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Technical Assessment of a Rail Profile Measurement System by Big Data Analysis Model & Processing

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Abstract

Mechanized Track Patrol inspection vehicle (also been known as track geometry inspection car or track recording car) has been widely utilized by the major railway authorities around the world for track geometry inspection/data collection, track condition assessment, as well as rail profile and surface defects collection since decades ago. The rail profile data is one of the most critical measurement of the track inspection system. The most state-of-the-art rail profile measurement system that are currently utilized by the modern track inspection system are the laser-based system.

To understand the measurement capacity and accuracy of the output results from the vehicle mounted Rail Profile Measurement System (RPMS) of a newly introduced mechanized track patrol inspection car, the reliability and repeatability of the Rail Profile Measurement System have been studied. This study is consisted of development of the algorithm/model for the data analysis and a series of data comparison of the rail profile data (Rail Profile Measurement System results vs. rail profile data from the Track data database, and Rail Profile Measurement System results vs. the in-field measurement results), develop/test/provide the special “rules”, which can be used to undertake further secondary alternative analysis to improve the accuracy of the output results from the Rail Profile Measurement System.

Keywords: assessment, rail profile, measurement system, big data, model, processing methodology.

1 Introduction

A modern mechanized track inspection vehicle usually is a self-propelled railway vehicle which is equipped with measurement systems to assess the track conditions that affect rail vehicle dynamics and safety. As a minimum, most MTPs measure track gauge, curvature, cross-level (super-elevation), alignment, and surface (or rail profile).

To understand the measurement capacity and accuracy of the output results from the vehicle mounted Rail Profile Measurement System (RPMS) on a specified Mechanised Track Patrol (MTP) inspection car (as example is illustrated in Figure 1), the reliability and repeatability of the RPMS have been studied.

Figure 1: A Specified Mechanised Track Patrol (MTP) inspection car (example)

The whole project is to be separated into three sub-projects (three phases). The three sub-projects including:

- Phase I of Reliability study: Assessment of RPMS' capacity of the identification of the rail type (53kg/m and/or 60kg/m rails);
- Phase II of Reliability study: Find out the reasons of why the rail types that predicted by MTP are not matched with the rail types which recorded within the railway company's database (track data) at some locations. In addition, the potential "rules" are to be developed to narrow down the ratio of tolerance; and
- Assessment of Repeatability.

2 The Raw Output Data from RPMS

The rail profile data from the MTP is obtained from two sets of vehicle amounted laser based measurement systems (as shown in Figure 2). The raw output data from the RPMS is consisted with two major parts, both of them can be obtained as the .csv format (ASCII data). Part I is the raw rail profile data (outputs of the data acquisition software). Within it, for each measurement point (just for one rail and measurement interval is 250mm), there are 1300 to 1500 two-dimensional coordinate points are provided to present the profile of the rail at that measurement points (The examples of these data are shown in Figure 3). In addition, the most significant feature of the MTP output data is the tremendous size - "Big Data", rail profile data of 200km track is 250GB.

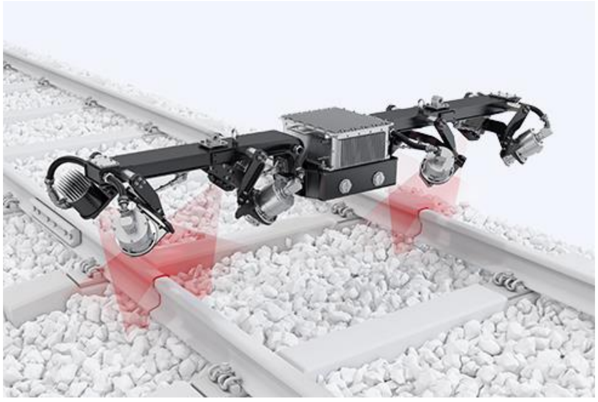

Figure 2: The rail profile data of the track inspection vehicle is obtained from two sets of vehicle-amounted laser-based measurement systems

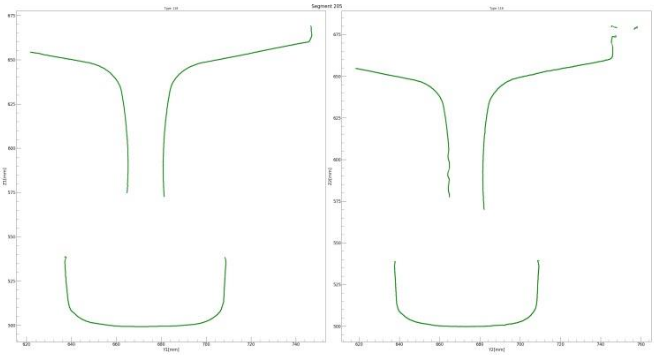

Figure 3: Good shapes of 60 kg/m rail (Note: All the output rail profile raw data are presented in the coordination by the fashion of turn the up side down)

The Part II of the output data includes the rail type and condition parameters, it is the output of the RPMS' data processing software. The raw data is available in two .csv format documents.

Within the RPMS system, for the rail type identification, some reference points of the rail head and rail foot are calculated based on the raw data of the laser measurement results. The profile type is to be recognized by matching the reference points on the reference standard rail profiles. The profile type is automatically recognized considering the distances among the reference points.

The RPMS rail profile system can distinguish different types of rail profiles, comparing the acquired ones with the ones contained in the database. Once the type of profile is detected, it is possible to calculate the sizes of the rail, by difference from the ideal one.

The maximum accuracy of the rail type detection and overlapping is obtained when the rail is fully visible from head to foot (match index 100%). When the foot is not visible (level crossing, excess of ballast, glued insulated joints) the wear calculation is still possible if at least part of the web is visible (match index at least > 30%). For any measured rail profiles, if their match index is ≤ 30% (or the data of the majority part of the rail foot and rail web are not available), the output parameter of "rail type" is to be labelled as "Unknown", i.e., the system cannot distinguish the type of rails.

3 Methodology and Algorithms for the Assessment of Accuracy

The plot of the raw data is upside down. The raw coordinate data of the rail shape is from the right to the left through the order ①→ ②→③→④→⑤→⑥. The raw data can be segmented into three parts:

- Right Bottom: the segment from ① to ②
- Rail Head: the segment from ③ to ④
- Left Bottom: the segment from ⑤ to ⑥

Extraction of rail head is to find the key points ③ and ④.

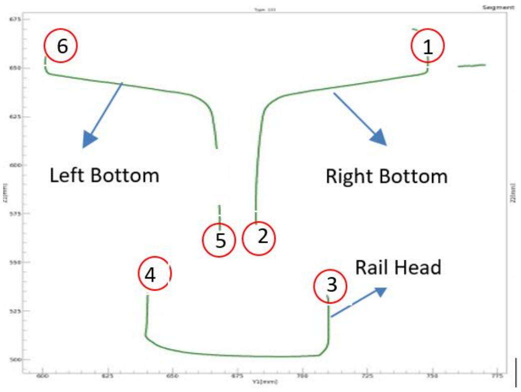

Figure 4: Rail profile segments

(1) Input:

– Chunk csv data: chunked data, raw profile coordinates

(2) Processing Steps:

Step1: Segmenting the data

For each SSCount, read the coordinates (y_i,z_i) sequentially in down rail If Z_{i-1}-Z_i > 20mm & Y_i-Y_{i-1}> 18mm, Find the right bottom Point 1 to Point *i*-1 If Z_j -Z_{j-1} > 20mm & Y_{j-1}-Y_j> 18mm, Find the rail head Point *i* to Point *j*-1, and left bottom Point j to the last point. Get the down rail segmenting points (*i*,*j*) Similarly for up rail to get the segmenting points

Step2: Validate segmenting points

The segmenting point is valid if it is within the coordinate's range of segmenting points based on the statistics.

If the number of the segmenting points >= 2:
    If Y_i in (Y_1,Y_2) & Z_i in (Z_1,Z_2), valid right rail head segmenting points
    If Y_{j-1} in (Y_3,Y_4) & Z_{j-1} in (Z_3,Z_4), valid left rail head segmenting points

(3) Output:

- Processed chunk csv data: df_chunk_001_processed, with additional columns
    - Segments 1: the segment part for the down rail, with values rail head, and right/left bottom

Segments 2: the segment part for the up rail, with values rail head, and right/left bottom.

Identified 3 potential "rules" and relative algorithms/models that can be used for the further secondary analysis for the questionable data and "unknown" railway types. These are including: side shape of rail head, turnout areas, and the asymmetrical switch rails of the tangential switch turnouts.

Match of Rail Type - MTP vs. database

To assess the capacity of the identification of the rail type by the track inspection vehicle (MTP), the quarter of meter (250mm) based predicted rail types from the Rail Profile Measurement System (RPMS) outputs have been compared with the rail type records in rail type data base (Track data). The MTP measurement results of the Up and Down tracks of a main line track on the date of December, 2019 were utilized to carry out this data comparison work. Before the raw data can be used for this analysis, the data pre-processing and pre-arrangement must been undertaken.

In brief, the data pre-processing and pre-arrangement is the work to get the "effective" data from the MTP results, i.e., if the mileage linked rail profile data could not get the relative rail profile information with its mileage from the track data, the MTP profile data will be removed from the data analysis. After this procedure, there are 1,151,016 profiles have been filtered out for the accuracy analysis.

The flow chart for the data comparison and relative raw data pre-processing is shown in Figure 5.

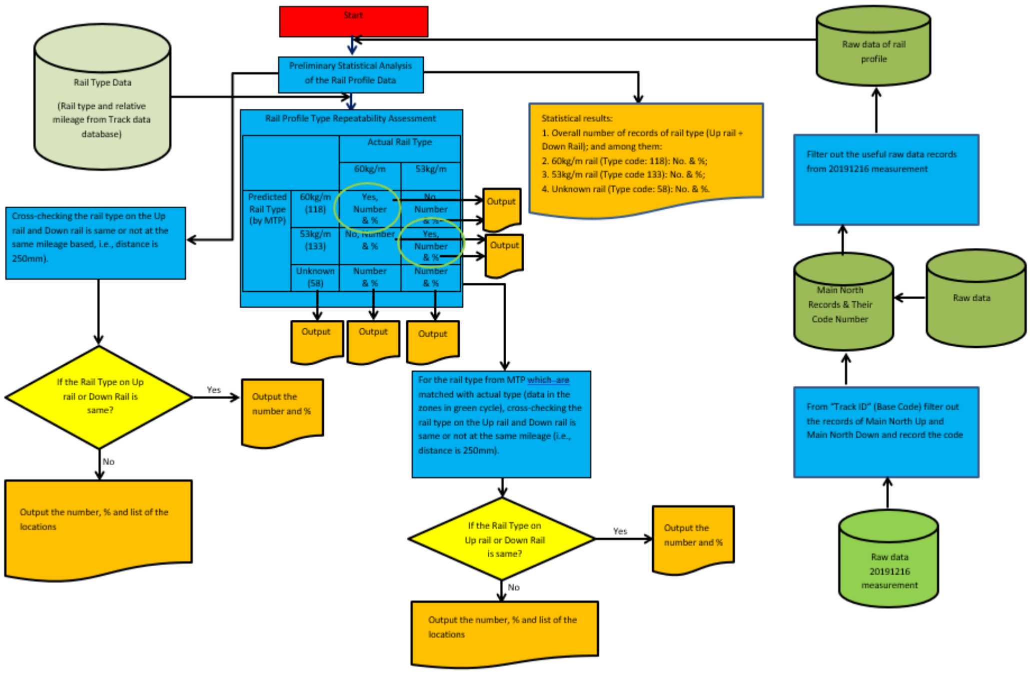

Figure 5: Flow chart that designed to study the capacity of the identification of the rail type by RPMS

Accuracy of the Rail Type Prediction of the Track Inspection Vehicle: To confirm the accuracy of the rail types which are predicted by the RPMS, a cross-checking matrix is introduced to undertake this work, as shown in Table 1. Within this matrix, the fully matched rail types are to be recorded as the accurate predicted rail profile type by the RPMS, the amount and percentage are represented in Table 2.

		Rail type recorded in track database	
		60kg/m	53kg/m
Rail type predicted by track inspection vehicle	Unknown	Not Matched	Not Matched
	60kg/m	Matched	Not Matched
	53kg/m	Not Matched	Matched

Table 1: The matrix used to cross-check the rail type information form database and RPMS

		Rail type recorded in database		
		60kg/m	**53kg/m**	**Grand Total**
Rail type predicted by RPMS	**Unknown**	141687	13890	155577
	60kg/m	899443	86397	985840
	53kg/m	4828	4771	9599
	Grand Total	**1045958**	**105058**	**1151016**
Accuracy				78.56%

Table 2: The cross-checking results of the rail type information form Trackdata and RPMS

Positive Predictive Value and Sensitivity

In pattern recognition, information retrieval and classification (machine learning), "positive predictive value" (also called "precision") is the fraction of relevant instances among the retrieved instances, while "sensitivity" (also known as "recall") is the fraction of the total amount of relevant instances that were actually retrieved. Both precision and recall are therefore based on an understanding and measure of relevance, as shown in Figure 6.

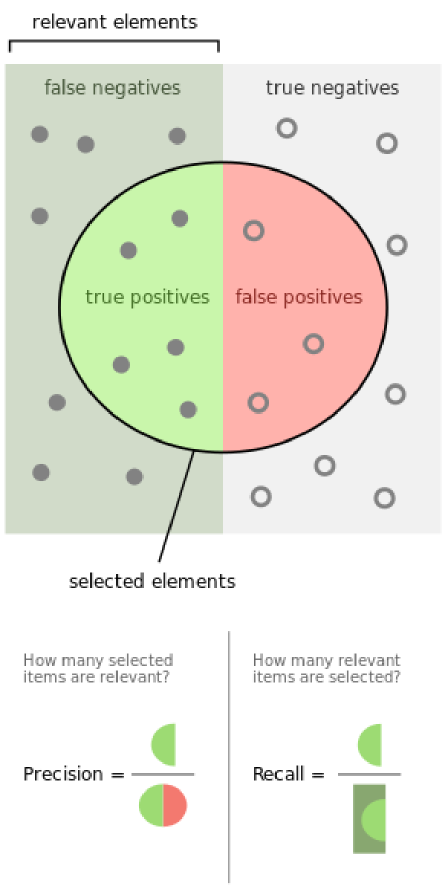

Figure 6: Concepts of the precision and recall

Studying the precision and recall of the MTP rail type identification results, based on the data comparison (MTP results vs. track data records) outputs, some observations have been obtained:

- The overall accuracy of MTP results is about 78.6%. However, the accuracy has dramatic diversity with the rail types. The accuracy for 60kg/m rails is approximately 91%, in contrast, for the 53kg/m rails, the precision rate is only 49.7%, i.e., more than 50% of the 53kg/m rails are not identified by the MTP.

- Recall is low. Similarly, as the precision accuracy, the recall rate is low, i.e., the high missing detection rate is mainly happened with the 53kg/m rails. From the breakdown details it can be found that only about 4.5% of 53kg/m rails (according to the records in the track data) have been identified as 53kg/m rails, i.e., more than 95.5% of the 53kg/m rails are classified as 60kg/m rails or "unknown".

The details of the analysis results of precision and recall of the MTP rail type identification results are tabulated in the Table 3 and 4.

		Rail Type (Recorded in database)		
		60kg/m rail	**53kg/m rail**	**Total**
Predicted Rail Type (by Track Inspection Vehicle)	Unknown	91.07%	8.93%	100.00%
	60kg/m rail	91.24%	8.76%	100.00%
	53kg/m rail	50.30%	49.70%	100.00%
	Total	**90.87%**	**9.13%**	**100.00%**

Table 3: Precision of the prediction of rail type by RPMS (Up and Down tracks of a Main Line)

		Rail Type (Recorded in database)		
		60kg/m rail	**53kg/m rail**	**Total**
Predicted Rail Type (by Track Inspection Vehicle)	Unknown	13.55%	13.22%	13.52%
	60kg/m rail	85.99%	82.24%	85.65%
	53kg/m rail	0.46%	4.54%	0.83%
	Total	**100.00%**	**100.00%**	**100.00%**

Table 4: Recall – the missing detection rate of rail type by RPMS (Up and Down tracks of a Main Line)

4 Potential Technical Solutions ("Rules")

To manage the not confirmed RPMS data, i.e. the "unknown" rail type rail profiles, some potential technical solutions ("rules") are need to be developed. The rules can be the algorithms and/or models that used to undertake the secondary analysis for the not confirmed RPMS data. After the analysis, at least part of the not confirmed results can be clarified with a determined rail type, and the results from the analysis have a high accuracy. The data process flow chart for the potential "rules" is shown in Figure 7.

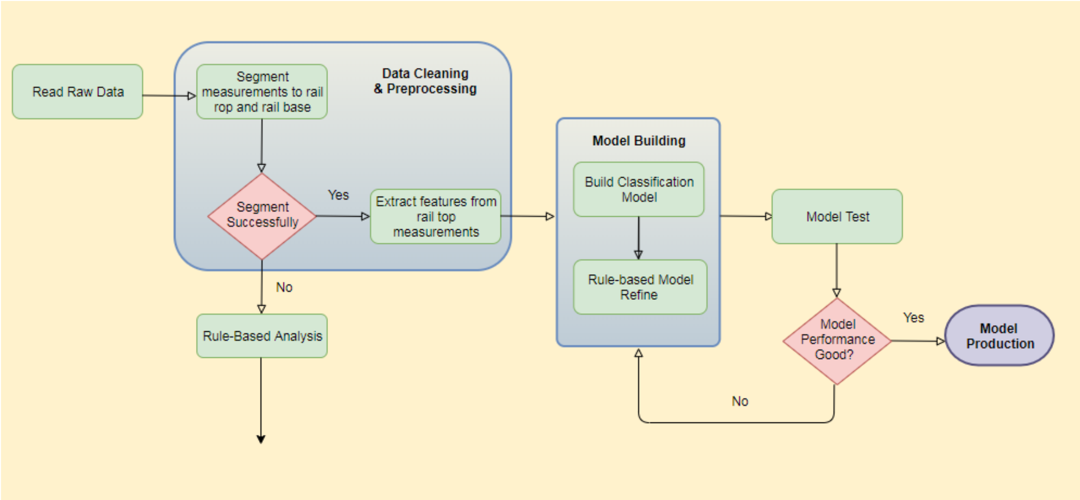

Figure 7: Data processing flow for any potential rules

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The target is to make the not-matched ratio lower than 5%, i.e., 95% match ratio is to be achieved. After detail study the “no confirmed data”, three rules have been designed to carry out the secondary analysis.

Rail head shape

Most of the “unknown” rail type is caused by the “match index” which is obtained by the RPMS is ≤ 30%. The rail profile information of rail web and rail base play the predominate role of the “match index”. On the railway track, at some locations the rail profile at the rail web and base cannot be obtained by the RPMS. This is mainly caused by the features of the special track structures. These locations including: level crossing, ballast ramp at the 4 feet zone or field side of rail, glued insulated joints, fish plated rail, massive ballast covered the rail base and rail web, narrow spacing between the rail and other track components (such as the check rail, check rail carrier and stock rail and the conventional switch turnout), excessive lubrication grease, etc.

Although the rail profile at rail web and base of the pre-mentioned “unknown” rail locations are not available, usually the shape of the rail head, especially the profiles of the field side of the rail head has still been caught by RPMS. Studying the features of the rail profiles of the AS60kg/m rail and AS53kg/m rail, the most significant difference between the shapes of their rail head is that the side of rail head of 60kg/m rail has a slope of 1:20 from the top to the bottom of the rail head (as shown in the red cycle zone of Figure 8).

It is supposed to filter out this feature of 60kg/m rail by a model for secondary analysis and help to identify the 60kg/m rails from the unknown rail profiles. In addition, as there are only two types of rails on the Main North Line, the rails that the field side of rail head do not have the 1:20 slope can be categorised as 53kg/m rail.

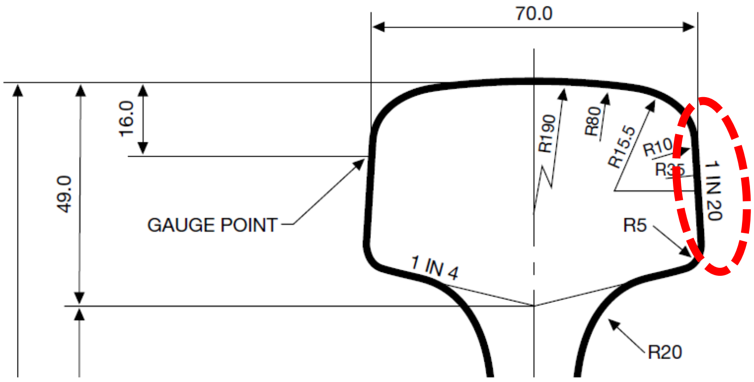

Figure 8: AS 60kg/m rail profile

The data processing procedures and analysis model that to be used for the rail head feature study including the following steps:

- Pre-treatment of the RPMS' profile data – filter out the profile coordination data for the rail head area;
- Extract the profile coordination data for the field side of rail head;
- Build linear regression model on the rail head side data to obtain the side slope of the rail head;
- Calculate the angles (artificial angle just created for the calculation) between the sides of rail head; and
- Create a model to identify/confirm the rail type from the calculation.

Influence by turnout

From the mileage of the "unknown" rail profiles, it is found that big amount of these profiles is located within the turnout zones. There are 189 turnouts on the tested Main North Line. The overall length is about 7km, which is equal to 2.3% of the length of track.

One classic questionable situation is a very short length (1.8m) of 60kg/m in about 40m length 53kg/m rails. One example is shown in Figure 9 (the short length “60kg/m rail” section is highlighted by the red cycle). From the mileage and the length of these rail profiles, it is found that they are the 53kg/m (No.10.5 and/or No.12) turnouts that installed on the 60kg/m rail tracks. The short lengths of 60kg/m rail sections are the crossing and/or the closed switch area of the conventional 53kg/m turnouts, and these locations are mistakenly identified by the algorithm of the RPMS as 60kg/m rails. Among the RPMS results, this false rail type identification is also resulted the false information of Up rail and Down rail at the same location are different rail types.

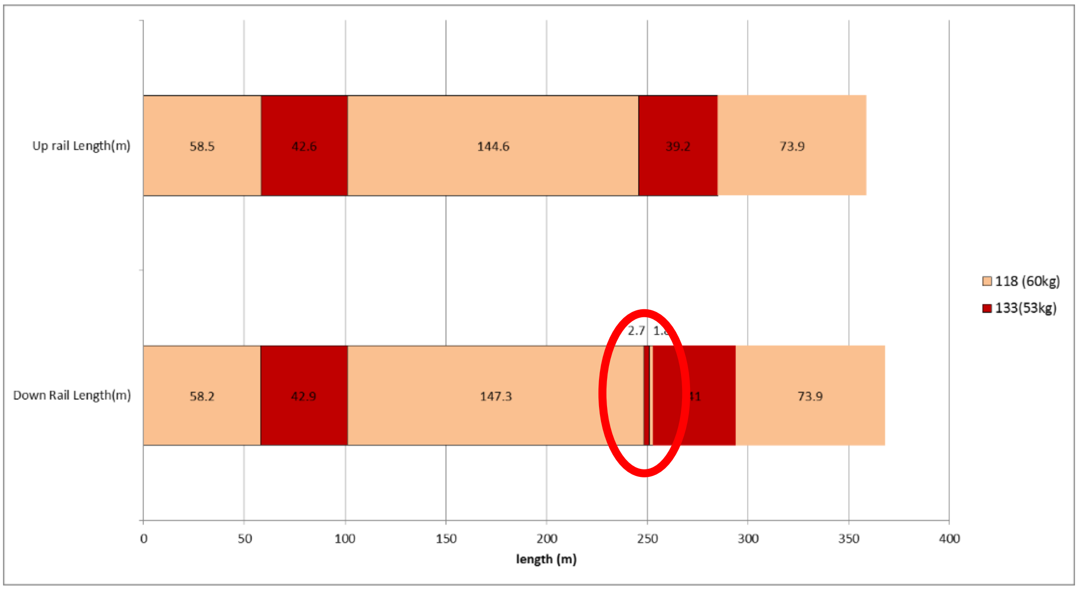

Figure 9: Rail profile type identified by RPMS for the 53kg/m conventional switch turnouts and their adjacent 60kg/m open tracks.

A special “rule” model has been developed to undertake the secondary analysis for any potential false identification of rail profiles by the RPMS.

The “unknown” rail profiles also caused by the non-standard rail profiles, especially the asymmetrical switch rails and asymmetrical stock rails of the tangential switch turnouts. The asymmetrical switch rails (as shown in Figure 10) have significant different height, rail top width, as well as web and base shape to the standard 53kg/m and 60kg/m rails. The stock rail with asymmetrical rail head which is designed to let the tip of tangential switch hidden below its rail head, made the PRMS algorithm could not find its reference point at the bottom of rail head and categorise it as “irregular” profile.

In addition, the non-standard rail profiles at the turnout area are also one of the biggest contributors for the locations where the Up rail and Down rail are identified as different rail types. A special “rule” model is to be developed to undertake the secondary analysis for any potential non-standard rail profiles.

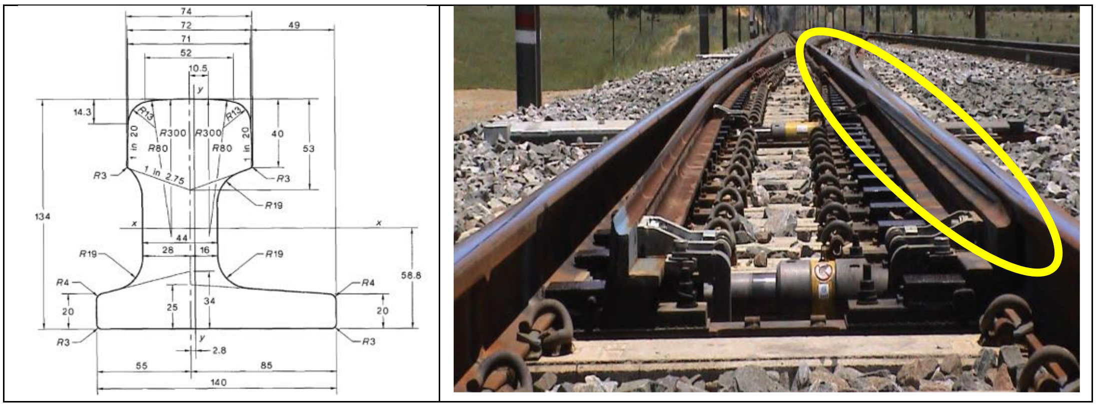

Figure 10: 60kg/m asymmetrical switch rail (left) & switch rail in the closed situation with a stock rail (right, zone in the yellow cycle)

5 Big Data Processing by Deep Learning Method

Modelling Method

It is known that the difference between two types of rail interception is very small and the side slopes of rail head is suggested as a strong predictor of rail types, as shown in Figure 8.

To extract the side slope feature from rail head and build the classification model to predict the rail type, the data is processed as follows:

- Step 1: Split the big data into multiple small dataset for processing;
- Step 2: Segment profile shapes into three parts: rail right base, rail left base, and rail head;
- Step 3: Extract side data from rail head and fit the data in the simple linear regression model to get the side slope of rail heads.
- Step 4: Calculate the angles between the sides of rail head and other features in the head.
- Step 5: Build the model on the extracted features to classify the rail types.

Get Slopes for Rail Head Sides

(1) Input:

Processed chunk csv data, indicating the segment part for each coordinate.

(2) Processing Steps:

For the down rail profile and up rail profile at each segment:

- Step 1: Extract the rail head segments
- Step 2: Extract left side data and right side data of rail head
- Step 3: Fit the left side data and right side data into the simple regression model to get the slope
- Step 4: Get the angle between two sides of rail head

(3) Output:

The Processed slope data with the following columns:

- Count: unique scanning point ID
- Km: kilometre
- Track Base Code
- Type ID *i*: up / down rail type in MERMEC, *i* =1 for down rail and *i* =2 for down rail
- Left slope *i*: left side slope of rail head, *i* =1,2 for down and up rail
- Right slope *i*: right side slope of rail head, *i* =1,2 for down and up rail
- Left slope sign *i:* negative, positive, and infinite
- Right slope sign *i:* negative, positive, and infinite
- Angle *i*: the angle between left side and right side, here *i* =1 for down rail, and *i* =2 for up rail.

Modelling process

(1) Input:

- Processed slope data: for the slope information for Count

(2) Models:

- Step 1: Get the true type from True Type data by km and track base code
- Step 2: Split the data into training and testing
- Step 3: Build decision tree model in the training data
- Step 4: Predict the type in the testing data
- Step 5: Compare the predicted type with true type

(3) Output:

- Prediction
- Accuracy of prediction

Other Resources of Profile Error

Most of the “unknown” rail type is caused by the “match index” which is obtained by the RPMS is ≤ 30%. The rail profile information of rail web and rail base play the predominate role of the “match index”. On the railway track, at some locations the rail profile at the rail web and base cannot be obtained by the RPMS. This is mainly caused by the features of the special track structures. These locations including: level crossing, ballast ramp at the 4 feet zone or field side of rail, Glued insulated joints, fish plated rail, massive ballast covered the rail base and rail web, narrow spacing between the rail and other track components (such as the check rail and check rail carrier; stock rail and the conventional switch turnout), excessive lubrication grease, etc. From the plot of the RPMS profile, the profiles are shown as irregular shapes.

6 Preliminary Findings and Conclusions

Some preliminary findings and conclusions are obtained from the practices of the data evaluation works for the RPMS project. These include:

- The procedure and model that designed to study the accuracy of the rail type identification of RPMS has shown its high performance and high productivity.
- The preliminary statistics analysis has been undertaken for the RPMS samples. Since the data is very big, the top 5,998,186 rows are used for analysis. It includes 4064 profiles between 2.19km distance on the mainline track.
- From the rail type comparison results, the percentage of 53kg/m rail profiles from RPMS' identification which are significantly lower than the records of Trackdata. It is believed that this is mainly caused by the re-railing work within past 3 years.
- Three potential technical solutions ("rules") have been chosen for the secondary analysis for the "unknown" and irrational rail profiles from the RPMS. The rules include the rail head shape study, turnout structures, and the non-standard rail profiles. The relative models for these rules have been utilised for considerable amount of rail profile samples (≥ 1000 profiles), both of the average precision and recall are high. Hence, these models have high effectiveness for the secondary analysis.

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