minimum vertical curvature of the track?	4 14000 m	We suppose the minimum vertical curvature of the track: Line 1 : 19.585 m Line 2 : 15.000 m		5000 m		
1.13 b	What is the percentage of track in a curve?		We suppose the percentage of track in a horizontal curve. Line 1 : 58 %, Line 2 : 52 %		~ 60 %		
1.14	What is the minimum horizontal curvature of the track?	4 3350 m	We suppose the minimum horizontal curve of the track: Line 1: 4.806 m, Line 2 : 4.650 m		11.63 mm		
1.15	What is the maximum track cant?	4 170 mm	Line 1 : 150 mm Line 2 : 130 mm (mixed traffic)		65 mm		
1.16 a	What are the typical intervals between mainline turnouts?	no typical intervals	Line 1 : 29 km/20 km/30 km Line 2 : 21 km/29 km/14 km	None.	-		
1.16 b	What are the typical intervals between switches	General requirement: every 25 km a place to overhaul trains	There is no typical interval between switches. On line 1 and 2 : an interval of 100 m between the ends of the switch blades. This distance can be reduced.	Switches are only located on the island of Sprogø. None on the West Bridge and in the East Tunnel	-		
1.17	What provisions are made to keep road vehicles, people, animals away from the right of way (fencing)?	General no special provisions, but most of the line is fenced by noise protection walls, wind protection walls and other earthworks	For people and animals, everywhere fenced. For road vehicles, several dispositions: - or embankment - or new jersey - or concrete walls (can be noise barriers)	The road vehicles are kept on the motorway by means of crash barriers. There is no public access to the islands of Sprogø.	-		Fencing Any trespassers are banned by national law
1.18	How is broken rail detected?	No special detection	By failing of the track circuit		Electronic testing (every two years)		Information not for Public domain
1.19	What types of rail fasteners are used?	Vossloh, different types for slab track and ballasted track	Pandrol system (elastic fastening clips)		Pandrol fast clips		
1.20	What types of pads are used under tie plates?	ZW 700 and ZW 900	Elastic pads, 10 mm thick		Pandrol		
2	Rolling Stock						
2.1	What type of rolling stock is used?	ICE 1, ICE 2, ICE 3, ICE-T	TMST-sets (Transmanche) PBKA en PBA-sets (Paris-Bruxelles-Köln-Amsterdam) TGV-Réseau	The diesel passenger trains at present are IC3 trains consisting of up to 5 sets of carriages. Each set consists of three carriages, the one in the middle has no engine and the two others have diesel engines. The electrical passenger trains are mostly ER trains consisting of up to five sets of carriages. Each set consists of four carriages, the two in the middle have no engine and the two others have electrical engines.	Oeresund-Trains (trainsets)	Information not for Public domain	
2.2	What is the length of a standard HSR train?	ICE 1: 360 m; ICE 2: 205 m (Double 410 m); ICE 3: 200 m (Double 400 m); ICE-T: (7) 185 m (5) 133 m	PBKA, PBA, TGV-Réseau = 200 m TMST = 394 m	During design a 300 m long IC3 train with 5 sets of carriages carrying 720 passengers was used as basis.	78,90 m		

		DB	SNCB	Great Belt (Storebælt) railway link Denmark	Oresund Link Sweden	Japan See note 1.
2.3	How many train sets support the HSR service?	ICE 1: 59; ICE 2: 44; ICE 3: 63; ICE-T: 43	Eurostar = 10 + reserve Thalys = 35 TGV Bruxelles-France (also called TGV-Interconnexion) = +/- 8 + reserve	The trains are the trains generally used by the main Danish operator, DSB, in Denmark. See www.dsb.dk	n.a.	
2.4	Are they tilting train sets?	yes, ICE-T	No	No	No	Information not for Public domain
2.5	How many passenger cars?	ICE 1: 12; ICE 2: 7; ICE 3: 9, ICE-T: 7 or 5	TMST = 18 cars / set PBKA, PBA, TGV-Réseau = 8 cars/set	See 2.1	n.a.	
2.6	How many power cars (or other cars)?	ICE 1: 2 (Loco); ICE 2: 1 (Loco), ICE 3: 4; ICE-T: 1	2 powercars per unit (TMST, PBKA,...)	See 2.1.	n.a.	
2.7	How many passengers can a train set carry?	ICE 1: 645; ICE 2: 370; ICE 3: 415; ICE-T: (5) 250, (7) 381	TMST = 794 passengers PBKA, PBA, TGV-Réseau = 375 passengers	See 2.2	237	
2.8	What is the annual ridership and the distance operated?	ICE 1: 500 000 km/a/train; ICE 2: 515 000 km/a/train; ICE 3: 520 000 km/a/train; ICE-T: 400 000 km/a/train	L1 : 533 rides/week x 71 km x 52 1/7 weeks per year, L2 : 98 rides/week x 64 km x 52 1/7 weeks per year	In 2015 the number of passengers is assumed to be 9 million. Distance: See 1.2.	n.a.	
3	Infrastructure					
3.1	How much track (by percentage or mile/km) is installed: • in tunnels? • on viaducts? • on filled embankments? • at grade?	1 Tunnel 122,3 km; Viaducts 32,6 km; Embankments/ at grade 172,5 km 2 Tunnel 30,3 km; Viaducts 5,6 km; Embankments/ at grade 63,4 km 3 Tunnel 0 km; Viaducts 3,1 km; Embankments/ at grade 156,0 km 4 Tunnel 40,5 km; Viaducts 8,1 km; Embankments/ at grade 115,8 km	Line 1: Tunnel: 1.177 m or 1.65 % Viaducts : 4.142 m or 5.83 % On filled embankments:20.600 m or 29 % At grade (of the ground) : 12.600 m or 17.7 % Line 2: Tunnel: 757 m (Bierbeek) or 1.18 % Viaducts (on ground): 3.266 m or 5.1 % On filled embankments: 20.800 m or 32.5 % At grade (of the ground) : 11.746 m or 18.35 %	6.6 km on the West Bridge 8 km in the East Tunnel The remaining km are at filled embankments leading to or from the West Bridge or at ramps leading to or from the East Tunnel.	Tunnel: 3.510 km Bridge: 7.845 km	Information not for Public domain
3.2	How many highway rail grade crossings are included in the HSR network? (Typical intervals 1 or 2 or 3 km)	none	No grade crossings. There are no grade crossings authorised at a speed higher than 160 km/h	None	-	
3.3	How many highway overpasses are included in the HSR network? (Typical intervals 1 or 2 or 3 km)	unknown	Highway overpasses and underpasses Line 1 : 11 bridges (over or under) on 71 km - A bridge, every 6 to 7 km (N508; N507; N52, A16, N50, N60, N56, N57, N55, N6, and N203) Line 2 : 8 bridges (over or under) on 64 km - A bridge every to 8 km (N3, N25, E40, N29, N64, N80, N69 and N614)	None within the 19.4 km.	-	
3.4	How many bridges are included in the system?	Railway bridges 1 206 2 39 3 73 4 101	Bridges = viaducts + road overpasses and underpasses + river overpasses + footbridges + aqueducts (concrete bridges and pipes) Line 1: 79 bridges and 94 aqueducts Line 2: 76 bridges and 87 aqueducts	6.6 km long West Bridge	1	
3.5	How many tunnels are included in the system?	1 62 2 14 3 0 4 31	Line 1 : Tunnel of Halle: 551 m Tunnel of Tubize : 270 m Tunnel of Antoining: 356 m Line 2: Tunnel of Bierbeek : 757 m	8 km East Tunnel	1	
3.6	How many mainline turnouts are installed in the track?	unknown	Line 1: 14 mainline turnouts Line 2: 10 mainline turnouts	None	8	

		DB	SNCB	Great Belt (Storebælt) railway link Denmark	Oresund Link Sweden	Japan See note 1.
3.7	How is the track structure supported (sleepers on ballast, concrete sleepers, concrete slab, etc.)?	ballastless track (slab track) ballasted track with concrete sleepers	The Track structure is: - rail UIC 60 kg/m (long welded rails) - prestressed monobloc concrete sleeper - elastic fastening system pandrol - elastic pads 10 mm thick - ballast 35 cm minimum thick under the sleeper - mainline turnouts in rails UIC 60 with mobile heart	Ballast track	Tunnel: concrete slab track Bridge: ballasted on monoblock sleepers	Information not for Public domain
3.8	Are train speeds reduced over certain types of track or infrastructure features?	speed restriction in tunnels on lines 1-3: 250 km/h	There is no speed restriction in section with a authorised speed of 300 km/h	For some of the trains including IC3, the speed in the East tunnel is limited to 140 km/hr.	No	
3.9	Who takes responsibility for maintaining the DCP?	Infrastructure owner, maintenance departments	The Belgian railway company has created special multi-disciplinary staff for the maintaining of DCP of high speed line.	The infrastructure operator is Banedanmark, Rail Net Denmark, www.bane.dk.	Oeresundbro Konsortiet (Infrastructure Manager)	
4	Track Standards					
4.1	What track standards are applied to the HSR line?	slab track, by exception only concrete sleepers on ballast with UIC 60 rails.	Technical specifications interoperability of the European community, EN and the UIC		These are detailed in the Register of Infrastructure	Company established standard which covers tracks, civil engineering structures, electrical and signalling facilities and rolling stocks. This standard is approved by the Transportation Ministry of Japan.
4.2	Do the track standards include any derailment containment strategies (for example, do you require guard rails on bridges)?	Guard rails are required only on lines with mixed traffic under certain conditions, not on Cologne – Frankfurt/Main	The track standards include derailment containment strategies.	There are guard rails on the West Bridge in accordance with the practice used on major Danish railway bridges for a long time. The East Tunnel is a bored tunnel, two bores with one track each. There are elevated walkways on both sides of each track. These walkways are made of concrete and designed for a horizontal accidental load of 100 kN per metre length at any level and position along the tunnel. Providing guard rails in the tunnel was considered, but this was abandoned as not being cost efficient in view of the walkways acting as derailment containment. Hot box detectors, gauge control and derailment control facilities are installed at both sides of the Great Belt crossing reducing the probability of derailment.	- Yes, concrete and steel “side walls” or guiding devices - No guard rails - The devices are part of the bridge/tunnel construction, so their instalment did not trigger additional investments - Concrete is used in the tunnel and on the approach bridges, steel is used on the span bridge due to constructional reasons (weight)	Yes

		DB	SNCB	Great Belt (Storebælt) railway link Denmark	Oresund Link Sweden	Japan See note 1.
4.3	If so, what types of derailment containment strategies are used? <ul style="list-style-type: none"> • DCP Type 1 – Guide Rails inside the gauge • DCP Type 2 – Guide Rails outside the gauge • DCP Type 3 – Guide mechanisms that work on the bogie frame 	DCP Type 1	DCP type 1 - Guide rails inside the gauge especially on high embankments and on bridges + overflowed platform detectors at the low points of the HSR line + hot boxes detectors for the rolling stock + concrete platform on chalky and old mining areas On single track viaducts there are two guide rails; on the other places only one guide rail near the outside rail Stability control of the bogie More information has to be requested from SNCB	DCP Type 1 for the West Bridge.	n.a.	DCP Type 1 and DCP Type 3
4.4	How did you make the decision to use a specific derailment containment strategy?	Railway standard requirements	According to the Belgian railway rules for the track and the local characteristics for the stability of the platform. The Belgian regulations are close to those of France.	See 4.2. The general approach used for the Great Belt project is that risk acceptance criteria were first established. Then the risk was estimated and compared to the risk acceptance criteria. It is found that these criteria are met, such that additional containment provisions are not required.	Technical risk analysis and a small survey	Information not for Public domain
4.5	What type of information was available to help you make a derailment containment strategy decision?	Regulations (Railway standards) and expert reports	According to the Belgian railway rules for the track and the local characteristics for the stability of the platform, after sound geographical, geological and geophysical campaign of measures and studies	See 4.5. It is noted that in Denmark there has been one derailment on a bridge. In this case the guard rails served their purpose: In 1978 there was a derailment on the Storstrøms Bridge which carries a single track railway and a two lane highway between Zealand (Sjælland) and the island of Falster south of Zealand. On a stormy night wind caused a lightly loaded lorry to turn over and hit a lamp post. The lamp post fell across the track. The post was hit by a locomotive and caught beneath the cowcatcher of the locomotive such that the locomotive derailed. The locomotive was caught by the guard rail.	No other railway used the system when construction began. System is a unique development, so no information was available	
4.6	Have you considered and rejected other derailment containment strategies? Why?	yes, on the base of expert reports for special projects	Attention is paid to the piles of bridges and viaducts; on existing bridges the piles became an extra protection against damage.	See 4.2.	No, as the used strategy seemed to be the “most natural and logic” one	
4.7	What are/ were the expectations of Derailment Containment Provision?	To prevent <ul style="list-style-type: none"> • the deflection of a car body in the clearance of the opposite track, • the impact of a train to structures near the track. 	We have considered no possibility of derailment	Question not understood.	To keep trains in the guiding device	
4.8	If you use derailment containment strategies, have the results been positive? What if any were the adverse effects?	1992: collision on a bridge was prevented by guard rails. 1996: impact to an abutment of a road bridge was prevented by guard rails	No derailment since the begin in 1995 of the operation at 300 km/h of the line 1 (2003 for the line 2).	There has been no train accident on the Great Belt Link since opening for train traffic in July 1997.	No experience	Yes. Our standard is working.
5	Derailments					
5.1	Have you experienced any derailments on your HSR operation?	not on the special HSR lines, but in Eschede.	No derailment	See 4.8	No	None on Shinkansen.
5.2	If so, under what circumstances did they occur?	broken tyre of wheel 6 km in front of a bridge, then a deflection at a switch directly before the bridge, impact on bridge piles, bridge collapsed speed 200 km/h, 100 victims	-		n.a.	Information not for Public domain
5.3	What was the cause of each derailment?	break of tyre of wheel and deflection at a switch	-		n.a.	

		DB	SNCB	Great Belt (Storebælt) railway link Denmark	Oresund Link Sweden	Japan See note 1.
5.4	Do you use any specific technology to detect a derailment (dragging equipment detectors, impact sensors, etc.)?	Indirectly with special sensors at the bogies to detect extraordinary shunting movement	No technology to detect a derailment but some technology to prevent a derailment (see after) and stability control of the bogie	See 4.2.	Detectors on both endings of the bridge (tunnel) - Cable lying on the sleepers as an electric circuit	Yes, on bogies.
5.5	Do you consider preventive measures in the rolling stock (Hot Boxes etc.)?	At the moment no special detectors exist to detect a derailment, but this would be the best solution	Yes, hot box detectors in track	See 4.2.	There are rail break detectors on the trains (further information available at DSB)	Information not for Public domain
5.6	Did the derailment escalate (per HSL definitions)? <ul style="list-style-type: none"> • Train failed to follow track • Train failed to remain upright • Train entered into the clearance envelope for a train potentially travelling in the opposite direction • Other 	Yes, after the deflection at the switch the train failed to follow track.	-		n.a.	
5.7	Did derailment containment strategies adopted for your operation play a role in controlling the derailment?	No	Yes, in case of derailment, objective is to keep the train upright and outside the clearance of the opposite track (for example, two guide rails inside the gauge). Ballast is very helpful to keep the rolling stock upright.		n.a.	Information not for Public domain
5.8	Could the application of a derailment containment strategy have reduced the consequences of the derailment?	Theoretically, yes	-		n.a.	
6.0	Other questions					
6.1	What derailment scenarios do you worry about most when considering derailments on your HSR system?		A ground collapse in chalky and in old mining areas which can affect the stability of the platform and the tracks. In such areas, we use a concrete platform which allows a gate of 4 m diameter under the platform.	Derailment on the West Bridge resulting in carriages falling off the bridge. In the risk analysis carried out, the escalation of consequences in the event of derailment at the West Bridge was considered including: <ul style="list-style-type: none"> - Train entering into the clearance envelope of trains on the other track. - Train driving off the bridge and falling into the sea, which in the analysis was assumed to be fatal to all passengers in the carriages falling off the bridge. 	A train damaging the bridge structure	Information not for Public domain
6.2	Are there specific facilities or structures located along the right of way that could escalate a derailment?	No experience	No	Open water as described above. It is noted that the carriages may fall into the sea at one side of the railway girder. At the other side there is a 1.35 m wide gap between the railway girder and the adjacent road girder for the motorway crossing such that carriages cannot fall into the sea here.	Bridge structure	
6.3	Are there natural factors or considerations that could cause or escalate a derailment (earthquakes, floods, brush fires, etc.)?	High water for lines besides a river	Yes: <ul style="list-style-type: none"> • The ground collapse in chalky and old mining areas (see above) • the overflowing of the platform at the low points of the HSR lines (detection devices are installed in these areas) • earthquakes, but in a limited way (viaducts and tunnels are calculated for preventing any derailment of high speed train by an earthquake) 		<ul style="list-style-type: none"> - Collision of a ship with a column while a train is running on the bridge - Most of the columns are protected by islands which would let the ships ground before hitting a column 	

		DB	SNCB	Great Belt (Storebælt) railway link Denmark	Oresund Link Sweden	Japan See note 1.
6.4	Do you have any experience with derailments being caused or escalated due to one of these natural phenomena?	No	No experience, only information about a ground collapse on line 3 in France near Amiens		No	No.
6.5	In your opinion, what differentiators between a low-speed derailment and a high-speed derailment should be considered?		For the same rolling stock, it is obvious that a high speed derailment is more dangerous for the passengers and damages the rolling stock and infrastructure. But, on a high speed line, the eventual damages of a derailment have been reduced by the use of a special rolling stock (high speed trains with bogies between the cars which keep the train as one) Note that ICE-3 trains will be allowed to ride on Belgian HSL; this rolling stock has no bogie between the cars	The consequences of a high-speed derailment of course may be larger than the consequences of low-speed derailment. In the risk analysis carried out for the West Bridge, it was considered that the guard rails would be less efficient in the event of a high-speed derailment than in the event of a low-speed derailment.	None	Information not for Public domain
6.6	In your experience, what are the most important factors that cause a simple derailment to escalate to a more serious accident?	Track irregularities like switches, crossings and others	No experience		Speed, weight, derailment containment provisions	
6.7	What do you think can be done to control these escalation factors?		No experience	Derailment containment provisions		
6.8	What would you like to see from the DCP in the future?			Entrance of tunnels need to be equipped with derailment containment provisions (from 500 m before the entrance) so that a derailed train cannot collide with the walls of the tunnel entrance		
6.9	Which specific prevention measures are taken (i.e. gates, (more) maintenance, nets near viaducts) and how effective are these measures?	Passive protection systems along roads, on road bridges to prevent the deflection of vehicles to the rail.	No specific prevention, only a regular visit of the installations according to the UIC leaflet "Maintenance of high speed lines" (1996)	Normal preventive maintenance strategy Additional inspections at the connection between slab track and ballasted track		
7	Any Further Information?		Each morning the lines are declared secure for operation after a ride of an "opening train" (train balai according to the French practice). This opening train can be commercial or non-commercial ride of any train at 160 km/h maximum. These opening rides are very helpful to avoid unexpected obstacles when the rides at 300 km/h start. It is considered as a major contribution to our DCP-strategy.	Information on the Great Belt project and the risk analysis work carried out can be obtained from "J. Kampmann, K. Kieler and B. Kohl: Risk Analysis of the Railway Tunnel under the Great Belt. Safety in Road and Rail Tunnels. Basel, Switzerland, Nov. 1992". It is noted that the risk acceptance criteria for user risk presented in this document are no longer valid, as the risk acceptance criteria for the Great Belt Link have been revised recently such that changes in the traffic across the Link, both road and rail, can be taken into account. These new criteria have not been published.		

Appendix C Summary of Questionnaires, Interviews & Media Search

Notes for Appendix C:

- 1) Shading indicates information from media source.
- 2) A shaded row indicates the source material was from the reference stated in the left column.
- 3) Where text only is shaded then this is from the stated source stated at the end of the block of text.
- 4) No shading indicates text from interview.

Organisation / Project	Type of DCP	Why	Comments	Identified Adverse Effects
Deutsche Bahn AG	Type 1	Regulations (Railway standards) required that guard rails are required only on lines with mixed traffic under certain conditions, (not on Cologne – Frankfurt/Main) and the decision to use DCP 1 was also based on expert reports.	There is a common practice for derailment provision which involves the use of a guard rail. The derailment provision is not specific to high speed lines. Source: [RD 14]	None identified
SNCB	Type 1 Type 3	According to the Belgian railway rules for the track and the local characteristics for the stability of the platform, after sound geographical, geological and geophysical campaign of measures and studies.	The Belgian regulations are similar to the French regulations.	None identified

Summary of Questionnaires, Interviews & Media Search

Organisation / Project	Type of DCP	Why	Comments	Identified Adverse Effects
Great Belt (Storebælt) Railway Link Denmark	Type 1 Type 3	There are guard rails on the West Bridge in accordance with the practice used on major Danish railway bridges for a long time. The East Tunnel is a bored tunnel, two bores with one track each. There are elevated walkways on both sides of each track. These walkways are made of concrete and designed for a horizontal accidental load of 100 kN per metre length at any level and position along the tunnel. The walkways act as derailment containment.	The general approach is that risk acceptance criteria were first established. The risk was estimated and compared to the risk acceptance criteria. It was found that these criteria have been met, such that additional containment provisions are not required	None identified
Oresund Link Sweden/ Denmark	Type 3	The system is a unique development, so no information was available at the time of construction, therefore a technical risk analysis was undertaken.		None identified

Summary of Questionnaires, Interviews & Media Search

Organisation / Project	Type of DCP	Why	Comments	Identified Adverse Effects
Central Japan Railway Company & Massachusetts Institute of Technology (SHINKANSEN Japan)	Type 1 Type 3	Company established standard which covers tracks, civil engineering structures, electrical and signalling facilities and rolling stock. This standard is approved by the Transportation Ministry of Japan.		None identified
Lyon Turin high speed link France / Italy	Planning to use Type 3	Based on the experience on the Channel Tunnel.		None identified
Italy	Increased separation of track on High Speed Lines	The selection of these measures was the result of technical considerations and empirical evidence on derailments on traditional lines.	There is no common practice for DCP. [RD 14]	There are no adverse affects on low speed lines
Lyon Turin high speed link France / Italy	Planning to use Type 3	Based on the experience on the Channel Tunnel.		None identified
High Speed Lines France	Type 1	No Information		None identified

Summary of Questionnaires, Interviews & Media Search

Organisation / Project	Type of DCP	Why	Comments	Identified Adverse Effects
SNCF [RD4]	Type 1 and Const- ruction design		<p>The approach on all railway lines is focused on the provision of DCP where the risk is greatest. The current practice is to use DCP Type 1.</p> <p>For structures under, adjacent to, or over the railway LGV used the approach of UIC leaflet 777-2, plus the addition of a safety rail on existing LGV where this is an adjacent structure nearby.</p> <p>DCP Type 1 is used for railway bridges and viaducts where the length is greater than 50m or the speed is higher than 130Km/h, or where the risk is high i.e. housing under the viaduct, or where a derailment off the main line could infringe on the main line.</p>	Robust kerbs are not preferred since they interfere with mechanical track operations.
SNCF[RD14]			<p>There are exceptions. If a bridge is wide enough and the track distance is wide enough (>4,5m), no derailment provisions are installed, and at transition curves where alignment changes into a narrow curve (less than 2000m).</p> <p>On high speed lines derailment provision is used. Here a standard design is used (similar to Belgium).</p>	Because of the torsion (change of cant) of the track some stiff vehicles may derail at very low speeds due to wheel climb. Some times this is solved by lubrication of the track.

Summary of Questionnaires, Interviews & Media Search

Organisation / Project	Type of DCP	Why	Comments	Identified Adverse Effects
SNCF [RD15]			<p>The following high speed derailments have occurred:</p> <ul style="list-style-type: none"> • A TGV travelling at 270 km/h at Macon Loche, France caused derailment of one bogie due to wheel defect. No fatalities, 27 injured. • A TGV travelling at 294 km/h at Haute Picardie, France caused collapse of track structure due to WW-I trench. No fatalities, 2 injuries. • A Eurostar travelling at 300 km/h at Croisilles, France caused by mechanical failure of bogie component. Emergency braking caused additional cars to derail. No fatalities, 14 injuries. <p>Derailments involving High Speed Trains Less than 200 km/h;</p> <ul style="list-style-type: none"> • A TGV train travelling at 120 km/h at Laval, France caused by Derailment due to emergency brake application in response to mud slide. No fatalities, no injuries; • A TGV train travelling at 130 km/h at Dax, France caused Obstruction on track caused a derailment and the overturn of a power car. No fatalities, 5 injuries. 	No Information

Summary of Questionnaires, Interviews & Media Search

Organisation / Project	Type of DCP	Why	Comments	Identified Adverse Effects
Netherlands [RD14]			Common practice is to use DCP only at bridges (steel) and flyovers (note a concrete plinth is constructed on the Hemboog line).	No Information
Netherlands [RD3]			<p>A passenger train derailed in Baarn in 1999 at 40 km per hour with minor consequences. The cause of the derailment was the failure of a wheel due to fatigue cracks. As a result of the accident the investigation recommendations were:</p> <ul style="list-style-type: none"> • Mitigating the technical risk of failure the wheel sets by developing a maintenance strategy • Reconsider the policy instrument of compulsory certification of maintenance companies (assessment of business processes). 	No Information

Summary of Questionnaires, Interviews & Media Search

Organisation / Project	Type of DCP	Why	Comments	Identified Adverse Effects
UK CTRL	Type 1 Type 3	Based on a Derailment Containment Strategy (ALARP Risk assessment)	<p>CTRL recognised that no DCP is 100% effective and that the attention should be focused on preventing the causes of derailments and rather than managing the consequence.</p> <p>The approach to DCP was based on their Train Accident Model which is an averaging model in the sense that it takes and average embankment etc.</p> <p>There was no justification for the provision of DCP if CTRL was to have been a passenger only line. The additional risk introduced by mixed traffic required DCP to be installed at strategic and high risk locations.</p> <p>Due to the absence of derailment data and evidence of DCP effectiveness, the risk analysis used assumptions and estimated ranges and considered common derailments. The report identified that check rails (DCP Type 1) and guard rails (DCP Type 2) were not effective at high speed.</p> <p>CTRL undertook an approach which was a variation on UIC Leaflet 777-2 'Structures built over Railway lines- Construction requirements in the track zone'. In addition the positioning of the DCP Type 3 is designed so that during a derailment the concrete kerb acts and the running rail act as a barrier to the laterally displaced wheelset.</p> <p>A key lesson from CTRL is that the theoretical approach to DCP as a result of analysis has to be technically feasible and practicable and compatible with the track bed design.</p>	None identified

Summary of Questionnaires, Interviews & Media Search

Organisation / Project	Type of DCP	Why	Comments	Identified Adverse Effects
UK			There is no common practice for DCP in the UK [RD14] The risk of derailment is assessed on a case by case basis in accordance with the ALARP principle used in the UK. Therefore there is no single standard on derailment prevention, however the most relevant is GC/RC 5510 – Recommendations for the design of bridges.	No Information
UK Heathrow Express Tunnels [RD6]	Type 3	The HMRI required that the project should incorporate derailment containment throughout the lengths of the tunnels.	Derailment containment consists of a central concrete up-stand in the four-foot area. The up-stand extends to rail level, and permits 215mm excursion of a derailed wheel. At the locations of equipment to be installed in the four-foot; the derailment containment is stopped.	No Information
UK Rail Safety & Standards Board Report “Engineering Overhead line structure design to cater for collision” [RD12]			The RSSB research paper concludes that when there is an impact with Overhead lineside structures there may be a significant amount of damage to the train. The severity is dependent on which part of the train absorbs the impact. A more significant finding for this report is that the lineside structures can have a beneficial containment effect.	No Information

Summary of Questionnaires, Interviews & Media Search

Organisation / Project	Type of DCP	Why	Comments	Identified Adverse Effects
<p>UK Rail Safety & Standards Board Report “Engineering Derailment mitigation – categorisation of past derailments” [RD13]</p>			<p>This report produced for RSSB was a result of a review of derailments in the United Kingdom over the period 1992-2001 to identify the casual events and their associated mitigating standards.</p> <p>The derailments were split up into 3 categories:</p> <ul style="list-style-type: none"> • Category 1: Derailment due to track or vehicle factors where either the track OR the vehicle were non-compliant with the pertaining standards (32% of derailments) • Category 2: Derailment due to track or vehicle factors where both the track AND the vehicle were compliant with the pertaining standards (10 of derailments) • Category 3: Derailment not due to track, vehicle or track/vehicle interaction. (43 of derailments) • Uncategorized (15% of derailments) <p>Key findings of the report showed that of the derailments identified as category 1 (32% of all derailments) 92% solely affected freight services.</p> <p>The report identified that the speed of derailment was known in 60% of Category 1 & 2 derailments. Nearly 50% of the derailments occurred when the train was travelling at less than 16km/h.</p>	<p>No Information</p>

Summary of Questionnaires, Interviews & Media Search

Organisation / Project	Type of DCP	Why	Comments	Identified Adverse Effects
Economic Commission for Europe Recommendations of the Multidisciplinary group of experts on safety in tunnels (rail) [RD9]			Extract: Mitigation of the consequence of accidents Infrastructure measures Standard C.2 01 Derailment containment measures Derailment containment measures should be provided in all tunnels. The tunnel profile should be kept as free as possible from obstacles, which might snag a derailed train.	No Information
Korean High Speed Railway Source: [RD4]	Type 3		Concrete containment kerbs are used, which are high enough to align with the bearing axle box of the train to prevent undue force on the wheelsets or the train body. These kerbs are situated sufficient distance from the rails to allow ballast-cleaning machines.	No Information
Taiwan High Speed Rail Corporation	Type 3	Based on expert judgment		Cost
New South Wales Australia [RD2]			Statistics on: <ul style="list-style-type: none"> • Number of Derailments • Number of Derailments by Line Type, by Rolling Stock Type and by Top 5 Reasons 	No Information

Summary of Questionnaires, Interviews & Media Search

Organisation / Project	Type of DCP	Why	Comments	Identified Adverse Effects
US AMTRAK Source [RD 12]	None	Amtrack does not have DCP on the track. The track is designed to keep the train upright or within a certain envelope. (The trains are equipped with locking couplers which provide some constraint between the vehicles to prevent one vehicle from twisting relative to another).	The focus is on derailment prevention through good track and train maintenance practices	DCP installed on infrastructure interferes with maintenance and at times, can potentially become a higher risk than no containment provision.
Federal Railroad Administration, Safety of High Speed Guided Ground Transportation Systems, Intrusion barrier Design Study. [RD4]			The Federal Railroad Administration has undertaken extensive research including modelling of intrusion barrier design. (DCP Type 3). They have found that structural rather than earthwork barriers are more effective. In the instance of using structural barriers on one side there were distinct differences in the output from the modelling. At high speeds the train experiences a glancing blow with the barrier and travel down the track and come to rest in a shallow zig-zag. Whereas at low speed the coaches remain in contact with the barriers longer and rest in a sharper zig-zag.	Where barriers are applied on both sides of the track then high speed and low speed trains have a tendency to get wedged between the two barriers, and get pushed into the barriers further by the coaches behind.

Summary of Questionnaires, Interviews & Media Search

Appendix **D** Causes of Derailment

D1. Introduction

The following causal factors are common reasons for derailments that have occurred in the past on all types of trains - not just high-speed trains.

D2. Track Related

The discussion on track related derailments includes the track roadbed, track structures, and any special track work included on the system.

The roadbed consists of the rails, the sleepers, the fasteners between the rails and sleepers, and the ballast, concrete slab, or subgrade used to support the track. The entire track structure is designed to support the weight of passing trains while maintaining the required geometry of the track. The track structure is not perfectly rigid but flexes with the passing of trains. The track structure, whether based on ballast, concrete slab, or other subgrade material, must support the train and maintain the tolerances on the geometry of the track. A subgrade that does not provide the required support will move under the train and quickly deteriorate.

A common cause of subgrade problems is inadequate drainage. Inadequate drainage can result in soft spots forming under the rail and sleepers. The soft areas allow the track to sag under passing trains and allow variations in the alignment and cross-level of the track. The more the track moves, the more the geometry of the track can deteriorate. Excessive cross-level can allow a car to rock back and forth and derail by walking off of the rail. More serious problems can cause the roadbed to collapse under the weight of a train.

Another type of track condition that can cause a derailment is track buckling. Track buckling usually occurs during hot weather on continuous welded rail. As the temperature rises, the rail tends to expand (grow longer). The internal stresses from rail heating are normally counteracted by the resisting forces of the track structure and subgrade. If the resisting forces are inadequate, the rail will buckle and the track will assume an "S" shape. A train travelling at a high enough speed will derail when it encounters the sharp curve of the track buckle. Even if the first carriage to encounter the rail buckle does not derail, the forces transmitted from the wheels to the track buckle tend to accentuate the buckle causing following cars to derail.

Broken rail is another common cause of derailment. Broken rail is the physical parting of the rail through a lateral break. The moving train causes the track to flex and pushes down the leading edge of a rail break. The wheel then strikes the opposite (unloaded) end of the broken rail until it fractures and can no longer support the train. Rail breaks

are often initiated with an inclusion of an impurity in the rail from the time of manufacture. Cracks propagate from the inclusion until the fatigue crack passes completely through the rail.

Other types of rail breaks can also result in a derailment. Occasionally, a piece of rail will break out and cause a derailment.

Finally, track caused derailments can also result from improper rail geometry. Rail gage and cross-level and other critical dimensions on the rail must be tightly controlled to prevent failure. Wide gauge, tight gage, excessive cross level variation, and other geometry variations that cause the track to be out of tolerance can cause a derailment. Inspection and maintenance of the right of way is key for detecting and correcting these anomalies.

D3. Special Track Work

Special arrangements of track in the form of switches, turnouts, crossovers, or other configurations can initiate or escalate a derailment. Defects in the adjustment and maintenance of switches can cause an accident. They represent an incongruity in the track structure and if not maintained, can quickly cause a derailment. Special track work often occupies the space between the two running rails where it can cause an obstruction for a derailed wheel. For example, a facing point turnout uses a curved rail that guides a railed wheel from one running rail across the opposite running rail. The configuration of a facing point switch can also capture a derailed wheel and direct it off the side of the right of way. Through this process, the rail and roadbed can be heavily damaged and a general derailment can occur.

Other issues associated with special track work can also contribute to derailments. Components used for points, frogs, or the switch mechanism itself can become worn or broken and cause a wheel to lose contact with the rail, climb on top of the rail, or split a switch. When a train splits a switch, part of the train takes one route and the rest of the train takes the diverging route.

D4. Vehicle Defects

Defects in the rail vehicle can also cause a derailment. Broken wheels, broken axles and problems with the bogie or suspension are common causes of accidents. Wheels are manufactured from cast steel and machined to provide the tread and flange on the wheel profile. Wheels can crack or overheat and fail catastrophically. Wheel profiles can be worn to the point where they cause the train to derail. Worn or defective wheel treads can also allow a wheel to derail

Vehicle bogies can develop mechanical problems that make it difficult for the bogie to rotate in curves. Excessive forces build up at the wheel flange forcing the flange to climb over the rail and derail.

D5. Operational Issues

Derailments may also be associated with operational issues such as collisions, excessive speed, train handling, or failure to adhere to operating rules. Train handling derailments are sometimes caused by the application of emergency brakes on curving or undulating track. The forces that build up between carriages can become excessive during a brake application and can actually push a carriage sideways out of the train.

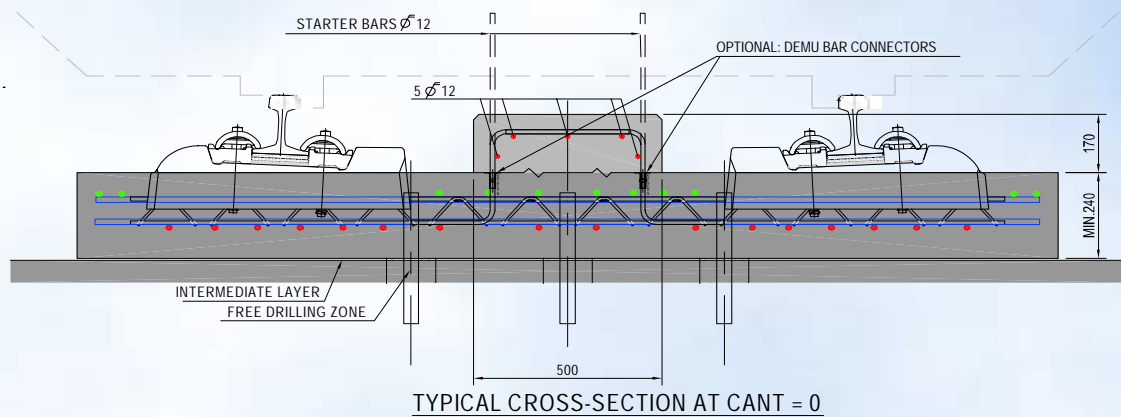
Excessive speed is another common reason for a derailment. Failure to comply with speed restrictions - especially on curves - is a significant cause of accidents.

D6. Collisions

Other derailments can be caused by collisions. Collisions can occur train-to-train, train to highway vehicle, or train to obstruction. Although train-to-train collisions often result in a derailment, the more important issue in that type of accident is the cause of the initial train-to-train collision. Train to highway vehicle collisions are common in areas where grade crossings are used to allow highway vehicles to cross the railway tracks. Collisions with obstructions on the track are also common. The obstruction may be natural (rock slides, mud slides) manmade debris from passing trains, or debris that has been intentionally placed on the track by vandals. In any case, hitting another train, a highway vehicle, or an obstruction can cause serious derailments.

Appendix
E **Infraspeed Concrete Plinth Illustrations**

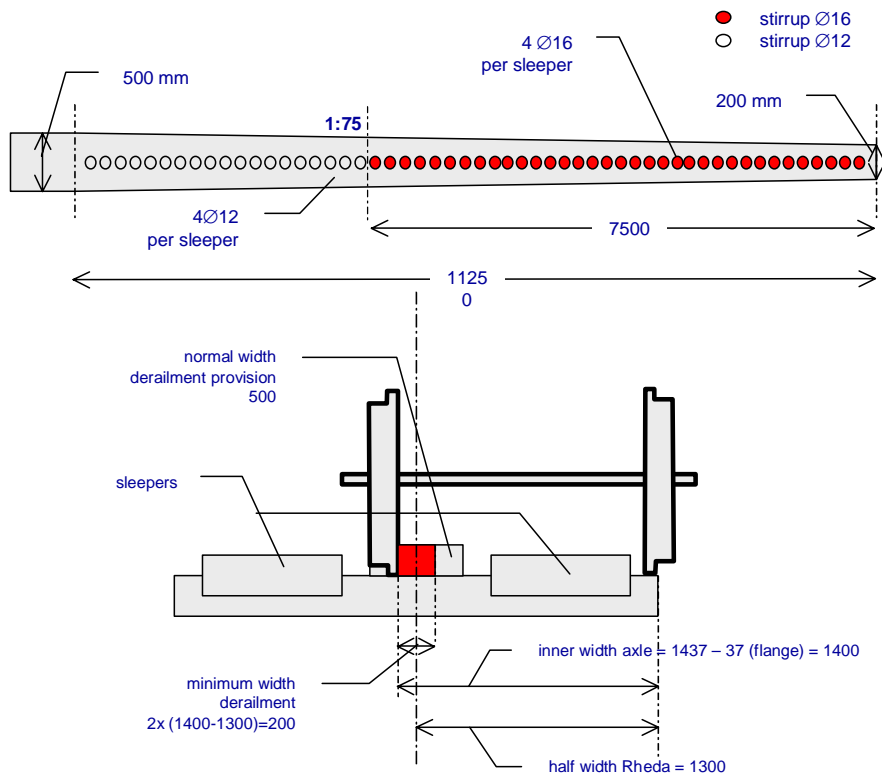
Concrete plinth for Rheda track



Slide 1

July 2004

Derailment Provision Concrete plinth – end sections



Slide 2

July 2004

Appendix **F** Accidents For Expert Panel Assessment

Introduction

This appendix contains accidents initiated by train, operations, infrastructure and human factors causal events. The accidents will be reviewed by the expert panel in accordance with the methodology described in section 1.3 of the main report.

F1. Accident 1 - Eschede, Germany

On Wednesday 3 June 1998, at about 10:59 am local time, northbound ICE (Inter City Express) Train 884 en route from Munich to Hamburg derailed near Eschede, Germany. The ICE Train consisted of two power units (one on each end of the train) and 12 passenger cars. The accident occurred on the Hanover to Hamburg line that was part of the original ICE system. The Hanover to Hamburg section of the ICE system was not newly built but was a renovated line that was upgraded in 1991 from an existing rail line; consequently the line does not meet all Deutsche Bahn (DB) engineering standards for a new high-speed rail line. Mixed traffic, freight and passenger operates on this line. On this section of the rail line, the maximum allowable speed is 200 km/h.



The area of the accident is fully equipped with an LZB signal system. The LZB on this section of rail line was installed in 1965 and upgraded in 1990. LZB is an Automatic Train Control (ATC) system overlaid on the current signal system. It is a moving block system that continuously calculates the safe stopping distance for the train and monitors the traffic ahead. The LZB continuously transmits and receives train and signal information through an induction cable that runs down the middle of the track structure. This induction cable is configured into circuit loops that span the wayside signal blocks. When a train enters a loop, the wayside system takes and records data from the train and time stamps it. The time stamp is only accurate to ± 1 minute. This data is also available to the train dispatcher. In the event that communication between the induction cable and the lead power unit is lost due to malfunction or damage, the system reverts to the wayside signal system. Train speed is also automatically governed to provide adequate braking distance between the wayside signals. The LZB system is required on lines where the train speed is greater than 160 km/h.

The accident sequence began about 5.6 km before the scene of the general derailment. In this area, the track is tangent and there are no tight curves. The train was operating at 180 km/h, 20 km/h below the authorized speed of 200 km/h for this section of track. At this time, a wheel rim on a two-piece resilient wheel broke on the 3rd axle of the first car behind the lead locomotive. The tread of the wheel separated

from the resilient core and wrapped itself around the track brake on the trailing truck. Debris including broken bolts, pieces of under car bulkheads, and under car baffles was found within a 100 m section of track. There was also evidence of physical damage to concrete ties in this same area. Passengers from the first car interviewed after the accident reported noise and vibration about 2 minutes before the general derailment.

The damaged wheel cut the LZB inductive cable loop approximately 5.5 km south of the bridge (loop 9). The wayside system recorded this event. The lead power unit equipped with the receiving antennae, was past loop 9 and had entered loop 10 at the time loop 9 was cut; thus the engineer received no indication of a problem with the LZB system. The inductive cable loop varies in length but typically is 2 km long. When the train entered loop 11, the induction cable was damaged again. The lead power unit was still in loop 11 when communication between the train and the LZB was lost. There was a delay in time in the recording of this event due to the computer receiving an overload of information from a variety of sensors detecting malfunctions in the train's systems as a result of the derailment. Although there was a delay in recording the data, the brakes were automatically applied when the damage was detected. At the time of the general derailment, the train was still operating at a speed of 180 km/h.

There are four tracks in the area of the accident, two main tracks and two siding tracks. The main tracks were located between the two sidetracks and were numbered track 1 and 2 from west to east. The accident train was travelling North on track 2 at the time of the general derailment.

There were two turnouts in the area of the general derailment. The first turnout the accident train encountered was a trailing point turnout that went from track 1 to track 2. The second turnout was a facing point turnout from track 2 to the east siding track. When the accident train approached the first turnout, the broken wheel tread, still hung up on the track brake, fouled the guide rail of the first turnout. The force of this collision caused the entire length of the 9-metre guide rail to be torn from the roadbed and penetrate the floor of car 1. The guide rail then broke in two pieces. The first piece of guide rail pierced the ceiling and water tank in the roof of car number 1. The second piece of the guide rail went up through the floor of car 1 and passed through the diaphragm of cars 1 and 2. The guide rail wedged itself against car 2 causing the car to lean sideways. The driver of the train received a track brake applied light when this occurred but did not experience any other sensation and did not realise anything was wrong with the train.

After striking the guide rail, the train continued towards the second switch. At this point the lead power unit and the lead bogie of car 1 traversed the switch still on the rail. The trailing bogie of car 1, as a result of impacting the guide rail, veered sideways causing the left wheel to impact and break the open switch point. The switch point was damaged and the switch locks were broken. The trailing bogie of car 1 continued past the switch on the wrong side causing the switch to be pushed over, lining the tracks for the siding. Car 1 struck the wayside signal located just prior to the bridge. Car 2 followed car 1 and proceeded straight through the switch. The front truck of car 3 followed car 2 but the rear truck of car 3 was diverted to the

siding track and derailed, this caused car 3 to be forced out towards the bridge supports. The trailing end of car 3 knocked out the bridge supports. One of the supports was found several hundred meters from the bridge and driven directly into the ground.

Striking the bridge support caused the bridge to collapse. Each car is 23 m in length and the train was travelling about 50 meters per second. One and a half additional cars passed under the bridge before the bridge collapsed. The fourth car veered off into the woods and the fifth car was partially crushed by the falling bridge. The following seven passenger cars and the trailing power unit piled up on the south side of the bridge.

Cars six and seven were directly under the concrete bridge and were crushed by the falling bridge.

Some time during the accident sequence, the head power unit separated from the rest of the train and the locomotive coasted to a stop at the Eschede station. Only then did the engineer realise he had lost his train.

Ninety individuals died at the scene of this accident. Eleven more died of their injuries in the weeks after the accident. It was estimated that 200 to 250 passengers were injured in the accident. Neither the DB nor the local authorities were able to provide a number of total passengers on board the train.

The Eschede accident was initiated when a resilient wheel mounted on the trailing truck of the first passenger car broke. The wheel had succumbed to a fatigue crack. The thickness of the broken wheel that initiated the derailment was found to be under the condemning limit. There were no signs of impurities or inclusions at the point where the crack initiated. The resilient wheel was specially designed and tested for high-speed service on the ICE. Resilient wheels, however, are not normally used in high-speed applications. Their use is normally confined to trams and light rail vehicles where the consequences of wheel problems are tempered by the lower speeds.

The original design of the ICE-1 series trains used a solid wheel. Resilient wheels were applied after problems with the solid wheels developed. The solid wheels were wearing eccentrically and developing an oval shape. The cause of the unusual wear pattern was never determined. The resulting noise and vibration was very apparent to the passengers. Although the resilient wheels also wear in an oval pattern, the noise and vibrations were no longer transmitted into the car body. Later versions of the ICE train-sets returned to solid wheels but used an air spring suspension to isolate the car body from the noise and vibration.

Cracks in wheels can propagate very fast. To reduce the chance of a broken wheel, ICE train-sets are fully inspected at the end of each run using ultrasonic testing equipment. Resilient wheels are very effective at damping out vibration. Unfortunately, the same qualities of resilient wheels that damp out vibrations also impair the ability of ultrasonic wheel testing equipment to find internal defects.

Wheel tread condition can also invalidate ultrasonic wheel tests. Flat spots, surface cracking, marring and other common conditions found in a worn wheel mask the defects in the same way that surface conditions on rail can mask internal track defects. Ultrasonic testing - although somewhat effective on solid wheels - is not adequate for detecting internal flaws on resilient wheels.

F2. Accident 2 – Waterfall, Australia

At about 7:15 am on Friday 31 January 2003, State Rail Train C311 derailed and overturned on a curve about 2 kilometres south of the Waterfall Station. The train was carrying 47 passengers and 2 crewmembers. Six passengers and the train driver were fatally injured in the accident. Nineteen others were seriously injured and required hospitalisation.



On the day of the accident, the 6:24 am passenger service on the Illawarra Line from Sydney Central Station to Wollongong was provided by a four car Tangara train set designated G7. The train proceeded normally from Sydney to Waterfall, arriving at the Waterfall Station about 2 minutes late. At 7.13 am, the train left Waterfall Station travelling towards Helensburgh station. The Illawarra line between Waterfall and Helensburgh is a two track main containing areas of twisting curves. The train was travelling south on the “down” or easternmost track. At about 7.15 am, the train entered a 240 metre radius left hand curve restricted to 60 km/h when the derailment took place.

All cars in the train rolled onto their right side and landed on the “up” or westernmost track. As the train slid down the adjacent track, it struck two overhead catenary stanchions and then collided with the rock face of a cutting. The collision with the rock face righted the first two cars. The train came to rest with the front two cars in the upright position and the two rear cars on their right side.

The Special Commission of Inquiry who investigated the accident found that the driver had been incapacitated by a heart attack shortly after leaving the Waterfall Station. The train continued to accelerate and reached a speed in excess of 117 km/h before overturning on the 60-km/h curve.

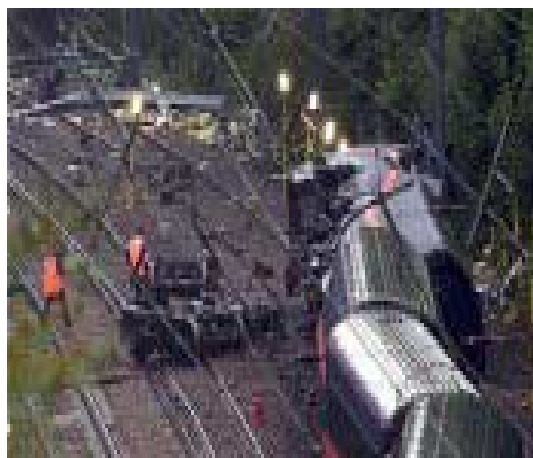
F3. Accident 3 - Hatfield, United Kingdom

Details of the Incident

On 17 October 2000 four people were killed and 70 injured as a result of a derailment of an Intercity 225 near Hatfield. The Great North Eastern Railways Intercity 225 trainset was travelling at or close to the line speed of 185 km/h.

The following hyperlink provides an animation of the crash

<http://www.guardian.co.uk/hatfieldtraincrash/flash/0,7365,383951,00.html>



Causes of the derailment

The Hatfield derailment happened because a rail, in which there were multiple cracks and fractures due to rolling contact fatigue (RCF), fragmented when a high-speed train passed over it. The Investigation Board identified, under the heading 'direct causes', a number of interim recommendations intended to prevent this type of catastrophic rail fracture occurring again.

In addition, there were a number of contributory factors which made it more likely that this derailment would occur, and a range of aggravating factors may have made the consequences of the derailment worse than they might otherwise have been.

The incident happened because a train travelled at the permitted speed over a rail that had been identified as in poor condition, and which should have either been replaced or a temporary speed restriction applied.

The following recommendations relate to the management systems which could have prevented these circumstances.

- Health and safety management-
 - Increased training and competence.
 - Quicker and more responsive mechanisms established by which employees can bring safety critical matters to the attention of managers.
 - Performance of infrastructure maintenance contractors and other track-related contractors.
- Management of maintenance
 - Implement an effective maintenance programme to ensure that the probability of a safety critical rail fracture is as low as is reasonably practicable.
- Inspection of track
 - Current best practice in detecting RCF should be implemented i.e. automated.
 - Procedures for rail inspection, both visual and using NDT techniques.

Aggravating factors

These interim recommendations address matters which, in the opinion of the investigation board, may have made the outcome of the derailment worse than it might have been.

- Train sets should be designed, built and maintained to maximise the chance of their remaining upright and intact during high-speed derailment. Particular aspects of rolling stock design which should be reviewed are:
 - bogie and suspension component retention.
 - Strengthening of the attachment systems should be considered;
 - 'Tightlock' couplers; their propensity to open when rotated should be assessed and the design loads reviewed.
 - strength of vehicle roofs and walls;
 - passengers seats; the risks to passengers as a consequence of seat damage or failure should be reassessed
 - design of catering facilities should be reviewed to minimise the risk to staff in the event of an accident
- The design of overhead line equipment stanchions should be reviewed with a view to making them less likely to penetrate passenger space in the event of a collision. In addition, the risks associated with trains striking any trackside equipment in a derailment should be assessed.

Key Findings

Key findings included:

- obvious and significant evidence of a rail failure.
- evidence of significant metal fatigue damage to the rails in the vicinity of the derailment.
- the only evidence to date of wheel damage is consistent with the wheels hitting defective track.
- there is no evidence, so far, of a prior failure of rolling stock.
- The most extensive damage appears to have been caused by derailed carriages impacting line side structures.

F4. Accident 4 - Mobile, Alabama, United States America

In the early morning hours of 22 September 22 1993, Amtrak's "Sunset Limited" plunged into Big Bayou Canot near Mobile, Alabama. Forty-seven people were killed. It is the worst U.S. railroad accident in over 46 years.

At 2:53 am, Amtrak's "Sunset Limited" struck the girder on a displaced span of the CSXT railroad bridge and derailed into Big Bayou Canot. Access to the accident site was difficult. The accident site could only be reached by rail or by boat.

The first locomotive was buried 50 feet in the mud on the upstream side of the bridge. The 3-man crew was killed instantly and were trapped in the locomotive. The second locomotive unit came to rest on the upstream side of the bridge in about 15 feet of water.

The third locomotive and a baggage car landed on the downstream side of the bridge.

The next car in the train was an On Board Service Crew car. On Board Service Crew cars are included to provide a place for the OBS crew to rest. Two OBS crewmen were killed in the fire that resulted from diesel fuel spilled from the locomotives.

The first passenger coach was partially submerged but one end was supported by the bridge structure. There were many fatalities in the first car, especially on the lower level. The second passenger coach was completely submerged in the bayou. Most of the 42 passenger fatalities occurred in this car.

The third coach was left dangling off of the end of the bridge. The rest of the train consisted of a lounge car, diner, and sleeper. These cars all derailed but remained on the bridge or the right of way.

The steel girder span across the bayou was destroyed in the accident. A towboat had struck the bridge and knocked it out of alignment.

The pilot took a wrong turn in the fog and struck the fixed bridge at Big Bayou Canot displacing the bridge by 38 inches. The lead locomotive of the Sunset Limited struck the displaced bridge at about 116 km/h - flew through the air - and embedded itself 50 feet into the mud.

The National Transportation Safety Board conducted an accident investigation and addressed several safety issues including towboat operator training and evaluation, bridge risk assessment, bridge identification, emergency response and evacuation procedures, and event recorder crashworthiness.



Appendix
G

Derailment Accidents - Further Reading

G1. Accident 5 - Potters Bar, United Kingdom

Details of the Incident

On Friday 10 May 2002, a train from London Kings Cross to Kings Lynn derailed at high speed on the points south of Potters Bar station. Seven people lost their lives; over 70 people were injured, some seriously.

The train was a four-coach electric multiple unit, powered through the first and last coaches. At the time of the incident it was travelling at about 156 km/h.

The rear part of the train derailed at points numbered 2182A located about 160 metres south of Potters Bar. The rear bogie of the third coach and both bogies of the fourth coach derailed. The fourth coach slewed sideways so that it was moving broadside to the direction of travel, skidded along the track and detached from the rest of the train. As the fourth coach struck Darkes Lane bridge, the rear bogie was torn off and the coach became airborne. The coach came to rest on its side almost perpendicular to the running lines, straddled across both island platforms and wedged under the station canopy. The coach rolled nearly 360 degrees at least once before coming to a stop. A small waiting shelter on the up platform was partially demolished as the coach skidded towards the canopies. Six passengers travelling in the derailed coach were killed. A number of passengers sustained varying degrees of injuries.

The leading three coaches, with the trailing bogie of the third coach derailed, continued travelling along the Down Fast line passing between the platforms at Potters Bar station. The emergency braking system had been initiated and the coaches came to a halt with the front coach about 400 metres from the northern end of the station platform.



The rear bogie of the fourth coach caused considerable damage to the bridge that passes over the main street (Darkes Lane) of Potters Bar. Debris from the bridge structure and the underside of the rear coach fell on pedestrians and cars below, killing one person.

The following hyperlink provides an animation of the crash
<http://www.guardian.co.uk/flash/0,5860,713560,00.html>

Derailment mechanism

The lock stretcher bar of the points was subject to fatigue stresses and eventually failed at one of its right-hand bolt holes, causing it to withdraw from its insulating jacket as the train passed over the points, and allowing the switch rail to which it was attached at this side to spring out against the right-hand stock rail. This resulted in the right-hand switch rail being set for the turnout route, with the left-hand switch rail already set for forward running.

This happened when the rear wheels of the third coach were travelling over the points. The wheels on each axle were then forced in two opposing directions, derailing the rear of the third coach and the fourth coach entirely. The rear of the fourth coach re-railed and took the turnout route towards the Down Slow line.

The fourth coach hit the Darkes Lane bridge parapets, detached from the rest of the train and became airborne. The rear bogie of this coach was ripped off along with underbody equipment, causing damage to the bridge and causing debris to fall through the gap between the bridge parapets onto pedestrians and vehicles below. The fourth coach then slid across the station platforms, struck a waiting room and rolled through 360 degrees, eventually coming to rest wedged under the station canopy roofs.

The incident took place over 5 to 6 seconds.

G2. Non-High Speed Derailment 1 (track related) Southall East, United Kingdom

On Sunday 24 November 2002, a high speed train (HST) made up of eight coaches and two power cars, was passing over a set of points east of Southall Station at approximately 193 km/h, the leading bogie of coach D (the fifth coach) derailed towards the down main line. The train remained upright and in line, and finally came to a halt just before West Ealing station, some 3 km further on. There were no serious injuries.

The bogie was derailed when the flange of a wheel struck one half of a broken fishplate which had lodged in the nose of a cast manganese steel crossover forming part of the points.

There is some evidence that the derailed bogie was constrained by a length of rail in the six foot between the up and the down lines. Had the coach been able to move further across towards the down fast line, or had more vehicles derailed, then the consequences of a collision with a train on the adjacent line could have been catastrophic.

G3. Non-High Speed Derailment 1 (track related)

A track related derailment occurred in New York State in 1994. Amtrak Train No. 49, derailed on 3 August 1994, near Batavia, New York. A total of 14 cars including all of the passenger occupied cars were derailed in the accident.

The accident sequence began about 5km before the general derailment. The train was operating at about 127 km/h when one car in the train derailed one axle. The derailed car was dragged the 5km to the site of the general derailment. The general derailment occurred in the vicinity of a crossover where 13 additional cars in the train derailed. The 9 rear cars of the train separated from the front of the train, struck a signal bridge, and went down an embankment on the south side of the track. Five of the nine cars turned on their sides.

There were no fatalities in the accident but 45 passengers and crew were injured. The cause of the initial derailment was a condition on the track known as a crushed head. The material handling car derailed one axle at this point and bounced along the ties for over 5 km before encountering the turnout that caused the general derailment.

The general derailment took place within sight of a dragging equipment detector that would have detected the derailed axle and require the locomotive engineer to stop the train.

G4. Non High Speed Derailment 2 (Special Trackwork)

An accident that took place in 1992 in Lugoff, South Carolina illustrates how important maintenance of special track work can be. On 31 July 1991, Amtrak train 82, the Silver Star, was en route from Tampa, Florida to New York City. The train consisted of two diesel electric locomotives, 3 baggage cars, and 15 passenger cars. At 5:01 a.m., the last six passenger cars derailed on the CSX Transportation main track at the Orlon crossover in Lugoff, South Carolina. The train was travelling north on a straight track with a clear signal at an authorized speed of 129km/h.

The accident occurred on a single main track parallel to an auxiliary track. The derailment occurred at the crossover switch that connects the main track and the auxiliary track, also known as the Dupont Siding. The last six passenger cars (13 to 18) derailed moving left (westward) towards the siding. The cars collided with the first of nine freight cars parked in the siding. The collision caused a hopper car to turn over and a wheel set (an axle and a pair of wheels) to penetrate the west side of the last passenger car. The derailed passenger cars came to rest 0.5 km north of crossover. They remained upright and parallel to the track.

After the accident, the main track crossover was found to have the connecting rod disconnected from the switch stand crank. The switch point was not secured to the stock rail, the cross pin that attached the switch stand crank to its spindle was not in

place, and the crank had dropped into the safety plate. The cross pin was found near the switch stand.

A total of 22 crew and 407 passengers were on board the train at the time of the derailment. There were 8 fatalities and 77 injuries resulting from the accident.

The cause of the derailment was that the poorly maintained switch opened underneath the passing train because of inadequate track inspections and switch maintenance.

G5. Non-High Speed Derailment 3 (Vehicle defect)

A defective wheel was responsible for a derailment that occurred on a train near Lakeland, Florida. On 13 January 1994, a witness observed the train go by and saw two pieces of a wheel fly off a passenger car and land in nearby woods. A company employee onboard the derailed car knew there was a problem and headed back through the train to the trainmaster's car to have him stop the train. The train continued 4.3 km, across five grade crossings, with the broken wheel. When the train reached the Park Spur turnout, 15 additional passenger cars and three freight cars derailed. Of the 16 derailed passenger cars, five turned on their sides; the rest remained upright. There were two fatalities and five injuries.

The Lakeland, Florida accident train was remarkable in that it travelled for over 4.3 km with a derailed wheel. The wheel bumped along the track and left marks on the sleepers and on the grade crossings. The general derailment only occurred when the derailed wheel encountered the turnout.

G6. Non-High Speed Derailment 4 (Operational)

On 17 December 1991, Amtrak Train 87, operating south on CSX Transportation Inc. track, derailed on a curve in Palatka, Florida. Train 87 consisted of a locomotive and eight passenger cars. The locomotive and first six cars derailed. The derailment occurred while train 87 was negotiating a 6 degree 6 minute curve to the right (west). The derailed equipment struck two homes and blocked the street north of the Palatka station. Eleven passengers sustained serious injuries and 41 received minor injuries. Five operating crewmembers and four on-board service personnel had minor injuries.

The cause of the accident was the failure of the operating crew to slow the train to negotiate the 48 km/h curve. At the time of derailment in the curve, the train was travelling at approximately 113 km/h.

G7. Non-High Speed Derailment 6 (Collisions)

One such serious derailment occurred at a grade crossing in Bourbonais, Illinois. On 15 March 1999, Amtrak Train 59, with 207 passengers and 21 employees on board and operating on Illinois Central Railroad (IC) main line tracks, struck and destroyed the loaded trailer of a tractor-semi trailer combination that was traversing the McKnight

Road grade crossing in Bourbonnais, Illinois. Both locomotives and 11 of the 14 cars in the Amtrak consist derailed. The derailed Amtrak cars struck two of ten freight cars standing on an adjacent siding. The accident resulted in 11 deaths and 122 people being transported to local hospitals.

The cause of the accident was the failure of the truck driver to yield the right of way to the train at the grade crossing.

G8. Non-High Speed Derailment 6 (Environment)

A train carrying 105 passengers derailed when it ploughed into a landslide caused by torrential rain. The locomotive was travelling at 8 km/h due to the danger of landslides in the area, and the first carriage slewed off the track but stayed upright. Most of the passengers managed to get off the train themselves. The driver saw the mound of mud and chalk as the train emerged from a tunnel near Redhill, Surrey, England, but could not prevent the locomotive hitting it. Nobody was seriously hurt.

The landslide was in a stretch of track, which engineers for the infrastructure operator, Network Rail, had omitted from recent reinforcement work. A kilometre north of the Merstham tunnel, the engineers had recently built a retaining wall alongside the track after deeming the area to be a "weak point" vulnerable to possible landslides.