Railway Systems Engineering & Integration Comes of Age
21st Anniversary Celebration
University of Birmingham, 4/5 Dec 2015
Overview of Presentation

- Different views of railway systems;
- Railway subsystems, interfaces and interactions;
- Railway complexity, complication and people;
- What are human factors? What is ergonomics?
- Why do we need ergonomics?
- Ergonomics in the railway industry;
- Some railway operations examples;
- Recent major railway accidents;
- Where are the REAL failures?
Poor Management of Change Causes Accidents

Many Subsystems and Interactions

- Electrification & Power Supplies
- Communications & Signalling Systems
- Traction & Braking Systems
- Vehicle Structures
- Axles & Wheels
- Bogies
- Rail
- ATP
- Rail
- Sleepers & Ballast
- Substructure System

CIS: Customer Information Systems / VCS: Vehicle Control Systems

Complicated and Complex Aspects

- Staff Performance
- Staff Demand
- Third Party Activity
- Economic Context
- Funding Changes
- Earth Movement
- Ground Stability
- Weather & Adhesion
- Degradation & Wear
- Time Tables
- Rosters/Schedules
- Regulations & Standards
- Product and Process
- Rules / Standards
- By-laws & Standards

Le Papillon de la Complexité Ferroviaire
Der Schmetterling des komplexen Systems Bahn
Complication and Complexity result in Railway Safety Risk

Types of Railway Risks and Parties Involved

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Types of Railway Risk

- Technical Safety Risk:
  - Train component failure;
  - Track component failure;
  - Signalling system failure.

- Operational Safety Risk:
  - Poor timetabling;
  - Human performance;
  - Maintenance quality.

- Societal Safety Risk:
  - Behavioural changes;
  - Poor change awareness.

- Financial Risk:
  - Budget overrun;
  - Compensation demand;
  - Company failure.

- Project Risk:
  - Time overrun;
  - Technology failure;
  - Performance risk.

- Security Risk:
  - Malicious acts;
  - Cyber technology issues.

Poor Management of Change Causes Accidents
Safety and Security for Travelling Public

- Concern since early days of railways;
- Travelling by train:
  - Collisions;
  - Fires and;
  - Derailments;
  - HV AC Electrification;
  - Other passengers.
- Travelling in and through stations:
  - Slips, trips and falls;
  - Shelter and warmth.

Safety of Operating Personnel

- Operating trains:
  - Driving activities;
  - Shunting activities;
  - Guard / conductor duties.
- Handling goods:
  - Lifting and shifting;
  - Fighting fires
  - Hazardous cargo spills.
- Dealing with incidents:
  - Derailments;
  - Animals and suicides.
Safety of Trackside Workers

- Maintenance of way:
  - Packing, greasing.
- Maintaining equipment:
  - Replacing light bulbs;
  - Adjusting points.
- Maintaining structures:
  - Pointing brickwork;
  - Replacing bridge bearing.
- Construction activities:
  - Build new platforms etc.
- Track-side workers not considered until ca. 1900.

Safety of Third Parties

- Level crossing accidents:
  - Vehicular interface;
  - Pedestrian interface.
- Overbridge / Underbridge:
  - Bridge-bashing;
  - Falls / drops onto railway.
- Trespass & vandalism:
  - Risks to perpetrators;
  - Risks to railway.
- Adjacent development:
  - Construction;
  - Drainage.
Defences against Risks

- Introduction of technical assist and intervention systems:
  – Redundancy and diversity.
- Better planning and scheduling:
  – Remove in-built conflicts.
- Rules and regulations:
  – Proscribe and prescribe.
- Management;
- Supervision and control;
- Laws and deterrents;
- Training and education:
  – Competency management and assessment.
- Automation (get rid of fallible human being).

Reason’s (Emmental*) Cheese Model

Risk Bearing Events

Realisation of Risk

* Swiss
People create Hazards and prevent Accidents

Human Factors / Ergonomics

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Poor Management of Change Causes Accidents

Traditional Perception of Human Error

- Negligence;
- Lack of commitment;
- Failure to follow rules or procedures.

From this perspective, people could avoid making errors by choosing to behave ‘correctly’…

Too simplistic - we’re only human, and we can all fail, in predictable ways!

How likely we are to fail is “shaped” by …
Performance Shaping Factors

Personal / Individual Factors
- Competence (training, experience, skills, knowledge)
- Stress / Personality (fatigue, time pressure)
- Physical Ability / Co-ordination (drugs, alcohol)
- Risk Perception
- Attitudes and Motivation

Job Factors
- Equipment (compatibility, usability, design, layout)
- Task Demands & Characteristics (perceptual load, frequency, workload etc.)
- Shift Patterns
- Communication
- Environment (workspace, lighting, vibration etc.)

Organisation and Management Factors
- Procedures and Standards (ease of use, design, accuracy and relevance of context, format)
- Planning
- Communication
- Rewards / Punishment Systems
- Roles and Responsibilities, “culture”

[HSE publication HSG 48 (Reducing Error and Influencing Behaviour)]

Signal Passed at Danger – Human Error?
Collision on a set of Points
No Fatalities / 26 Injuries
Light Weight Local Train derails Loco

Main Issues:
- 20% more services;
- Punctuality essential on single track railway line;
- Much higher performing trains;
- More ergonomic operation;
- Human error;
- Lack of ATP.

Collision between S33 / S11 at 07:35

Running at 37 km/h by time of reaching Points!

Slowed to 1.5 km/h by time of reaching Points!

Neuhausen Station

Schaffhausen

S11

S33

Rhein

Winterthur

200 m

100 m
### Causal Analysis of recent Accidents

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Lac Mégantic Disaster
Canada
2013-07-06, 01:15

Lax Attitude to Safety – Human Error?
8 m litres of Bakken oil exploded and burnt!
Huge Fire / Town Destroyed / 45 Deaths
Poor Management of Change Causes Accidents

Satellite Image Normal / after Accident
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**Spuyten Duyvil Curve**  
New York, USA  
2013-12-01, 08:10  

Microsleep by the Driver – Human Error?  
Classical Overspeed Scenario on a Curve
Poor Management of Change Causes Accidents

As Reported in New York Daily News

The Classical Overspeed Scenario

Permitted Speed: 70 mph / 110 km/h

Actual Speed: 82 mph / 130 km/h

Poor Management of Change Causes Accidents

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Poor Management of Change Causes Accidents

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5 m / 100 m more: Greater Consequences
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<td>SPAD (50 km/h)</td>
<td>No ATP, train stop site wrong</td>
<td>Minor routes not enhanced</td>
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<td>New York, USA</td>
<td>No vigilance device in cab</td>
<td>Microsleep Overspeed</td>
<td>No ATP, no speed traps</td>
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**Casselton Collision**  
North Dakota, USA  
2013-12-30, 14:00

Derailment of 112 Wagon Soy Bean Train  
106 wagon shale-oil train collides with wreckage and results in 21 wagons burning for a day.  
Casselton had to be evacuated but no casualties.
Poor Management of Change Causes Accidents

Bakken Shale-Oil is similar to Diesel

Wagons of Crude Oil in 2008: 10,000 / in 2013: 400,000

Courtesy T. Schmid
## Causal Analysis of recent Accidents

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<td>Poor track maintenance</td>
<td>New type of fuel oil, wagons</td>
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Signal Passed at Danger – Human Error?
Collision on a set of Points
No Fatalities / 6 Injuries of which 1 Serious
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Normal Weekday Peak Timetable

Station Throat to Single Track Section
Poor Management of Change Causes Accidents

View from Platform 3/4

Accident Timeline

- Line from Rafz to Neuhausen is single track;
- IR 2858 is timetabled to pass Rafz at ca. 06:31:
  - Non-stop Inter-Regional Zürich to Schaffhausen.
- S 18014 peak hours train starts day in Rafz:
  - Mo-Fr only, normal departure 06:40;
  - Arrived ECS (empty coaching stock) from North.
- IR 2858 is running 10 minutes late;
- S 18014 leaves platform on time at 06:40;
- IR 2858 hits S 18014 on points leaving station.
Layout and Accident Scenario

Poor Management of Change Causes Accidents

Electronic Timetable as a Factor?
Observations about Rafz Accident

• Both trains had two drivers:
  – Instructor plus trainee;
  – Instructor and trainee discussion may have diverted attention.

• Only one train a day starts journey in Rafz;

• Block entry signal (beyond last point) may show green, even though starter is red;

• Electronic timetable may have led drivers to start ‘on-time’:
  – Is there a live update about delays?

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Slide No: 47  21st Anniversary of Railway Systems Engineering and Integration

Slide No: 48  21st Anniversary of Railway Systems Engineering and Integration
Halifax, North Carolina 2015-03-09

Collision of Amtrak North East Corridor Train with Truck on Level Crossing

Poor Management of Change Causes Accidents

LC Collision between Train and Truck
Level Crossing Incidents are High Risk

- 55 people injured but no fatalities;
- Truck carried mobile equipment building;
- Truck was accompanied by state trooper to deal with highway / road traffic issues;
- Difficult turn into main road – truck stalled on level crossing for 20 minutes before crash;
- Poor instructions for level crossing users;
- Similar incident with a bacon truck on 5 June 2015 near Wilmington, no casualties.

Situation and Aftermath
Causal Analysis of recent Accidents

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21st Anniversary of Railway Systems Engineering and Integration

Frankfort Junction, Port Richmond, Philadelphia 2015-05-15

Derailment of Amtrak North East Corridor Train due to Overspeed on Curve
Immediate Aftermath of Derailment

Safely Travelling on Curves

\[ F_c > \frac{M \times v^2}{R_c} \]
Speed Data from 10, 11 and 12 May

Median Speed (3 days)
- 49 mph
- 29 mph

Train 188
- 90 mph from Washington
- 49 mph

Most Trains Speed-up to 100 mph

Train 188
- 102 mph
- 106 mph

Trajectories of Loco and Carriages
Poor Management of Change Causes Accidents

Beginning of Recovery Operation

Roof Removal from first Carriage
Poor Management of Change Causes Accidents

Consequences and Theories

- 238 staff and 5 crew on board;
- Locomotive stayed upright;
- 8 deaths and 200 injured, of which 11 seriously;
- Driver behaviour normal before accident;
- Report of damage to locomotive windscreen;
- Mobile phone records of driver being investigated;
- PTC installed on track and train but not in use;
- Legacy ATC (=ATP) system allowed overspeed;
- FRA now actively reviewing PTC implementation.

Causal Analysis of recent Accidents

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Eckwersheim, High Speed Train Derailment 2015-11-14, 15:10

Derailment of LGV-Est Test Train due to Overspeed on Curve

• Test train on the Ligne à Grande Vitesse (LGV) Est from Beaudrecourt to Vendenheim derails on curve that connects phase 2 of LGV-Est to classic network;
• Last of 200 test runs at a 10% over-speed to assess ride quality and stability;
• 53 people were on board, 49 test personnel and colleagues as well as 4 children;
• 11 people are killed and 42 injured, of which 4 in a life threatening state;
• 7 people were in the cab at the time of the accident: driver, second driver, traction inspector, engineer from SYSTRA and 3 others;
• Traction inspector took a mobile phone call at time where braking was due to start;
• Statement from SNCF: We shall punish responsible people!
Poor Management of Change Causes Accidents

Geographic Context of Derailment

Section of railway that is not part of national infrastructure: Vendenheim Connection of LGV-East Europe

Aerial View of Results of Derailment
Poor Management of Change Causes Accidents

Train Speed Pattern Leading to Accident

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Bridge hit by Front Power Car

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Poor Management of Change Causes Accidents

Rear Bogie of Front Power Car

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General Lessons from Railway Accidents

- Human beings at all levels are fallible;
- Accidents are rarely caused by a single mistake;
- Alignment of errors and failures creates precondition;
- Early risk assessment can mitigate outcome.
Felix Schmid

**Railway Transport is a total ‘System’**

- System includes both people and machines;
  - People in the system include users and staff;
  - Machines in the system include amplifiers of human strength and information handling.
- Machines are often software based:
  - Can change behaviour quickly.
- Railways are joint cognitive systems:
  - Systems that require much Human-Machine interactions so as to produce a coherent product. (Erik Hollnagel et al., 2005)
- The railway is a socio-technical system.
  - (Wilson et al., 2007)

Socio-Technical Systems Thinking

- Cherns (1976, 1987) principles of socio-technical design, e.g.:
  - Compatibility;
  - Information flow;
  - Power and authority.
- Social factors, e.g.:
  - Personnel;
  - Interactions;
  - Training.
- Technical factors, e.g.:
  - Technologies;
  - Materials;
  - Standardisations.
- Automation to manage growing complication & complexity.
Automation and System Performance

- Onnasch et al. (2014) propose a ‘degree of automation’ variable to explain trade-offs in human-machine relationships;
- With any increase in degree of automation:
  - Routine performance improves;
  - Performance in failure scenarios declines;
  - Workload from automated task reduces progressively;
  - Loss of Situational Awareness (SA) grows steadily: as automation is doing more cognitive/physical work, the human is doing less.

Ergonomics in Railway Operations

- Increasing emphasis on improving rail safety, but with pressure to improve business performance:
  - Higher speeds and higher performance trains;
  - Increasing traffic reduces time/space between trains;
  - Tilting trains and other advanced systems.
- New human interface and performance issues arise from new systems:
  - Human aspects of train control & signalling systems, Automatic Train Protection systems etc. need to be assessed.
- Increasing traffic levels and need for reliability.
Railway Human Factors are Challenging

- Large numbers of very distributed staff;
- Complex and legally binding hierarchies;
- Many monotonous jobs;
- Antisocial hours work;
- Dangerous work places;
- High levels of responsibility, little authority;
- Need for high reliability organisations;
- Regulatory influences must be managed.