THE CONCEPT OF "RISK RANKING – PRIORITISATION MATRIX" METHOD AND ITS APPLICATION FOR PRIORITISATION OF THE NON-COMPLIANCE RAIL ULTRASONIC TESTING TRACKS

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ABSTRACT

Rail internal failure related derailments are a major class of derailments costing, within Australia, efforts have been made to minimise service failures and risk of derailments, through more often and more effective ultrasonic testing. The major Australian railway authorities such as Sydney Trains and ARTC have issued explicit regulations of the schedules for a continuous search for internal rail defects. These regulations provide a minimum guideline for test frequency scheduling, and some railway corridors test more frequently to minimise the probability of service defects (broken rails) occurring, thus minimising the risk and cost of derailment. However, due to the availability of the possessions or traffic planning reasons, as well as the capability and/or breakdown of the ultrasonic testing vehicles, the planned rail testing work cannot be finished within the schedules and overdue was happened. The non-compliance rail ultrasonic testing track sections have left high risk of rail broken and derailments, which is a critical issue and must be processed by additional rail testing works in a very short time frame. Within this paper a newly developed "Risk Ranking – Prioritisation Matrix" method is presented. This method has been successfully utilised for the risk assessment and prioritisation of the non-compliance rail ultrasonic testing track sections since 2017 within Sydney Trains' Network.
Key words: risk ranking, prioritisation matrix, non-compliance, rail, ultrasonic testing.

1 INTRODUCTION

Rail internal failure related derailments are a major class of derailments costing, within Australia, efforts have been made to minimise service failures and risk of derailments, through more often and more effective ultrasonic testing.

The major Australian railway authorities such as Sydney Trains and ARTC have issued explicit regulations of the schedules for a continuous search for internal rail defects. These regulations provide a minimum guideline for test frequency scheduling, and some railway corridors test more frequently to minimise the probability of service defects (broken rails) occurring, thus minimising the risk and cost of derailment.

However, due to the availability of the possessions or traffic planning reasons, as well as the capability and/or breakdown of the Speno ultrasonic testing vehicles, the planned rail testing work cannot been finished within the schedules and overdue was happened. The non-compliance rail ultrasonic testing track sections have left high risk of rail broken and derailments, which is a critical issue and must be processed by additional rail testing works in a very short time frame.

2 CONCEPTS OF THE "RISK RANKING AND PRIORITISATION MATRIX"

To minimise the potential risks which are caused by the non-compliance rail ultrasonic testing, a risk assessment-based prioritisation and updated testing plan are developed. This technical solution is by using a so-called "Risk Ranking – Prioritisation Matrix" model to undertaken the data process of the non-compliance rail sections.

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Figure 1: The Speno ultrasonic testing vehicle.

Regarding to the risk ranking model, based on the standards of track maintenance and practices from all the major railway authorities in Australia, the potential risks of ultrasonic testing plans are mainly affected by two factors – the frequency and the condition of rail (e.g. the fatigue of rail materials, which is presented by the number of defects that has been found in per km of track in the history). In addition, considering the severe rail head wear distortion can alter the normal angle refraction of the ultrasonic probes, the impact of rail wear conditions has also been included within the risk ranking model.

To finalise the analysis by combing the final scores of risks ranking of “frequency and overdue date”, “rail defects & critical defects” and “condition of rail wear”, a prioritisation matrix is developed to “weighting” the priorities for every non-compliance track section.

This method and relative model have been successfully utilised for the risk assessment and prioritisation of the non-compliance rail ultrasonic testing track sections since 2017 within Sydney Trains’ Network.

3 RAW DATA AND PRE-PROCESSING FOR ANALYSIS

The length of these individual non-compliance track sections can be varying from the minimum 0.010km to the maximum 50km, and, the involved tracks including main lines, loops and yard crossover points, etc.

Before the data process, all the non-compliance rail ultrasonic testing track sections and the locations of the defects are arranged by tabulating them in Microsoft Excel Spreadsheet with the information of “Base code”, “Description of the Track Section”, “Start km”, “End km”, “reason missed”, “frequency”, “latitude”, “overdue date”, “overdue cycle represented by %”, “number of defects” and “number of critical defects” within each specified track section which were found in the past, etc.

In addition, the "2015–2016 re-railing program" is provided as the reference to be utilised to confirm if the defective rails that were listed in the non-compliance rail sections have been replaced since they have been found by the ultrasonic testing vehicle that ran in last time.

The raw data of non-compliance rail ultrasonic testing track sections were pre-processed by deleted all the rail defects that have been replaced by the previous re-railing works by means of cross-checking the mileage of the re-railing sections and the locations of the existing rail defects. Hence, it was ensured these removed defects are not to be involved for the calculation.

Finally, all the rail defects which exist in these non-compliance track sections and among them how many defects can be categorised into the level of "critical defects" need to be worked out. The critical defects are defined and included as shown in the Table 1.

Table 1: Definition of the types of critical defects.

Types of critical defects			
Code	Location within rail	Size	Description of rail defects
HSH	Head	S	Horizontal Split Head 25 to 100mm
HSH	Head	M	Horizontal Split Head 101 to 200mm
HSH	Head	L	Horizontal Split Head over 200mm
HSW	Web	S	Horizontal Split Web 20 to 40mm
HSW	Web	M	Horizontal Split Web 41 to 75mm
HSW	Web	L	Horizontal Split Web 75 to 150mm
HSW	Web	E	Horizontal Split Web over 150mm
TD	Head	M	Transverse defect 11 to 30%
TD	Head	L	Transverse defect over 30%
TDX	Head	S	Multiple Transverse Head Defects 5 to 10%
TDX	Head	M	Multiple Transverse Head Defects 11 to 30%
TDX	Head	L	Multiple Transverse Head Defects over 30%
VSH/IB	Head	N/A	Vertical Split Head < 50mm in length or up to 3mm in height*
VSH	Head	S	Vertical Split Head 50 to 200mm
VSH	Head	M	Vertical Split Head 201mm to 400mm
VSH	Head	L	Vertical Split Head over 400mm
VSH	Head	E	Vertical Split Head Visible cracking or rail head collapse
VSW	Web	S	Vertical Split Web longitudinal Any registration in one rail length

4 METHODOLOGIES AND TECHNICAL DETAILS FOR THE MODELLING

Based on the standards of track maintenance and practices from all the major railway authorities in Australia, the potential risks of ultrasonic testing plans are mainly affected by two factors – the frequency and the condition of rail (e.g. the fatigue of rail materials, which is presented by the number of defects that has been found in per km of track in the history).

Regarding to the risks from the frequency, both of the frequency itself and the overdue situation need to be considered and ranked.

4.1 Risk ranking based on frequency (month)

The frequency is dominated by the importance of the railway tracks in the whole network. The more important tracks have higher ultrasonic testing frequency. Focus on the railway network of Sydney Trains, the risk ranking based on testing frequency is tabulated as following:

4.2 Risk ranking based on overdue date

Because of the availability of the testing (such as overdue) can significantly impact to the levels of risk that based on the scheduled test plan, hence, the risks from overdue time needs to be considered and ranked. The Overdue of the testing in the Sydney Trains' ultrasonic test management is represented as "Overdue %", and calculated as:

$$\text{Overdue Date in } \% = [(D_{Today} - D_{LT})/121] \times 100\%, \tag{1}$$

where:
D_{Today} ---- The Date of Today;
D_{LT} ---- The date of last test (for the testing frequency of 12 months and 6 months tracks, the D_{LT} value are modified by subtract 360 days and 180 days respectively);
The 121 days are used to represent the time interval of 4 months, which is the standard ultrasonic testing schedule for the 1 class track.

The additional risks from overdue are ranked (can be seen as the "weight" of the risk ranking scores of the frequency) (Table 2).

Table 2: Risk ranking based on frequency (months).

Risk rank (Score)*	Consequences	Frequency of Speno ultrasonic testing (months)	Remarks
3	Band 1	2	
3	Band 1	4**	
2	Band 2	6	
1	Band 3	12	

Note: * Highest number is highest priority.
** Standard ultrasonic testing schedule for the 1 class track.
*** The scores of risks ranking for both 2 months and 4 months ultrasonic testing interval are equal, which is "3".

Table 3: Risk ranking based on overdue date.

Risk rank (Weight of risk rank of frequency)	Consequences	Overdue days of Speno ultrasonic testing (Overdue days represented by %)*	Remarks
5	Band 1	≥ 200%	
4	Band 2	< 200% and ≥100%	
3	Band 3	< 100% and ≥50%	
2	Band 4	< 50% and ≥0%	
1	Band 5	< 0%	

Table 4: Updated risk ranking of the combination of frequency and overdue date.

Risk Rank	Consequences	Remarks
16 – 20	Band 1	
12 – 15	Band 2	
8 – 11	Band 3	
4 – 7	Band 4	
1 – 3	Band 5	

4.3 Updated risk ranking by the combination of frequency and overdue date

As pre-discussed, because of the internal correlation of the risk of frequency and overdue date, risk ranking is further calculated by multiply them for each track section, i.e. calculate weighted scores for each track section as “score × weight”. Hence, the risk ranking of the combination of frequency and overdue date is obtained (Table 4).

4.4 Risk ranking based on rail defects

From the practices of routine maintenance of track, conclusions have been drawn for that the fatigue condition of rails (e.g. the fatigue of rail materials, usually is presented by the number of defects have been found in per km of track in the history) are directly related to the likelihood of rail broken/failure, hence, the risks from rail fatigue conditions must be included into the risk assessment.

Based on the available data of rail internal defects within a railway authority’s network those have been found by ultrasonic test in the history, for each non-compliance track sections the average defects per km were calculated for further analysis. And, the risk ranking based on rail fatigue conditions is shown in Table 5.

Table 5: Risk ranking based on rail defects that found in the history (number of defects).

risk rank	Likelihood	Rail defects/km that found by the Speno ultrasonic test vehicle (number)	Remarks
5	Almost certain	Higher or equal to 10	
4	Likely	≥7 & <10	
3	Possible	≥4 & <7	
2	Unlikely	>0 & <4	
1	Rare	0	

4.5 Risk ranking based on critical rail defects

For the risk assessment that caused by the rail internal defects, there is no doubt for that the different types and size of the defects should have the different "analysis weight" for the risk assessment. So, the numbers of critical defects among the defects that have been found in the history by ultrasonic test are risk ranked as shown in Table 6.

Regarding to the threshold of the critical defects for this analysis, according to the risk based theory used for scheduling ultrasonic test frequencies which is developed by the US Department of Transportation (DOT), the number of "0.1 "Service" (i.e. "Critical" in Australian railway) defects/mile" is acknowledged as the allowable baseline for US freight line (ZETA-TECH Associated, Inc. [1]). And, the risk value for "US Freight Average" and "Low Speed Passenger Service" are 0.1 and 0.03 respectively, i.e., the risk ranking weight of "Low Speed Passenger Service" is 3.33 times higher than the track which is predominated by freight traffic. Hence, the threshold value is set by: $(0.1/1.6)/3.33 = 0.0188 \approx 0.02$ critical defects/km.

4.6 Risk ranking by the combination of rail defects and critical defects

Similarly, the risk ranking is updated by combine the number of rail defects and critical defects among them in each specified track sections. This is calculated by multiply the risk ranks for each track section.

4.7 Risk ranking based on the condition of rail wear

Severe rail head wear distortion can alter the normal angle refraction of the ultrasonic probe from the transducer to such a critical level that the ultrasonic signals do not penetrate at the expected angle, or to the expected location, in the specimen. Especially, the 70° and 0° probes

Table 6: Risk ranking based on critical rail defects that found in the history (number of defects).

Risk rank	Likelihood	Critical rail defects/km that found by the Speno Ultrasonic test vehicle (number)	Remarks
10*	Almost certain	Higher than 0.02	
3	Likely	> 0 & ≤0.02	
1	Possible	0	

Note: The "step" of risk ranking for the situation of below and above the threshold value of critical defects is not linearly changed, which is used to represent the risk to rail broken/failure during the traffic revenue.

Table 7: Risk ranking by the combination of rail defects and critical defects.

Risk rank	Likelihood	Remarks
≥ 20	Almost certain	
10–19	Likely	
5–9	Possible	
2–4	Unlikely	
1	Rare	

of the Speno Ultrasonic testing vehicle are to be experience difficulties when they fit with the rails with severe rail worn (Sydney Train [2]). This situation will impact the accuracy and productivity of the ultrasonic testing work (International Heavy Haul Association, [3]). For this reason, the situation of the existing worn and condemned rails of each of the non-compliance rail sections needs to be included into the prioritisation work by using of the logical and rational risk rankings.

For the risk ranking of the rail wear, both of the quantity (percentage of worn rail in each track sections) and severity are need to be considered.

Based on the available statistical methods of the raw data of worn rails, the locations and length of the worn rails are counted in two categories based on their conditions – reportable and condemned.

From the current available references, there is no information can be used to help to determine the thresholds of the risk ranking levels. For this analysis, the severe rail wear (reportable) and condemned rails are to be considered as two types of rail "defects" in two different classes. Based on this assumption, the concepts that have been used to risk-ranking the rail defects and critical defects can be transplanted and utilised for this work. In addition, the percentage of the length of worn rail is used rather than the number of locations as the unit for threshold.

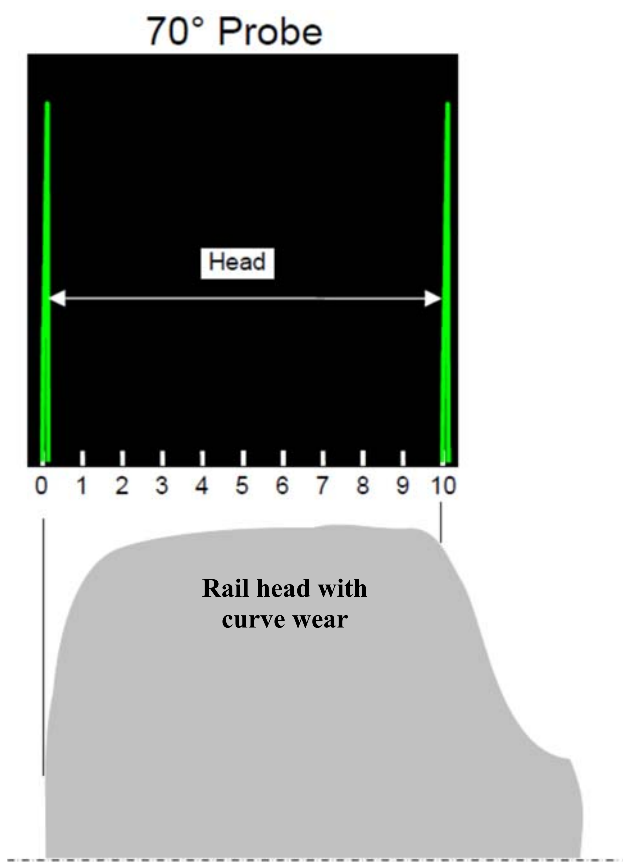

Figure 2: Setting bottom of rail head.

The risk ranking based on the percentage of length of reportable worn rail and condemned rail are shown in Tables 8 and 9.

Because of the reportable and condemned rails are counted separately, hence, the risk ranking for the combination of reportable and condemned rail wear can be calculated by simply add up the scores of reportable rail and condemned rail together. The results are shown in Table 10.

Moreover, it is very clear that the risk of rail broken which is caused by the fatigue of rails is higher than the non-reliable which is caused by the ultrasonic probes work on the head worn rails. For this reason, the risk ranking scores is multiplied by a "weight of modification" which is 30%, i.e., the risk from non-reliable that caused by rail head wear is equal to 30% of the risk from the condition of rail fatigue.

4.8 Prioritisation matrix

To finalise the analysis by combing the final scores of risk ranking of "frequency and overdue date", "rail defects & critical defects" and "condition of rail wear", a prioritisation matrix is

Table 8: Risk ranking based on the length (%) of reportable rail wear.

Risk rank (Score)*	Likelihood	Length of reportable rail wear (% of km of track)	Remarks
5	Almost certain	Higher 2%	Reportable rail wear
3	Likely	> 0 & ≤ 2%	
1	Possible	0	

Note: * Highest number is highest priority.

Table 9: Risk ranking based on the length (%) of condemned rail wear.

Risk rank	Likelihood	Length of reportable rail wear (% of km of track)	Remarks
10	Almost certain	> 0	Condemned rail wear
1	Possible	0	

Table 10: Risk ranking based on the length (%) of the combination of reportable and condemned rail wear.

<table>
<tr><th colspan="3">Risk rank</th><th rowspan="2">Likelihood</th><th rowspan="2">Remarks</th></tr>
<tr><th>Score after combination</th><th>Weight of modification to the prioritisation matrix</th><th>Scoring values after modification to the prioritisation matrix</th></tr>
<tr><td>5–15</td><td>30%</td><td>1.5–4.5</td><td>Almost certain</td><td rowspan="3">Condemned and reportable rail wear</td></tr>
<tr><td>3</td><td>30%</td><td>0.9</td><td>Likely</td></tr>
<tr><td>2</td><td>30%</td><td>0.6</td><td>Possible</td></tr>
</table>

developed to “weighting” the priorities for every non-compliance track section. It is used to represent that the reliability is a combination of the results of all factors of evaluations.

Within this prioritisation matrix, the available “risk ranking scores of the combination of frequency and overdue date”, “risk ranking score of the combination of rail defects and critical defects” and “risk ranking score of the combination of reportable and condemned rail wear” are to be used as the “weight criteria”. The risk ranking scores of the combination of frequency & overdue date are input as the importance of “Consequences” in the order of from small to large in the longitudinal direction into the matrix. Then, the risk ranking score of the combination of rail defects and critical defects are input as the importance of “Likelihood” in the order of from large to small in the vertical direction into the matrix. The risk ranking scores of the combination of reportable and condemned rail wear are input as a “factored/modified” importance of “Likelihood” in the order of from large to small in the vertical direction into the matrix. The prioritisation matrix is shown in Fig. 3.

By using this specified prioritisation matrix, overall score of risks are obtained by simply add up the risks from the factors of “Consequences” and “Likelihood” together (Australian Rail Track Corporation Ltd [4]). The results of risk assessments are categorised into 4 risk levels based on the values of the risk scores after adding up the values of consequences and likelihood (Carpenter [5]). The areas (grids) of different risk levels are highlighted by “Red” colour for “very high”, “Golden” colour for “High”, “Yellow” colour for “Medium” and “Green” colour for “Low”, as shown in Fig. 3.

4.9 Remedial actions

Adequate amount of samples have been used for determine the threshold value of different risk levels. The final results of the threshold value are shown in the grids of the prioritisation matrix.

Likelihood (Rail Defects & Critical Defects)	Consequences (Frequency & Overdue Date)					Situation of Rail Wear
	Band 5 (0-3)	Band 4 (4-7)	Band 3 (8-11)	Band 2 (12-15)	Band 1 (16-20)	
Almost Certain (≥20)	M (≥20, & within 20-23)	H (≥24, & 24-27)	VH (≥28, & 28-31+)	VH (≥32, & 32-35+)	VH (≥36, & 36-40+)	Almost Certain (1.8 – 4.5)
Likely (10-19)	L (≥10, & 10-22)	M (≥14, & 14-26)	H (≥18, & 18-30)	H (≥22, & 22-34)	VH (≥26, & 26-39+)	Likely (0.9 – 1.5)
Possible (5-9)	L (≥5, & 5-12)	L (≥9, & 9-16)	M (≥13, & 13-20)	M (≥17, & 17-24)	H (≥21, & 21-29+)	
Unlikely (2-4)	L (≥2, & 2-7)	L (≥6, & 6-11)	L (≥10, & 10-15)	L (≥14, & 14-19)	M (≥18, 18-24+)	Possible (0.6)
Rare (1)	L (≥1, & 1-4)	L (≥5, & 5-8)	L (≥9, & 9-12)	L (≥13, & 13-16)	L (≥17, & 17-21+)	

Figure 3: Likelihood – severity risk ranking matrix (prioritisation matrix).

The remedial actions are suggested for each risk levels:

- Very high (VH) – Immediate action required / control obligatory;
- High (H) – Attention is needed and expected;
- Medium – Management responsibility must be clear and specified; and
- Low – Manage by routine Sydney Trains procedures.

4.10 Manual work

Although after some preliminary analysis works by using this “Risk Ranking – Prioritisation Matrix” have shown this is a good and effective tool for prioritise the non-compliance rail ultrasonic testing track sections, sometimes additional manual works are still essential and indispensable. The reasons are from the following considerations:

- The condition of in-field rail track structures is extremely complex. Many special cases need to be determined based on experience;
- Present version of the model (Risk Ranking - Prioritisation Matrix methodology) still have some shortcomings and limitations, fine tune work is still on the way;
- The raw data and analysis results both from computer analysis and in-field survey sometimes could be questionable, hence, the double and cross checks are required.

5 RESULTS OF ANALYSIS AND RECOMMENDATION

After the methodology of analysis has been developed, it has been fine turned by used it to undertake some preliminary analysis works against the different testing samples. The results have shown that it is a good and effective tool for undertaking the prioritisation works.

5.1 Procedure for data analysis

The basic procedures of the data processing are:

- Raw data pre-processing.
- Copy and paste the current “non-compliance rail ultrasonic testing track section” records into a specially designed Microsoft Excel Spreadsheet, the necessary information of each record should including: “Base code”, “Description of Track Section”, “Start km”, “End km”, “Length”, “Standard Run”, “Last Tested Date”, “Planned Test Date”, “Reason Missed”, “Frequency (Months)” and “Latitude (days)”.
- Calculate the scores of risks ranking of “frequency & overdue date”, “rail defects & critical defects” and “rail head wear – reportable & condemned” by using the risk ranking guidelines in the previous tables.
- Obtaining the final risk assessment results by add up the risk scores from of “frequency & overdue date (Consequences)” “rail defects & critical defects (Likelihood)” and “rail wear – reportable & condemned (factored/modified Likelihood)” for each of the specified track sections.
- Re-ordering the sequence of the track sections by sorting of the risk assessment results from large to small.
- Comparing the final risk assessment results of each track section with the threshold values of different risk levels that shown in the grids of the Prioritisation Matrix to determine the risk level of each track section.

- Manual double checking.
- The final list of these prioritised track sections are to be re-sorted into the priority order (from high to low) and highlighted in the last column by the different colour for its related risk level to make clearer.

5.2 Recommendations

Both of the methodologies and analysis procedures will be keeping improved by the utilisation and outcomes.

REFERENCE

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