NTNU

Norwegian University of Science and Technology

DESTination RAIL

Decision Support Tool for Rail Infrastructure

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Analysis of Failures within Switches and Crossings using Failure Modes and Effects Analysis Methodology

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Outline of Presentation

1. Background
2. FMEA methodology
3. Common Damage Mechanisms
4. Failure Classification
5. FMEA Failure Analysis
6. Conclusions

Background

Turnout populations

Countries	Track (km)	S&C population	S&C units per track kilometre
Belgium	6,500	12,200	1.88
Italy	27,100	42,700	1.58
Netherlands	6,500	7,800	1.20
UK	31,100	25,800	0.83
Sweden	**14,900**	**12,000**	**0.81**
France	65,100	25,600	0.40

- Belgium – 1.88 units/km
- Sweden – 0.81 units/km
  < 5% of infrastructure
- France – 0.40 units/km
- In Sweden over 12% of track maintenance and 25% of track renewals are spent on S&Cs

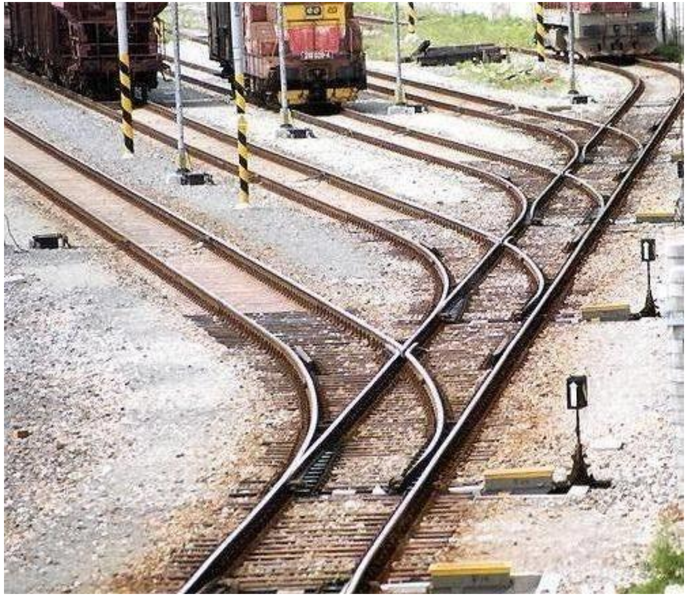
- Network Rail is using about 17 % of the track maintenance budget and ca. 25 % of the track renewal budget in Switches and Crossings
- In addition, cost for disruption and delays in train operation are very high

Background

Different researchers propose different remedies to reduce maintenance costs:

1. reducing turnout population (# turnouts)
2. using more durable and advanced materials
3. optimizing turnout geometry (layout), support stiffness (structure) and rail profiles
4. adopting preventative maintenance strategy instead of corrective maintenance

Over 30% of the failure modes are related to **rail mechanical** and **track geometry** failures



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Aim of this study

- The aim of this study is to identify and predict the potential failures and failure risks based on historical data and failure occurrences

Identification of possible failure modes

- Identify most critical components
- The likely failure mechanism
- Determination of corresponding rectifications
- Better categorization of different modes in terms of severity and criticality

Better understanding and used as input to enable

- Optimised layout and components
- Improved/new S&C design
- More durable and advanced materials
- Better approach to preventive maintenance

FMEA methodology

FMEA methodology

Failure Modes and Effects Analysis (FMEA)

- FMEA is a procedure used to
  - identify potential failure modes
  - determine causes and effects of failure modes, and
  - mitigate or remove its effects on system functional performance

based on the recorded data (past experience)

- FMEA/FMECA tools are well established method for safety and reliability analysis of systems, or for product improvement of systems in aerospace, nuclear, electronic, and automotive industries

FMEA/FMECA standard tools

- FMEA consists of breaking a system down into specific data

- **IEC-60812**: procedure for failure modes and effect analysis (FMEA) from electronic industry
- **SAE-J1739**: FMEA for automobile industry: Potential Failure Mode and Effects Analysis in Design and in Manufacturing and Assembly Processes
- **SAE ARP 5580**: Recommended failure modes and effect analysis (FMEA) practices for non-automobile application

FMECA sheet

System: ______________________ Performed by:___________________

Ref. drawing no: _______________ Date:________ Page __ of ___

Description of unit			Description of failure			Effect of failure		Failure Rate	Severity Ranking	Risk Reducing Measures	Comments
Ref	Function	Operational Mode	Failure Mode	Failure Cause/Mechanism	Detection of failure	On the subsystem	On the system function				
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)

Failure Modes and Effects Analysis (FMEA)

- Questions that must be answered in a FMEA

1. **Function**: what is the function(s) of the components analyzed?
2. **Failure mode**: in what ways can the system fail in performing its intended function?
3. **Failure causes and failure mechanisms**: what are the causes?
4. **Consequence**: what can happen when a failure occurs?
5. **Failure frequency**: how often the failure occurs?

Definitions

Failure:

- The termination of the ability of an item to perform a required function

  Example: a train unable to run over a switch with the intended speed

Function

- The normal or characteristic "operational tasks" to an item

  Example: to guide train from one track “track 1” to a separate track “track 2”, with a certain required speed

- For a unit to give this function, all the components must provide the intended function

  Example: switching machine drives the switch rails to the intended direction by the help of stretcher bars

Definitions, Cont'd

Failure mode

- The way in which an item fails to perform its required function

  Example: Line blocked, derailment, switch functioning with reduced speed

Failure cause

- The circumstances or the causes that result to the failure to occur

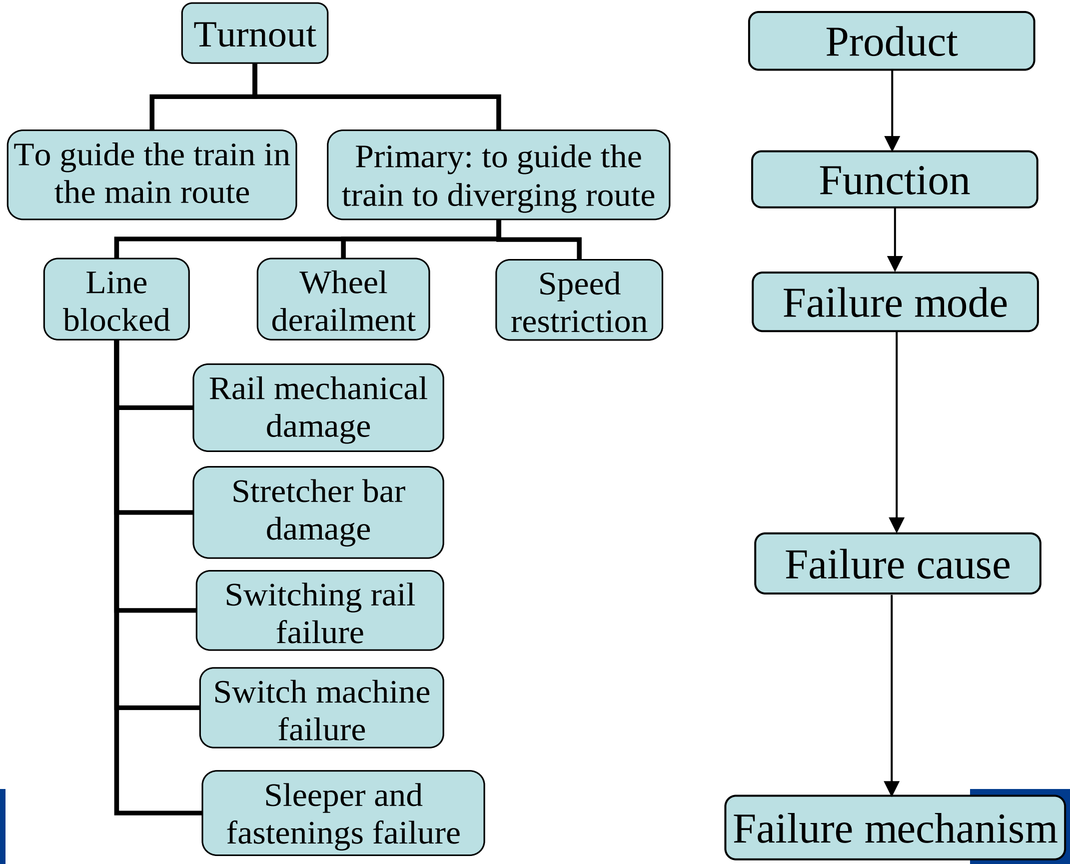
  Example: missing of rail fastening bolts, dry or contaminated switch rail sliding chair, rail breakage or fracture

Failure mechanism

- Physical, chemical or other processes that causes failure

  Example: wear, corrosion, plastic deformation, RCF

Failure hierarchy for a turnout unit

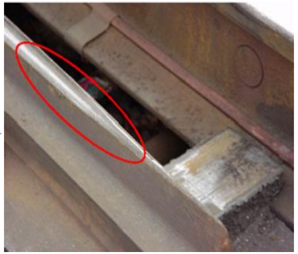


Common Damage Mechanisms

Common Damage Mechanisms

Fracture

Plastic deformation



Wear

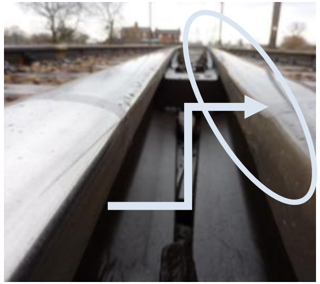
RCF on stock rail

Switch rail breakage

Common Damage Mechanisms

Damage on swing nose crossing

Rail Head Cracks



Plastic deformation (lipping)

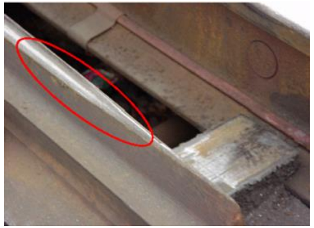
Damage on fixed nose crossing

Failure Classification

Failure classification by components

- Failure may be classified based on failing components

Failure cause/mechanisms in rail failure
- Rolling contact fatigue
- Wear
- Rail head deformation
- Rail head cracks
- Rail web cracks
- Transverse & Longitudinal rail foot cracks





Failure classification by components

Failure cause in switching system

- Dry slide chair or baseplate
- Broken stretcher bar
- Switch Anchor Loosing
- Broken Bolts

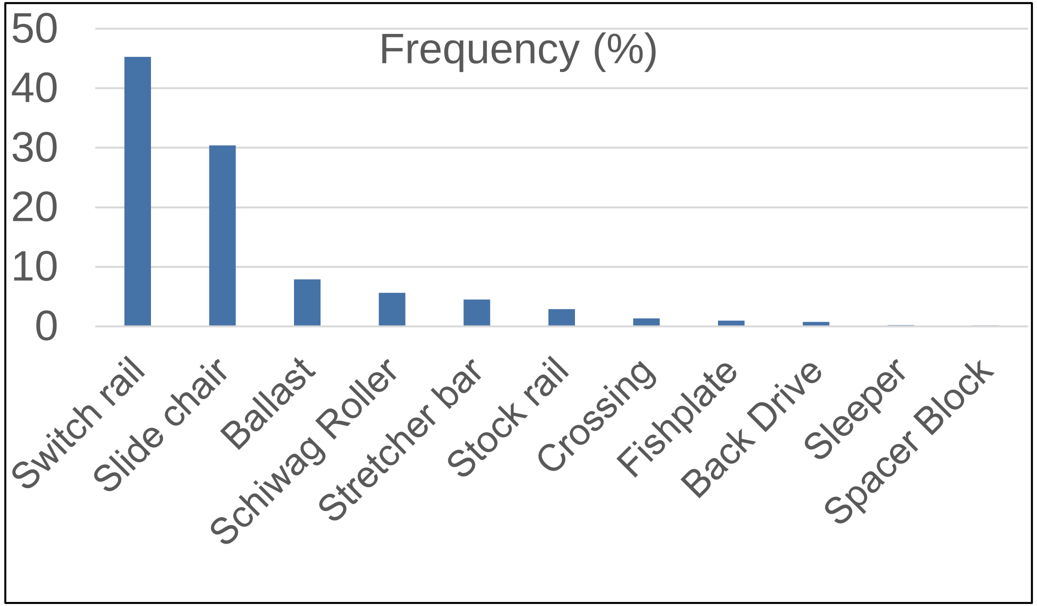
Failure classification by components

- Failure may be classified based on failing components

Components	Failure causes/mechanisms
Rail	Wear, rolling contact fatigue, plastic deformation, rail head cracks, rail foot fractures, rail web cracks
Stretcher bar	Stretcher bar bracket breakage
Switching machine	Too much or too little power, unable to close the switch rail against the stock rail
Sliding chair and rollers	Dry slide chair, rusty slide table or fully contaminated lubrication which blocks the movement of switch rail from sliding
Fastening system	Missing bolts, damaged rail pad, broken base plate
Sleeper	Rail seat deterioration, flexural cracking at the sleeper centre, and transverse cracking at the fastening bolt

Failure data analysis

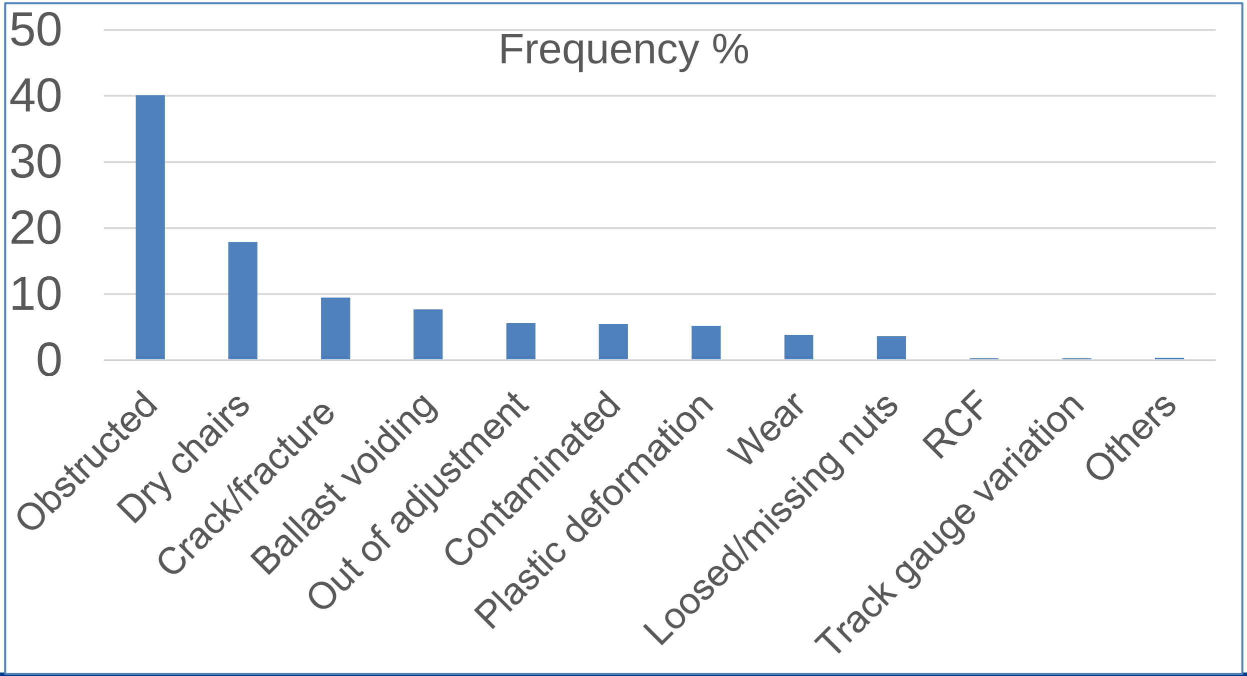
- Example of failure data analysis based on the failed components



Failed Components	Total Number	Frequency (%)
Switch rail	1113	45.3
Slide chair	747	30.4
Ballast	194	7.9
Schiwag Roller	138	5.6
Stretcher bar	111	4.5
Stock rail	71	2.9
Crossing	33	1.3
Fishplate	24	1.0
Back Drive	18	0.7
Sleeper	5	0.2
Spacer Block	4	0.2
Sum	2458	100

Failure data analysis, Cont'd

- Data assessment based on possible failure causes (mechanisms)



Failure classification by severity

- Severity level is one way of failure classification method to categorise the criticality of the effects on the function of item or component

Severity level	Criticality nature
Category I - Catastrophic	A failure which may cause death or total system loss
Category II - Critical	A failure which may cause severe injury, major property damage, or major system damage
Category III - Marginal	A failure which may cause minor injury, minor property damage, or minor system damage which will result in delay or loss of availability or speed restriction
Category IV - Minor	A failure not serious enough to cause injury, property damage, or system damage, but which will result in unscheduled maintenance or repair

Failure data analysis, Cont'd

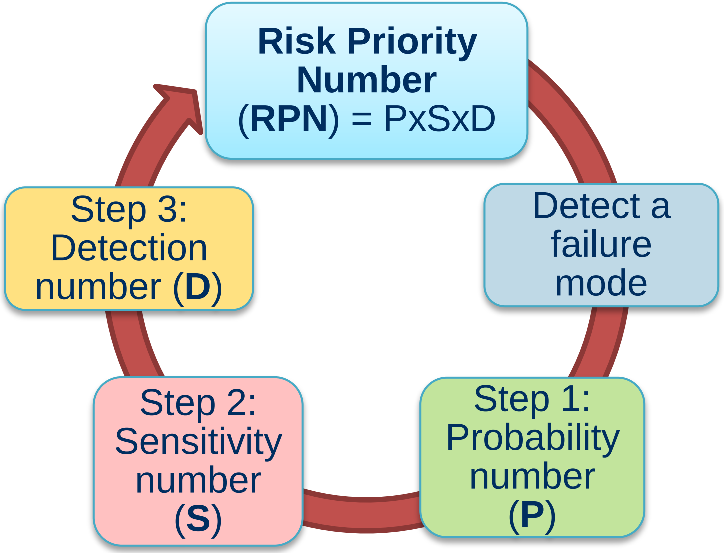
- Data assessment based on rectification

Rectification	Total Number	Frequency %	Failed Components
De-iced	559	22.7	Switch rail, Slide chairs, Schiwag Roller, Back drive, Stretcher bar
Lubricated	445	18.1	Slide chairs, Schiwag Roller
Removed obstacle	427	17.4	Switch rail, Slide chairs, Stretcher bar, Back drive
Replaced/Renewed	243	9.9	Stretcher bar, Slide chairs (broken), Crossing (nose crack), Fish plate, Switch rail, Stock rail, Sleeper, Space block, Ballast
Lift & Pack	190	7.7	Ballast
Grind	167	6.8	Switch rail, Stock rail, Rail weld
Adjusted	143	5.8	Schiwag Roller, Switch rail, Stretcher bar, Back drive, Slide chairs, Ballast
Cleaned	136	5.5	Slide chairs, Switch rail, Schiwag Roller
Weld repair	71	2.9	Switch rail, Stock rail, Crossing
Tightened	70	2.9	Slide chairs, Stretcher bar (nuts), Back drive, Fish plate
Gauged	7	0.3	Track gauge

Failure Analysis using FMEA

FMEA analysis

- In the rail industry, the procedure used is based on Risk Priority Number (RPN)



FMEA cycle

- **Occurrence (P):** Failures Frequency Distribution
- **Sensitivity Ratings (S):** Very minor if no immediate effect to Very high if results in unsafe operation
- **Detection (D):** Easy to Hard to detect the failure

FMEA analysis, Cont'd

Step 1. Occurrence

Rating	Meaning	Range (%)
1	No Effect	OCCUR = 0
2	Low (few failure)	0 < OCCUR < 5
3	Moderate (occasional failure)	5 < OCCUR < 10
4	High (repeated failure)	10 < OCCUR < 20
5	Very high	20 < OCCUR

Step 2. Sensitivity

Rating	Meaning
1	No Effect
2	Very Minor (no immediate effect or long term effect)
3	Minor (affects little of the system)
4	Moderate (causes a less primary function failure)
5	High (causes a loss of primary function)
6	Very High (results unsafe operation or injuries)

FMEA analysis, Cont’d

Step 3. Detection

Rating	Meaning
1	High
2	Moderate
3	Low

- **Risk Priority Number (RPN)**

$$RPN = P \times S \times D$$

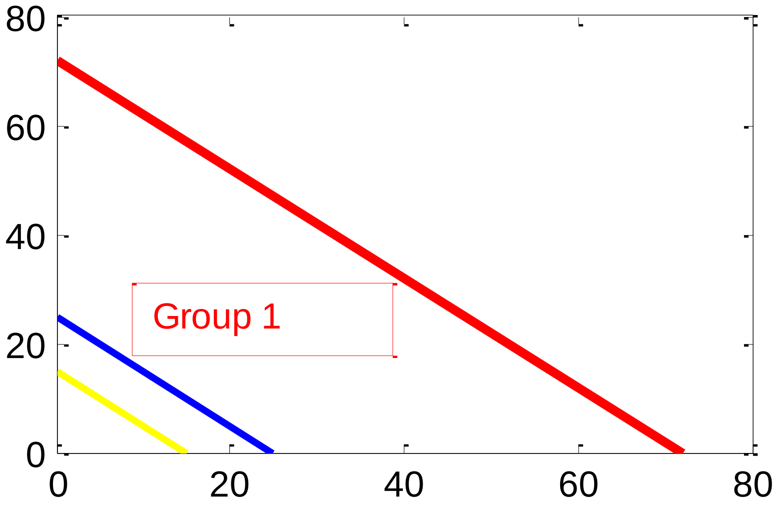
Failure Analysis Results

Results

Failure causes / Failure mechanisms	Occurrence Rate (P)	Sensitivity Rate (S)	Detection Rate (D)	RPN
Obstructed (Iced, ….)	5	5	3	75
Dry chairs	4	5	3	60
Crack / broken rail	3	5	2	30
Voiding	3	3	3	27
Contaminated (Leaves,..)	3	3	3	27
Out of adjustment	3	4	2	24
Plastic deformation /Lipping	3	4	2	24
Wear	2	4	2	16
Loose/missing nuts	2	2	3	12
Squat, RCF	2	2	2	8
Track gauge variation	2	3	1	6

Results, Cont'd

- Group 1. High Risk Priority Number
  - highest priority for preventive maintenance
  - components associated with these failure mechanisms need new or improved design



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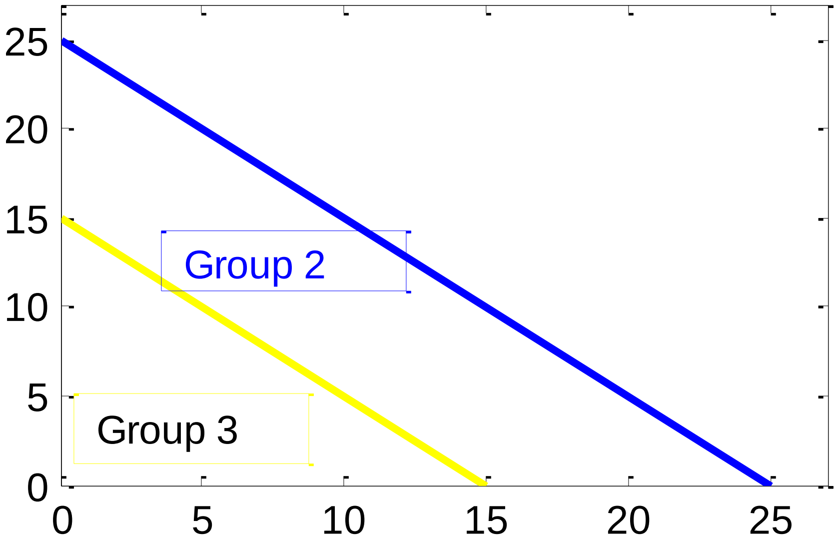
Track gauge variation	2	3	1	6

Group 1

Results, Cont'd

- Group 2. Moderate Risk Priority Number
  - the second priority for preventive maintenance
  - components may need some improvements

- Group 3. Low Risk Priority Number
  - need to get rectified before imposing a serious effect on the system in long term



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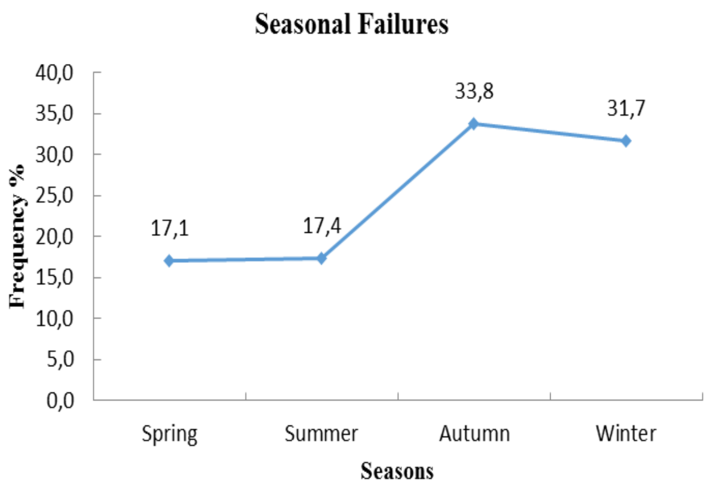
Group 1

Group 2

Group 3

Failure occurrences vs. seasons



The largest number of failures occurred

- autumn period - contamination of rail running surface by falling leaves
- winter period - switch obstruction by ice

Conclusions

- Failure risk in turnouts has been assessed based on historical data and occurrence of failures
- FMEA procedure has been applied to approach the classification of critical failures in turnouts
- Two failure mechanisms are identified to critically affect the turnout primary operation: switch obstruction and dry chair
- Several years of data, and wide range of data is required for an accurate judgment
- Such kind of failure risk evaluation may support maintenance planning and design improvement

Thank you for your attention!

Questions?