TRAINSAFE

New Member States

Workshop
1 - 2 June 2004
Prague Czech Republic

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European Rail Safety Technology Accession States Workshop

1 and 2 June - Prague

Workshop Objectives

- To raise the awareness of the Accession States in European Rail Safety State of the Art and current practices.
- Provide interpretation on existing Legislation
- Provide a foundation on current developments in Rail Technology to meet those requirements.
- Provide a forum for the Accession States Rail Industry experts to meet and join the European expert network.

Workshop Programme - Day 1

- 09:00 Registration
- 09:30 Welcome - Miloslav Kepka
  - Vojtech Kocourek – Deputy Minister
  - Zdenek Zak – General Supervisor Railway Inspection Czech Republic
  - Pavel Kodym – Director of the Railway Office
- 09:45 Introduction to Trainsafe – John Roberts
- 10:00 Coffee break
- 10:30 European State of the Art and Current Practices
  - Infrastructure – Alex McCann
  - Fire Safety – Bruno Schrieber
  - Rail Inspection – John Davenport
- 12:30 Lunch
- 13:30 European State of the Art and Current Practices
  - Vehicle Structures Safety – Andrew Bright
  - Vehicle Interiors Safety – Paul Murrell
- 15:00 Coffee break
- 15:30 European State of the Art and Current Practices
  - Safetrain and Safetram project – Dr Wilfred Wolter
  - Economically sound systems – Dr Markus Hecht
- 17:00 Summary session and overview of Day 2 – Andy Wild
- 17:30 End
- 19:30 Optional walking tour of historic Prague
- 20:00 Evening event

Workshop Programme - Day 2

- 09:00 Overview of day 2
- 09:15 European Approval Process – Allan Sutton
- 10:00 Coffee break
- 10:15 Research Strategy – John Roberts
- 10:30 Question and Answer Session
    - Infrastructure
    - Fire Safety
    - Vehicle Structural Safety
    - Vehicle Interiors Safety
    - European Approval Process
- 11:45 Database of Competences and Network of Excellence – Richard Gardiner
- 12:00 Lunch
- 13:00 Focus Group Session
- 15:30 Feedback
- 15:45 Next Steps – John Roberts
- 15:30 Closing remarks – Miloslav Kepka
- 16:00 Close
- 16:45 Optional visit to the Prague Metro Control Centre

Presenter Profiles

Name: Andrew Bright

Qualifications: Maters in Engineering Science from Oxford University. I am a Chartered Engineer and Member of the Institute of Mechanical Engineers.

Relevant Experience: I am a Principal Consultant and Team Leader for twenty engineers who specialise is structural dynamic issues. I work for Atkins Consultants and have done so for seven years, throughout that time I have contributed to crash, impact & structural integrity projects on behalf of clients in the aerospace, nuclear, marine & rail industries. My key specialism is rail vehicle crashworthiness. I led teams responsible for investigating the rail vehicle aspects of the Ladbroke Grove, Great Heck, Potters Bar & Chancery Lane rail incidents. I was a member of the Cullen Inquiry panel of rail crashworthiness experts and gave expert evidence at the Great Heck Formal Inquiry, the Great Heck Coroner's Inquiry and at the Chancery Lane Formal Inquiry. I have assisted rail vehicle leasing companies improve the safety of older existing rolling stock and have assisted rail manufacturers with the development of passive safety systems for new trains. I have conducted this type of work in the UK, France, Belgium and Japan.

Name: Paul Murrell

Qualifications: MEng (Hons) CEng MIMechE

Relevant Experience: Business Manager with over 7 years experience in rail vehicle passive safety. Project Director for the rail vehicle crashworthiness programmes undertaken by Atkins Consultants Ltd, covering structural/interior analysis and design, impact dynamics, R&D and accident investigations. Paul has worked on the majority of crashworthy rolling stock being introduced into the UK and has acted as independent observers and panel members on the major public national railway and underground accident Inquiries.

Alex McCann. Proposals Manager, Corus Rail Technologies.

Alex started his working life in the railway industry as a Production Management / Process Development Engineer at the rail rolling mill at Workington. A change of direction then saw Alex become the Sector Sales Manager for Central & Eastern Europe, with responsibility for the generation of new business and maintenance of existing business relating to the supply of rail, sleepers and accessories. An expansion of this role then saw Alex become the Railway Project Manager for Corus Rail, responsible for the identification, progression and Project Management of railway projects which included design, build and maintenance requirements. After a brief excursion from Corus, as Product / Marketing Manager for UCB Films plc, responsible for new business development of polypropylene and cellophane films, Alex then returned to the rail industry as a consultant with Corus Rail Technologies responsible for progression of technical solutions relating to the 'in service performance' of railway components and the behaviour of the complete track and railway system.

John Roberts Associate Institute of Physics (AInstP), Diploma Management Studies (DMS), Diploma in International Marketing (DipM), Member Chartered Institute of Marketing (MCIM)
Bombardier Transportation for seven years
Present position – Group Engineering Centre of Competence for Crash Safety
Speaker for the Economic Evaluation Group for Conventional Interoperability
Member of the Revision Group for High Speed TSI
Member of T256 CEN WG2
Coordinator of Trainsafe Thematic Network
Manager Crash Test Laboratory at MIRA for six years
Manager Certification for Rolls-Royce and Bentley Motor Cars for 15 years
Crash tested 14 Rolls-Royce cars during that period. Two of which were accidental.

Richard Gardiner, Research Assistant, ARRC

Richard Gardiner graduated in Mechanical Engineering at the University of Sheffield, before continuing his study by completing a Master of Science in Rail System Engineering, also at the University of Sheffield. He was sponsored though his studies by Freightliner Ltd. A UK rail freight operator, for whom he analysed the systems impacts of new freight operations. Upon graduating he worked as ski technician in Val d'Isere for a winter, before returning to real life and taking up a research assistant post at the Advanced Railway Research (ARRC). At this post he has developed and participated in a variety of projects ranging from intermodal freight operations, Intelligent Transport Systems, black box recorder casing design, light rail articulation, safety statistical analysis and rail vehicle passive safety.

Andy Wild , Principal Consultant,
Process & Business Consultancy, ABB Ltd

Professional Associations : Member of the Institute of Management Consultants

Career Summary: Andy has been supporting change projects as a consultant for the last 10 years in a wide range of industries. As a Principal Consultant with ABB Process & Business Consultancy, Andy specialises in the equipping of, and practical support to management teams and project teams on the issues of planning and managing change. Andy has strong facilitation skills and has particular skills in working with large scale change processes.

Andy’s practical experience in project management and operational improvement was in the rail industry and it has taught him the importance of establishing the necessary climate to enable change to be successful and for management and operational teams to flourish.

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Andy has significant international experience including facilitating international change teams from the US, Australia, Switzerland, Sweden Germany, Portugal, Italy and France.

He has worked extensively on the issues of co-operation across organizational boundaries which has led to work with companies as diverse as Bombardier, BMW, Daimler-Chrysler, Easyjet, Bovis, Nortel Networks, Pfizer Inc, Canary Wharf Management and Swiss Railways.

**Mrs Gabrielle Cross – Project Manager, MIRA Ltd**

Gabrielle has worked at MIRA for 10 years in a variety of roles, initially within the Photographic Department through to the Automotive Information Centre as a researcher. Keen to learn more about "real" research and development she became a technician within MIRA's Safety Test Group where she calibrated, installed and instrumented the entire fleet of crash dummies. She studied part-time for her Higher National Certificate and Diploma in Business Management and is also a member of the Chartered Management Institute.

Currently Gabrielle's main role at MIRA is to manage an EC funded airbag safety project, (PRISM) which is researching how to reduce injuries caused by restraints. She also sits on the Steering Group Committee for the Trainsafe project as well as looking after the dissemination of information for this project. Within her group at MIRA, Advanced Engineering she is locally known for being the resident "problem solver".

**Nigel Skellern – Senior Engineer MIRA Ltd**

Qualifications B Eng (hons) in Mechanical Engineering, MiMechE
Company MIRA Ltd for the last seven years and prior to this Lecturing in Mechanical Engineering for eight years.
Relevant Experience
Worked as an industry consultant in the field of vehicle structural design for crashworthiness and also vehicle interior design for occupant protection over the last four years. Experience mainly in the UK automotive testing sector.

Trainsafe

An Introduction to the Thematic Network

New Member States Workshop
1 and 2 June 2004
Prague

The Fundamentals

- The **TRAINSAFE** network considers all forms of rail transport: passenger, regional, high speed, metro and light rail (trams) systems. It will identify new priorities for safety in the rail industry.
- The **TRAINSAFE** thematic network improves the exchange of information and experience between Partners and Members and transfers knowledge and best practice within the various sectors.
- The project identifies gaps in European research infrastructure compared with actual and future requirements and with other geographical regions.
- The aim is to achieve the development of the partnership for future research, industrial and infrastructure cooperation.

1. Trainsafe aims

- Enhance safety standards within the rail industry.
- Improve global system safety through vehicle research, procedural systems analysis and training.
- Integrate the land transport industries by cross-fertilisation and full co-operation between researchers, systems integrators and suppliers.
- Recommend innovative research (leading to individual proposals), priorities for future research actions
- Identify and sustain (virtual) centres of excellence.

Questions to answer

1. What are the critical passive safety issues relating to the topic?
2. What are the issues relating to standards?
3. What are the overall recommendations for addressing the critical passive safety issues identified in question 1?
4. What are the business benefits in addressing the critical passive safety issues identified in question 1?
5. What are the priorities for future research activity?

Importantly

1. Network
2. Exchange information
3. Build up contacts
4. Extend the Network of Excellence
5. Enjoy the workshop

Integration of New Member States
-
Safe Infrastructure Workshop
Presentation of Topic and Results

June 1st & 2nd 2004 - Prague

Mr Alex McCann
Corus Rail Technologies
alex.mccann@corusgroup.com

Trainsafe – Safe Infrastructure

- Safe Infrastructure – presentation overview
  - Why Safe Infrastructure?
  - What were the main topics of the event?
  - Conclusions & Recommendations
  - Future Business

Safe Infrastructure

- Railways are unlike every other transport system.
- The **infrastructure** guides the vehicles, **not the driver**.

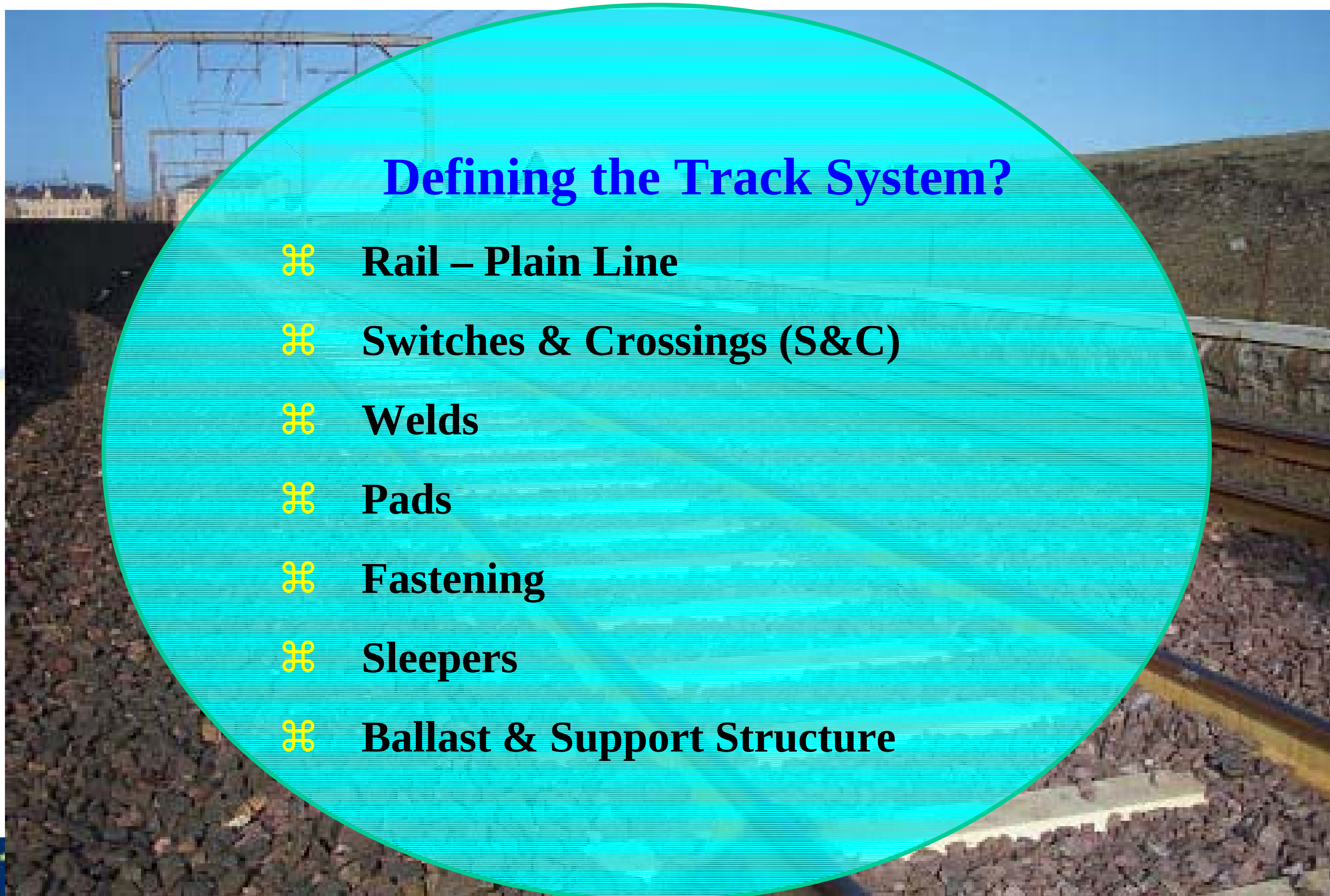
200 years of the railway: 1804 - 2004

The Importance of Safe Infrastructure

- Infrastructure is defined as being everything below the vehicle wheels
- The Safe Infrastructure Workshop examined possible failure modes and safety improvement factors for 5 main themes

Safe Infrastructure Workshop
5 Main Themes

- Track degradation & Sub-structure integrity
- Track welding
- Inspection technologies
- Condition monitoring
- Adhesion management



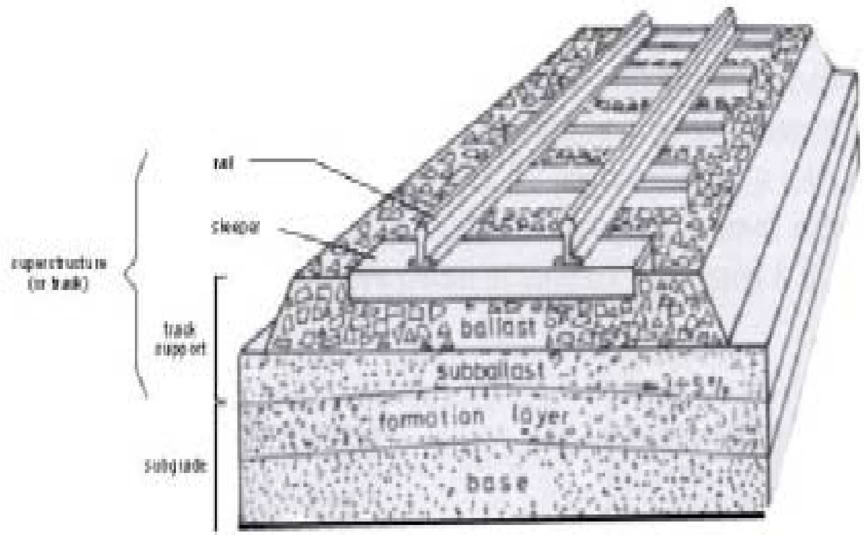
Defining the Track System?

- **Rail – Plain Line**
- **Switches & Crossings (S&C)**
- **Welds**
- **Pads**
- **Fastening**
- **Sleepers**
- **Ballast & Support Structure**

Safe Infrastructure - Theme 1
Sub-structure Integrity

- The layers of the sub-structure are:
  - Ballast
  - Sub-ballast
  - Foundation layer/base

- How do we assess the contribution of each of these structural layers?



The traditional construction of a railway track sub-structure .

Track Degradation and Sub-structure Integrity
Conclusions & Recommendations

- Understand the forces
- Understand the metallurgy
- Understand the interaction with other systems
- Define new standards recognising degradation issues of both track and sub-structure

Safe Infrastructure – Theme 2
Track Welding

- Geometric differences in railway joints can occur when the rail parent material wears at a different rate to the welded joint.
- Dynamic forces and stress-states also contribute to rail breaks

Safe Infrastructure – Theme 2
Track Welding
Conclusions & Recommendations

- Continuously Welded Rail has lower maintenance costs and is considered an essential technology for high-speed lines
- Imperfections generate additional dynamic forces in the track when impacted by a wheelset
- Recommend development of welding & inspection technologies

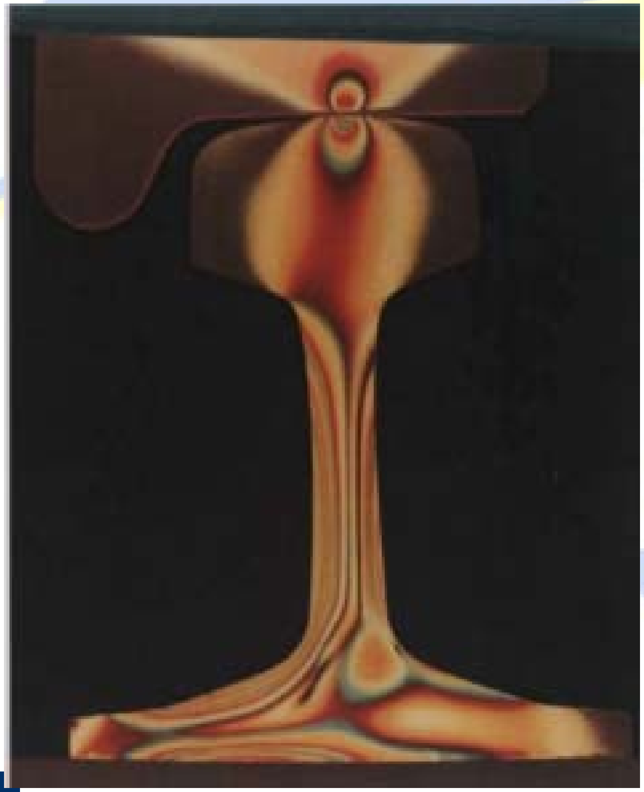
Safe Infrastructure – Theme 3
Track Inspection Technologies

- Surface visual inspection at speeds up to 200kph (~270kph in Japan– 'Yellow Doctor')
- Ultrasonic inspection only possible at ~70kph
- Eddy current (surface) v Ultrasonic (sub-surface) inspection

Safe Infrastructure – Theme 3
Track Inspection Technologies
Conclusions & Recommendations

- Measurements of residual stress are generally destructive
- Current **ultrasonic** technology only suitable for relatively low-speed use
- Need high-speed ultrasonic technology which immediately gives the ability to decide whether to replace rails
- On-line image analysis?

Safe Infrastructure – Theme 4
Condition Monitoring

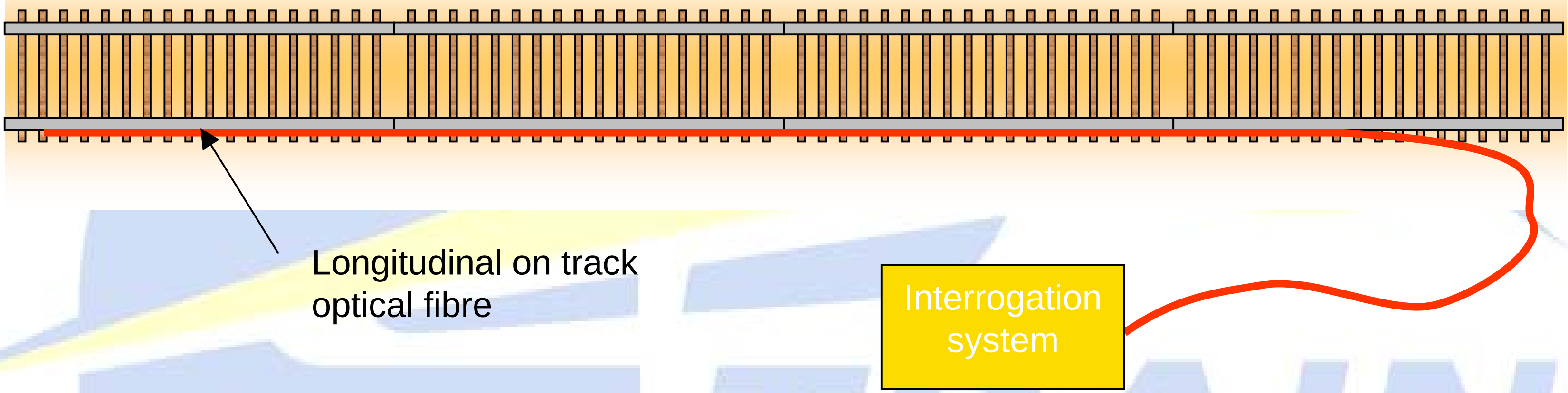


Required to **continually monitor** the Track.

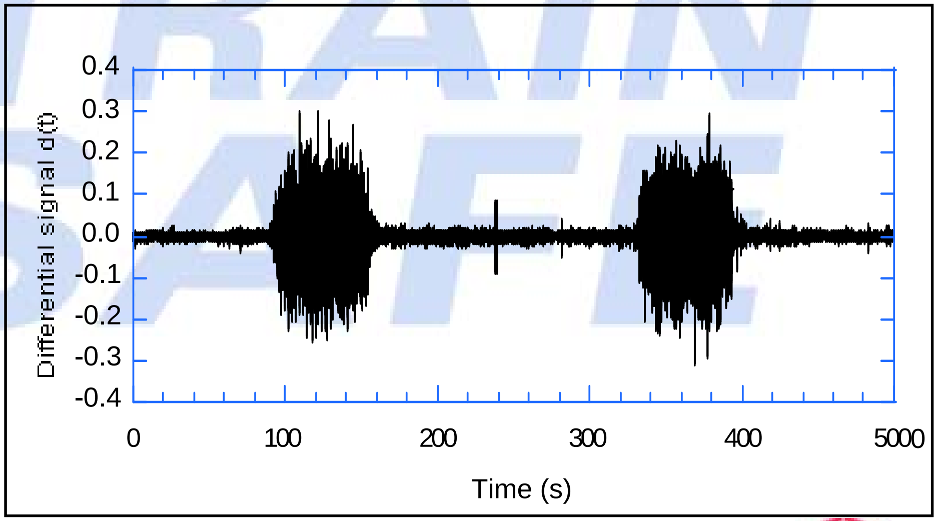
Applications:

- Wheel Impact Load Detection
  - Wheel Flat Detection
  - Weigh-in-motion
- Track Condition Monitoring
  - Rail Breaks
  - Track Buckling
- Rolling Contact Fatigue Measurements
- Signalling
  - Train Detection
  - Speed Measurements
  - Automated unattended crossing warnings

Longitudinal sensors



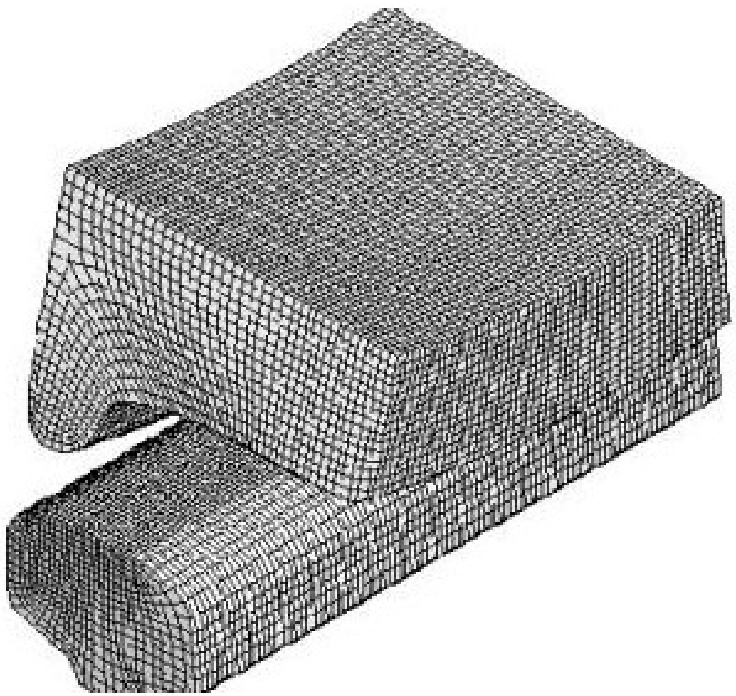
- Single fibre attached to web of rail
- Track detection achieved via distributed sensing techniques
- Range of 10’s of kilometres possible with several metre resolution



Safe Infrastructure – Theme 4
Condition Monitoring
Conclusions & Recommendations

- Improvement is required in the understanding of infrastructure status v condition
- Improvement in Asset Management is required
- Recommend investigation into track based monitoring systems to complement vehicle based systems

Safe Infrastructure – Theme 5
Adhesion Management



- Major safety issue
  - Need to minimise emergency braking distances
  - Need to increase traction
- ~3000km of track affected by organic residue in the UK

Safe Infrastructure – Theme 5
Adhesion Management
Conclusions & Recommendations

- Co-efficient of friction (μ) needs to be maintained between 0.15 and 0.4
- Organic residue (wet leaves) can reduce μ to 0.01
- Need to develop reliable adhesion measurement technology
- Need to develop track cleaning technologies
- Need accurate definition of threshold levels for ‘low adhesion’ and ‘high adhesion’.
- Chemical development of solid lubricants to counteract high adhesion?

Safe Infrastructure - Summary

- Specific technological areas identified for future development AND IMPLEMENTATION
- Research brokerage topics under discussion
- The consequences of not progressing this technology research and implementation are potentially catastrophic, but…

Safe Infrastructure

…Railways are still one of the safest forms of transport

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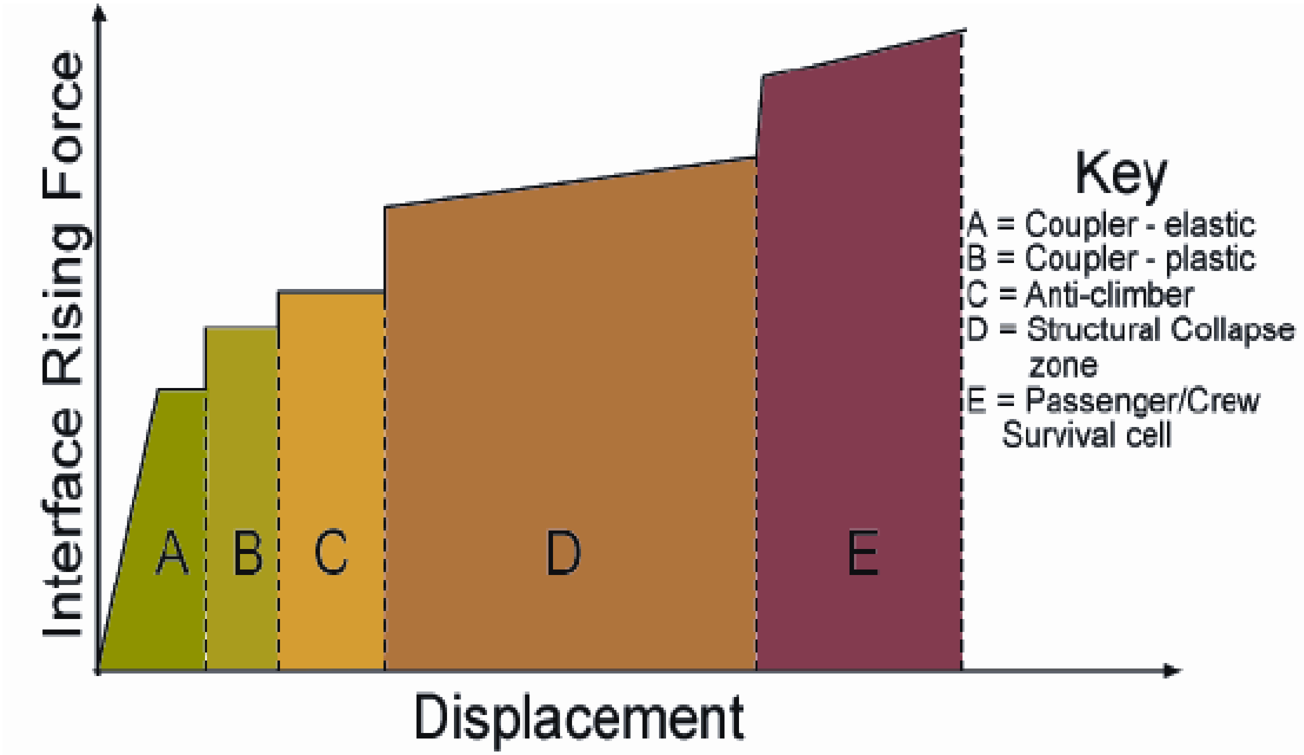
Safe Vehicle Structures
A Guide to Current Practice

Andrew Bright - Atkins

- Energy Absorption
- Structural Integrity
- Interface Systems
- Derailment Protection

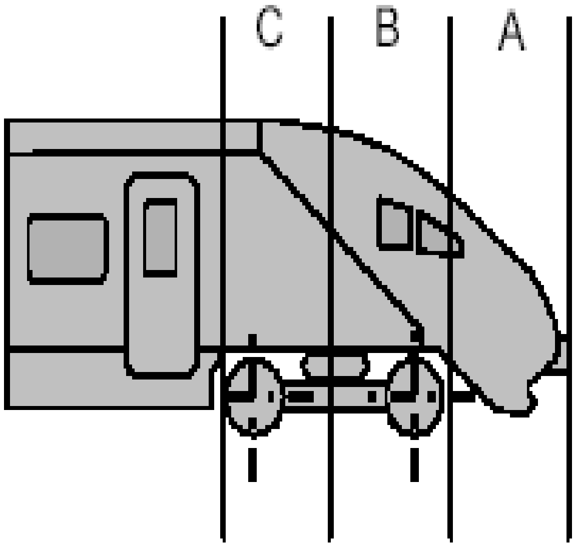
Safe Vehicle Structures – Energy Absorption



Key Benefits

- To dissipate Kinetic Energy
- To reduce peak decelerations
- To add control, predictability and stability

Safe Vehicle Structures – Energy Absorption



Short Nosed Vehicle

Photographs & Graphics Courtesy of Bombardier Transportation

European Driver's Desk

- For short nosed cabs it is difficult to have a long enough energy absorption zone to achieve a 5g deceleration
- An alternative is to absorb energy in front (A) & behind (C) the driver
- Driver is protected in the survival space (B) but his deceleration is > 5g
- An airbag is a good secondary means of protecting the driver

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Safe Vehicle Structures – Energy Absorption

The TRAINSAFE consortium recommends:

- That standards should define performance objectives they should not be unnecessarily prescriptive
- That standards should enable the rail industry to utilise modern & innovative design & construction methods
- That standards should consider bogie & underframe equipment attachment loads

Recommendations for Future Research Activity:

- Understanding how future control systems (e.g. ERTMS) will change the nature of accidents.
- Behaviour of composite materials, especially degradation in the rail environment
- The stability of rakes during head-on & asymmetric collisions, including determining the best method of predicting the onset of instability using computer modelling the onset of instability

Safe Vehicle Structures – Survival Space Integrity

- Protect against occupant ejection from the survival space
- Protect against debris intrusion into the survival space
- Glass should be laminated
- Welded / bolted connections should be strong

Great Heck, UK, 2001

Piacenza, Italy, 1997

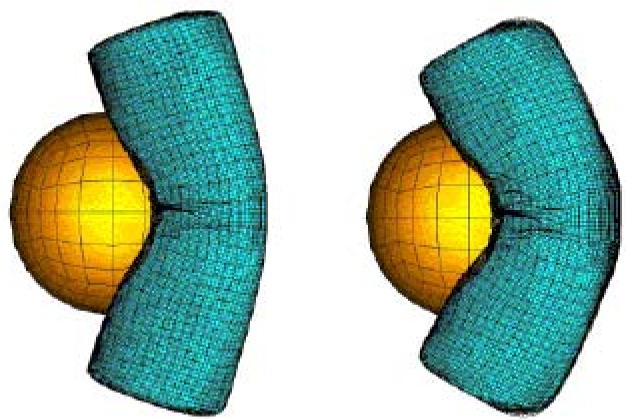
Potters Bar, UK, 2002

Safe Vehicle Structures – Survival Space Integrity

Graphics Courtesy of SNCF

Real Life Level Crossing Collisions Differ from Theoretical Collisions with Rigid Walls

- Trucks tend to impact rail vehicles above the underframe
- Approx. 20% of the energy absorbed is absorbed by the truck
- During the collision the truck tends to roll towards the drivers cab



Graphics Courtesy of SNCF

Safe Vehicle Structures – Survival Space Integrity

The TRAINSAFE consortium recommends:

- That “real” accidents are investigated to identify the most important issues
- That guidance is produced specifying preferred vehicle behaviour beyond the existing design collision scenarios
- That suitable standards are produced as soon as is reasonably practical

Recommendations for Future Research Activity:

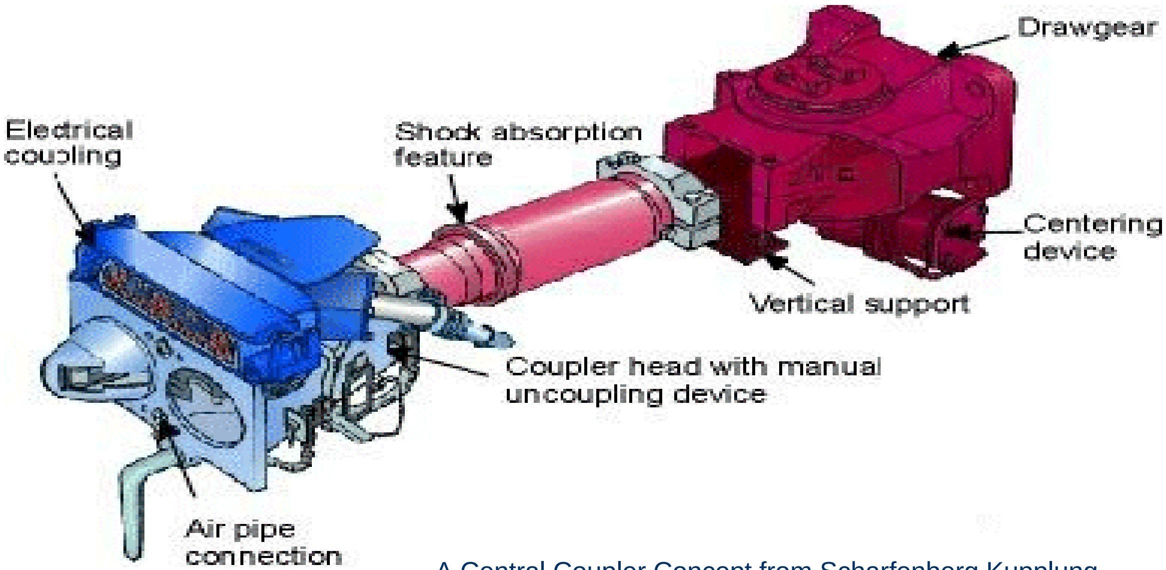
- Production of an accident database, updated and extended to include data from the New Member States
- Driver Protection, especially the driver-seat-desk interface, the use of airbags, human behaviour issues.
- Gathering of data about joining methodology to improve FE modelling techniques.

Safe Vehicle Structures – Interface Systems

During a Collision or Derailment

- Vehicles Should Remain on the Ground – No Overriding
- Vehicles Should Remain Upright
- Vehicles Should Remain Connected
- Vehicles Should Remain In-Line

A Typical Design of Anti-Climber



A Central Coupler Concept from Scharfenberg Kupplung

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Safe Vehicle Structures – Interface Systems

- Overriding at Coppenhall Junction, UK, 1962
- Mark 1, all steel, buffered vehicles
- Collision speed believed to be 10kph
- 18 Fatalities, 34 Serious Injuries

Overriding Believed to be the Biggest Vehicle Interface Risk

Safe Vehicle Structures – Interface Systems

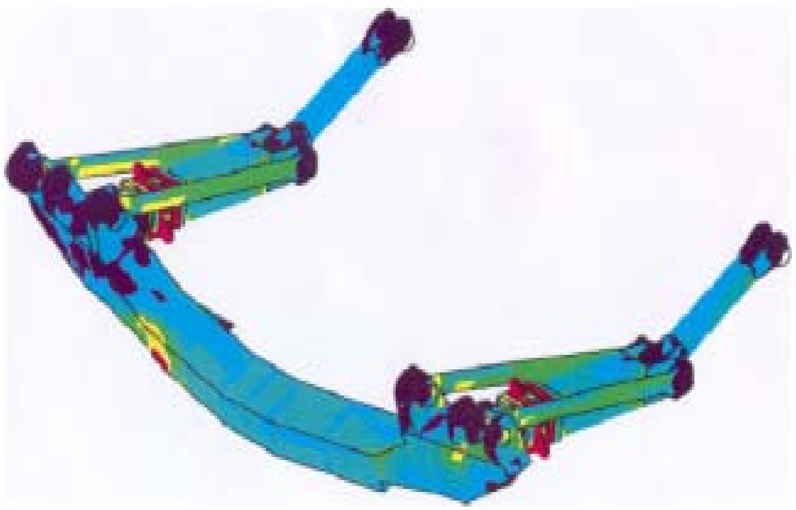
The TRAINSAFE consortium recommends:

- The CEN TC 256 WG2 should draft interface systems safety performance standards
- That the standards once implemented ensure operational functionality
- That full use should be made of the SAFETRAIN project & other previous research

Recommendations for Future Research Activity:

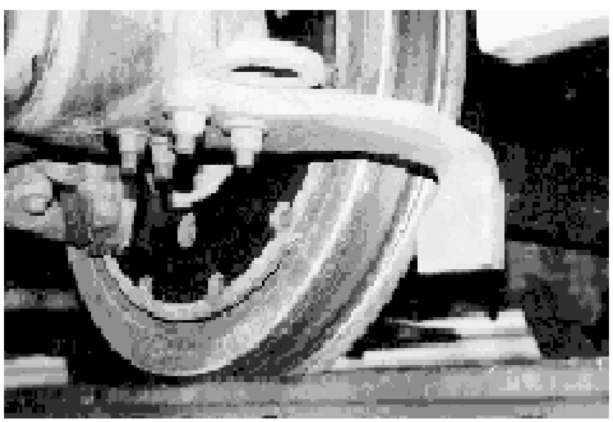
- Understand the risk associated with overriding, jack-knifing, rake separation, vehicle roll-over
- Determination of methods to validate anti-climber performance. To include lateral & vertical misalignment
- Investigation into the feasibility of pre-crash adaptable interface models

Safe Vehicle Structures – Derailment Protection



Obstacle Deflector Design Support

Obstacle Deflector Quasi-Static Testing



A Lifeguard

A Class 66 Locomotive

Safe Vehicle Structures – Derailment Protection

The TRAINSAFE consortium recommends:

- An EU wide statistical review of obstacles
- A state of the art report on derailment protection, incorporating, obstacle deflectors, lifeguards, axle weight, push-pull effects, wheel-rail interface issues, crosswind effects

Recommendations for Future Research Activity:

- Research into the dynamic performance of obstacle deflectors
- Research to determine best practice for lifeguards
- Research into the degradation of the wheel-rail leading to derailment (to be conducted in conjunction with the TRAINSAFE Infrastructure Cluster)

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Safe Vehicle Interiors
A Guide to Current Practice

Paul Murrell - Atkins

- Injury Criteria
- Interior Design
- Occupant Dynamics
- Evacuation and Egress

Overview

Interior passive safety is concerned with:

- **Minimising the risk of injury** from secondary impacts between occupants and the interior of the train
- Effective management and control following an incident to **prevent occupants from further harm**

Minimising the Risk of Injury

We need to understand how occupants respond to train deceleration pulses and how they interact with the interior environment of the train:

- **Vehicle Behaviour**: Defining the deceleration environment
- **Occupant Dynamics**: Understanding how the human body responds to vehicle decelerations
- **Interior Design**: Minimising the consequences of an impact
- **Injury Criteria**: Quantifying relevant injury metrics to enable robust assessments and judgements to be made

Prevention of Further Harm

We need to understand how to manage and control people in the post accident environment:

- **Communication**: Ensuring people know what to do
- **Egress/Evacuation**: Ensuring occupants can be moved away from hazardous situations if required
- **Human Behaviour**: Understanding how people behave under extreme conditions
- **Training**: Ensuring staff know how to deal with accidents

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Safe Vehicle Interiors Workshop

Topics chosen for discussion included:

- **Injury Criteria**
- **Interior Design**
- **Occupant Dynamics**
- **Evacuation and Egress**

Injury Criteria – Key Issues

- Injury criteria link the injuries sustained by a person as a result of an impact with an object, with engineering appraisals of that impact
- Majority of research and development has been done by the automotive industry. This is not always appropriate for train collisions
- No European standard approach for deceleration pulses or standards for assessment exists
- We are interested in the range and severity of injuries. There are many possible occupant types and orientations

Impact of Dummy against Rail Seat

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Injury Criteria – Recommendations

- "Development of an EU wide standard for rail interior crashworthiness that utilises rail-specific injury criteria in order to assess and reduce the injuries that a rail occupant receives due to secondary impacts"
- Research priorities:
  - Identify high risk rail injuries and appropriate assessment criteria
  - Compile a consistent European data set of historical rail injuries
  - Develop a European assessment device for assessing injuries (e.g. crash test dummy, computer models, component models)
  - Define crash pulses for the four high speed TSI collision scenarios

Interior Design – Key Issues

- No European-wide standard for rail interior crashworthiness
- Diversity of interior layouts and operations makes standardisation difficult
- Aggressiveness of interior features (e.g. sharp edges) should be minimised
- Issues such as luggage retention are also important

OH3 Review, UK, 2002

"Good" Interior Design – This fixed table has rounded corners

Potters Bar, UK, 2002

"Bad" Interior Design – This foldaway table fractured to leave thin, sharp edges

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Interior Design – Examples

Great Heck, UK, 2001

"Bad" Interior Design – This oven has sharp edges and could be impacted by an occupant at head height

"Good" Interior Design – This proposed oven is at floor level and flush with the other galley equipment – no sharp corners

OH3 Review, UK, 2002

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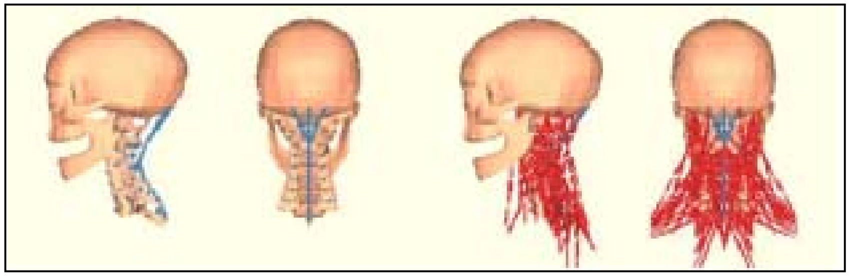
Interior Design – Recommendations

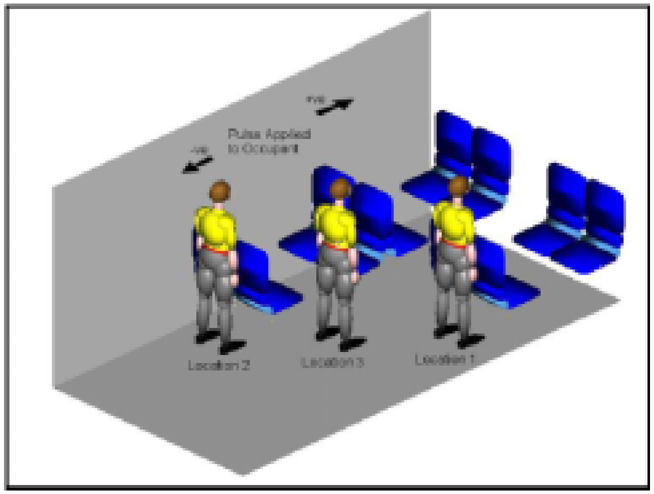
- "Development of an EU wide guidance document for rail interior furniture that considers an advisory as well as a prescriptive approach"
- Research priorities:
  - Development of a common methodology for carrying out European wide risk analysis of casualties
  - Use these results to improve the safety of rail vehicle interior design
  - Categorisation of trains according to type and risk of accident and development of appropriate design guidelines
  - Cross reference with injury criteria development work
  - Collate a document pooling current interior design knowledge

Occupant Dynamics – Key Issues

- Should we standardise on a single standard rail occupant?
- Rail occupants are unrestrained - there are many possible initial orientations and interior layouts
- Do we need to assess other types of impact with other items which may become loose inside the train?



Modelling skull, spine and neck muscles – de Jager (1994)



Modelling standing rail occupants – Picture courtesy of MIRA

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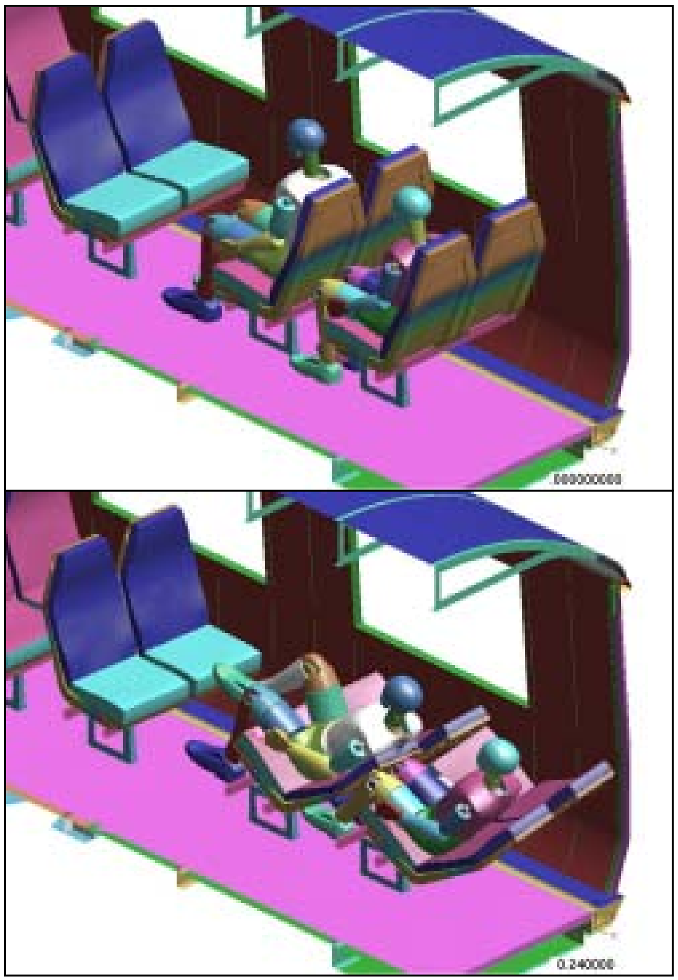
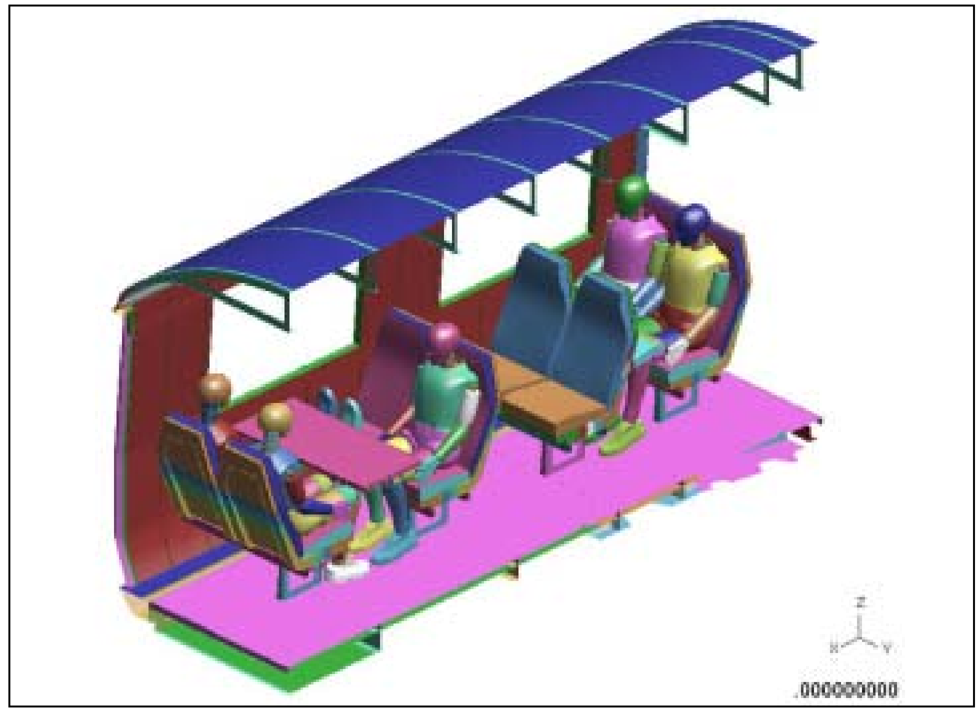
Examples – Occupant Dynamics



Rail Vehicle Impact – Rear Facing Occupants (Atkins, 2002)



Modelling Different Seating Configurations (Atkins, 2002)

Occupant Dynamics – Recommendations

- “Putting in place a process to ensure timely delivery of a European standard for rail vehicle interiors”
- Research priorities:
  - Deciding a scope of the standard
  - Defining crash pulses
  - Developing categories of occupants
  - Ensuring equality by developing models for disabled occupants
  - Development of modelling techniques to assess occupant kinematics in impacts with different postures, seating arrangements and unsecured items

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Evacuation and Egress – Key Issues

- Three-model approach - scientific, risk and human
- No common approach to egress issues in the EU
- Balancing of risks (to stay or to go)?
- Communication of emergency information
- Abuse/vandalism of emergency equipment

Picture courtesy of AEA Technology

Hatfield, UK, 2000

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Evacuation and Egress – Recommendations

- "Further debate into the merits of the three model approach"
- Research priorities:
  - Scientific Model research
    - Consider EU-wide rail structures, fire safety issues and interior layouts
  - Risk Model research
    - Identify the most common accident scenarios through risk analysis and assessment
    - Gather EU-wide information on egress performance in past accidents and any subsequent enquiry recommendations
    - Develop a common methodology for safe egress after an accident
  - Human Model research
    - Understand the psychological behaviour of humans under extreme conditions
    - Develop common specifications for emergency lighting, with independent, robust and redundant power supplies
  - Consider the use of CCTV cameras onboard rail vehicles

TRAINSAFE – Safe Infrastructure: A Guide to Current Practice

Author: Mr Alex M[C]Cann
Corus Rail Technologies, Rotherham, UK
E-Mail: alex.mccann@corusgroup.com

Abstract:

This paper offers a critical assessment of the current understanding for the key components of the railway track system, which collectively form a Safe Infrastructure.

The track components are categorised into five main themes, each of which is briefly described in terms of their impact on the safe operation of the railway infrastructure system. The main themes are:

- *Track degradation and sub-structure integrity*
- *Track welding*
- *Track inspection technologies*
- *Track condition monitoring*
- *Adhesion management*

Conclusions and recommendations are then proposed for each of the themes.

1. Introduction

The complexity of the track infrastructure is widely recognised, but more importantly, despite considerable research, the track system interfaces and their implications for track & vehicle degradation and maintenance continue to challenge the industry. Reference is often made to "the System's Solution Approach" for engineering a 'through-cost' solution to meet the requirements of the track engineer. However, evaluating proposed solutions in a system's context is often overlooked in favour of the isolated assessment of an individual parameter affecting system performance.

Hence, it is necessary to establish the definition of the track system and the disciplines required to achieve and maintain the desired level of track integrity.

In the context of the track, the system boundaries extend from the wheel-rail interface downward into the rail, pad, fastening, sleeper and finally into the substructure and formation. The optimisation of this complex system requires the bringing together of a range of disciplines including:

- Vehicle dynamics and contact mechanics
- Permanent way and civil engineering
- Metallurgy and materials technology

The functionality required of the rail is highly dependent on the track and traffic characteristics and hence even within a single network the demands made of rail steel can vary widely, from those for high-speed plain line to tight curves on mixed passenger and freight lines. It is, therefore, essential that the choice of rail steel be based on its ability to address the issues that affect the life cycle costs identified by the track engineer.

2. Track Degradation and Sub-structure Integrity

Track types

Conventional railway track construction is generally considered to be made up of two sub-systems:

- The substructure – ballast, sub-ballast and formation layer. This group can also include earthworks and drainage.
- The superstructure – consisting of rails, pads, fastenings and sleepers.

The sub-structure

Figure 1 illustrates the components of a traditional railway track sub-structure.

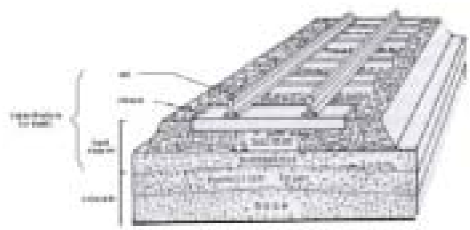

Fig. 1 – Traditional Construction of railway track infrastructure

The superstructure

Rail metallurgy: In general, the three key causes of a rail requiring rectification or being cascaded down or removed from service are:

- Loss of transverse section and/or longitudinal profile.
- Loss of rail integrity through fatigue (rolling contact and bending fatigue).
- Increased risk of rail breakage from internal quality, residual stresses, surface quality and / or welding.

Rail wear and Rolling Contact Fatigue crack growth

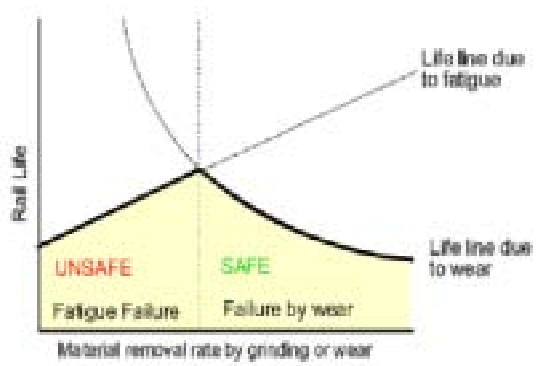

Figure 2 Maximising rail life is a balance between failure by fatigue and wear.

Rail wear can actually be beneficial in inhibiting crack growth; the removal of material from the surface of a railhead is an effective means of reducing the lengths of any cracks. Grinding is the intentional erosion of material from the railhead, and can have the added benefit of moving the wheel / rail contact patch. It has been shown that careful grinding can dramatically reduce crack growth rate. If managed optimally, the maximum life of a rail is the delicate balance of wear, grinding and fatigue (Fig. 2).

Rail-life models consider the interaction between wear and crack growth, and also take account of variations in traffic, axle loads and vehicle dynamics. **Work is urgently required to refine these models.**

Track Welding

Railway track can either be mechanically fastened (i.e. bolted) or continuously welded. Most modern high speed / heavily used lines are continuously welded, but mechanically fastened track still continues to have a significant share (e.g. approximately 30% in the UK).

Continuously welded rails are most usually laid on either steel or pre-stressed concrete sleepers and fixed with clip fastenings (Figure 3b). The second most commonly used fixing technology for continuously welded rails are "AS1" track plates that clamp the rail in place (Figure 3c). Continuously welded rails offer several advantages over traditional mechanically fastened track. These include higher travelling comfort and a reduction in the levels of noise generated. Continuously welded track also has lower maintenance costs, and is considered an essential technology for high-speed lines.

Figure 3 – Common methods of joining and fixing track: (a) mechanically fastened, (b) continuously welded and fixed with clip fastenings, and (c) continuously welded and fixed with AS1 track plates.

In normal operation, the stress state in continuously welded track will vary with the ambient temperature due to thermal expansion and contraction. Low temperatures tend to induce tensile stresses, whereas high temperatures can induce compressive stresses.

The latter, if excessive, could result in the buckling of the rail. To prevent this occurrence, continuously welded rails are installed with a pre-tension. This has the effect of providing a neutral stress state at a higher temperature than ambient. Ongoing studies are investigating the effect of this pre-tensioning on crack growth within continuously welded rails.

Geometric defects in railway joints can occur when the rail parent material wears at a different rate to the welded joint. Imperfections generate dynamic forces in the track when impacted by a wheelset and contribute to a proportion of rail breaks occurring near to the ends of rails.

This area could benefit from further research in welding techniques, metallurgy and the maintenance regimes of weld.

Track Inspection Technologies

There are a multitude of commercial systems that are based around surface visual inspection. These commonly offer detection of rail surface and sleeper anomalies as well as missing fastening elements and deviations in the contour of the ballast at inspection speeds up to 200km/h. One of the most high profile rail maintenance systems is the Central Japan Railway Company's "Doctor Yellow" inspection train. This inspection vehicle is a 7 car EMU that inspects track geometry, catenary, signalling and telecom systems at speeds of up to 270km/h.

Ultrasonic testing of railway tracks is currently limited to approx 70km/h. The test speed is limited by the travel time of the ultrasound in the rail, and by the distance required between measurements. Ultrasonic testing has good penetration but poor near surface resolution. More recently, the use of guided ultrasonics, acoustics, and refined hand-held ultrasonic measurement devices has been evaluated.

Eddy current testing is becoming a more common mechanism of inspection. When an AC current flows in a coil close to a conducting surface, the magnetic field of the coil will induce circulating (eddy) currents in that surface.

The magnitude and phase of the eddy currents will affect the loading on the coil and thus its impedance. Any cracks in the material of the railhead will interrupt, or reduce, eddy current flow, thereby reducing the load on the coil and increasing the impedance. It is the monitoring of the voltage across the coil that, when calibrated correctly, can actively monitor the rail condition. However, a limitation of eddy current examination is that cracks parallel to the circular eddy current flows may not cause sufficient interruption to be detected. Also, eddy current density decreases exponentially with depth into the test material. Where eddy currents excel is in surface scanning. Eddy currents will pick up surface breaking cracks that ultrasonic testing will not detect at all.

Overall, to meet the ERRAC objectives of increased traffic volume and lower maintenance times, the strategic solution may be to allow inspection vehicles to run seamlessly alongside passenger or freight vehicles, actively monitoring rail wear and crack propagation.

Condition Monitoring

From a safety perspective, the purpose of the railway infrastructure is:

- To provide a safe mechanism of guidance for rail vehicles.
- To provide a safe signalling system.
- To provide for the safe integration of transport systems.

As the primary focus of TRAINSAFE is passive technologies, this chapter will concentrate on the civil infrastructure aspects of the first and third points, i.e. track, bridges, level crossings, and line side installations.

The influence of infrastructure on railway safety

A UK-based study by the Rail Safety and Standards Board evaluated the risk associated with the occurrence of a series of hazardous events. The risk for a given event was calculated as the product of its estimated frequency (events per year) and the severity of the consequences (fatalities per event). A fault tree analysis was used to model each hazardous event.

Table 1 presents the results of this analysis in terms of the accidents involving trains. The role of infrastructure is clearly demonstrated, with four of the six most risky train-related events involving aspects of infrastructure (level crossings, derailments, buffer stops).

Hazardous Event	Risk (Equivalent Fatalities per Year)
Passenger train collision with a road vehicle on a level crossing	6.2
Collision between two passenger trains (other than at a platform)	5.8
Derailment of a passenger train	4.3
Derailment of a non-passenger train	3.0
Collision between a passenger train and a non-passenger train	1.2
Collision with buffer stops	1.2

Table 1 - Risk profile for all UK rail accidents involving trains with equivalent fatalities per year > 1 (from Muttram[2])

It is recommended that consideration is given to:

1. Harmonisation of what is measured across EU – standardisation and how transmitted same interfaces
2. Improvement in the understanding of infrastructure status v/s condition.

Adhesion Management

In order to minimise emergency braking distances, it is important to maintain good adhesion between the wheel and the rail. The organic residues associated with Autumn leaf fall have been found to accumulate on rails and have the effect of lowering the coefficient of friction/adhesion at the wheel-rail interface to the extent that train braking and acceleration efficiency is seriously impaired. Some 2000 track miles (4000 miles of rail) are affected in the UK alone and the problem is known to affect many other European countries. In the worst affected areas of the UK, there is a risk that the reduced level of adhesion can compromise passenger safety and consequently remedial measures are taken through the application of 'Sandite' (a gelatinous suspension of sand) or grinding to ensure satisfactory wheel-rail adhesion. Alternative methods include applying chemical or organic treatments that breakdown the residue, although the implementation of such methods is very limited.

The organic residues range from 'heavy leaf mulch' to nano-thick layers and both their fundamental nature and their behavioral characteristics with respect to friction changes are not clearly understood.

It is therefore necessary to undertake a programme of fundamental investigations to develop suitable methods that can predict or measure adhesion in order that a warning message can be communicated to the train driver. This will allow the driver to take appropriate actions and mitigate the risks of signals passed at danger (SPADS) or in the worst-case scenario, train collision. Furthermore, the resulting increased understanding will also assist in the development of effective preventative solutions.

Adhesion management relates to the control of the coefficient of friction, μ, at the railhead. The challenge is to consistently maintain a value of μ between approximately 0.15 and 0.40, although the exact boundaries of the desired range are open to debate. Low adhesion (μ less than ~ 0.15) can lead to extended braking distances and failure to stop at signals. Indeed, in the UK, incidents have occurred in which sliding trains have over-run signals by up to a mile. A recent study found that in a five year period between June 1997 and June 2002, there were 140 adhesion related SPAD* incidents in the UK. Annually, the breakdown of these SPADS was as follows:

Category	Severity	Average Annual Occurrence
1	0-25 yd over-run	12.4
2	25-200 yd over-run	10.0
3	200 yd+ over-run	5.0
4-8	Damage to people / equipment	0.8

Table 2 - Analysis of UK SPADS, June 1997 – June 2002

It is recommended that a new standard for adhesion measurement should be developed. For European interoperability, this should be through a TSI.

3. CONCLUSIONS AND RECOMMENDATIONS

Recommendation for future Research into Passive Safety Issues

Subject Area – Track Degradation & Sub-structure Integrity

The key aspects recommended for further research under the above topic are:

1. **Formulation of standards taking account of track degradation:** In general, the formulation of standards is dictated by safety requirements and therefore the minimum levels of any quality parameter that does not compromise the desired safety levels are specified. However, the increasing need to make railways the most competitive and customer favoured mode of transportation, necessitates further research into the factors influencing the cost of safety and the adherence to specified safety standards. In this context, the recommended area of research is to evaluate the effect of the following, on the projected life span of the track, when maintaining to the specified safety standards becomes impractical or uneconomic:
   a. The level of installed track quality,
   b. The intervention intervals, and
   c. The rate of degradation between the intervention intervals

   Although such a study could be undertaken empirically on selected stretches of track, the pan-European application of the concept requires a mechanistic study of track degradation as a function of the design characteristics and imposed duty conditions. Such a project would combine the technical aspects of track degradation with economic considerations to develop guidelines for more informed decisions on initial investment and through life maintenance.

2. **Reducing Track Degradation:** Although both the traffic density and the duty conditions on the track have been increasing for a number of years, replacement of life expired track in European Railways is undertaken to principally the same standard as the track being replaced. Hence, in view of the increased duty from heavier and greater density of traffic, the expected life of this newly installed track should be shorter than that it replaced. Thus both the more frequent installation interval and the potentially increased maintenance requirements will add to the cost of the track. Consequently, there is an urgent need to undertake a fundamental study to evaluate and produce alternative designs of the track system to reduce the rate of degradation.

Subject Area – Track Welding

The key aspects recommended for further research under the above topic are:

1. **Understanding Weld Failures to Improve Integrity**: Although significantly longer hot rolled lengths are now available to the railways, welds are likely to remain an essential part of the track system and hence the continued need for improved integrity. In general, alumino-thermic weld failures account for 25% to 35% of all rail breaks in most railways while those for flash butt welds are very significantly lower at around 2%. The number of defective alumino-thermic welds is even larger and emphasizes the need to understand the correlation between a variety of parameters including process parameters, track characteristics, traffic carried, initial defect type, size and location and those of the final defect causing the break. The research would help to:
   - Identify process improvements necessary to improve integrity including development of grinding techniques to provide better control of profile around the weld.
   - Develop a system to define the criticality of defects as a function of shape, size and location within the weld. This would also involve examination of existing old welds in track.
2. **Accelerated Development of Inspection Technologies:** There has been a recent trend in some railways indicating an increase in weld failures within the first 2-3 years of manufacture. This has largely been attributed to welder competence and addressed through training and weld identity tracking. However, the incidence of early life failures could be significantly reduced through the development of a robust inspection technology that enables the welder to approve the weld almost immediately.

Subject Area – Inspection Technologies

The key aspects recommended for further research under the above topic are:

1. **Intelligent Inspection to Identify Life-expired Rails:** The task within this research project is to combine robust inspection technology with understanding of fracture mechanics to enable identification of life-expired rails based on defect type, size, and location and the expected duty conditions.

2. **Intelligent Image Analysis of Track Video and Audio Inspection:** Very significant advances have been made in image analysis techniques in many other industries and the recent introduction of high speed video inspection of track clearly identifies the need for research to combine the two technologies. The aim of the research would be to extend the capability of video inspection of track from the identification of key components to accurate, reproducible, and numeric assessment of RCF cracks, weld dips and cupping, other rail head defects, and running band position and width on the rail and wheel.

3. **Measurement of Residual Stress:** The effect of residual stresses in the rail head and foot for the development of cracks and rail breaks indicates the need to develop a reliable non-destructive means of measuring the residual stresses in the rail. Since, the passage of traffic changes the residual stresses in close proximity to the running surface, the project also needs to consider the implications of such changes on the susceptibility o rolling contact fatigue. The project should also be aimed at developing a non-destructive means of establishing the stress free temperature of the rail

Subject Area – Track Condition Monitoring

The key aspects recommended for further research under the above topic are:

1. **Harmonisation of Measured Parameters and their Analysis:** Significant developments have been made in sensor technology and a number of these have been incorporated into modern inspection vehicles. Although these advances have significantly increased the quality of inspection and reduced the safety issues associated with manual inspections, there is still a need to examine whether the key parameters that closely describe the integrity of the track are being measured or can be derived from the measurements. Equally, such inspection operations generate vast quantities of data and therefore it is essential to develop intelligent data analysis systems to convert the data into information to enable more informed decision making. Harmonisation of the parameters measured and their subsequent analysis will also provide greater confidence for interoperability.

2. **Development of Total System Condition Monitoring Technologies:** There is an increasing trend towards the division of responsibilities of track and rolling stock which has also highlighted the need to develop condition monitoring tools that are capable of identifying the passing vehicle and measuring the key responses of the track. The aim would be to establish a signature tune produced by each vehicle that can be monitored and compared with original to establish both the degradation of the track and the vehicle. Such a system would also promote the development of more track friendly vehicles since the associated track degradation rates would be reflected in the access charges. The system is analogous to the development of environmentally friendly cars promoted by a more favourable tax regime in some countries.

Subject Area – Adhesion Management

The key aspects recommended for further research under the above topic are:

1. **The definition of a standardised approach for the measurement of the co-efficient of friction (μ) between wheel and rail.**

   Adhesion management relates to the control of the coefficient of friction, μ, at the railhead. The challenge is to consistently maintain a value of μ between approximately 0.15 and 0.40, although the exact boundaries of the desired range are open to debate. As well as being a safety issue, low adhesion can also impact upon the availability of rolling stock. This is because sliding generates wheel flats, leading to the withdrawal of vehicles from service for repair. The most common causes of low adhesion are leaf films, oil spillages, and rust. Moisture generally exacerbates the problem and wet leaves can result in values of μ as low as 0.01. Consequently, chronic low adhesion is both a regional and a seasonal problem. The worst affected areas are the UK and similar latitudes in Northern Europe, during periods of autumnal leaf fall. High adhesion (μ greater than approximately 0.4) can lead to high creep forces and the initiation of rolling contact fatigue. Again, it is predominantly a regional issue, particularly in climates with high temperatures and low humidity. In the US, μ values as high as 0.7 have been recorded.

2. **Improvement in the fundamental understanding of the chemical, mechanical and electrical properties of the contaminants that cause a decrease in the friction coefficient, e.g. organic leaf films.**

   Organic residues associated with autumn leaf fall have been found to accumulate on rails and have the effect of lowering the coefficient of friction/adhesion at the rail-wheel interface to the extent that train-braking efficiency can be seriously impaired. Some 2000 track miles (4000 miles of rail) are affected in the UK alone and the problem is known to affect many other European countries. Such organic residues range from 'heavy leaf mulch' to nano-thick layers and neither their fundamental nature nor their behavioural characteristics with respect to friction changes are clearly understood. This will then naturally lead onto the development of track cleaning technologies suitable for the particular contamination issue.

3. **The definition of a new standard for Adhesion Management, which for European interoperability should be via a Technical Specification for Interoperability (TSI).**

   There are currently no mandatory legal standards relating to adhesion management. A UIC product acceptance standard for wheel-slide protection does exist (Leaflet 541-05), and this is based on a water / soap solution test. However experience shows that this test is not particularly useful.

Die Bahn DB

Railway and Tramway Crashworthiness

Overview of crashworthy vehicle structure solutions for passenger carrying rolling stock

Based on the EC funded projects SAFETRAIN and SAFETRAM

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DB Systemtechnik
Am Südtor
14774 Brandenburg-Kirchmöser

Example for future application: ICE and Tram-train in track-sharing operation at DB lines

SAFETRAIN Consortium

Operators:

DB AG

SNCF

Manufacturers:

Bombardier Transportation Portugal (project coordinator)

Alstom Valenciennes

Alstom DDF Reichshoffen

Bombardier Transportation Berlin (former IFS)

Siemens TS Krefeld (former Duewag)

Universities:

FMH Lisboa

IST Lisboa

TU Dresden

UVHC Valenciennes

Research Centres:

AEA Derby (former BRR)

Cranfield Impact Centre

CNTK (former PKP)

ERRI (representing UIC)

Main contractor:

BT - DWA Görlitz

SAFETRAM Consortium

Operators:
BVG Berlin
DB AG
RATP Paris
SNCF

Manufacturers:
Bombardier Transportation Portugal (project coordinator)
Alcan Mass Transportation Systems Zürich
Alstom La Rochelle
Ansaldo Breda Pistoia
Bombardier Transportation Nürnberg

Universities:
IST (Lisboa)
TU Berlin

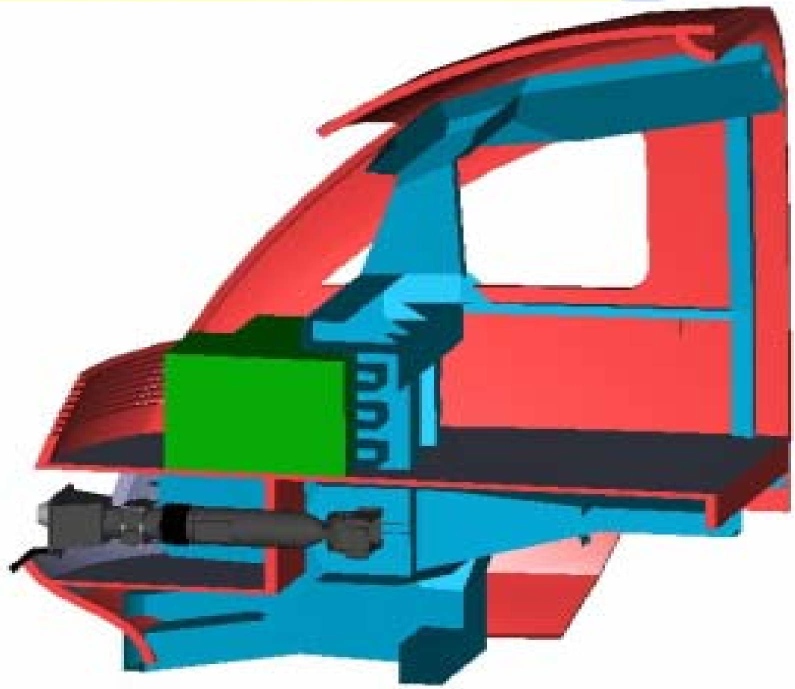
Research Centres:
CNTK Warszawa
MIRA Warwickshire

TRAIN SAFE

SAFETRAIN Safetrain Die Bahn DB

Railway and Tramway Crashworthiness

SAFETRAIN: Crashworthy driver's cab structure of VT 642 type (study)

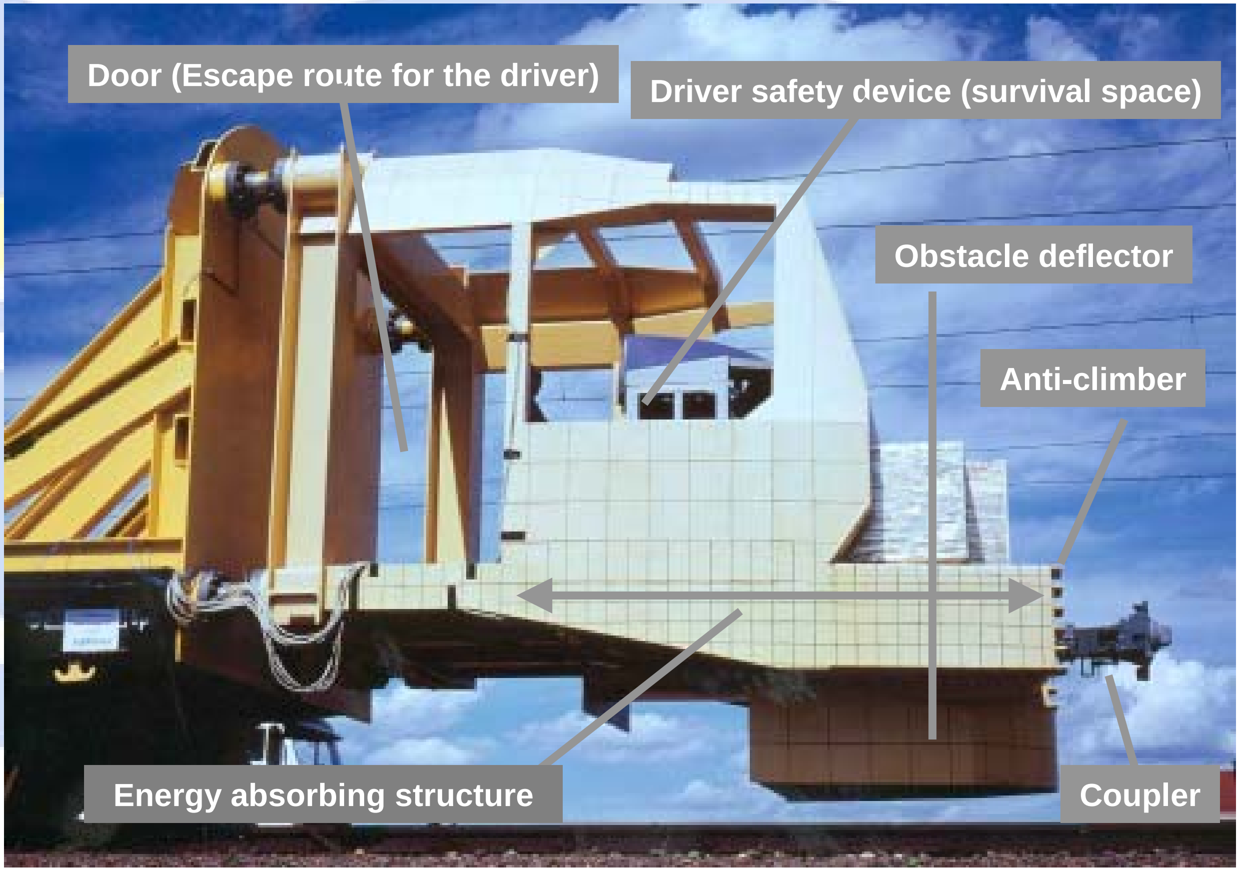


Design objectives: Minimisation of
1. Loss of survival space;
2. Injuries caused by secondary impacts.

Railway and Tramway Crashworthiness

SAFETRAIN: Design and Crash Concept

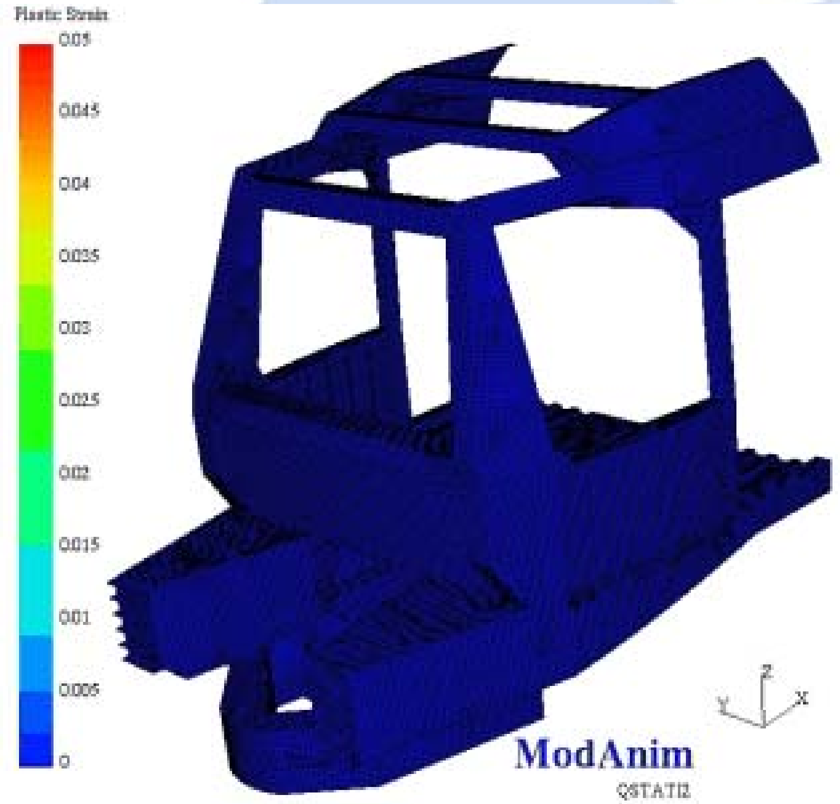
Inter-trailer

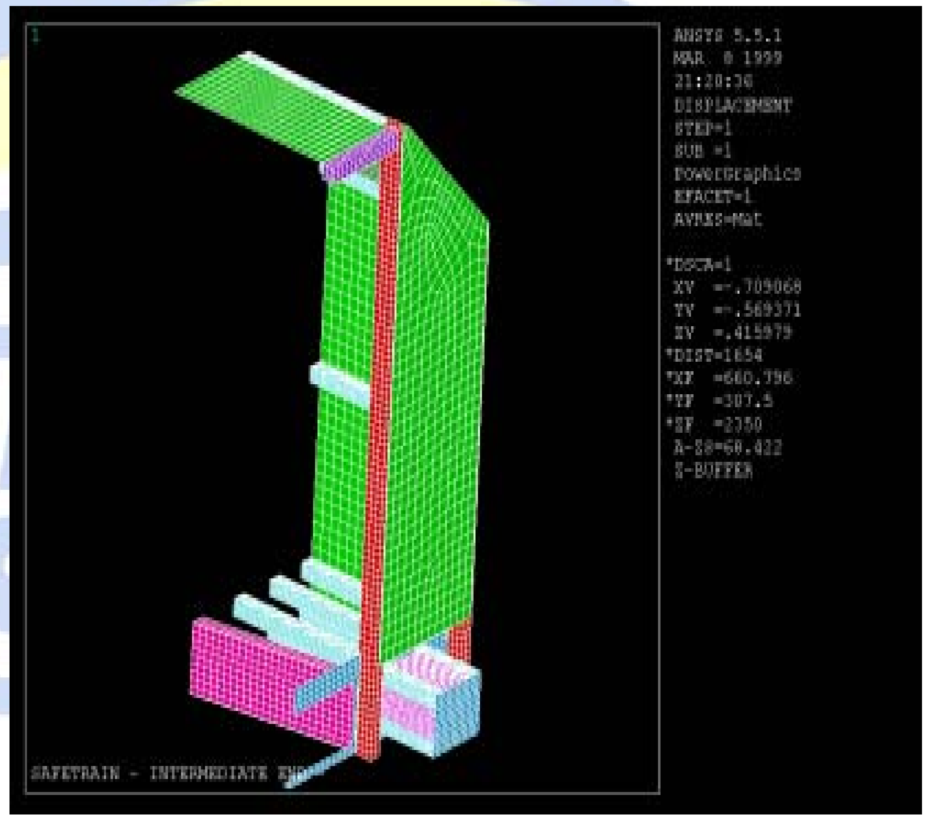


Train front

Railway and Tramway Crashworthiness

SAFETRAIN: Validation by Numerical Modelling
Front end and inter-trailer end





SAFETRAIN: Validation Methods Comparison

Crashworthy front structure after collision with:

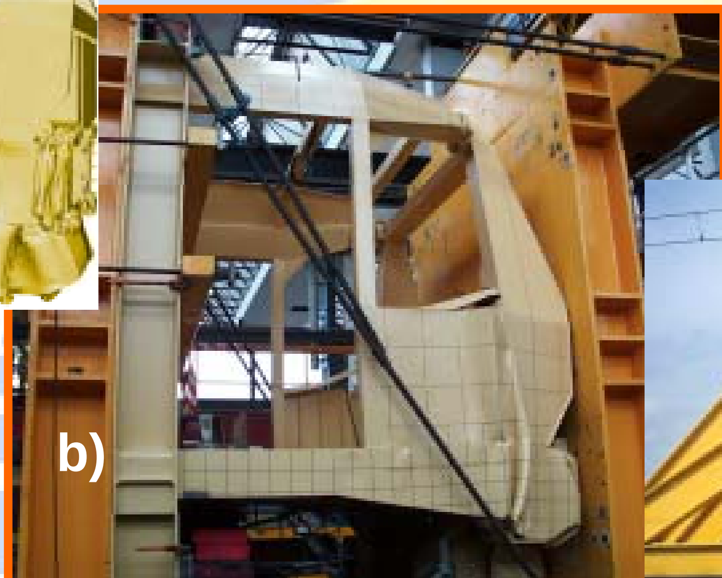
- 129 t regional train, collision speed 55 kph;

- 16,5 t lorry at level crossing, collision speed 110 kph.

Test-scenario covers ca. 80% of European railway collision accidents

a)

b)



c)

a) Numerical simulation

b) Quasi-static (crush-) test

c) Dynamic (crash-) test

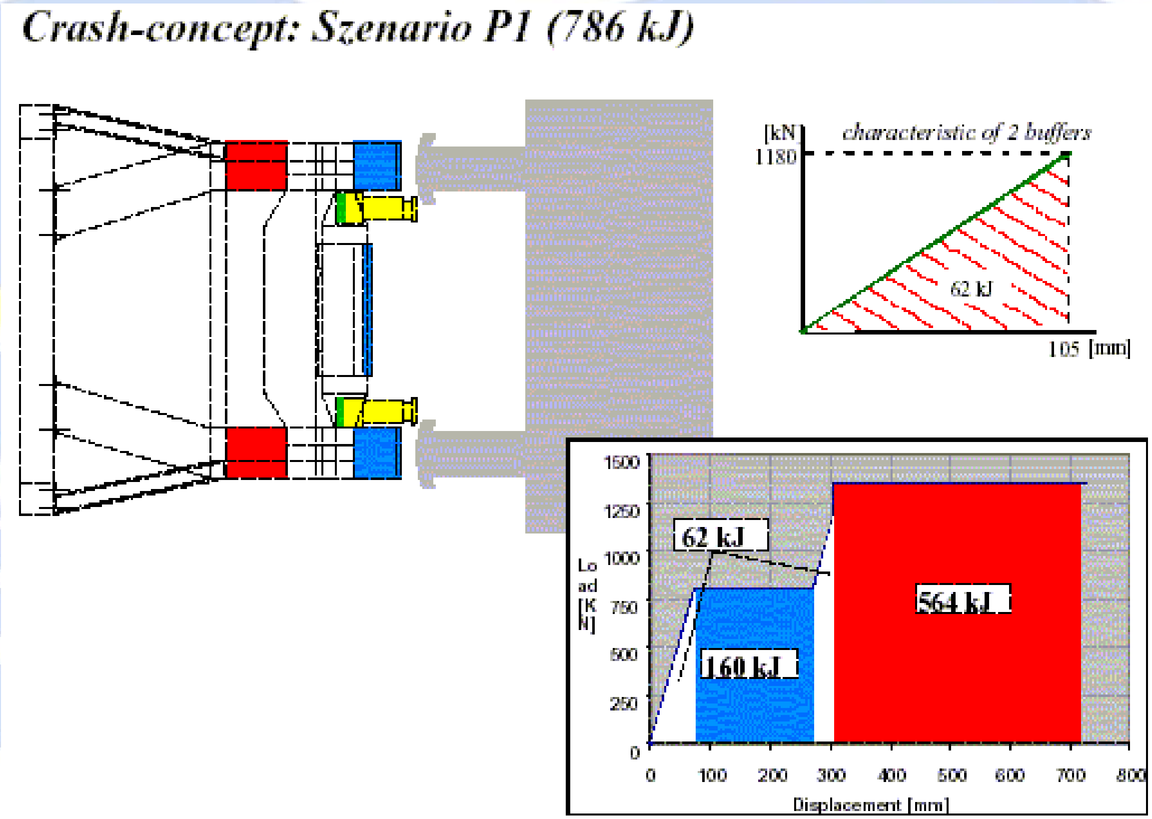
Railway and Tramway Crashworthiness

SAFETRAM Periurban Tram: Reference Design Concept

SAFETRAM Periurban Tram: Design Collision Scenarios

Periurban Tram Scenario *Crashtest-Szenario: P1*	Rel. Speed [km/h]	Total Crash Energy [kJ]	Remark
P1: Frontal collision with freight wagon (80 t)	25	786	Each of the freight wagon buffers absorbs ca. 31 kJ collision energy
P2: Frontal collision with a regional train (129 t)	22	722	The train coupler (530 kJ) contributes ca. 60 kJ to collision energy absorption
P3: Frontal collision with an identical Periurban tram	36	1375	Each periurban tram absorbs 50 % of the collision energy
P4: Frontal collision with a truck (16,5 t)	40	783	The truck is replaced by a rigid wall, covering the whole front of the periurban tram

SAFETRAM Periurban Tram: Crash Concept

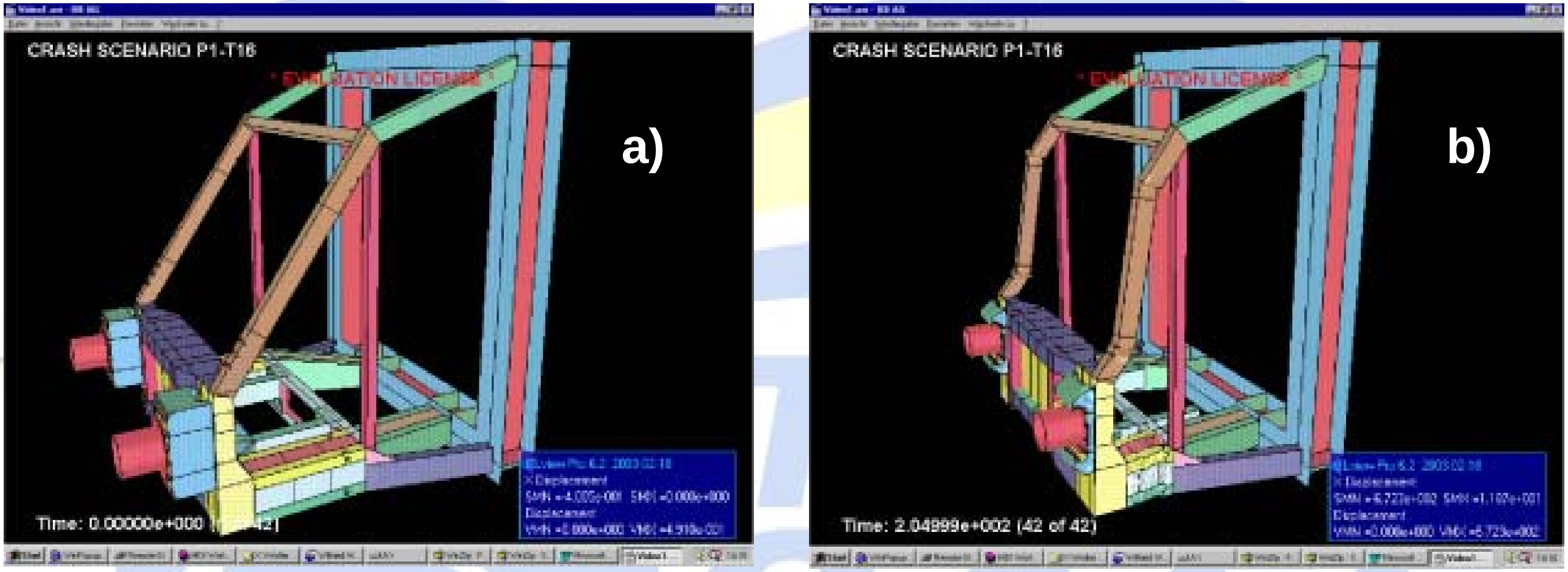


Scenario P1 (freight wagon)

SAFETRAM Periurban Tram: Test Structure and Measurement Preparation

Parameters	Channels	Primary elements
Force:	6	Load cells
Acceleration:	9	Accelerometers
Strain:	16	Strain gauges
Displacement:	30	Measurement points

SAFETRAM Periurban Tram: Validation by Numerical Modelling



SAFETRAM Periurban tram structure with external and internal deformation areas. a) before scenario P1. b) after scenario P1. The side absorbers (light-blue) are locking the buffers of the freight wagon (red) to prevent overriding. Survival space maintained.

SAFETRAM Periurban Tram: Validation by Dynamic (Crash-) Test

a) Tram-train cabin before test

b) after collision with a 80 t wagon, coll. speed 25 kph

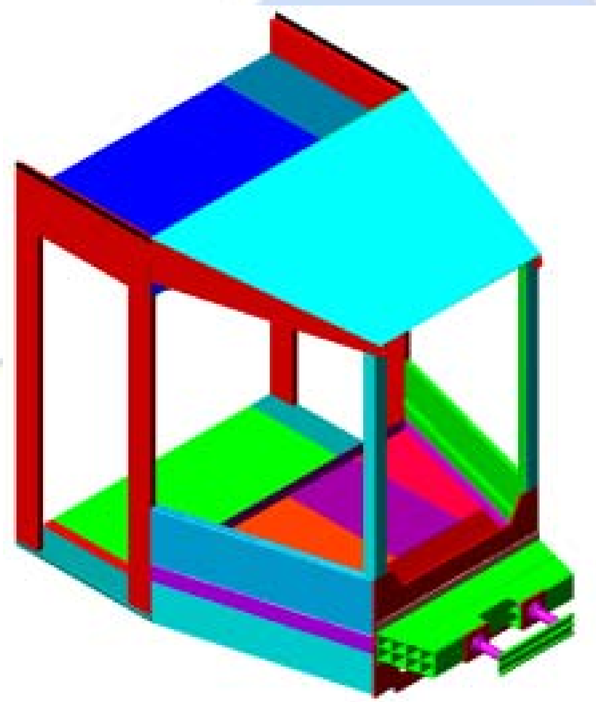
Railway and Tramway Crashworthiness

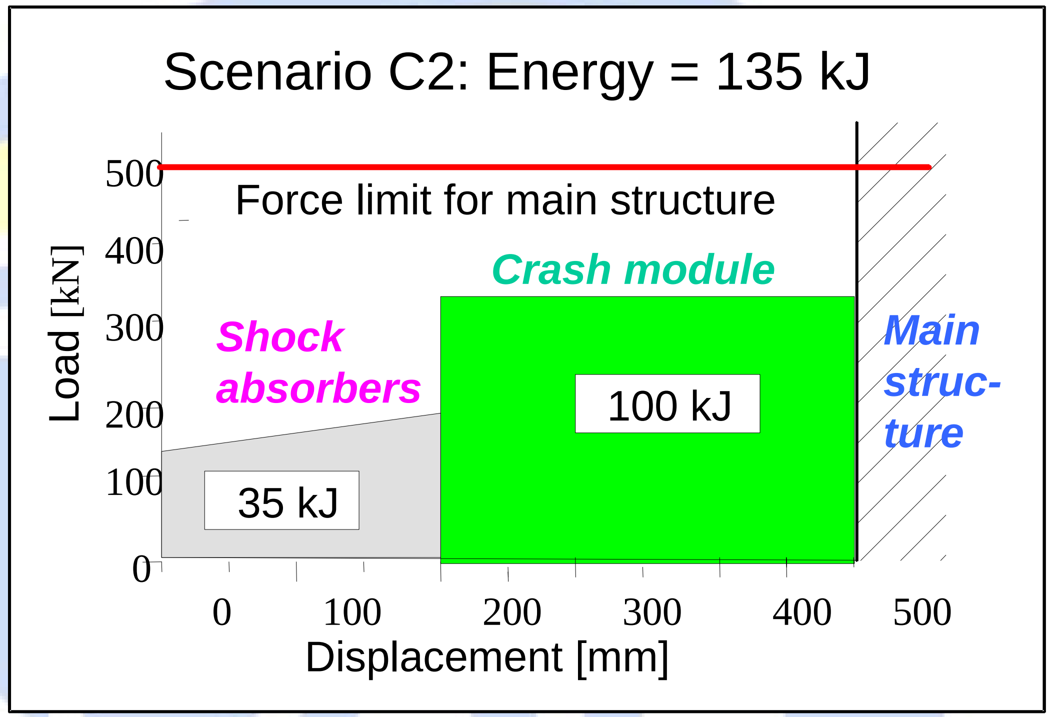
SAFETRAM – City Tram: Reference Design Concept

SAFETRAM City Tram: Design Collision Scenarios

City Tram Scenario *Crashtest-Szenario: C2*	Rel. Speed [km/h]	Total Crash Energy [kJ]	Remark
C1: No collision – emergency braking	70	-	Mean braking deceleration: 2,73 m/s
C2: Frontal collision with an identical City tram	20	270	Each city tram absorbs 50 % of the collision energy
C3: Right corner collision with an 3t - light truck	25	66	Light truck defined as a rigid wall covering the whole corner area surface of the city tram
C4: Frontal collision with a periurban tram (55 t)	10	83	Periurban tram defined as a rigid wall covering the whole frontal surface of the city tram

SAFETRAM City Tram: Crash Concept





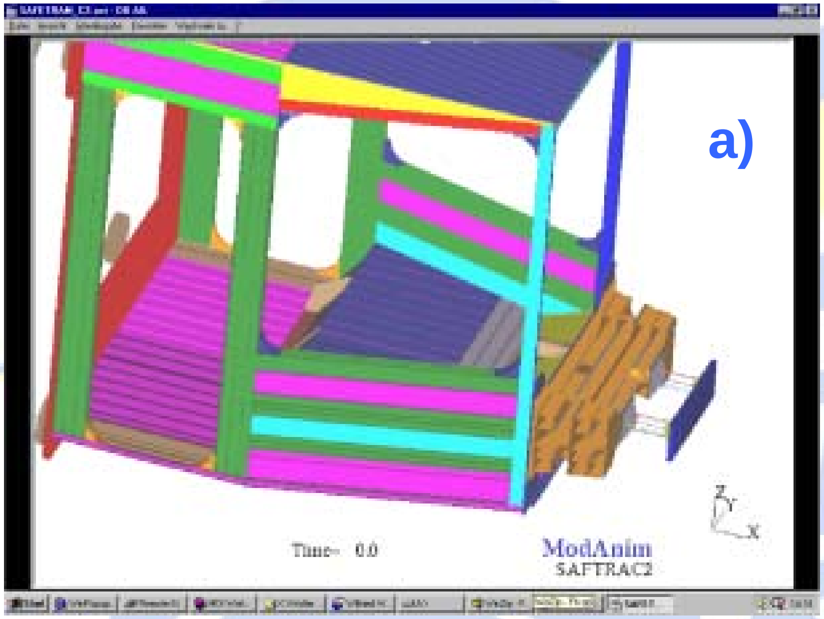
Scenario C2 (identical city tram)

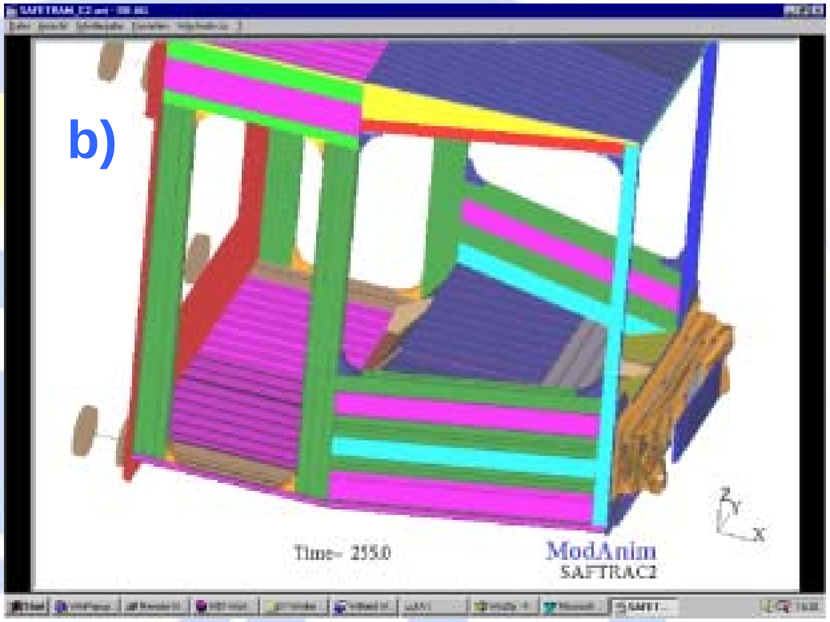
SAFETRAM City Tram: Test Structure and Measurement Preparation

Parameters	Channels	Primary elements
Force:	4	Load cells
Acceleration:	9	Accelerometers
Strain:	17	Strain gauges
Displacement:	45	Measurement points

Railway and Tramway Crashworthiness

SAFETRAM City Tram: Validation by Numerical Modelling





SAFETRAM City tram structure with crash module
a) before scenario C2. b) after scenario C2. Shock absorbers and crash module completely deformed, cab structure non-deformed.

SAFETRAM City Tram: Validation by Dynamic (Crash-) Test

a) City tram crash-module before test

b) after collision with an identical City tram, collision speed 20 kph

Train Mounted Sensors and Systems for the Inspection of Rails

Contents

1 Introduction

This paper gives an overview of work carried out within the EC funded CRAFT Project Rail-Inspect, project number CRAF-1999-70907. The work was carried out by six SMEs supported by two RTDs. Partners are listed in the final section.

Across Europe there have been increases in train traffic, train speeds and tonnage carried on the rail network. These have put an increasing amount of strain on rail tracks and have increased the interest in train mounted detection systems which can identify crack-like defects in the track, before the defects are able to grow and possibly cause a broken rail. Already a number of train mounted systems exist which are in use. The Rail-Inspect project has sought to explore and develop techniques with the objectives of:

- Improving the probability of detection of significant defects while reducing the incidence of false positive indications ('false calls').
- Increasing the extent of the rail head and web which can be tested, even if the rail head is severely worn.
- Carrying out inspection at up to 80km/hr.

One beneficial consequence of improving train mounted inspection is to reduce the reliance on manual inspection. This is a dangerous operation which involves walking along the track with an inspection 'walking stick'. Not only is the work dangerous, but manual inspection relies heavily on operators maintaining concentration and due care, not an easy task given the conditions under which testing is often carried out.

Recognizing that no single NDT technique provides all the required information from the cross-section of a rail, the project investigated a number of techniques. The strategy was to develop the strengths of individual techniques, and then combine them into a system that provided the operator with a user friendly means of gaining maximum useful information on the state of the track. The combination of techniques was a key novel feature of the project. Three techniques were investigated, for the following reasons:

- Ultrasonic, for volumetric inspection: rail head, web and foot.
- Eddy current, for sensitive rail head surface inspection.
- Flux leakage, which is less sensitive than eddy current but applicable to large surface breaking defects.

As with all railway equipment, it is important to ensure that there is no interference with signalling systems. This aspect requires further investigation.

The following sections summarise the results obtained from the different techniques and how the data was fused to provide a single report for the operator.

2 Ultrasonics

One issue with ultrasonics is how to achieve a reliable way of coupling the ultrasound into the rail. Water coupled sliding probes are not reliable and so a wheel probe was developed by the consortium. The wheel consists of a flexible membrane which contains the transducers. The membrane supplied by Sonatest contains a liquid which couples the ultrasound to the track as the wheel is rolled over the track.

The wheel was designed to incorporate three phased array transducers designed and provided by Imasonic. Use of phased array ultrasonics allowed a reduction in the required number of probes and, most importantly, allowed the system to steer the beam to compensate for rail wear. A 3D record of defect position was obtained. Software was developed which enabled the identification of the location of defects, while ignoring low amplitude noise. Speeds of up to 16km/hr were obtained with this system, limited by the nature of the research instrumentation which was used. The use of faster electronics would allow trials to be carried out at higher speeds.

A signal from the eddy current system was used to detect the extent and shape of the rail wear. This was used to steer the phased array transducers so that the energy always interrogated the full rail head, web and centre of the rail foot.

3 Eddy currents

The eddy current sensor assembly was developed and manufactured by Technitest. This consists of a total of four probes, one pair of which are designed to detect surface breaking fatigue cracks in the centre of the rail head and the other pair of probes are designed to detect gauge corner cracking. Each pair of probes consists of an absolute probe, sensitive to changes in lift-off and a differential probe sensitive to defects. All four probes are positioned in a single housing which is contoured to suit the rail head.

The system is capable of detecting surface breaking defects at all orientations and it provides some information on defect size. Successful trials were carried out at up to 80km/hr.

4 Magnetic flux leakage

Sonatest developed a flux leakage system with six probes across the width of the rail. The system was non-contact, with permanent magnets generating the magnetic flux. Trials were carried out at up to 80km/hr, clearly demonstrating that the system reliably reported major defects of depth 4-5mm or deeper, while not reporting surface blemishes and minor defects of depth 1-2mm.

5 Radiography

In addition to train mounted sensors, the project investigated the use of digital radiography for the inspection of aluminothermic welds. This technique would not be deployed from a moving vehicle. The results have shown that the CIT system which was used is relatively portable and reduces environmental ionising radiation exposure for a given radiograph. Digital radiography can be used instead of conventional radiography for picture storage without any degradation in the stored image resolution. The technique was found to have potential benefits in speed of application and was particularly applicable to thinner sections of the rail.

6 Data fusion and presentation of results

By combining the results of the techniques, their complementary features can be highlighted to useful effect. For example, if a defect is detected in the rail head by the eddy current system, but is not detected by the magnetic flux system, it will be known that the defect is likely to be less than 5mm deep. Such a defect may not require immediate attention, but its presence can be fed into a regime of planned maintenance.

7 Conclusions

A prototype system for rail inspection from a moving train has been developed and tested at speed. Its novel features include the use of phased array ultrasonics and other NDT techniques which, together, provide a comprehensive examination of the rail cross-section, even in cases where the rail is substantially worn.

8 Acknowledgements

The authors wish to thank all the partners in the Rail-Inspect consortium for their contributions to the work described and for their permission to publish this paper: Sonatest (UK), Computerised Information Technology (UK), Imasonic (France), Isotest (Italy), Tecnitest (Spain), Zenon (Greece), TWI (UK) and Technical University of Sofia (Bulgaria).

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Safe Vehicle Structures
A Guide to Current Practice

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Project Co-ordinator:	Bombardier Transportation
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Approval Signatures:-

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Introduction to Trainsafe

The **TRAINSAFE** project, funded by EU FP5, began on 1st January 2002 running for 30 months ending on 30th June 2004. It deals with the questions of rail transport passive safety.

TRAINSAFE aims are to:

- Enhance safety standards within the rail industry.
- Improve global system safety through vehicle research, procedural systems analysis and training.
- Integrate the land transport industries by cross-fertilisation and full co-operation between researchers, systems integrators and suppliers.
- Recommend innovative research (leading to individual proposals), priorities for future research actions and identify (virtual) centres of excellence.

The **TRAINSAFE** network considers all forms of rail transport: passenger, regional, high speed, metro and light rail (trams) systems. It will identify new priorities for safety in the rail industry.

The **TRAINSAFE** thematic network improves the exchange of information and experience between Partners and Members and transfers knowledge and best practice within the various sectors. The project identifies gaps in European research infrastructure compared with actual and future requirements and with other geographical regions. The aim is to achieve the development of the partnership for future research, industrial and infrastructure cooperation.

Information on the project and papers on other topics relating to Railway Passive Safety together with links to the expert group, Centre of Excellence, can be found on the web site www.trainsafe.net.

Contents

1 Safe Vehicle Structures Conference

TRAINSAFE held a two-day conference on Safe Vehicle Structures from 27th – 28th April 2004, at the Belfry Hotel, near Birmingham, UK. The aim of this conference was to bring together members of the **TRAINSAFE** consortium from across the EU, to discuss and share their current knowledge of safe vehicle structures and to identify the priorities for future research activity.

The workshop was attended by 29 delegates, from eight European countries: the Czech Republic, Finland, France Germany, Italy, Portugal, Spain and the United Kingdom. The delegates represented a diverse range of voices from across the rail industry: rail safety experts; rail vehicle manufacturers; academics; rail operating companies; and rail consultants.

Four workshops were held during the conference, addressing the following topics:

- **Energy Absorption**
- **Survival Space Integrity**
- **Vehicle Interface Safety**
- **Derailment Protection**

Prior to each workshop, one or two papers were presented on the topic.

During each workshop, delegates were asked to discuss the topic by answering five questions:

1. What are the critical safety issues (relating to the topic)?
2. What are the issues relating to Standards?
3. What are the overall recommendations for addressing the critical passive safety issues identified in question 1?
4. What are the business benefits in addressing the critical passive safety issues identified in question 1?
5. What are the priorities for future research activity?

The output gained from answering the five questions was then presented to the conference.

The aim of this report is to provide in-depth details of each workshop discussion. Chapter 2 provides background information that is relevant to all topics. Chapters 3 to 6 deal with each topic in turn (Energy Absorption, Survival Space Integrity, Vehicle Interface Safety, and Derailment Protection). Following a brief introduction to the topic the salient inputs to the workshop are described. The inputs include current Standards, the TRAINSAFE State of the Art Report and the papers prepared by the conference presenters. The results of the workshop topic discussion are then presented in the workshop output section. Each chapter ends with two highlighted tables, which give:

- The **TRAINSAFE** consortium's main recommendations
- Details of the priorities for future research activity

Chapter 7 of the report gives details of the business benefits that should result from addressing the critical safety issues identified for each topic. Chapter 8 of the report summarises the main conclusions from each topic.

It is hoped that from the recommendations given in this report, new research programmes can be set in place which will improve the safety of rail vehicle structures, while providing real business benefits to the EU rail industry .following conclusions:

- Controlled structural collapse to absorb energy was feasible
- The required design tools were available
- A crashworthy cab specification, covered by UIC regulations, could be defined for future vehicles.

However, the UIC member railways could not agree on the merits of the recommendations and they have never been incorporated in UIC Codes, [1].

Technical Specifications for Interoperability (TSIs)

There are plans to introduce both High and Low Speed Technical Specifications for Interoperability across Europe. These standards will apply to new rolling stock, but will not be enforced retrospectively on existing stock, [1, 2].

Work on the High Speed interoperability standard is complete. The main collision scenarios mandated are:

- Train into train collision at 36 kph
- Train into heavy truck on a level crossing at 110 kph
- Train into 80 tonne buffered wagon at 36 kph.

It must be demonstrated that under these collision conditions, driver and passenger survival space is preserved.

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For each European member state the relevant Operating Safety Authority will decide which scenarios are applicable to the rail vehicle in question taking into account its future operating environment. The Authority will determine the limiting case (i.e. collision speed) for each applicable scenario.

In addition the following essential vehicle requirements are stated:

- Resistance to anti-climbing shall be provided at all interfaces
- Collision energy shall be absorbed in a controlled manner
- Passenger and crew survival space shall be preserved
- Maximum deceleration levels within survival spaces shall be in the range 5 to 8g.

1.1 SAFETRAIN Project

The SAFETRAIN project was a 4 year project with a budget of €4.5M. Funding was provided by the European BRITE initiative. Train operators, universities, consultants and manufacturers all contributed to the project. The work programme included accident analysis, computer modelling, prototype design and validation testing. The Safetrain project, [1], produced the following conclusions:

- The impact speed in most train to train collisions is below 50 kph
- Collision risks vary from country to country
- In some countries level crossing collisions with heavy trucks are a major risk
- The technology currently exists to design, simulate and validate the behaviour of crashworthy vehicles.

1.2 References

[1] Sutton A. "Vehicle Crashworthiness" Keynote Presentation, TRAINSAFE Safe Vehicle Structures Conference, April 2004

[2] TRAINSAFE Thematic Network "Passive Safety in the Railways: A State of the Art Review", December 2003

2 Energy Absorption

2.1 Introduction

Energy absorption devices improve the crashworthiness of colliding vehicles in several ways. Firstly, and most obviously, they dissipate kinetic energy. Secondly they limit the forces transferred to the occupants. Thirdly, they help control the stability of the rake of vehicles.

Modern rail vehicles, built to current crashworthiness standards, typically incorporate a range of features that absorb energy during an end-on collision. These include:

- Central couplers
- External energy absorbing devices
- Internal structural collapse zone

Typically, the central coupler is the first component that makes contact during a collision. The coupler is thus ideal as a first stage energy absorber. Modern couplers contain both a reversible or elastic energy absorbing element as well as an irreversible or plastic energy absorbing element. Modern couplers are capable of absorbing all the energy associated with light collisions thus reducing vehicle repair costs.

Energy absorption devices may also be incorporated into other external components e.g. buffers, ribbed front plate anti-climbers.

Rail vehicles are built to withstand specified proof loads. When a vehicle is subjected to loadings above these proof loads, the structure should collapse in a controlled, predictable and safe manner. Significant amounts of energy may be absorbed by these internal collapse zones. Many vehicles use square section steel tubes as internal energy absorbers, typically wall thicknesses are in the region of 2 to 5 mm.

In severe collisions, bodyshell materials should absorb as much energy as possible through plastic deformation. In order to optimise energy absorption, joint failure should not occur. If premature joint failure occurs, the scope for absorbing energy is vastly reduced.

2.2 Energy Absorption – Workshop Input

The High Speed TSI, [1], prescribes a maximum deceleration level of 5g. To ensure that this level of acceleration is experienced by all passengers and crew it is necessary to absorb energy in front of the driver. The length of energy absorbing element and hence the length of the cab required is dependent both upon the collision speed and the stroke efficiency of the energy absorber, [2].

A square section mild steel energy absorber typically has a stroke efficiency of 70%. The stroke efficiency is defined as the collapse distance divided by the original length. It is worth noting that it is possible to construct energy absorbing elements using composite materials that have a stroke efficiency of virtually 100%. However, the problem with composites is understanding and validating the material ageing effects within the rail environment.

There is currently an ongoing debate concerning the collision speed which rail vehicles should be designed to. The current High Speed TSI requires a collision speed of 36 kph; the SAFETRAIN project recommended a collision speed of 55kph and one UK operator has recently requested a design collision speed of 120kph. Assuming traditional metallic elements, energy absorber lengths of 0.36, 0.85 and 4.05m respectively would be required.

For certain types of short nosed vehicle, some of these lengths are not acceptable due to operational considerations. For these cabs one solution is to absorb energy both in front of and behind the driver whilst maintaining the volume of a survival zone for the driver. The driver's desk seat module is required to move backwards as the structure behind the driver's survival space collapses. This concept was tested recently as part of the SAFETRAIN project. It should be noted that this concept allows the driver to experience accelerations greater than the allowable 5g. An air bag system could be used as a secondary means of adding further protection for the driver, [2].

The process of crashworthiness design is complex for the case of multi purpose locomotives, driving trailers and passengers coaches used in multiple combinations. Optimising the crashworthiness of these rakes involves absorbing a substantially higher proportion of the collision energy at the leading vehicle ends compared to the intermediate vehicle ends. Thus the design of locomotives and driving vehicle trailers is most important when considering the crashworthiness of flexible multi-purpose rakes.

With these facts in mind Bombardier has recently designed two new crashworthy TRAXX locomotives. The first is a dual frequency Class 185.2 for Deutsche Bahn (German Railways). The second is a multi-system Class Re 484 locomotive for Swiss Railways (SBB). Both are 5.6 MW locomotives with a top speed of 140kph, a starting tractive effort of 300kN and a mass in the range of 85 tonnes.

The crashworthiness features have been incorporated into the structure of the carbody as far as practicable in order to minimize additional weight. The protection for the driver during high speed collisions with other rail vehicles or other large obstacles has been increased and the likely repair costs after low and medium speed collisions have been reduced.

The main energy absorption features of the new Bombardier TRAXX locomotives are described below:

1st Stage — Buffers with an elastomeric spring system, incorporating approximately 0.06MJ of energy absorption per vehicle end.

2nd Stage — Screw-mounted external deformation elements (EST Duplex G1.A1) mounted in front of the head stock, incorporating approximately 1.7MJ of energy absorption per vehicle end.

3rd Stage — Designated collapse zone located in the front part of the drivers cab incorporating approximately 3MJ of energy absorption per vehicle end.

The collapsible front area of the driver's cab is designed as a protective cage consisting of sections of strong beams with deformation zones and plastic hinges between them.

The crashworthy design of the TRAXX locomotive was developed using computer simulation. The computer models were verified at a recent test performed at CNTK in Poland. A test with a closing speed of 62kph and collision energy of 4.5MJ was successfully conducted. Finite element model predictions were found to match well with the actual test results, [3].

2.3 Energy Absorption – Workshop Output

Critical Issues

The critical issues relating to the topic of energy absorption are summarised below:

When determining the energy absorption characteristics of rail vehicles, it is important to consider the rake of vehicles as a whole rather than individual vehicles. There is currently little information available regarding the dynamics and stability of rakes during high speed collisions. It is possible to use kinematic analysis software (e.g. ADAMS) to model colliding rakes of vehicles, but many parameters need to be carefully defined if the results are to be believed. Flange-climbing resistance, jack-knifing resistance, vehicle mass, inertia & stiffness properties and coupler properties are just a few of the required parameters. It is believed that with the technology that is currently available, it should be possible to accurately predict the onset of rake instability during a collision or derailment. It is considered however that currently it is not possible to predict what happens to individual vehicles after a rake has gone unstable.

When calculating the kinetic energy of a rake of vehicles, it is important to consider the effective mass at the point of impact which will be less than the total mass. At every interface, some of the effective mass will be lost due to the flexibility of the coupling system. Further whilst the rake remains stable the effective mass will be greater than after the rake has gone unstable. It is believed that with the technology that is currently available, it should be possible to accurately predict the onset of rake instability during a collision or derailment. It is considered that currently it is not possible to predict what happens to individual vehicles after a rake has gone unstable.

The infrastructure as well as vehicle structures may be used to absorb energy. In many accidents the ballast has dissipated significant amounts of kinetic energy. The ability of the ballast to absorb energy is considered to be significantly greater if the bogies remain attached to the vehicle.

Standards should define performance objectives. These should be performance based and should not be overly prescriptive. It is noted that this is notoriously difficult to achieve in practice, for example, the CEN working group TC 256 WG 2 has failed to date to determine a concise definition for mean-deceleration.

Future standards should take into account the fact that the railway is changing new signalling systems and automatic train protection systems (e.g. ERTMS) are being introduced. These systems will change the nature of future accidents.

Standards should also describe in detail the allowable methods of validating designs.

Standards must ensure that economically viable solutions are available.

Recommendations for addressing the energy absorption critical issues

The TRAINSAFE consortium recommends:

1. That standards should define performance objectives they should not be uneccesarily prescriptive.
2. That standards should enable the rail industry to utilise modern and innovative design and construction methods.
3. That standards should take into consideration operational requirements for short nosed cabs. For these types of vehicle it is sometimes impossible to achieve a mean deceleration level of 5g in the driver's zone.
4. That standards should consider all categories of rail vehicle and should cater for collisions between different types of vehicle.
5. That standards should consider bogie and underframe equipment attachment loads during collisions.

Recommendations for future research activity into energy absorption

1. Understanding future rail and control systems, and how this may influence accidents
2. Understanding the behaviour of suitable composite materials including their degradation in the rail environment
3. Research into asymmetric crashes and rake instability
4. Research into software parameters (vehicle and inter-vehicle)
5. Gathering of data on joining methodologies to improve FE modelling techniques

2.4 References

[1] High Speed TSI

[2] Roberts J. "Energy Absorption is Prescription Constructive?", TRAINSAFE Safe Vehicle Structures Conference, April 2004

[3] Carl F. "Locomotive Energy Absorption", TRAINSAFE Safe Vehicle Structures Conference, April 2004

3 Survival Space Integrity

3.1 Introduction

Historically, the biggest cause of fatalities in rail accidents is loss of survival space. In simple terms, these fatalities are caused when the space or volume occupied by a person is significantly reduced. Modern rail vehicles are constructed such that designed-in energy absorption is located at vehicle ends away from where passengers are normally located. The area between the crush zones, the passenger survival space, should be designed to be significantly stronger than the collapse zone in order to best maintain the volume of the survival space.

As well as maintaining the volume of passenger survival space, it is important to maintain its integrity. The bodyshell should prevent accident debris from entering the passenger area and the bodyshell should prevent passengers from being ejected.

It should be noted that bodyside windows are particularly vulnerable since they are relatively easily broken during accidents.

If the integrity of the passenger survival space is to be maintained during an incident, then it is crucial to maintain the integrity of the bodyshell joints.

In the majority of accidents the train driver is most at risk. Therefore, particular attention should be paid to the maintaining the volume and integrity of the driver's survival space.

3.2 Survival Space Integrity – Workshop Input

Level Crossing Collisions

In Europe the most frequent type of accident involving casualties occurs at level crossings. The most serious level crossing incidents involve trains colliding with heavy obstacles such as trucks, buses and tractors. Considering both the frequency and severity of this type of collision it is one of the major risks. In many European countries, the number of accidents of this type is increasing as road traffic increases. Further, this type of accident is difficult to mitigate against using active safety methods. For example, the implementation of automatic train protection systems (e.g. ERTMS) will not protect trains from this type of accident.

Real life collisions with heavy obstacles on level crossings have been found to differ significantly from theoretical collisions with rigid walls. The major reasons for the differences are listed below:

- Heavy obstacles such as trucks impact rail vehicles above the underframe. Therefore energy absorption devices that are located at underframe level are not activated during this type of collision.
- In a typical level crossing collision, between 1.5 MJ and 2.5 MJ is absorbed by the rail vehicle. This tends to be about 80% of the total energy absorbed. The remaining 20% is absorbed by the heavy obstacle.

- During level crossing impacts, the heavy obstacle tends to roll towards the train cab. This increases the risk of the front windows being pushed into the driver's survival space.

SNCF have studied three level crossing collisions in detail:

- On 31st March 1999, a train travelling at 125kph impacted an aluminium lorry carrying a pay load of wheat (mass, 33 tonnes) on a level crossing near Neuillé-Pont-Pierre.
- On 2nd May 1995, a train travelling at 110kph impacted a steel lorry carrying a pay load of sand (mass, 39 tonnes) on a level crossing near Morcenx.
- On 8th September 1997, a train travelling at 115kph impacted a fuel tanker (mass 29 tonnes) on a level crossing near Port-Ste-Foy.

SNCF engineers constructed detailed finite element models of the leading rail vehicles and the heavy obstacles involved in each of the above three collisions. The three collisions were then simulated using dynamic non-linear finite element analysis. The results of the simulations were verified by comparison with the damage incurred during the actual collisions.

Since conducting analyses using detailed finite element models of trucks is a costly and time consuming method of developing crashworthy rail vehicle designs, SNCF wished to develop a simplified heavy obstacle model that would cause similar levels of damage to the detailed truck models. To this end SNCF have developed a numerical deformable obstacle that consists of a steel tube filled with honeycomb. The simplified obstacle model has been extensively tested its performance has been verified against the performance of the detailed truck computer models, [1,2].

Missile Protection

Drivers are particularly at risk from missile penetration. In the UK in one year alone (1996/1997) 468 incidents of damage to cab windows were reported. 87% of these incidents were deliberately caused by vandals. Rail vehicles also require overhead protection to guard against objects being dropped from over bridges, [3].

The UK standard GM/RT2100, [4], includes the following clauses that mitigate against local impact penetration:

- The roof should resist against a 100kg concrete cube dropped from 1m.
- The front window should resist a 0.9kg hollow steel cube travelling at 220kph (137mph) if the train travels at speeds below 130kph (81mph) and 410kph (255mph) if the train travels at speeds up to 299kph (186mph).
- The cab structure below the front window should resist the penetration of the above cube travelling at a speed that is twice the operational speed of the vehicle.
- Side windows should resist against a 0.25kg steel ball travelling at an impact speed of 100kph (62mph) for laminated glass and 50kph (31mph) for toughened glass.

In Germany the front window is tested with 1kg steel balls travelling at 200kph plus the maximum speed of the vehicle.

3.3 Survival Space Integrity – Workshop Output

Critical Issues

The critical issues relating to the topic of survival space integrity are summarised below:

During a collision or derailment it is important to maintain the volume of the passenger area. It is important to guard against ingress by accident debris and to guard against passengers being ejected.

Windows create additional risks during accidents. Windows are relatively easy broken debris can then enter the vehicle or passengers can be ejected. Laminated glass is less easily broken than toughened glass but laminated glass windows cannot readily be used as emergency exits. Therefore, there is a compromise between structural integrity and ease of egress. The resolution of this compromise may be different for different train types. For example, on underground trains escape through the bodyside windows is usually not possible due to the tunnel wall, therefore laminated glass is more preferable. In addition it important to consider the strength of the window fixing as well as the glass itself. For example it is important that the driver's window frame is adequately attached to the cab structure, otherwise the window may become detached and compromise the driver's safety.

The bodyshell should be designed to cope with bodyside and roof impact loads as well as end-on loads. Bodyshells should also be designed to cope with vehicle roll-over.

In order to cost-effectively improve the structural integrity of rail vehicles it is necessary to study real incidents throughout Europe. The incidents can then be categorised and the frequency and severity of each category can be determined. This will allow the most significant risks to be identified and mitigated against through design improvements. ERRI conducted this type of research for the period 1991 to 1995.

Issues Relating to Standards

The survival space integrity issues relating to standards are summarised below:

There is no European wide standard that considers the following issues:

- Roof impact loads
- Bodyside impact loads
- Vehicle roll-over loads
- Driver front window retention loads

Collision scenarios contained within standards need to utilise deformable obstacles rather than rigid obstacles. Therefore deformable obstacles need to be agreed and carefully defined.

Standards currently make no mention of the expected performance of rail vehicles beyond the design collision speed. It is desirable to ensure that there are no cliff edge effects i.e. the performance of a crashworthy design should not suddenly deteriorate once the design collision speed has been exceeded. Performance should degrade progressively as the speed increases.

Standards should adequately take into account collisions between dissimilar vehicles. For collisions between vehicles of significantly different mass it is important to consider force as well as deceleration.

Maintaining the integrity of the driver's survival space is a complex issue since energy absorbing collapse zones are located directly in front of the driver. If the driver's survival space is to be maintained it is important for the design to take into account the relative movements of the driver's desk, the front window and the driver's seat.

Recommendations for addressing the Survival Space Integrity critical issues

The TRAINSAFE consortium recommends:

1. That analysis is carried out into "real" accidents to identify the most important issues relating to survival space integrity
2. That guidance is produced specifying preferred vehicle behaviour, beyond the existing design collision scenarios.
3. That suitable standards are produced as soon as is reasonably practicable

Recommendations for future research activity into Survival Space Integrity:

1. Production of a survey of accident analyses, updated and extended to include data from new member states when and where it becomes available.
2. Driver protection, especially the driver-seat-desk interface, and the possible use of airbags.
3. Collisions between dissimilar vehicles – for example locomotives, freight trains and light weight commuter vehicles.
4. Human behaviour issues within cabs
5. Non end-on impacts – for example side swipes and roll-over incidents

3.4 References

[1] Jumin P. and Leveque D. "An Example of the Experience Return: The Equivalent Deformable Obstacle", TRAINSAFE Safe Vehicle Structures Conference, April 2004

[2] Aînoussa A. "A Discussion of the Level Crossing Collision and Train to Train Collision Scenarios", TRAINSAFE Safe Vehicle Structures Conference, April 2004

[3] TRAINSAFE Thematic Network "Passive Safety in the Railways: A State of the Art Review", December 2003

[4] UK Railway Group Standard, GM/RT2100, "Structural Requirements for Railway Vehicles", Issue 3, October 2000

4 Vehicle Interface Safety

4.1 Introduction

In passive safety terms, vehicle interface systems are of primary importance. If appropriately designed, they can help to control the dynamics of the collision or derailment thus enabling other passive safety features to play their role. Rail vehicle crashworthiness designers aim to ensure that rakes remain upright, in-line and on the ground for as long as possible during a collision or derailment. Section 4.2 below begins by deriving desirable passive safety characteristics from this philosophy. Essentially this is a list of the passive safety features needed by a vehicle interface system in addition to the required operational features. Section 4.2 continues by comparing the designs of existing vehicle interface systems (buffers, couplers and anti-climbers) to the derived passive safety characteristics. Where shortfalls are identified, design modifications to existing vehicle interface systems are considered.

4.2 Vehicle Interface Safety – Workshop Input

Vehicles Should Remain Upright

The belief that vehicles should remain upright leads to the passive safety characteristic that vehicle interface systems should provide rotational restraints between vehicles. Thus if an overturning moment is applied to one vehicle in a rake the moment may be resisted by the mass and inertia of the other vehicles in the rake.

Clearly, if the overturning moment is large enough, there is a risk that the whole rake will overturn. This risk is dependent upon the number of vehicles in the rake so it is necessary to consider whether this design requirement should apply to short rakes of two or three vehicles.

This characteristic is also related to bogie retention; rail vehicles are considerably more likely to remain upright if their bogies remain attached, [1].

Vehicles Should Remain Connected

The belief that vehicles should remain connected leads to the passive safety characteristic that vehicle interface systems should be strong in both tension and compression since during a collision or derailment both types of forces can develop at vehicle interfaces. The compressive proof strength of the vehicle interface system is required to be a little less than that of the crush strength of the vehicle ends. This is to ensure that damage is sustained by the vehicle's interface system, in preference to the vehicle body.

The tensile strength requires more careful consideration. One could argue that the requirement should be as great as practicable to ensure connectivity between vehicles. Hence, it is again necessary to take into consideration the strength of the vehicle body since it is generally more preferable to have the vehicle interface fail rather than the bodyshell. However, there is also an alternative argument that states that in some instances the tensile failure of an interface is inevitable. On these occasions, it may be argued that it is preferable for the interface to fail sooner rather than later. For example, during the Potters Bar, UK derailment the fourth trailing vehicle became detached from the leading three vehicles. This coupler failure probably occurred when the fourth vehicle impacted a bridge parapet.

Because of the coupler failure, the leading three vehicles were able to continue on the rails until they came to rest some 500m later. As a result, no injuries were sustained in these vehicles. Had the coupler failed at a significantly higher load then it is likely that the leading three vehicles would have also been derailed. This may have led to all four vehicles being significantly damaged, and hence additional injuries, [2].

Vehicles Should Remain In-Line

The belief that vehicles should remain in-line leads to the requirement that the vehicle interface system should resist jack-knifing. Most couplers do utilise side control units which limit the lateral rotation of the coupling system and hence the relative rotation between adjoining vehicles. However, further work is required in order to determine the magnitude of the force that may be applied to these side control units during a collision or derailment. It may prove impractical to rely solely on the coupler system during high speed events. Other independent methods of transmitting the required moment may be devised.

Vehicles Should Remain on the Ground

The belief that vehicles should remain on the ground during a collision or derailment leads first to the requirement that the vehicle interface system should prevent overriding and secondly to the requirement that the vehicle interface system should help prevent vehicles from becoming temporarily airborne. The dangers of vehicles becoming temporarily airborne were highlighted during the Great Heck, UK accident; significant loss of survival space and fatalities resulted from airborne vehicles landing on top of the other vehicles, [3]. One of the causes of the vehicle interfaces becoming airborne is believed to be the compression wave that travels down a rake following a head-on collision. The compression wave is analogous to the wave that can be made to travel down a rope when one end of the rope is moved rapidly.

Past research has tended to focus primarily on the prevention of override, thus a lot less is currently known about the mechanism which cause vehicles to become temporarily airborne. Thus it is not known whether any existing vehicle interface system is particularly successful at preventing vehicles from becoming airborne during high speed collisions.

Buffers

The problem with buffers is that they tend to increase the propensity of vehicles to override. During a collision the piston has a tendency to deform plastically close to its connection with the buffing plate. This allows both buffing plates to rotate. The lower buffing plate thus forms a ramp over which the upper buffing plate is able to slide. The curved shape of the plates means that only a very small initial vertical offset is required. In this manner, one vehicle underframe is able to climb on top of the other, [4].

Buffers have been shown to be capable of inducing override even at relatively low speeds. For example, in 1962 at Coppenhall Junction, UK a diesel locomotive impacted the rear of a rake of electrically hauled Mark 1 (all steel) passenger vehicles. The collision speed was believed to be only 10 km/h (6 mph). Due to the impact the two rear Mark 1 vehicles overrode one other killing 18 passengers and seriously injuring 34, [5].

Side buffers are not the only concern; research has shown that certain types of vestibule buffers can also increase the propensity of vehicles to override, [4].

There is a need both to prohibit the use of side buffers on new vehicles and to review all instances where side buffers are still in use. The risk should be appropriately evaluated.

The presence of side buffers also prevents serrated front plate style anti-climbers from being fitted. However perhaps it is possible to turn this apprarent design conflict into a design opportunity. Many side buffers are only used for shunting operations in the depot or for vehicle recovery. It therefore should be possible to design a novel system that combined the two functions.

Many freight wagons still use draw hook and side buffers. The cost and benefit of replacing these with a more modern type of central coupler should be investigated. At freight wagon intermediate interfaces there is no risk to passegers due to overriding. In fact one might imagine some cargoes to be efficient energy absorbers. This is acceptable if the freight wagon is carrying a hopper full of coal, but not if it is carrying a flammable liquid or a nuclear waste flask.

Couplers

In the majority of head-on collisions the central coupler is the first component to be impacted. Furthermore, at intermediate interfaces, the coupler is the only permanent structural connection between vehicles. For these reasons the central coupler has an important role during the early stages of collisions and derailments.

Many modern couplers contain capsules which are able to absorb energy in an irreversible manner. The use of these capsules has several benefits:

- Firstly, in a light collision they may be able to absorb all the kinetic energy of the collision thus preventing costly bodyshell damage.
- Secondly, the capsules reduce the initial peak of the deceleration pulse transmitted through the rake.
- Thirdly, as the capsule absorbs energy the length of the coupler decreases this brings the two vehicle ends closer together, thus allowing other safety features, for example, serrated front plate style anti-climbers, to contact one other and play their role.

Since the coupler is the only permanent structural connection between vehicles, the job of providing roll over restraint naturally falls to the coupler. Thus the torsional moment carrying capacity of the coupling system, including its connection to the vehicle body should be greater than the moment required to roll a vehicle. Alternatively, it may be possible to develop other methods of transmitting torsional loads between vehicles.

It is worth noting that the locking mechanism for coupler heads should be robust. It should be ensured that couplers do not un-lock if vehicles do overturn or become airborne. For example, the locking mechanism should not rely on gravity.

Anti-Climbers

Anti-climber is the term given to a device or system that allows vertical forces to be transmitted between adjacent vehicles during a collision or derailment. Current UK Standards, [6], require anti-climb devices and their supporting structure to be capable of transmitting 100kN. This requirement was derived from the study of relatively low speed impacts, i.e. less than 48kph (30mph). However further research is needed to determine the vertical forces that are likely to be developed between vehicles during a higher speed impact. Initial research using two-dimensional mass & spring modelling has indicated that the vertical forces developed can rise as high as 1MN, for short durations, [7].

Serrated front plate anti-climbers are a common form of anti-climber. Typically for each vehicle end they consist of two horizontally ridged square plates. The plates are connected to the headstock at approximately the location of the buffers on older stock.

Modern rolling stock uses this type of anti-climber at the leading ends and occasionally at the intermediate interfaces. There are several concerns with this type of anti-climber:

- Firstly, there are no standards controlling the precise height and transverse location of anti-climbers. Thus if two different vehicle types are involved in a head-on collision, it is unlikely that either of their anti-climbers will be effective. Furthermore there are no standards controlling either the pitch or the shape of the serrations.

- Secondly, because the serrations run in a horizontal direction they cannot control any lateral forces that develop during an incident. Engaged anti-climbers are free to slide over one another laterally. Thus this type of anti-climber is not capable of maintaining lateral alignment. In addition, if there is a vertical offset present between the engaging anti-climbers this offset will remain constant.

A cup and cone style of anti-climber can correct and then control the level of vertical and lateral misalignment between colliding vehicles. When each cup and cone is fully engaged the two vehicle underframes will be perfectly aligned. This issue is important since the underframe usually contains most of the energy absorption capacity of the vehicle end. With the underframes aligned the collapse will be axial and more energy should be absorbed.

A disadvantage of the cup & cone style anti-climbers is that unlike serrated front plate style anti-climbers they cannot easily be designed to include energy absorption.

Many modern vehicles use the coupler to provide anti-climb restraint at intermediate vehicle ends. Vertical anti-climb forces are transmitted from the coupler interface through the coupler and into the vehicle end. This option usually requires local strengthening of the headstock coupler aperture (letterbox).

This method benefits from the fact that during a collision or derailment no pre-requisites are required before it can begin to work, i.e. the method does not rely on the coupler system reducing in length and the vehicle ends coming together unhindered. The method does however allow some relative vertical movement between vehicles; this is required for normal operation, [8].

Median or Spanning Bogies

The French TGV utilises median bogies, each of which supports the ends of two adjacent vehicles. This type of vehicle interface removes the need for buffers, couplers and anti-climbers. The connection between the two adjacent vehicles is able to articulate (i.e. rotate about the vertical axis) but all other degrees of freedom are restrained. Because adjacent vehicles are connected by a bogie and not by a coupler the connection is naturally strong in both tension and compression. The system also counteracts the rotation of the bodyshell around the trainset axis, thereby significantly reducing the likelihood of any vehicle rolling. In addition, the system is resistant to jack-knifing. Thus the rake is much more likely to stay upright, connected and in-line during a collision or derailment.

The main disadvantage of this system is that energy absorption capacity can only be located at the leading ends of the rake. No energy absorption will occur at the intermediate ends.

4.3 Vehicle Interface Safety - Workshop Output

Critical Issues

The critical issues relating to the topic of vehicle interface systems are summarised below:

It is important to understand the risk associated with each desirable passive safety characteristic:

- Vehicles should remain upright
- Vehicles should remain connected
- Vehicles should remain in-line
- Vehicles should remain on the ground

The delegates of the Safe Vehicle Structures Workshop believe that the most significant risk is associated with overriding. Overriding is considered a subset of the characteristic that vehicles should remain on the ground.

Overriding has long been recognised as a significant risk: many different methods (e.g. anti-climbers) of mitigating the risk have been designed and implemented. The problem is that often these methods are often incompatible with each other. In general terms if two similar trains collide the risk of overriding is mitigated but if two dissimilar trains collide the risk is not mitigated.

There is thus a need to identify a single solution that will mitigate the risk of overriding. The solution should be compatible with the majority of existing rolling stock.

It is beneficial to absorb energy at every interface along a rake of vehicles as well as at the leading end. This increases the net energy that can be absorbed in the event of a collision, and averages the deformation between vehicles. This technique is now commonly used in modern crashworthy distributed traction multiple unit vehicles. The formation of these rakes is normally fixed and thus the components of the vehicle interface systems can be tuned to achieve distributed energy absorption.

By contrast distributed energy absorption is more difficult to achieve for trains consisting of locomotives and conventional passenger vehicles. These rakes are usually not fixed formation and thus it is difficult to tune the vehicle interface system components for all combinations of vehicles.

A further topic for consideration with distributed energy absorption is the increased requirement for repairing multiple vehicles in the event of a collision.

Vehicle interface systems can help to control the vertical and lateral offset between impacting vehicle ends. These offsets can lead to instabilities in energy absorption devices thus significantly reducing the amount of energy absorbed.

Pre-Crash

The automotive industry is currently leading the way in terms of crash safety technology. The rail industry is trying to catch up. The objective is for the rail industry to be leading the way. An example of how the automotive industry is leading the way, together with an idea of how the rail industry might catch up, is given below.

The 2003 Mercedes Benz S-Class sedan was the world's first production car to be equipped with a new type of safety system. The system, named. 'Pre-Safe', can sense a possible collision up to 5 seconds before the actual impact and take pre-crash protective measures. If an impending collision is sensed the following safety measures may be taken:

- Tensioning of seat belts
- Adjustment of seats
- Closure of doors and sunroof

Mercedes have stated that in the future 'Pre-Safe' could include additional sub-systems such as extending bumpers, smart crumple zones or moveable interior door panels designed to help keep occupants further away from dangerous deformation zones. Radar, infrared or ultrasound technology could be used to monitor the vehicle's surroundings and measure the speed, angle and mass of an approaching object. If the object is a truck or van, the vehicle height could be raised to improve crash compatibility.

The pre-crash concept could, in the future, be applied to the rail industry. In rail collisions sensors should be able to sense a possible collision even further in advance than in the automotive industry. In the past many train drivers have sensed an imminent collision and made their way a considerable distance towards the back of the train before the occurrence of the collision. The technology for trains to detect derailment or large obstacles in their path should already be in existence. Sensors such as these could in the future be used to trigger some of the following functions:

- Reduction of the distance between rail vehicles
- Stiffening of yaw, pitch and roll dampers
- Extension of anti-climber mating faces (so they are closer to contacting)
- Extension of energy absorption devices to allow greater levels of energy absorption for a given length of vehicle end

Issues Relating to Standards

The vehicle interface systems relating to standards are summarised below:

Standards need to ensure that anti-climbers on different types of vehicle are compatible.

Standards should define in detail the method of validating anti-climber performance. The method of validation must consider the performance of the anti-climber when the underframes of the colliding vehicles are vertically and/or laterally misaligned. Anti-climbers should be designed to cope with pre-determined levels of vertical and lateral misalignment. These levels or a method of calculating these levels should be specified in the standard. For example the standard could set a performance based objective i.e. anti-climbers should engage 95% of the time.

It should be noted that tilting vehicles are likely to have higher maximum levels of vertical and lateral misalignment than conventional vehicles. Therefore it is likely to be more difficult to design robust anti-climbers for these vehicles.

Many modern couplers contain shear-out devices. During a collision these devices fail at a specified compressive load. The device allows the coupler's length to shorten, thus reducing the distance between vehicle ends. This distance reduction allows anti-climbers to engage. The issue is whether these couplers should be capable of transmitting tensile loads after the shear-out device has failed. It is known that during collisions, compression waves travelling down rakes are often followed by tension waves. This combination could lead to the rake becoming disconnected.

In addition it should be decided whether and in what manner standards should consider the following issues:

- Jack-knifing performance
- Overturning performance
- Energy absorption capacity
- Vertical shear strength
- Compressive loads

Recommendations for addressing the vehicle interface safety critical issues

The TRAINSAFE consortium recommends:

1. The CEN TC 256 WG2 should draft (leading and intermediate end) interface system safety performance standards.
2. That sufficient technical solutions already exist but a technical debate should be held to choose the optimum solutions to be included in the performance standards.
3. That the standards once implemented ensure operational functionality, interoperability and improved safety.
4. That full use should be made of the findings of the SAFETRAIN project and other previous research & development work.

Recommendations for future research activity into Vehicle Interface Safety:

1. Understanding the effect of vehicle interfaces on rake dynamics
2. The risks associated with each of the following should be evaluated: overriding, jack-knifing, rake separation, vehicle roll-over
3. Determination of methods to validate performance. These should consider, for example, lateral and vertical misalignment due to curves and tilting
4. The development of simple, efficient, realistic obstacle computer models
5. Investigation into the feasibility of pre-crash adaptable interface models
6. Investigation into the optimum method of providing rotational restraints between vehicles

4.4 References

[1] Bright A. “Vehicle Interface Safety (Buffers, Couplers and Anti-Climbers)”, TRAINSAFE Safe Vehicle Structures Conference, April 2004

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[5] Kichenside, G “Great Train Disasters” Parragon, 1997 ISBN 0-7525-2229-9

[6] UK Railway Group Standard, GM/RT2100, “Structural Requirements for Railway Vehicles”, Issue 3, October 2000

[7] Bell H. “Feasibility Study on Anti-Climbers for IC225 Rakes”, Atkins Report, Issue 1, April 2002

[8] TRAINSAFE Thematic Network “Passive Safety in the Railways: A State of the Art Review”, December 2003

5 Derailment Protection

5.1 Introduction

This chapter of the report considers the passive safety issues associated with derailment protection. The focus is on medium and small obstacles located on the track. A medium sized object is defined as one able to pass under a rail vehicles under frame (e.g. car or farm animal). Such an object will be of significantly less mass than a rail vehicle but may still be capable of causing a derailment. The risk of derailment due to a medium sized object is usually mitigated through the use of obstacle deflectors and/or minimum leading axle weights.

A small object (e.g. brick or stone) is defined as one that is able to pass under the obstacle deflector. The risk of derailment due to a small sized object is usually mitigated through the use of lifeguards.

5.2 Derailment Protection – Workshop Input

Obstacle Deflectors

The design objective for most obstacle deflectors fitted to leading rail vehicles is to address collisions with medium sized objects (e.g. farm animals or cars). These objects are capable of derailing vehicles through the lifting effect of the impact or through the influence of crash debris on the wheel / rail interface.

Of the EU member states, only France and the UK have official standards for the design and operation of obstacle deflectors (Railway Group Standard GM/RT2100, [1], “Arrêté du 5 juin 2000” and SAM C201). Annex L of the high speed TSI states that it is an “aspect not specific to high speed and for which notification of national rules are required”. No further reference to obstacle deflectors is made, leaving scope for a harmonized approach in this area, [2].

A particular design aspect of obstacle deflectors that is becoming increasingly important is their use in conjunction with tilting rolling stock. If the deflector is attached to the vehicle body, then the blade must be chamfered to prevent fouling with the rail head when the vehicle tilts. Thus the overall size of the blade is reduced and the gap between the blade and the rail is increased increasing the probability that an object is able to pass underneath the obstacle deflector and cause a derailment.

Lifeguards

The purpose of a lifeguard is to protect the wheel / rail interface from small debris that could cause a derailment. Lifeguards are usually bolted to the axle box, thus the environment in which lifeguards exist is from a vibration viewpoint hostile, since it is positioned below the primary suspension. The gap between the lower edge of the lifeguard and the rail head should ideally be no greater than the depth of the wheel flange. However, due to wheel wear the gap is often larger when the wheels are new. Lifeguards are typically designed to resist a proof load of 20kN and a transverse load of 10kN. In addition, lifeguards should be able to resist an ultimate load of 35kN during plastic deformation. Lifeguards should not be brittle and should deform in a way that will not foul the wheel / rail interface.

Despite these design requirements, there have been several derailments the cause of which has been attributed to the detachment of the lifeguards leading to fouling of the wheel/rail interface.

5.3 Derailment Protection – Workshop Output

Critical Issues

The critical passive safety issues relating to the topic of derailment protection are summarised below:

A good understanding of the wheel/rail interface is critical to the topic of derailment protection. For a given vehicle, it is important to be able to predict what magnitude of vertical and lateral force is required to initiate and then sustain flange climbing.

In the UK obstacle deflectors are designed and tested quasi-statically. However, real impacts between medium sized obstacles and obstacle deflector blades are dynamic events. It is therefore considered important to develop a cost effective method of verifying the dynamic performance of obstacle deflectors. When considering dynamic events, time is an important factor. When an object strikes an obstacle deflector the impacted object must be accelerated by the obstacle deflector up to the speed of the train over a very short period of time. The load applied to the deflector will be of high magnitude but short duration. A load pulse of short duration is considerably less onerous than a load pulse of equal magnitude and long duration.

If a deflector blade is raked forwards or backwards in side elevation, impact debris will either be forced downwards onto the track or upwards into the body structure, from where it could later fall. In both cases, debris would not be efficiently cleared and the risk of derailment would be increased. Experiments show that to minimise the risk, the deflector should be vertical and that the underframe forward of the deflector should be smooth to encourage sideways flow of debris. A slightly concave curvature, as in a snow plough, is acceptable. However, in practice there is an additional complexity. Obstacle deflectors are required to plastically deform under load therefore the blade may be vertical in elevation when unloaded but the blade may rotate and rake backwards as the blade is loaded. Guidance on this issue is required since the vertical force component required to rotate the blade may significantly increase the likelihood of derailment, [3].

The issue of push-pull rakes was highlighted following the Great Heck accident in the UK. During the accident a leading Mark 4 Driving Vehicle Trailer was derailed following an impact with a Land Rover. At the time the rake was being pushed by the significantly heavier Class 91 locomotive. Many people have asked the question, would the Class 91 have derailed had it impacted the Land Rover whilst pulling the rake? Clearly, heavier vehicles are more resistant to derailment but heavier vehicles have many other negative attributes. For example, they are less fuel efficient and they present a greater risk during impact with lightweight commuter type stock.

There is currently an ongoing debate as to whether it is safer to operate rail vehicles with or without lifeguards. Research is required in order to provide a robust and defensible answer to this question. If it is found that it is possible to operate rail vehicles more safely with lifeguards then best practice guidelines need to be made widely available.

Issues Relating to Standards

The derailment protection issues relating to the Standards are summarised below:

The draft crashworthiness Euro Norm, like the current UK standard, specifies a quasi-static test. There is some concern that a quasi-static test is not an appropriate means of verifying the performance of obstacle deflectors that in reality are required to deal with highly dynamic impacts.

It is believed that obstacle deflector requirements need to be relatively prescriptive, so that they are not left open to misinterpretation.

The Intergovernmental Organisation for International Carriage by Rail (OTIF) was established in 1985. Forty-two states from Europe, North America & North Africa are currently members. The organisation resides over about 240 000 km of rail road. The work of the organisation is carried out by several divisions, one of which is The Committee of Experts for the Carriage of Dangerous Goods (RID). The committee is responsible for the continuous development of regulations on this topic. From 2005 freight trains carrying dangerous goods through member states will be required to have a derailment detection system installed. Clearly the ongoing work of OTIF is a valuable source of information, [3].

Recommendations for addressing the derailment protection critical issues

The TRAINSAFE consortium recommends:

1. The production of an EU wide statistical review of obstacles to be found on and near railway tracks
2. Production of a state of the art report on incorporating, obstacle deflectors, lifeguards, axle weight, push-pull effects, wheel-rail interface issues and crosswind effects

Recommendations for future research activity into Derailment Protection:

1. Research to determine best practice for lifeguards
2. Research into onboard wheel disintegration detection systems
3. Research into the dynamic performance of obstacle deflectors
4. Research into the degradation of the wheel/rail interface leading to derailment (to be conducted in conjunction with the TRAINSAFE Infrastructure Cluster)
5. Research into the effects that the rotational stiffness of couplers has on the likelihood of derailments

5.4 References

[1] UK Railway Group Standard, GM/RT2100, "Structural Requirements for Railway Vehicles", Issue 3, October 2000

[2] TRAINSAFE Thematic Network "Passive Safety in the Railways: A State of the Art Review", December 2003

[3] UK Railway Group Guidance Note, GM/GN2560, "Structural Requirements for Railway Vehicles" Issue 1, October 2000

[4] OTIF, Organisation Intergouvernementale Pour Les Transport Internationaux Ferroviares, www.otif.org

6 Business Benefits

During the workshop discussion for each topic the following question was raised:

- What are the business benefits in addressing the critical safety issues?

The answers to this question were broadly similar across the four different workshops so are given here in one section.

Most importantly, it was thought that an improvement in rail safety, leading to fewer rail casualties and fatalities, would reduce insurance and litigation costs for train operating companies. Further safer trains are likely to have increased residual costs leading to increased revenue for rail vehicle leasing companies. Improving rail safety in general, would also improve the way that the rail industry is seen by the media. This could reduce the number and length of post-accident Public Inquiries. Improved safety could also reduce the costs arising from "bad press" – i.e. travellers avoiding the rail system because of safety fears and the resulting loss of revenue.

Intelligent crashworthiness designs should reduce repair costs and the mean time to repair. Some couplers and anti-climbers already contain replaceable energy absorption components. These and other external energy absorption devices protect the vehicle bodyshell from expensive damage during lower speed collisions. Bombardier has for several years designed vehicles with bolt-on crashworthy ends. These ends may be manufactured in mild steel even if the remainder of the bodyshell is manufactured from aluminium extrusion. If this type of vehicle is involved in a medium speed collision a new end may simply be bolted on.

Crashworthy vehicles collapse at a lower force than non-crashworthy vehicles. Therefore in a collision crashworthy vehicles are less aggressive and likely to cause less damage.

Harmonizing safety standards across Europe should lead to the harmonization of crashworthiness features. For example, currently there are many different designs of coupler and anti-climber. If the number of different designs is reduced then research & development costs will be reduced leading to a reduction in the cost associated with each device.

Improved derailment protection systems combined with a better understanding of the derailment mechanism will lead to fewer derailments. Derailments can cause significant damage to rail infrastructure. This is infrastructure is costly and time consuming to repair. The rail route may remain closed for a significant period of time this will affect the efficiency of the railway and reduce its revenue.

Finally, it was considered important that the current high level of safety seen on European railways compared to other forms of travel (i.e. road and air travel) should be aimed to be maintained and improved where possible, with reducing costs. Reducing the costs of maintaining and improving rail safety means that rail prices are lower for passengers and thus more passengers will use the rail system, which strengthens the EU economy.

Safe Vehicle Interiors
A Guide to Current Practice

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Acronym:	TRAINSAFE
Project Title:	TRAINSAFE – Pooling Knowledge To Promote Rail Safety
Project Co-ordinator:	Bombardier Transportation
Contractor:	Atkins
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Approval Signatures:-

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Introduction to TRAINSAFE

The **TRAINSAFE** project, funded by EU FP5, began on 1st January 2002 running for 30 months ending on 30th June 2004. It deals with the questions of rail transport passive safety.

TRAINSAFE aims are to:

- Enhance safety standards within the rail industry.
- Improve global system safety through vehicle research, procedural systems analysis and training.
- Integrate the land transport industries by cross-fertilisation and full co-operation between researchers, systems integrators and suppliers.
- Recommend innovative research (leading to individual proposals), priorities for future research actions and identify (virtual) centres of excellence.

The **TRAINSAFE** network considers all forms of rail transport: passenger, regional, high speed, metro and light rail (trams) systems. It will identify new priorities for safety in the rail industry.

The **TRAINSAFE** thematic network improves the exchange of information and experience between Partners and Members and transfers knowledge and best practice within the various sectors. The project identifies gaps in European research infrastructure compared with actual and future requirements and with other geographical regions. The aim is to achieve the development of the partnership for future research, industrial and infrastructure cooperation.

Information on the project and papers on other topics relating to Railway Passive Safety together with links to the expert group, Centre of Excellence, can be found on the web site www.trainsafe.net.

Summary

To minimise fatalities and injuries arising from rail accidents, it is important to know the common injuries that occur during an incident, and to relate the causes of these injuries to the dynamics of the rail vehicle interior and to the occupants during the incident. There are many factors that will contribute to the protection or otherwise of a rail occupant during an accident scenario. The design of the interior of the rail vehicle is one of the most important of these. Injuries will occur to the rail occupant through impact with some part of the vehicle interior, or through ejection from the vehicle. Therefore the interior must be carefully designed to minimise the force of any impacts between its fittings and its occupants, and must also be designed to contain passengers in the case of an accident. However, this need must be balanced with the need for egress from a rail vehicle in certain emergency situations.

The TRAINSAFE consortium held a conference on Safe Vehicle Interiors on 28-29 April 2004. 36 delegates were in attendance, from seven EU countries, representing different stakeholders in the EU rail industry. Four workshops were held during the conference, addressing the following topics:

- Injury Criteria
- Interior Design
- Occupant Dynamics
- Evacuation and Egress

Injury criteria are the tools used for linking the actual physical injuries sustained by a person as a result of an impact with an object, with an engineering appraisal of that impact. Interior design is concerned with passenger protection during an accident by crashworthy design of rail interior fixings, fittings and layouts. Occupant dynamics research involves simulating the trajectory of a rail occupant, and any subsequent impacts with rail vehicle interiors, after a rail accident such as a collision. Evacuation and egress is concerned with deciding whether or not passengers should evacuate a rail vehicle after an accident, and if so, providing them with the tools and escape routes to do so.

During each topic discussion, the critical issues facing the EU rail industry facing that topic were identified. Recommendations were made for addressing issues of Standards and the main way forward for the topic. The business benefits of addressing the critical issues in rail vehicle interiors were defined and priorities for future research in each topic were drawn up. This document provides current practice information for each topic and, most importantly, the Safe Vehicles Interiors conference workshop results and recommendations.

Contents

1 Introduction

TRAINSAFE held a two-day conference on Safe Vehicle Interiors from 28-29 April 2004, at the Belfry Hotel, near Birmingham, UK. The aim of this conference was to bring together members of the **TRAINSAFE** consortium from across the EU, to discuss and share their current knowledge of rail vehicle interiors and to identify the priorities for future research activity.

The workshop was attended by 36 delegates, from seven countries in the EU: France, Germany, Italy, the Netherlands, Portugal, Spain and the United Kingdom. The delegates represented a diverse range of voices from across the rail industry: rail safety experts; rail vehicle manufacturers; academics; rail operating companies; and rail consultants.

Four workshops were held during the conference, addressing the following topics:

- **Injury Criteria**
- **Interior Design**
- **Occupant Dynamics**
- **Evacuation and Egress**

Prior to each workshop, papers (either one or two) were presented on the workshop topics.

During each workshop, delegates were asked to discuss the topic by answering five questions:

1. What are the critical safety issues (relating to the topic)?
2. What are the issues relating to Standards?
3. What are the overall recommendations for addressing the critical passive safety issues identified in question 1?
4. What are the business benefits in addressing the critical passive safety issues identified in question 1?
5. What are the priorities for future research activity?

The results gained from answering the five questions were then presented to the whole conference during post-workshop discussions.
The aim of this report is to provide in-depth details of each workshop discussion. Chapters 2-5 deal with each topic in turn (Injury Criteria, Interior Design, Occupant Dynamics, Evacuation and Egress). Inputs to the workshop are described, (taken from current legislation, the TRAINSAFE State of the Art Report and papers prepared by the conference presenters). The results of the workshop topic discussion are then presented in the workshop output section. Each chapter ends with two highlighted tables, which give:

- The **TRAINSAFE** consortium's main recommendation for addressing the topic
- Details of the priorities for future research activity

Chapter 5 of the report gives details of the business benefits that have been identified in **TRAINSAFE** that should result from addressing the critical safety issues identified for each topic. Chapter 6 of the report then summarises the main conclusions for each topic.

It is hoped that from the recommendations given in this report, new research programmes can be set in place which will improve the safety of rail vehicle interiors, while providing real benefits to the EU rail industry.

2 Injury Criteria

2.1 Introduction

To minimise fatalities and injuries arising from rail accidents, it is important to know the common injuries that occur during an incident, and to relate the causes of these injuries to the dynamics of the rail vehicle interior and to the occupants during the incident. During rail accidents, passenger injuries are most likely to occur through secondary impacts. These are impacts provoked as a consequence of an initial impact (or derailment), such as passengers impacting other passengers or impacting interior features of the vehicle (seats, tables, windows etc).

Injury criteria are the tools used for linking the actual physical injuries sustained by a person as a result of an impact with an object, with an engineering appraisal of that impact. The object can then be designed and optimised so that physical injuries arising from impacts with it are reduced.

An injury criterion is defined as:

"a mathematical relationship, based on empirical observation, which formally describes a relationship between some measurable physical parameter interacting with a test subject and the occurrence of injury that directly results from that interaction"

S. W. Rouhana, 1993

That is, a physical parameter which most closely simulates the injury mechanism and the potential level of injury. For example, the mechanism and physical parameter that best simulates bone fracture is a force or bending moment, while for internal soft tissue injuries acceleration-based parameters are more appropriate.

Anthropomorphic test devices (ATDs) – commonly known as crash test dummies -, cadaver and animal testing, and computer modelling are commonly used to measure injury criteria in humans. When using crash test dummies, instrumentation within the dummy measures the injury criterion's critical parameter at the correct location. For example, a load cell is placed on the femur for femur fracture, and triaxial accelerometers are placed at the head centre of gravity for brain injury.
Using an applicable assessment technique (such as an ATD or computer model), tolerance levels can be established to predict whether an injury has occurred, or the potential level of an injury, after a specific impact.

Historically, injury criteria research has been led by the automotive and aerospace industries and the test dummies and models produced have been designed for assessing automotive and aerospace accidents. Whilst the rail industry can make use of these existing test dummies and computer models, it may be more beneficial to develop specific "rail" dummies and/or computer models to assess better the sort of injuries that are likely to occur during rail accidents.

This chapter looks at the historical development of injury criteria, and the injury criteria currently used by the rail industry in Europe. A number of questions are identified. The answers to these questions, it is hoped, will improve the definitions of injury criteria used by the rail industry and hence improve rail safety for train occupants and crew.

2.2 Injury Criteria – Workshop Input

Historical Development of Injury Criteria in the Automotive Industry

Most current injury criteria were developed during the 1960s – 1980s, for the automotive industry. They were the result of a considerable amount of biomechanical testing and research, from which both injury criteria and the present range of crash test dummies were developed. Because they were developed by the automotive industry, they were concerned with the injuries caused by car accidents and developing techniques for improving car crashworthiness and occupant restraint systems. Therefore, the injury criteria concentrated on the main occupant fatality and life-threatening injury impact areas: head, chest and femur.

The crash test dummies developed for injury criteria assessment culminated in the Hybrid III frontal ATD, developed by General Motors, which is currently accepted globally for all legislative standards. The dummy was made to measure human dynamic impact responses for car occupant impact areas: specifically, for head, chest and knee impacts.

Injury Criteria Currently in Use in the Rail Industry

Currently, there is no European-wide standard that gives recommended injury criteria levels to be used when specifying rail vehicle interiors. However, in the UK, new and refurbished rail vehicles are required to comply with the ATOC Vehicles Standard AV/ST 9001, “Vehicle Interior Crashworthiness” [2]. This Standard is considered to be at the forefront of specifications for rail interior crashworthiness at this time.

The purpose of this Standard is:

“To ensure the interior crashworthiness of rail vehicles maximises the survivability of passengers and crew, and minimises those injuries that may preclude their subsequent escape.”

It places high importance on rail vehicle interior crashworthiness, and designing interior furniture such as seats and tables for occupant protection in the case of an impact situation.

To comply with the Standard, all seats and tables, including those situated within the driver’s cab, must meet injury criteria levels specified in the Standard, assessed by carrying out tests that are also specified in the Standard. The tests performed are dynamic sled tests, using an ATD (the Hybrid III dummy described in section 1.2). The test pulse envelope for the passenger tests specified in the Standard is reproduced below in Figure 1.1:

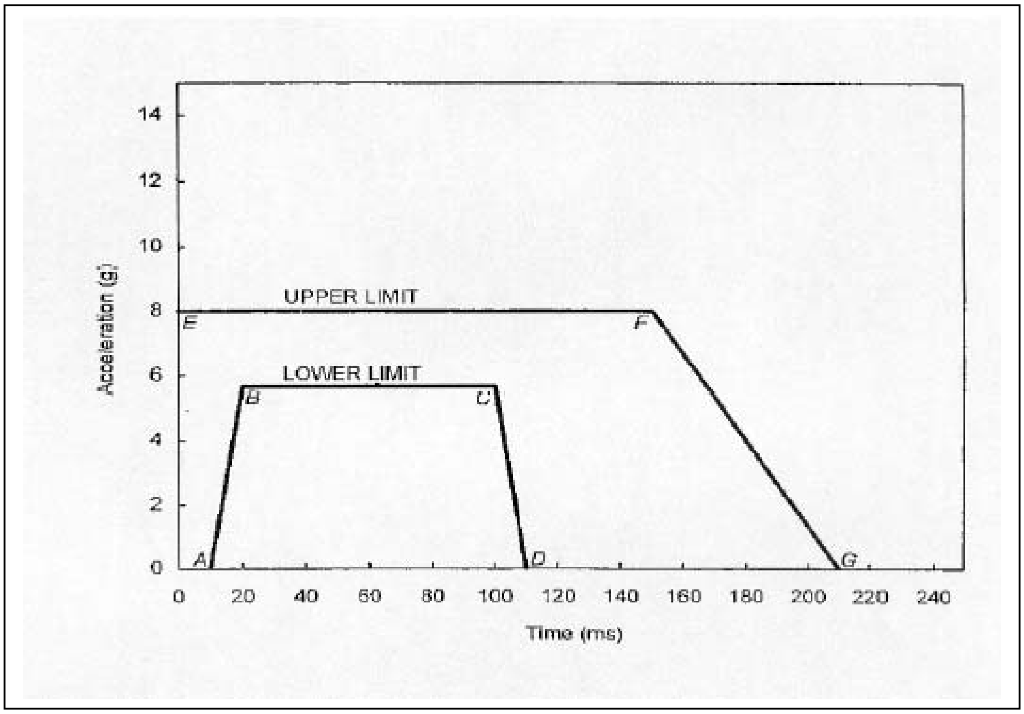


Figure 2.1: Test pulse envelope for passenger seat and table tests, from AV/ST 9001 ATOC Vehicles Standard "Vehicle Interior Crashworthiness"

For passenger seats, the injury criteria that must be considered include measurements of head acceleration, neck bending moment, femur and tibia fracture measurements and shearing of the knee joint. The criteria levels to be reached are slightly different depending upon the orientation of the seat in question.

For passenger tables, the injury criteria that must be considered include measurements of head acceleration, chest deflection and compression of the abdomen.

The injury criteria specified in AV/ST 9001 are mostly taken from automotive industry tests. However, abdomen to table impacts are not common in automotive accidents although they cause 16% of recorded injuries to specific body regions in the rail industry [1]. Therefore, tests were devised by the rail industry using a frangible abdomen to establish a suitable abdominal compression injury criterion, which was then used in AV/ST 9001.

The tests specified in AV/ST 9001 use 50th percentile male dummies when testing for passenger and driver injury resulting from secondary impacts.

2.3 Injury Criteria – Workshop Output

Critical Issues in Injury Criteria

The UK ATOC Vehicle Interior Crashworthiness Standard, AV/ST 9001, states that:

"Originally injury criteria were based on research into injury prevention in road vehicle crashes, and as a result some of the criteria may not be transferable to train safety"

If we wish to improve the measurement of rail injury criteria, and thus the design of rail vehicle interiors, to increase rail occupant (passenger and crew) safety, we need to develop injury criteria assessment techniques that specifically address rail injury criteria issues. Some of these issues are highlighted below.

The first issue is to identify which injury criteria measurements are the most useful for the rail industry. This can be done by the use of historical rail accident data and assessment tests. For the automotive industry, injury criteria have been developed to avoid fatalities or serious injuries. For the rail industry, it may also be important to develop injury criteria for measuring minor injuries such as those causing disabilities (which could hinder a passenger's egress from a rail vehicle) and disfigurement.

Developing rail injury criteria assessment techniques may require a widening of the range of people considered. The ATOC standard currently only tests rail interiors with a 50^{th} percentile male dummy. It may be necessary to also consider female models, models of older people, and models of children and babies.

As discussed in section 1.2, currently a Hybrid III ATD is used as the standard assessment device for the UK ATOC Standard AV/ST 9001. However, as this is not specifically designed for the rail industry, it may be advisable to develop new devices that are designed specifically to measure rail injury criteria. This could either involve development of physical ATDs or biofidelic computer models. One advantage of using computer modelling techniques is their versatility which can result in lower long-term costs – it would be cheaper to develop a "family" of computer models of different ages, stature and gender than to develop a physical family of dummies, as small changes to models are easy using computers.

It is also important to identify the correct crash pulses to be used in rail injury criteria tests. The current crash pulse used by the AV/ST 9001 standard may be sufficient: or commonality could be achieved with existing or future EU standards for rail vehicle crashworthiness. For example, the TSI high speed standard specifies three rail crash scenarios (with a mooted possible fourth) that must be modelled for new rail vehicles. The crash pulses could be extracted for these scenarios and used in the rail injury criteria tests.

Finally, the implications of new injury criteria tests need to be considered for the interior design of rail vehicles. The results of the tests may indicate that, for instance, all seats in railway carriage should be rear-facing as this configuration of seats provides better passenger protection than forward-facing seats, bay configurations or longitudinal seats. However, many passengers choose the comfort of forward-facing seats rather than the improved safety of rear-facing seats. Therefore, would it be practicable in business terms to make all seats rear-facing?

Issues relating to Standards

There is no current EU standard that specifies injury criteria levels for rail interior crashworthiness. In developing such a standard, the TRAINSAFE consortium considered that the issues below are of importance:

Firstly, the exact scope and extent of the Standard should be defined early on. This will involve knowledge of other areas of rail interior safety, for example interior design, fire safety, signage and evacuation/egress issues.

The objectives of the Standard should be clearly defined. Are we aiming to reduce the risk of fatalities and serious injuries only, or should we also look to reduce the risk of permanent disability and disfigurement? To improve rail safety, should the speed of injury criteria tests be increased, or should the injury criteria tolerance levels be lowered?

The Standard should utilise the most up-to-date research data into injuries resulting from rail accidents as possible.
The Standard should specify the actual device to be used in the injury criteria tests – there should be a consistent measurement tool. This may be either an ATD (or family of ATDs) or computer model.

Recommendation for addressing the critical Passive Safety Issues in Injury Criteria:

The TRAINSAFE consortium recommends:

1. Development of an EU-wide Standard for rail interior crashworthiness, that utilises rail-specific injury criteria in order to assess and reduce the injuries that a rail occupant receives due to secondary impacts

Priorities for future research activity:

1. Identify the high-risk injuries arising from accidents and develop suitable injury criteria to measure them
2. Compile an EU-wide dataset of those injuries that have occurred in historical incidents
3. Determine the objectives for improving injury criteria. Do we aim to reduce fatalities and serious injuries only? Should we also try to reduce minor injuries and disabilities? We should be aiming for continuous improvement in rail safety
4. Develop a European-wide rail dummy or other assessment device, such as a computer model, for assessing injury criteria
5. Extract crash pulses from the four TSI collision scenarios

2.4 References

1. ATOC Vehicles Standard, AV/ST 9001, “Vehicle Interior Crashworthiness”, Railway Safety, Issue 1, February 2002

3 Interior Design

3.1 Introduction

This chapter considers the importance of rail vehicle interiors in rail accidents. Currently, no European-wide Standard or Code of Practice exists that specifies good design practice for rail vehicle interiors. However, the European Driver's Desk project has carried out research into the safety of a rail driver in their cab, which includes reviewing the design of the interior of the cab. Also, the UK ATOC Vehicles Standard AV/ST 9001, "Vehicle Interior Crashworthiness" [1], contains detailed guidance and design requirements for new and refurbished rail vehicles in the UK.

When considering the design of rail vehicle interiors, both passive and active safety issues must be considered. Active safety systems will be those which anticipate an accident and try to prevent it – such as early warning systems and automatic braking for trains. TRAINSAFE deals with passive safety issues. Passive safety features are those which are an integral design of the rail vehicle interior and are not designed to automatically react in an accident scenario. They can be divided here into three main areas:

- Design of a rail vehicle interior to minimise occupant injuries due to secondary collisions: for instance, securing luggage items, avoiding the use of sharp edges in furniture design
- Effective use of signage informing occupants of the correct procedures to follow in the case of an accident, and encouraging good safety practice such as storing luggage under seats
- Provision of mechanisms such as window hammers to aid passenger egress, if needed, in the case of an accident

Many views exist on the suitability, or not, of installing seatbelts in passenger trains, and it is noted here that this is an important issue to be discussed in the design of, for instance, long-distance rail vehicles. However, TRAINSAFE is interested in a large range of EU rail systems, including those where passengers are unlikely to be seated for any length of time, for example underground trains and trams. The use of seatbelts will therefore not be discussed here further.

3.2 Interior Design – Workshop Input

This section examines current guidelines on rail interior design for safety, by examining the UK ATOC Standard AV/ST 9001 (as the most pertinent document that exists on rail vehicle interiors).

UK ATOC Vehicles Standard AV/ST 9001

This standard was produced in February 2002 (there has since been an upissue in April 2004) by UK Railway Safety on behalf of the UK Association of Train Operating Companies (ATOC), and the requirements within apply to new and majorly refurbished rail vehicles in the UK.

The aim of the Standard is:

"to ensure the interior crashworthiness performance of rail vehicles maximises the survivability of passengers and crew, and minimises those injuries that may preclude their subsequent escape"

The Standard addresses the design of rail interior bodyshell features (such as windows and ceilings) and rail interior furniture (such as seats, tables, toilets etc) by providing a mixture of prescriptive requirements and advisory guidelines.
The prescriptive requirements of the Standard include:

- Static load resisting requirements for seats, armrests, tables, luggage racks and windows
- Acceleration and inertia force requirements for all interior furniture and fittings, including secured wheelchairs, fire extinguishers and catering trolleys – all fittings must meet the accelerations and inertia forces specified in the UK Railway Group Standard GM/RT2100
- Specification of injury criteria level tests (with a detailed test procedure given in the Standard) for seats and tables
- Specification of heights of transverse seats – to provide support for the heads of a 5^{th} percentile female to a 95^{th} percentile male

There are many advisory guidelines given in the Standard for improved rail interior crashworthiness. Some of these are described below.

The Standard discusses the optimum seating layout for rail interiors, highlighting the dangers of using open bay seating arrangements (with or without tables) and longitudinal seating. Unidirectional seating is generally preferred to open bay and longitudinal seating as it provides more passenger containment and thus prevention of further impacts/excursions along the vehicle, in the case of an accident.

The use of glass is also discussed. Information is given that using toughened glass for interior features, such as luggage racks, could be detrimental to passengers' safety in an incident as shattered glass can cause lacerations and eye injuries. However, in general trains utilise a large amount of glass as it is aesthetically pleasing and windows contribute largely to passenger comfort on a journey. Therefore no advice is specifically given to restrict the use of glass.

When designing a piece of rail interior furniture to be crashworthy, it is important to minimise sharp edges and rigid objects, as these cause greater injury to a rail occupant for a given impact load than rounded edges, greater surface areas, and deformable objects. The Standard gives guidelines on both sharp edges and non-deformable materials:
"All areas which could be subject to a foreseeable secondary impact shall be free of sharp areas, inserts, edges and protrusions… where protrusions, etc are unavoidable the radii of all edges shall be maximised"

and

"Wherever possible use shall be made of energy absorbing features in areas where impact may occur".

3.3 Interior Design – Workshop Output

This section describes the main issues that were raised during the Interior Design Workshop.

Critical Issues in Interior Design

Currently, the design interior layout of a rail vehicle saloon can be unique to the fleet type, to the class of passengers using the vehicle (for example in the UK, first and standard class carriages) and to the position of the vehicle within the rake. Consideration should be given to harmonising rail vehicle interior layouts, i.e. to providing standard layout designs for categories of rail fleets (e.g. long-distance trains, metropolitan trains, light rail) across the EU. The advantage of this approach is that it could provide an interior safety benchmark for vehicles. The disadvantage of this approach is that harmonisation may stifle innovation arising from future research findings, and also that it may be costly to implement in countries which have a fragmented rail infrastructure.

Aggressive features, such as sharp edges, rigid surfaces and non-ductile materials, should be minimised in rail vehicle interiors to reduce the chance of injury to rail occupants should they impact with interior fixtures and fittings. It is generally not necessary to specify exact dimensions/materials to be used to avoid aggressive features, but common sense should be applied to collate good practice guidelines for EU-wide rail interiors (similar to the UK Standard AV/ST 9001).

The storage of luggage is a significant issue. Currently, luggage is stored in overhead racks on many trains. However, in the case of a rail collision, luggage items can fall from the rack and become missiles at head height, which is dangerous to vehicle occupants. Also, if the vehicle rolls over passengers may impact the luggage rack which again is dangerous. Therefore, consideration should be given to the design of underseat and vestibule storage of luggage, and designing all luggage storage areas to contain luggage items well in the case of an accident. Other items that are not permanently affixed to the vehicle bodyshell, such as fire extinguishers, should also be restrained to prevent them becoming missiles in the case of a collision scenario.

Issues relating to Standards

There is currently no European-wide Standard for rail vehicle interior crashworthiness. Should such a Standard be produced, and if so should there be different sections for different categories of train types? As described above, the UK Standard for rail interior crashworthiness is a mixture of prescriptive requirements and advisory guidelines. Should this approach be adopted for the European Standard?

As described above, the rail vehicle interior crashworthiness Standard in the UK is AV/ST 9001. However, the discussion group were not sure whether this Standard was always rigorously applied to the design of new and refurbished rail vehicles in the UK. It may be useful to devise a certification system for, e.g. seats and tables. Standard seats and tables could be designed that meet rail interior crashworthiness standards, and then bought “off the shelf” to furnish rail vehicles. Confidence in their crashworthy characteristics could be shown by using a mark similar to a kite mark that shows compliance with European standards.

Currently, there are EU-wide harmonised signs for e.g. emergency exits, that must be used in all workplaces. The discussion group considered that thought should be given to harmonising emergency signage across the EU.

Recommendations for addressing the critical Passive Safety Issues in Interior Design:

The TRAINSAFE consortium recommends:

1. Development of a set of EU-wide design guidelines for rail interior furniture, that consider an advisory as well as a prescriptive approach

Priorities for future research activity:

1. Development of a common methodology for carrying out an EU-wide risk analysis of casualties resulting from rail accidents
2. Use of the results from 1 to improve rail interior design for safety
3. Categorisation of trains according to type and risk of accident, and developing safer interior furniture/layouts for each of these categories
4. Cross-reference work on interior design safety features with injury criteria specifications (see Chapter 1)
5. Collation of a State of the Art Report of current knowledge in rail interior design, including data from new EU member states

3.4 References

1. ATOC Vehicles Standard, AV/ST 9001, "Vehicle Interior Crashworthiness", Railway Safety, Issue 1, February 2002

4 Occupant Dynamics

4.1 Introduction

At present, rail occupants in the EU are “unrestrained” – that is, they do not wear seatbelts. In the event of an accident or collision in which the rail vehicle rapidly decelerates, the unrestrained occupant continues to move at the pre-collision velocity until either being ejected from the train or impacting some part of the rail interior fixings and fittings. Several further impacts between body parts of the occupant with the vehicle may occur, until all of the body has achieved the final post-collision velocity and attitude of the rail vehicle. These impacts may cause injury or fatality to the occupant.

Historically, most research into occupant dynamics and injury criteria has taken place within the automotive industry which experiences a far greater number of fatalities than the rail industry. However, there have been several high-profile rail accidents (which have caused public concern for the safety of rail passengers. To restore public confidence in rail travel, it is important to address these safety concerns.

Understanding the dynamics of a rail occupant following a crash can aid in developing injury criteria (see Chapter 1), designing safer rail interior features and ultimately improving general rail safety. This chapter describes the main factors that are important when understanding occupant dynamics, the current legislation for rail interior crashworthiness that utilises occupant dynamics knowledge and gives TRAINSAFE’s recommendations for further improvements in rail safety arising from occupant dynamics research.

4.2 Occupant Dynamics – Workshop Input

Understanding Occupant Dynamics

The injury type and severity inflicted upon a rail occupant’s body part are dependent on four main factors, which are described below:
<u>Body Part Impact Velocity</u>

The body part impact velocity is the relative velocity of the occupant and that of the interior surface with which the occupant impacts. It is dependent on the rail vehicle deceleration and pre-collision distance from the body part to the impacted object. Occupant trajectory, which changes following the first body part impact, also affects subsequent body part impact velocities.

Reducing the body part impact velocity reduces the deceleration that the body part experiences when impacting the rail vehicle interior feature, and thus the extent of injury caused to that body part. The UK ATOC Standard for Vehicle Interior Crashworthiness, AV/ST 9001 [1], states that:

“The risk of serious injury is lessened … by reducing the length of excursion occupants make along the vehicle. The shorter the excursion the less likelihood of severe secondary impact of

interior features or other occupants, since the velocity of the passenger relative to the vehicle at impact will be less."

<u>Occupant Body Part Impact Location and Attitude</u>

This is dependent upon the position of the rail occupant and the configuration of the interior features (for example seats, tables, windows, partitions, handrails) of the rail vehicle.

The position-dependency feature of rail occupants is unique in the transport industry. For automotive and aviation accidents, the large majority of passengers will be strapped into their seats at the time of a crash, with the front of another seat close to the front of their heads (as in Figure 3.1). However, several different seating arrangements are found in EU rail vehicles:

- Uni-directional seating (with or without seatback tables)
- Bay seating (with or without fixed tables)
- Exposed seating
- Side facing/banquette seating

Figures 3.2(a) to (d) below (from Bernadette Stanley's TRAINSAFE paper, 2004 [2]) illustrate the different seating arrangements.

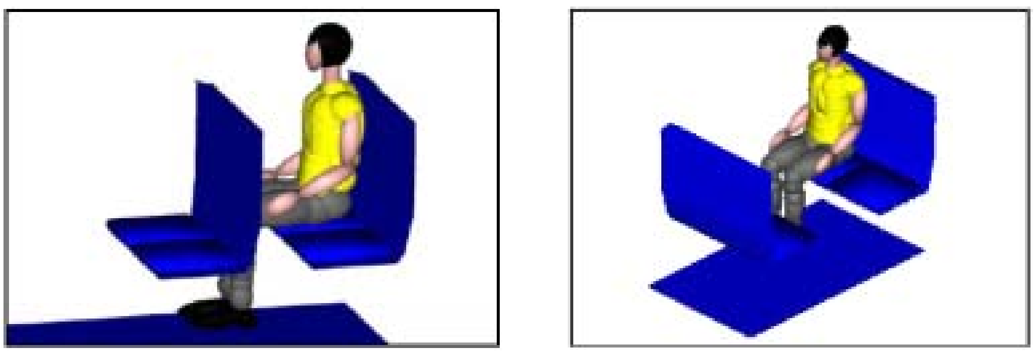


Figure 3.2: (a) Unidirectional seating (b) Bay seating

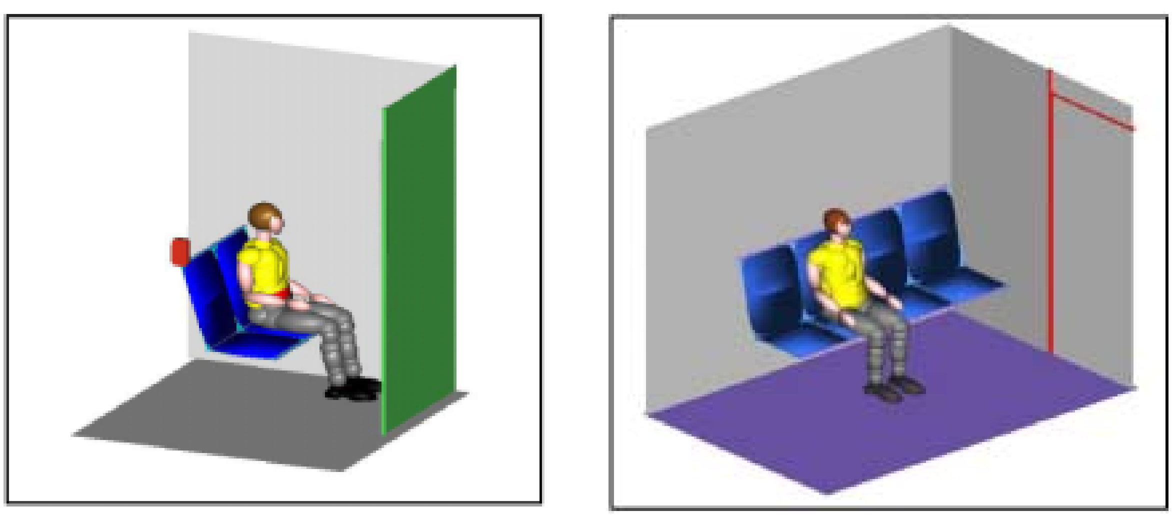


Figure 3.2: (c) Exposed seating (d) Side facing seating

As well as seating arrangements, impacts with tables, handrails and other interior features must be considered. The locations of these features will vary from train to train.
A further complication that does not arise when considering rail and aviation accidents, is that many passengers will be standing at the time of the collision. This may be because they are out of their seats, for instance walking to the toilet or buffet car, or because they are standing due to a lack of seats (this is common on light rail and tramway systems). Therefore, occupant kinematics needs to be considered from standing as well as sitting positions.

The above points illustrate that there are a large number of possible trajectories that a rail occupant can take following a collision. Therefore, it can be hard to be prescriptive about the optimal positioning of seats within a carriage. However, there is acceptance that in general, unidirectional seating produces the greatest passenger protection compared to the other seating arrangements, as it provides the best passenger containment. The UK ATOC Standard AV/ST 9001 provides non-prescriptive guidance on this issue:

"A study of passenger kinematics has indicated that unidirectional seating could provide an increased level of passenger protection, compared to open bay and longitudinal [side-facing] seating, by providing containment in the immediate seating area, thus preventing longer excursions in the vehicle and reducing the possibility of impacts or interaction with other passengers"

Impacted Object Shape and Material Characteristics

The severity of the injury that a rail occupant receives can be affected by the shape of the impacted object and by its material characteristics.

Generally, a flat surface such as a panel will produce a lower concentration of load than a surface such as grab handle or seat edge. For instance, a head impacting onto a flat surface will produce a relatively simple linear skull fracture. A head impacting a blunt object, such as a grab handle, with the same impact velocity, is more likely to produce a depressed fracture which has a higher potential for permanent brain damage or non survivability.

To minimise rail occupant injuries, it is also good practice to avoid the use of sharp edges on objects, which can stab passengers and crew in the case of a collision scenario. The UK ATOC Standard AV/ST 9001 defines a sharp edge as an edge with radius of less than 5 mm, and states:
"All areas which could be subject to a foreseeable secondary impact shall be free of sharp edges"

Further guidance and requirements to avoid sharp edges and maximise the surface area/depth of items such as grab handles and table edges are also given in this Standard.

The magnitude of a load imparted to a rail occupant in an impact with a rail interior feature depends in part upon the impacted object's stiffness and compliance. If the object moves, either due to its compliance (elastic motion) or deformation (plastic motion) the peak deceleration of the impacting body part will occur over a longer period of time. Plastic deformation is preferred to elastic deformation as then the energy is absorbed by the impacted object rather than being rebounded to the passenger.

In rail interior terms, it is thus good practice to use materials for rail interior features that display post-impact plasticity to absorb impact loads, and to use cushioned surfaces where practicable. The mounting of the interior object will also affect the object's dynamic stiffness. Some objects, like grab handles, are designed to be rigid. However, if a grab handle is

mounted to a seat back which itself has compliance, then it will have lower dynamic stiffness and therefore impart less impact load to the passenger.
The UK ATOC Standard AV/ST 9001 provides guidance for the compliance of rail interior features:

"Wherever possible use shall be made of energy absorbing features in areas where impact may occur, with due regard being given to the complementary requirements related to the fire and acoustic performance of such materials and features"

It also specifies that objects, such as chair arm-rests and passenger tables, should display post-yield plasticity and fail in a manner unlikely to cause injury, when subjected to higher loads than those specified in the Standard.

<u>Occupant Injury Mechanisms & Potential</u>

Improving rail occupants' safety depends upon understanding the type and magnitude injury mechanisms caused to rail occupants during a collision or other accident. Rail interiors can then be designed to reduce these likely injuries. To understand injury mechanisms, the rail industry uses injury criteria. That is, a measurable parameter such as acceleration, displacement, bending moment, etc, that mimics an injury mechanism. Models can then be built (either physical such as ATDs (anthropomorphic test devices) or virtually on a computer) that simulate impacts between the models and rail interior features. Chapter 1 has more details on how injury criteria are currently measured by the rail industry.

In many cases, it may be cheaper to develop computer simulations of the impacts between rail occupants and rail interiors than to build physical test models. The initial cost of a computer model may be large, but parameters in the models can be changed at low cost and repeatability is often unnecessary. It is important when developing computer models that they should be biofidelic. Jorge Ambrosio's TRAINSAFE paper 2004 [3], describes some of the current challenges in occupant kinematic modelling.

4.3 Occupant Dynamics – Workshop Output

Critical Issues in Occupant Dynamics

The TRAINSAFE discussion concentrated mainly on improvements in modelling occupant kinematics in rail vehicle interiors. The issues raised by the discussion are described below.
It is important to understand the crash pulses (time versus acceleration curves) that occur in real rail accidents, so that rail occupant impacts can be modelled more accurately. This may be done by carrying out research into historical accident data and by simulating structural rail vehicle collision events, see [4]. However, it should be ensured that the data is relevant to the situation. For instance, historical accident data from accidents/models where overriding takes place may not be useful for considering collisions involving those vehicles with effective anti-climbing measures in place.

Understanding the occupant kinematics during likely accident scenarios is also important for the improvement of rail vehicle interior design for safety. The TRAINSAFE consortium is anxious that, to ensure confidence in the results, some commonality and standardisation of occupant dynamics modelling is achieved (similar to developing the Hybrid III dummy for physical testing, which is now accepted globally for crashworthiness legislation). The scope of this standardisation needs to be agreed upon. This will include consideration of the following parameters:

- Definition of a “typical” rail occupant. Does a range of heights, ages and genders need to be considered in modelling?
- To ensure equal treatment for all, should models be developed of disabled rail occupants?
- What orientation/posture of occupants just prior to the crash should be modelled?
- What locations in the vehicle should be modelled – for example, seating areas, aisles or buffet car, (for standing occupants), toilet?
- Should unsecured interior items, or items that might become loose, be modelled – for example wheelchairs, prams, fire extinguishers, luggage, catering trolleys? These could cause injury on impact with a rail occupant. Further, should the restraint systems of e.g. wheelchairs and catering trolleys be modelled?

Issues related to Standards

The range of vehicles currently travelling within the EU is extremely diverse. Therefore, cost-benefit analyses should be carried out when the creation of rail vehicle interior Standards, that specify rail interior design according to the results of occupant kinematics research. Is it better to produce a number of prescriptive standards (eg individual standards for high-speed trains, commuter trains, underground trains, light rail etc) or an overall standard with non-prescriptive guidance on vehicle interior design similar to the UK ATOC Standard AV/ST 9001?

The same issue needs to be addressed when specifying occupant modelling simulations/tests for Standards. Should the same occupant model be used for each situation?

The test/modelling procedure should be accurately described in rail interior Standards. This will include defining the following precisely:

- Attributes of the rail occupant(s) to be tested – or stating that an established dummy/model should be used
- The rail interior layout that is to be tested
- The crash pulse(s) to be used in the tests
- The set-up protocol to be used in the tests

The TRAINSAFE consortium considers that a deadline should be considered by which time up-to-date EU-wide rail interior Standards will be produced. As a starting point, a process should be put in place to ensure timely delivery of the Standard.

Recommendations for addressing the critical Passive Safety Issues in Occupant Dynamics:

The TRAINSAFE consortium recommends:

1. Putting in place a process to ensure timely delivery of an EU-wide Standard for rail vehicle interiors

Priorities for future research activity in Occupant Dynamics:

1. Deciding the scope of the EU-wide standard for rail vehicle interiors
2. Extracting crash pulse data from existing standard specifications (such as the TSI high-speed standard) and from existing rail accident data
3. Developing categories of rail occupants (passengers and driver/crew) grouped by height, age, gender etc to improve occupant dynamic modelling
4. To ensure equality, developing models of disabled rail occupants for dynamic testing
5. Modelling the impact of rail occupants in different postures with different aspects of the rail interiors – seats, tables, toilets, unsecured items

4.4 References

1. ATOC Vehicles Standard, AV/ST 9001, "Vehicle Interior Crashworthiness", Railway Safety, Issue 1, February 2002

2. Stanley B., "Occupant Kinematics in Rail Crashes and the Subsequent Crashworthy Performance of the Interiors", TRAINSAFE Safe Vehicles Interiors Conference, April 2004

3. Ambrosio J., "Occupant Modelling for Impact Biomechanics", TRAINSAFE Safe Vehicles Interiors Conference, April 2004

4. Bright A., "TRAINSAFE Cluster Report – Safe Vehicle Structures", TRAINSAFE Thematic Network, June 2004Evacuation and Egress

5 Evacuation and Egress

5.1 Introduction

The safe egress of passengers from a rail vehicle is of the utmost importance following a rail accident. Evacuation and egress aspects exist for all aspects of rail interior passive safety issues: see Chapters 1 and 2 for examples.

In his paper for the TRAINSAFE project on Train Egress and Evacuation [1], Nick Swift of HSBC Rail puts forward a three-model approach for train safety and especially for evacuation and egress issues. The three models are as follows:

- Scientific
- Risk
- Human

Each model makes different assumptions as to how rail occupants are most likely to behave in an emergency situation and about what information they should be provided with to help them deal with the situation. Section 4.2, Workshop Input, describes each model in detail. Section 4.3, Workshop Output, describes the result of the Egress workshop discussion.

5.2 Evacuation and Egress – Workshop Input

Scientific Model

The first model described in [1] is the Scientific Model. This approach arises from trials that have been performed by the aircraft industry, where aircraft are designed so that all occupants can be evacuated within a set period of time.

The key premise behind the scientific model is that immediate egress from a rail vehicle is desirable following a rail incident, and provided that the length of time taken to fully evacuate a vehicle is shorter than the minimum time for the risk to passengers of staying on the vehicle to arise, the vehicle is safe.

The key assumptions behind the model are that occupants will behave rationally in an evacuation situation, that they can read and understand instruction signage provided and that they will perform in a manner that can be modelled and measured by evacuation trials.

The UK ATOC Standard for Vehicle Interiors Design for Evacuation and Fire Safety, AV/ST 9002 [2] takes a broadly scientific approach to egress situation issues. The standard states that:

"Each new design of rail vehicle, or vehicle in which the interior configuration or passenger carrying capacity has been altered or egress facilities have changed, shall undergo validation of the design by either structured evacuation trials, or by direct comparison with other vehicles which have been validated by such tests"

The Standard also provides details of the structured evacuation tests that must be performed to validate the rail vehicle design. These specify maximum periods of time/minimum passenger flow rates for maximum passenger loading of the vehicle in the following egress situations:

- Evacuation from the side of a vehicle onto a platform
- Evacuation from the end of a vehicle into an adjacent vehicle
- Evacuation from the end vehicle in a rake to track level

In the structured tests, the vehicles must be upright, there must be conditions of external darkness with emergency lights illuminating the vehicle interiors, and the interiors must be undamaged.

The main advantage of using the Scientific Model is that, if the rail vehicle under consideration undergoes the correct evacuation trials, it provides a pass/fail method for designing rail vehicles for evacuation. With the Scientific Model approach the main aspects to be considered when designing the rail vehicle for effective evacuation include:

- Designing the interior layout to maximise passenger flow rate out of the vehicle
- Use of fire-resistant materials. Materials which resist or retard the spread of fire will give passengers a longer period of time to exit the rail vehicle in the case of a fire
- The most effective colours, wording, size etc of emergency signage within the vehicle
- Design of doors so that passengers can open them (without power, if necessary) to aid egress following an incident

The problem with the scientific approach is the chaotic nature inherent in any emergency situation, and whether this can be adequately modelled in evacuation trials. For example:

- Is evacuation of the vehicle always necessary after a rail incident (e.g. collision, fire)? Historical data has shown that in many cases, it is safer to remain on the vehicle than to exit it, especially when the rail track involved has a third rail power supply
- The scientific model assumes no role for the train driver, staff and control centre in the case of a rail accident. It may be useful to utilise them, for instance in informing passengers whether or not to remain on the train as described above, and also to cut off any dangerous sources of power
- The scientific approach assumes that the interior of the rail vehicle is in an undamaged state. However, especially after a collision, it is likely that there will be a certain amount of damage to the rail vehicle interior which will hinder passenger egress. Also, the rail vehicle may not be in an upright position which, again, will hinder egress
- Smoke-filled carriages and loss of power will reduce the effectiveness of emergency lighting in the rail interior
- Rail occupants (passengers and staff) may panic, rather than conducting an orderly evacuation

Risk Model

The second suggested approach in [1] is the Risk Model. This approach relies on gathering data from historical railway incidents, and categorising that data according to risk. The different categories might include:

- Type of incident: for example collision, other derailment or fire
- Type of rail system involved: for example long-distance trains, metropolitan light rail, trams
- Human factors issues such as time of day (more passengers will be travelling at peak times, for instance)
- Extent of damage caused to the rail vehicle(s) involved

Having defined the different emergency situations that arise from the initial risk analysis, methods of dealing with each situation are then developed individually.

The use of a risk-based approach relies heavily on educating rail staff (driver/crew/control centre workers) in the best ways of dealing with different emergency situations. It assumes that the rail staff will be able to control, to a certain extent, the post-incident environment; will be trained to decide whether passengers should evacuate the vehicle or not; and will be able to supervise the evacuation process (either in person or remotely through electronic communication systems).

The main advantage of the Risk Model over the Scientific Model is that it takes into account the different nature of rail incidents, and trains staff to deal with different scenarios appropriately. For instance, the AV/ST 9002 Standard specifies in its structured evacuation tests that the rail vehicle interior should be in an undamaged state. This assumption need not be made when employing the Risk Model approach.

The main challenge to the Risk Model approach is the dependence it places on human factors. Some questions that should be asked when considering use of the Risk Model are given below:

- Each emergency situation is different. Will the situation that staff find themselves having to cope with match a past situation, or will it require reactive thinking? Because of the chaotic nature of emergencies, following procedures rigidly may not be the best approach to take
- Rail accidents are rare. A country may expect to have to deal with not more than one or two serious accidents in a year, and many rail staff will not have to deal with an emergency situation throughout their career. Therefore, how likely will they be to remember complicated training procedures?
- Historical data shows that in many rail incidents, it was or would have been safer for passengers to remain onboard the rail vehicle after the accident rather than making a rapid egress. However, the natural response for people in an emergency situation may be to flee. This could cause conflict with instructions given to them by railway staff

It is therefore considered that any use of a Risk Model would have to take into account the likely behaviour of people in an emergency situation, as well as historical statistical data on railway accidents.

Human Model

The final suggested approach in [1] is called the Human Model. This approach makes the key assumption that people will generally make the correct decisions for themselves in any particular situation. This differs from the Risk and Scientific Models, which assume that the post incident scenario can be quantified – either by designing a vehicle which meets structured evacuation tests (Scientific Model) or by categorising each emergency situation and fitting a staff training solution to it (Risk Model).

With regard to egress issues, a rail vehicle designed to fit Human Model specifications would need to provide rail passengers and staff with information on train egress and tools to aid them in egress, should they decide to evacuate the vehicle. The information provided could include, for example:

- The positions of doors and emergency exit windows (if any)
- The positions of fire extinguishers and emergency lighting
- The positions of alarms and manual override systems (for power-assisted doors)

The tools provided could include:

- Hammers or other devices to remove emergency exit windows for ease of egress
- Emergency hand-held devices such as snap sticks
- Escape chute systems to aid egress to track level and down embankments

The passengers and staff would then decide for themselves which would be the most appropriate course of action in any emergency situation, and use the information and tools provided when and where they were needed

The main advantage of the Human Model over the other two approaches is the fact that it recognises that each emergency situation is different and needs to be approached accordingly. It does not assume that the post incident environment in which passengers find themselves can be controlled, but rather that people should react as and when events happen. The lack of prescription and provision of options (through information and tools) will allow people to weigh up the best solution to egress and evacuation problems.

The main challenge to the Human Model approach is how far rail passengers are encouraged to think and act for themselves. Not providing trained staff to deal with emergency situations, or vehicles that can be proved to have been designed with optimal egress routes in mind, may lead to post-accident accusations by litigants that not enough concern was given to their safety when considering the design and operation of the railway system, and subsequent public outcry.

A secondary disadvantage of the Human Model approach is the issue of providing tools to aid passenger egress. In many cases it has been found that tools such as window hammers and alarms placed in carriages become vandalised, and are then unusable in the case of an accident. Providing CCTV cameras onboard rail systems would mitigate this problem, but might make passengers feel uncomfortable.

Discussion

This chapter has discussed the Scientific, Risk and Human Model approaches to improving rail safety through consideration of evacuation and egress issues. To what extent and by whom are these models currently used?

In the UK, the responsibility for deciding which model to adopt is split between more than twenty different train operating companies, train manufacturers and, to a certain extent, train leasing companies. Therefore, different policies are adopted for different fleets, often when they operate over the same route.

The AV/ST 9002 Standard, as described in section 4.2, takes a broadly Scientific approach. However it also incorporates some aspects of both the Risk and Human approach. The aspects of the Risk Model used in the Standard include statements such as:

"In order to reduce the risk to people… the vehicle design needs to have due cognisance of the environment in which the vehicle is operating and the particular risks that this may present!

The aspects of the Human Model found in the Standard are mainly specifications for the use of tools:

"Where only selected windows are breakable or removable as a designated bodyside escape device, a suitable and easily accessible device for breaking or removing the window shall be provided locally at each such exit."

It should be noted that the Standard only applies to new and refurbished vehicles.

On many occasions in the UK, including as a result of public inquiries, calls have been made for common standards: namely, similarity between vehicles and procedures to improve public safety. This may be interpreted as a call for a Scientific approach in terms of vehicle design and a Risk approach in terms of procedures. However, many different types of rail systems exist in the UK alone, as well as EU-wide, and a common, prescriptive standard may not be suitable to encompass the many different variables inherent in EU railway systems. Prescription can also stifle innovation.

The two conflicting demands – that of satisfying public demands for safe trains without using over-prescriptive standards that fail to address the detailed needs of each individual rail accident, need to be weighed up in terms of the three-model approach. How does each approach work when considering writing guidelines or standards? Ultimately, which model approach should we adopt?

5.3 Evacuation and Egress – Workshop Output

Critical Issues in Evacuation and Egress

The workshop topic group on evacuation and egress identified a number of critical issues, which should be addressed as part of the discussion on which model approach (as described in Section 4.2) is the best to adopt in the EU to improve rail passenger safety. These are described below.

Firstly, the risks should be considered of staying on the train during an emergency versus leaving the train. This is a complex issue as every emergency situation is different. It may involve research into the psychological behaviour of humans (rail passengers/crew/control centre staff) in extreme situations.

Secondly, the way in which emergency information is communicated to rail passengers during an incident should be considered. This includes: verbal communication between the driver and passengers/control centre staff; the clear marking of egress routes and emergency exits; and leaflets informing passengers of their options in an emergency situation.

There are several compromises to consider on the subject of evacuation and egress. Should tools, such as window hammers, be provided to aid passengers' egress? These can be vandalised or misused. Similarly, should doors be provided with a manual override in the case of emergency? If the manual override is misused this could result in passengers falling from the vehicle and being injured. Also, should there be designated windows for emergency egress? Although windows can be useful escape routes, windows that break easily can also eject passengers during, for example, roll-over of the rail vehicle. For vandalism issues, it may be sensible to use CCTV cameras on trains to see that emergency alarms, window hammers, manual door overrides, etc are not misused. However, the use of CCTV cameras should not alienate rail passengers and discourage them from using trains as a form of transport.

Issues relating to Standards

Currently, there is no European-wide Standard on rail design for evacuation. It is recommended that instead of a prescriptive Standard, a set of advisory guidelines should be drawn up. This may be considered as following the Human Model described in section 4.2. The advisory guidelines should consider:

- Cross-referencing with any interior design and fire safety standards that are drawn up, to ensure that there is no contradiction
- Harmonisation of emergency exit signage across the EU
- When considering further harmonisation, there must be recognition that each emergency situation is unique and needs to be treated as such

Recommendations for addressing the critical Passive Safety Issues in Evacuation and Egress:

The TRAINSAFE consortium recommends:

1. Further debate into the merit of the three-model approach, including research into the issues raised by considering the pros and cons of each model

Priorities for future research activity in Evacuation and Egress:

1. Scientific Model research
   - Consider EU-wide rail structures, fire safety issues and interior layouts
2. Risk Model research
   - Identify the most common accident scenarios through risk analysis and assessment
   - Gather EU-wide information on egress performance in past accidents and any subsequent enquiry recommendations
   - Develop a common methodology for safe egress after an accident
3. Human Model research
   - Understand the psychological behaviour of humans under extreme conditions
   - Develop common specifications for emergency lighting, with independent, robust and redundant power supplies
   - Consider the use of CCTV cameras onboard rail vehicles

5.4 References

1. Swift N., "Train Egress and Evacuation", TRAINSAFE Safe Vehicles Interiors Conference, April 2004

2. ATOC Vehicles Standard, AV/ST 9002, "Vehicle Interiors Design for Evacuation and Fire Safety", Railway Safety, Issue 1, December 2002

6 Business Benefits

During the workshop discussion for each topic the question was raised:

- What are the business benefits in addressing the critical safety issues?

The answers to this question were broadly similar across the different workshops so are given here in one section.

Most importantly, it was thought that an improvement in rail safety, leading to fewer rail casualties and fatalities, would reduce insurance and litigation costs for train operating companies. Improving rail safety in general, would also improve the way that the rail industry is seen by the media. This could reduce the amount of post-accident public inquiries, and subsequent costs as a result of public inquiries. It could also reduce the costs arising from "bad press" – i.e. travellers avoiding the rail system because of safety fears and the resulting loss of revenue.

Some recommendation has been made, specifically in the chapters on interior design and occupant dynamics, of designing standard rail interior layouts and furniture. If this recommendation was taken up and COTS (commercial off the shelf) items were used to furnish vehicles, then initial design costs/refurbishment costs for rail vehicles would be much reduced.

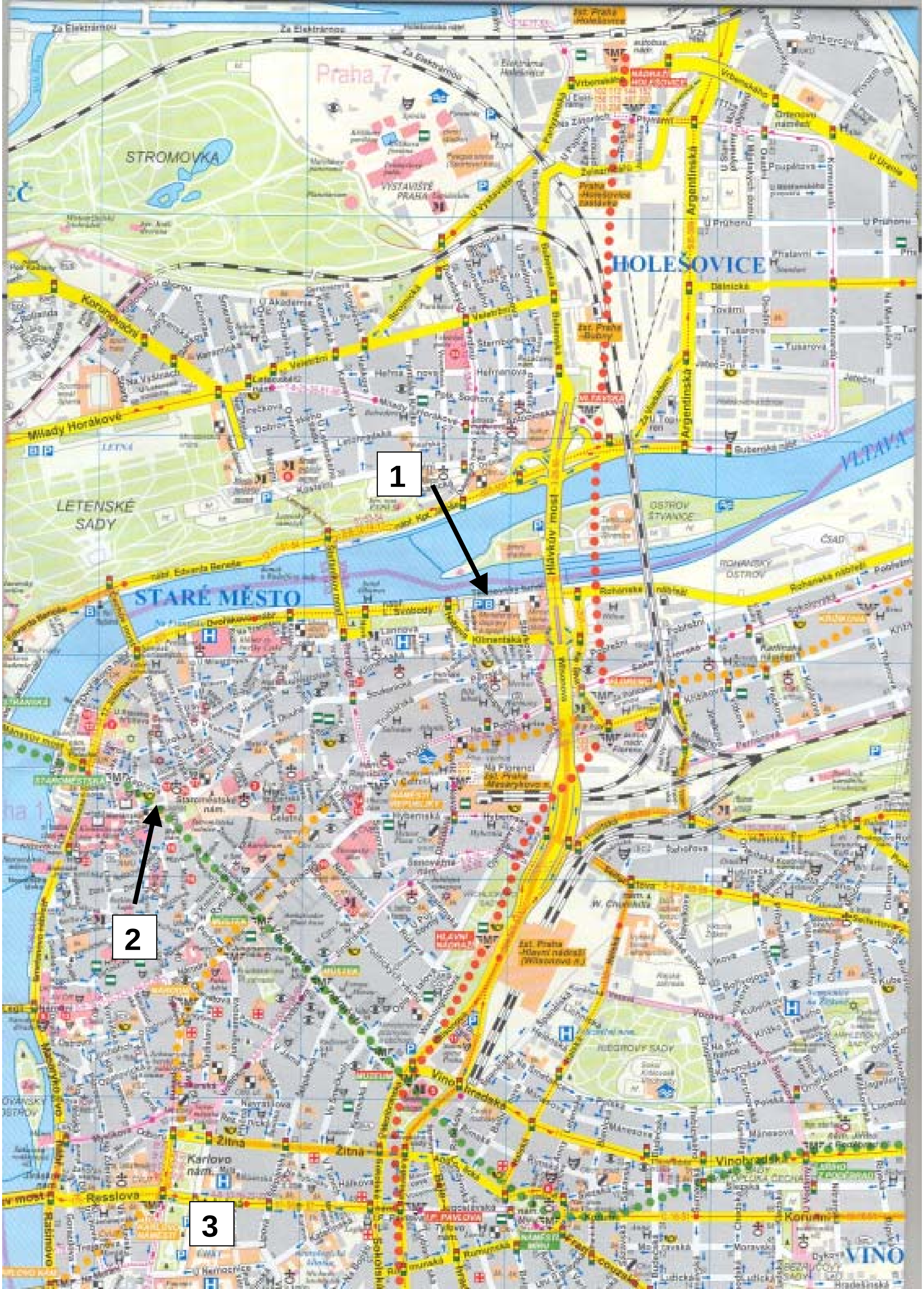
On the subject of rail occupant modelling, it was considered that increasing the amount of computer simulation, rather than physical testing, would reduce future research and development costs.

Finally, it was considered important that the current high level of safety seen on European railways compared to other forms of travel (i.e. road and air travel) should be aimed to be maintained and improved where possible, with reducing costs. Reducing the costs of maintaining and improving rail safety means that rail prices are lower for passengers and thus more passengers will use the rail system, which strengthens the EU economy.

7 Summary of Conclusions

Recommendations for addressing critical Passive Safety Issues in Safe Vehicle Interiors:

1. Development of an EU-wide Standard for rail interior crashworthiness, that utilises rail-specific injury criteria in order to assess and reduce the injuries that a rail occupant receives due to secondary impacts
2. Definition of a process to ensure timely delivery of an EU-wide Standard for rail vehicle interiors
3. Development of a set of EU-wide design guidelines for rail interior furniture, that consider an advisory as well as a prescriptive approach
4. Further debate into the merit of the three-model approach to evacuation and egress, including research into the issues raised by considering the pros and cons of each model



Praha 7
STROMOVKA
HOLEŠOVICE
VLTAVA
LETENSKÉ SADY
STARÉ MĚSTO
Milady Horákové
Argentinská
Dělnická
Hlávkův most
Karlovo nám.
Resslova
Žitná
Vinohradská
Korunní
RIEGROVY SADY
1
2
3

Key to the Prague City Map

No. 1
Venue for TRAINSAFE Prague´s meeting.
Ministerstvo dopravy České republiky
(Czech Republic, Ministry of Transport)
nábřeží L.Svobody 12
Praha 1
110 15

No. 2
Venue for common evening event.
Restaurace "U Rotta"
Malé náměstí 3
Praha 1
110 00
www.restaurace-rott.com
phone 00420 224 229 403

No. 3
Venue for possible excursion
Control Centre of Prague´s Metro
Na Bojišti 5
Praha 2
120 00

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