Bring Digitalization to an Enhanced Urban Transportation

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SUMMARY

In this paper a use case of root cause analysis (RCA) of a subsystem disturbance (false notification of section occupancy) based on the gathered data, is presented. The use case is taken from the Randstad Rail in the Netherlands, which is the light rail network in the southern part of the Rotterdam – The Hague area. Due to the high population in the area, the low downtime of maintenance is requested to ensure the passengers a safe and punctual journey.

For analyzing the system performance, the key point is to bring data to life, i.e. digitalization, to provide as much information as needed. The use case studied in this paper is related to the false notification of section occupancy which leads to the reset of axle counters. In order to find out the root cause of the problem, an analysis framework has been developed, which starts with the data collection from the systems, e.g. interlocking, followed by data analysis using appropriate tools, and visualization of results. RCA of this specific disturbance has then been performed, which reveals that problems lie in not only the cable connection between the axle counter and the interlocking, but also the failing interaction between the vehicle and the axle counter, which prevents the axle counter from receiving the magnetic field. Consequently, the axle counter misses counting of the wheels of the vehicle.

1 INTRODUCTION

RandstandRail (*Figure 1*) is the light rail network in the southern part of the Rotterdam – The Hague metropolitan area in the west of the Netherlands. RandstadRail has a high demand for capacity due to its location in a densely populated area. Therefore, downtime due to maintenance should be as low as possible. Understanding the system performance and root causes of disturbances is key to the optimization of the maintenance of peripheral systems by predicting the possible failures.

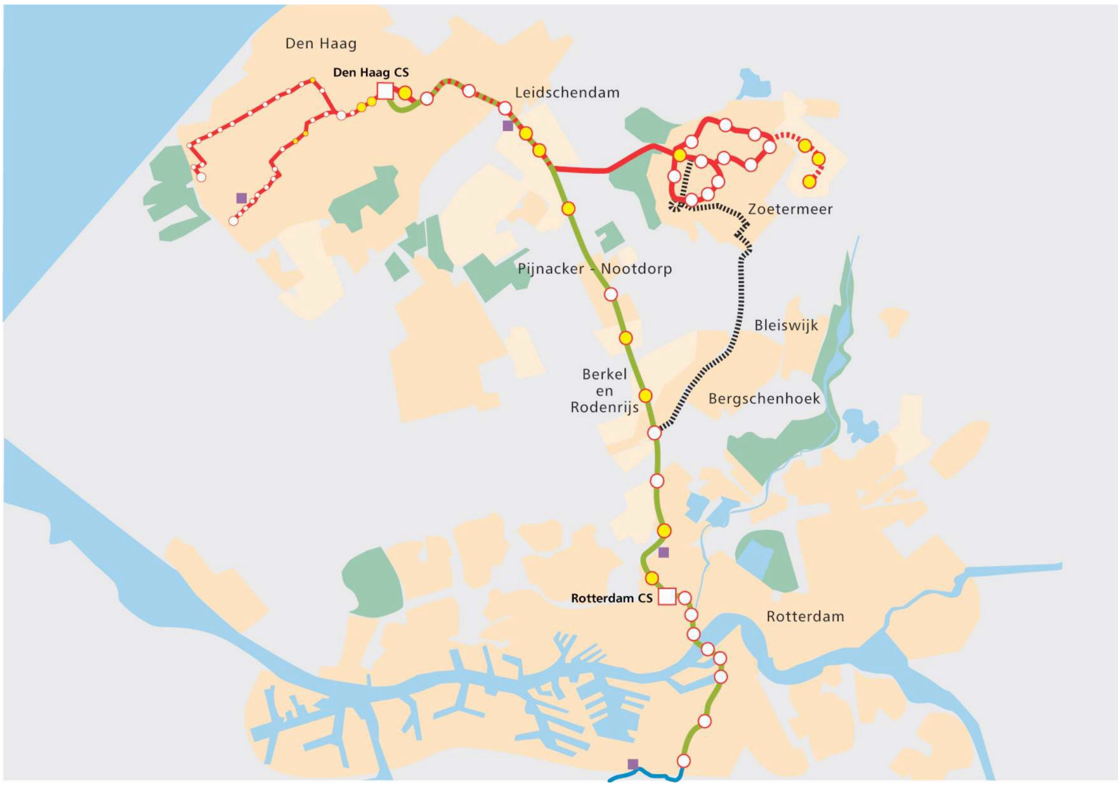

Figure 1: RandstadRail map [1]

For analysing the system performance, the main challenge resides in extracting information from the data, and to provide as much information as possible to the passengers to ensure a safe and punctual journey. Therefore, a framework has to be developed, which starts with the data collection from relevant but heterogeneous systems, e.g. interlocking, followed by data analysis using appropriate tools, and finally visualization of results. Further steps are to perform the root cause analysis of a specific disturbance and to optimise the predictive maintenance schedule.

2 SIGNALING SYSTEM

2.1 Track layout

From the track layout data (*Figure 2*), element numbering such as signals, points, axle counters and the corresponding sections can be found. The information will be used in the following study, for instance, to locate the sections with false notification and the related axle counters.

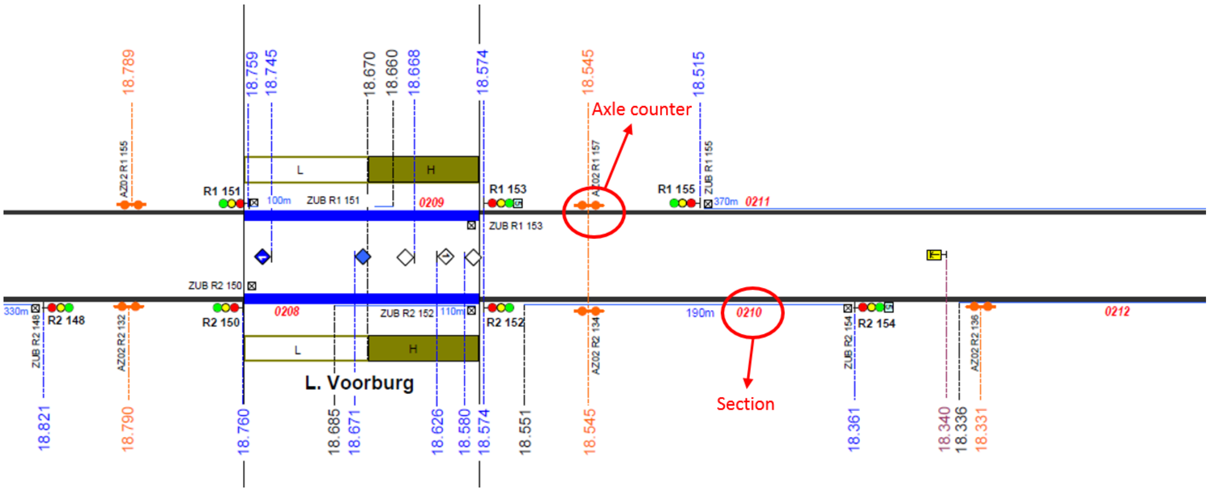

Figure 2 Example of track layout in Randstad Rail

2.2 System components

Figure 3 shows the schematic view of the signalling system deployed in RandstadRail. Note that not all the subsystems are shown in the figure; only the ones related to the current study.

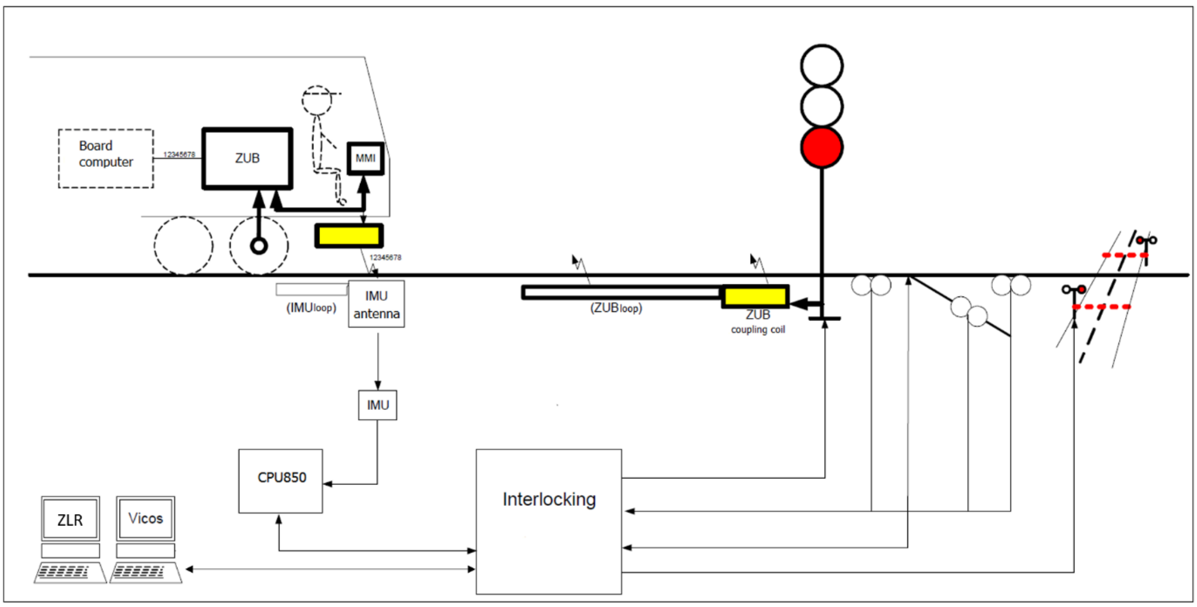

Figure 3. Schematic view of the signalling system in Randstad Rail [1].

The system contains the following main components:

- Interlocking (IXL): The interlocking type Sicas S7 is deployed.
- ZUB: automatic train control system. The system reads the signal aspect and sends information such as the current speed according to the signal, distance to the next signal to the train.
- IMU: an information transmission system, which is used for transmitting information from the vehicle to the track and vice versa.
- CPU850 (IMU receiver): processes the signals from IMU's, which has three input and one output to the central IXL
- Vicos: the operations control systems.
- ZLR (Zuglenkrechner): train-routing computer.

2.3 Available data and examples of use cases

From the above-mentioned subsystems, different data sources are available for the analysis. Here some of the data sources are listed below:

- ZLR data: log file, which records the information of the passing vehicles and the response state of the field elements.

```
2017-01-29 - 20:47:38,406 --- PTI-S7        IMU R4 233 ( 7, 228,   805): New Train Description 03081101
2017-01-29 - 20:47:38,406 --- CTTPTIManager::ProcessTNTelegram()               : PTI IMU R4 233 - TD 03081101 received.
2017-01-29 - 20:47:38,406 --- CTTPTIStrategy::ReplaceTD()                      : PTI replace IMU R4 233: TD 03081101 is already present
2017-01-29 - 20:47:38,406 --- CTTPTIStrategy::DetermineTrainMovement()         : PTI step IMU R4 233: TD 03081201 is already on track 0'
2017-01-29 - 20:47:41,000 --- Point         W870       ( 7, 200,    16): New State - Route not locked
2017-01-29 - 20:47:41,000 --- Point         W873       ( 7, 200,    17): New State - not locked
2017-01-29 - 20:47:41,109 --- Point         W870       ( 7, 200,    16): New State - not locked
2017-01-29 - 20:47:41,125 --- Track         0210       ( 2, 207,    49): New State - occupied
2017-01-29 - 20:47:41,125 --- CTTStepStrategy::StepOnOccupied()                : TD step: TD 03071201 steps from 0208 to 0210.
2017-01-29 - 20:47:41,125 --- CTTStepStrategy::MoveTrainDescription()          : TD step: TD 03071201 steps from 0208 to 0210.
2017-01-29 - 20:47:41,125 --- CTTStepStrategy::StepTrainDescriptionToTrack()   : TD step: TD 03071201 steps from 0208 to 0210.
2017-01-29 - 20:47:41,125 --- CTTTrainnumber::MoveTDToBerth()                  : TD berth step: TD 03071201 steps from ZN150 to ZN154.
```

Figure 4. Example of ZLR data

- hmp file (from Vicos): log file, which contains Vicos telegram for the purpose of 'record and play', which records the message sent between Vicos and IXL. For example, if replaying the telegram in Vicos R&P (Record and Play), when a route is set for an approaching train, one could see the changing of the element in the track layout display, as well as the telegram exchanged. However, the data is presented in hexadecimal format, which is not easy to read.

0	7C	F4	AC	01	86	33	00	00	FF	FF	FF	FF	01	02	00	00	D7	3A	00	00	01	00	04
35	44	00	00	05	00	04	00	01	00	01	00	1B	47	00	00	08	00	04	00	01	00	01	00
6A	04	00	01	00	01	00	07	5A	00	00	07	00	04	00	01	00	01	00	F6	61	00	00	0E
9F	00	14	6A	00	00	16	00	04	00	01	00	01	00	1C	6E	00	00	15	00	04	00	01	00
D4	80	00	00	00	00	00	00	00	00	00	00	00	7B	73	00	00	64	00	16	00	90	01	13
109	F3	9F	C8	0E	00	80	00	06	4A	85	00	00	00	00	00	8F	C3	00	00	0B	00	12	00
13E	9F	D1	A2	00	80	00	0D	30	00	00	00	00	00	00	EC	C3	00	00	16	00	0B	00	90

Figure 5. Example of hmp file (telegram)

- btb file (from Vicos): saved together with the hmp file, which logs the command from the operator, e.g. 'reset of axle counter is active'.

```
K   29.01.2017 05:54:24                    IXL3 0322                    Display van melding: reset assenteller is actief
zonder      29.01.2017 05:54:24     PZEEG          IXL3 0322                  Assenteller voorbereiden op reset
G   29.01.2017 05:54:25                    IXL3 0322                    Display van melding: reset assenteller is actief
zonder  29.01.2017 06:13:28     PZEEG          BAR2    PZEEG heeft zich als Treindienstleider afgemeld
zonder  29.01.2017 06:13:32     KIFRA          BAR2    KIFRA heeft zich als Treindienstleider aangemeld (Aanmelding zonder chipkaart)
zonder      29.01.2017 07:23:12     KIFRA          IXL3 R1 307 - R1 301           Rijweg instellen
K   29.01.2017 07:27:58                    IXL2 0219                    Display van melding: reset assenteller is actief
G   29.01.2017 07:27:59                    IXL2 0219                    Display van melding: reset assenteller is actief
B   29.01.2017 08:20:19     KIFRA          IXL3 0322                    Display van melding: reset assenteller is actief
```

Figure 6. Example of btb file (command from the operator)

With various data sources, several use cases can be performed to evaluate the system performance in Randstad Rail, such as:

- Monitoring of field elements, e.g. points and signal lamps.

  For instance, point throwing time, which is the time a point moves from one position to another. With this information, whether or not there is mechanical problem of the point can be detected. The information can be further correlated with the maintenance time scheduled on this specific point. This could lead to a preventive maintenance of the point, i.e. before the point reaches its state which causes the disturbance, maintenance can be already planned to minimize the disturbance.

- 'Travel time' of vehicles from one station to another, as well as the delay time on these routes.

  As there are different types of vehicles running on Randstad Rail and sometimes sharing the same part of the route, it can be useful to analyse the effect of the vehicle types on 'travel time'. Moreover, information such as congestion level of passenger flow of the station can be evaluated, which means that if vehicles always spend longer time on one section/station and cause delay, improvement of the time table could be considered.

- False notification of section occupancy (TOBS). This use case will be studied in details in Section 3.

2.4 Challenge of data processing

Processing substantial amounts of data is the key challenge in the whole analysis procedure. Setting up the connection to the data logging system, and extracting the real-time data safely and without interfering with the running safety system is the first, critical step.

Understanding raw data with specific structure can be also challenging. For example, not all data is saved in readable text or numbers, such as the hmp file (telegram) written in hexadecimal. One must explore in the big amount of telegrams and identify the information which is useful.

Moreover, when looking at the various data sources, a challenge presents itself in pinpointing the right data for specific use cases. Especially when using more than one data source for analysis, care should be taken in correlating datasets not to jump to wrong conclusions that don't represent reality. What is also critical is that the time stamp of all data sources is exactly the same to correlate the data from different sources.

Efforts have been made to dive deep into all data sources, from which the most challenging one is the hmp file from Vicos, which is in the format of telegram. It has been found out that it contains almost all information needed. For instance, from the telegram data it is possible to look for the point throwing time, which is not saved in other data sources. However, in this file only time stamp information is available; it is difficult to convert it to the UTC time.

3 USE CASES – FALSE NOTIFICATION OF SECTION OCCUPANCY

3.1 Background

In June 2017 a request was initiated to find out a solution to the increased number of false notification of the section occupancy (TOBS) in the past few months [2]. The impact of TOBS can be listed as follows [3]:

- The reset operations of the maintainers which have to be performed as a result of TOBS take up a large part of the work.
- When TOBS takes place, the section can only be released after it has been "wiped clean". The procedure is that the driver drives "on sight" at a lower speed. When this happens often, it has a direct influence on the punctuality of the vehicles. This is due to the accumulated time cost in the process of notification --> reset action --> driving through the section on sight.
- In the case of TOBS reports, the vehicles are exchanged which leads to a loss of availability. The vehicle maintenance department is then confronted with "TOBS-causing" vehicles that need to be checked in the

workshop with possible maintenance of the wheels. This in turn limits the availability of vehicles for specific lines and may even result in a trip loss.

Investigation of the data from Jan 1st 2017 to June 30th 2017 has revealed that most TOBS are related to a few specific sections (Figure 7). The data source used here is the 'btb file', which contains the operator command of axle counter reset.

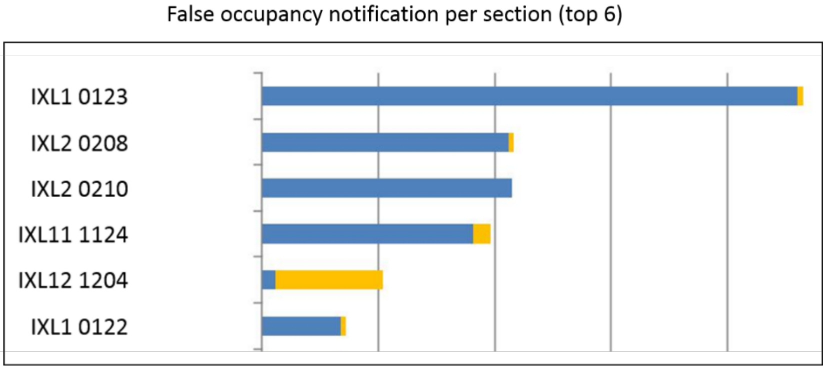

Figure 7. Failure history of top 6 sections (with most false occupancy notification). Notification in blue: during the operating time; notification in yellow: outside the operating time [2]

Section 0123 is located at the border of two interlocking controlling area. As the adjacent section belonging to the other IXL has very few TOBS message, the border axis counter can be excluded as a potential source of interference.

Therefore, Section 208 and Section 210 have the most TOBS; the axle counter connected the two sections is investigated. According to maintenance record of this axle counter, it can be seen that many activities have been performed, such as checking the cables on both counting head side and the IXL side. However, many attempts fail to solve the problem; only reconnecting the cable via the neighbouring axle counter to the IXL seems to work, which is however considered as a temporary solution [2].

It leads to the follow-up of the research, which is the focus of the paper, investigating whether the potential source of interference is related to some specific passing vehicles or not. The needed information includes:

- Section name, time stamp of the TOBS
- Number of the vehicle which passed that section at that time

3.2 Analysis process

As mentioned above, the following study will focus on two sections, Section 208 and Section 210, which have the most TOBS during the past months.

Figure 8 presents the analysis process, starting from the data selection to the investigation of the behaviour of the wheel and axle counter interaction.

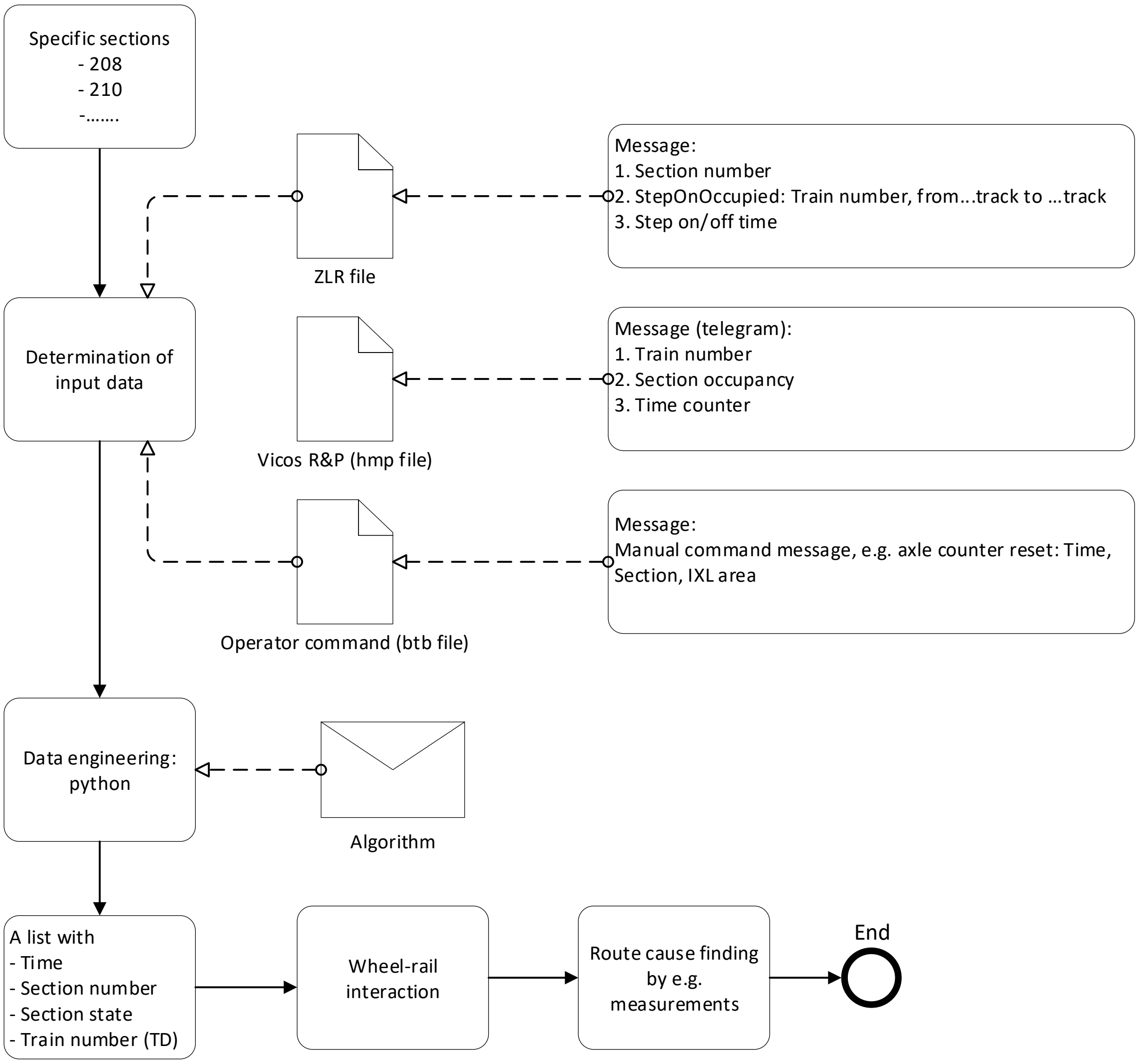

Figure 8: Analysis process for the RCA of the false occupancy notification of the section.

3.2.1 Data selection

Regarding to the selection of data sources, in the beginning the hmp file was considered as a good source as it contains almost all information needed, such as section number, section state and the vehicle number. Meanwhile, btb file is also needed as it contains information of each axle counter reset. However, when trying to relate the axle counter reset message (in btb file) with the hmp file, one uses the UTC time and the other uses a time counter.

Therefore, a second look has been taken at the ZLR data and the btb file. It seems that with this data source it is able to extract the needed information (Figure 8).

3.2.2 Data engineering

The data engineering is performed with Python, where the needed data is sorted. The information which is being searched, is that when a train steps from one section to another, there is no following message which contains 'Section is free'. Therefore, it is assumed that after this train passage, the section remains occupied, which is normally not correct.

3.3 Results

3.3.1 Train passage

Table 1 shows an example of the result of the data engineering with a list of train passage which is not correct, according to the algorithm stated in Section 3.2.2. Vehicle numbers (TD) will be used for the study in Section 3.3.2.

1	Time	Section	State	TD
	12/23/2017 7:57:57	210	from track 0210 to track 0212	TD 03021201
	12/24/2017 10:55:45	208	from track 0208 to track 0210	TD 03101211
	12/24/2017 10:55:59	210	from track 0210 to track 0212	TD 03101211
55	12/24/2017 13:34:49	208	from track 0208 to track 0210	TD 03101201
56	12/24/2017 13:35:01	210	from track 0210 to track 0212	TD 03101201
	12/24/2017 13:39:37	IXL2 0208	Assenteller voorbereiden op reset	
	12/24/2017 13:40:21	IXL2 0210	Assenteller voorbereiden op reset	
59	12/24/2017 13:40:50	IXL2 0208	Assenteller voorbereid op reset	
60	12/24/2017 13:41:34	IXL2 0210	Assenteller voorbereid op reset	
61	12/25/2017 9:26:32	208	from track 0208 to track 0210	TD 03061211
62	12/25/2017 9:26:44	210	from track 0210 to track 0212	TD 03061211
	12/25/2017 9:33:22	IXL2 0208	Assenteller voorbereiden op reset	
	12/25/2017 9:33:28	IXL2 0210	Assenteller voorbereiden op reset	
65	12/25/2017 9:34:36	IXL2 0208	Assenteller voorbereid op reset	
66	12/25/2017 9:34:42	IXL2 0210	Assenteller voorbereid op reset	

No message from btb file is found!
Train passage (from ZLR file)
well correlated!
Axle counter reset message (from btb file)
Train passage (from ZLR file)
well correlated!
Axle counter reset message (from btb file)

Table 1. Example of list of train passage which is not correct, as defined in the search algorithm in Python. TD: TrainDescription number.

In this example, it can be seen that some of the train passages from ZLR data (marked in orange) can be well correlated to the axle counter reset message in btb file (marked in blue), e.g. the train passage starting at [12/24/2017 13:34:49] and the one starting at [12/25/2017 9:26:32]. If taking the train passage starting at [12/24/2017 13:34:49] as example, at 13:34:49 and 13:35:01, the train passed Section 208, 210 and stepped onto Section 212, however, there was no following message which contains 'Section is free', which means that the section was still 'occupied'. At 13:39:37, there was a message from the operator (logged in btb file) that the axle counter reset was conducted. In this case, a good correlation of the ZLR and btb data has been found.

However, some of the train passages can not be related to the axle counter reset message in btb file, i.e. no message from btb file is found at that timestamp, e.g. the train passage starting at [12/23/2017 7:57:57] and [12/24/2017 10:55:45].

On the other hand, regarding to the axle reset message in btb file, it has been found out that some reset commands are not related to any false occupied section, when looking at the section status from Vicos R&P. Therefore, ZLR and btb file have to be combined and investigated at the same time.

3.3.2 Root cause analysis

According to the investigation mentioned above, the focus is now the possible incorrect detecting of wheels of those vehicles. One idea is that the false interaction of the wheel and rail. Due to wear and tear on the rails and/or wheels, the profile of the rails or wheels may have severely changed. When the wheel passes the axle counter, the magnetic field could not be correctly received by the receiver of the axle counter (Figure 9). As a result, an incorrect count is made.

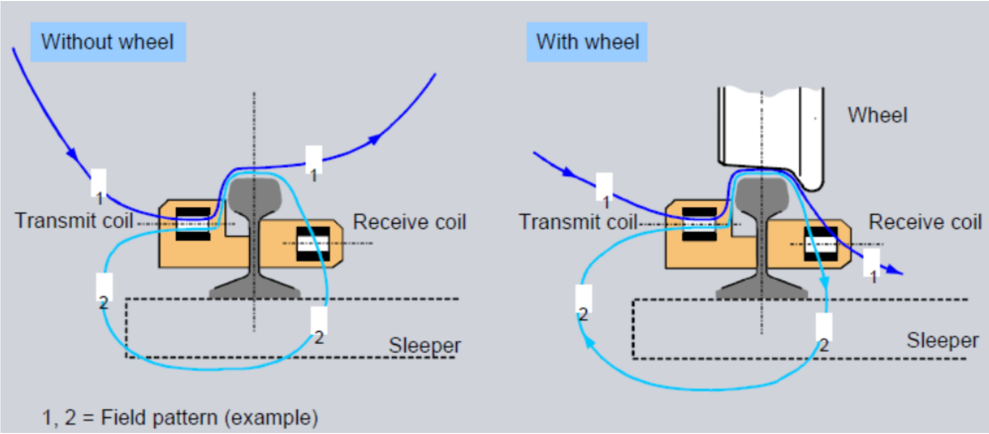

Figure 9. Mechanism of detecting a wheel passage by the axle counter [4]

The receiver's failure to receive or process the magnetic field correctly may be caused by [3]:

- Reception coil, cables, peripheral electrical components and interlocking do not work to specification.
- The rail controls/affects the magnetic field so that the magnetic field is not received by the receiver coil.
- The wheel controls/affects the magnetic field so that the magnetic field is not received by the receiver coil.
- A combination of the above-mentioned causes.

3.3.3 Characteristics of the vehicles which cause the problems on section 208 and 210.

Based on the results of the data analysis presented in Section 3.3.1, a follow-up investigation has been performed [3]. The procedure is as follows:

- Step 1: Measurements of the minimum wheel flange sizes of all vehicles and the ones causing TOBS at section 208/210.

  It has been found out that the average minimum flange thickness is significantly lower for the vehicles causing TOBS compared to the average minimum flange size of the whole fleet, 15.8mm and 18mm respectively. 100 out of the 109 TOBS reports concerned a minimum flange size smaller than 17 mm.

- Step 2: To further prove the assumption, using an oscilloscope, a one-day measurement of the voltage in the axis counter circuit of section 208/210 was performed. Each time an axle passes the axle counter, the voltage is "pulled down". An axis is counted when a low voltage value is reached.

  It has be found out that in this case TOBS is caused by the fact that the two axles of one bogie are not measured correctly. Correspondingly, the vehicle has relatively small wheel flanges on bogie.

- Step 3: Measurements of the track layout of section 208 and 210.

  The picture (Figure 10) on the left shows worn rails. As a result, for vehicles with a relatively short flange height, the magnetic field does not deviate sufficiently and is therefore not received by the receiver. For this reason, the axle counter was temporarily moved to the other rail. Here the wheel flange has a correct interaction with the rail, so that the magnetic field is received by the coil. For track replacement, the axle counter is rebuilt in its original configuration.

Figure 10. Track condition of section 208 and 210 [3].

3.4 Data visualization

One important aspect of the 'bring data to life' is the data visualization. With the help of the tooling, disturbance of the field elements e.g. signals, points and sections are directly presented. The following figure (Figure 11) gives an example of the visualization of axle counter resets on section 208/210 in May 2018.

Data visualization of the assets monitoring of all track elements in the Randstad Rail offers the direct information to the maintainer and the asset manager. Improvement of the behaviour of subsystems is more easily achieved, which brings the more safe and efficient transportation to the passengers.

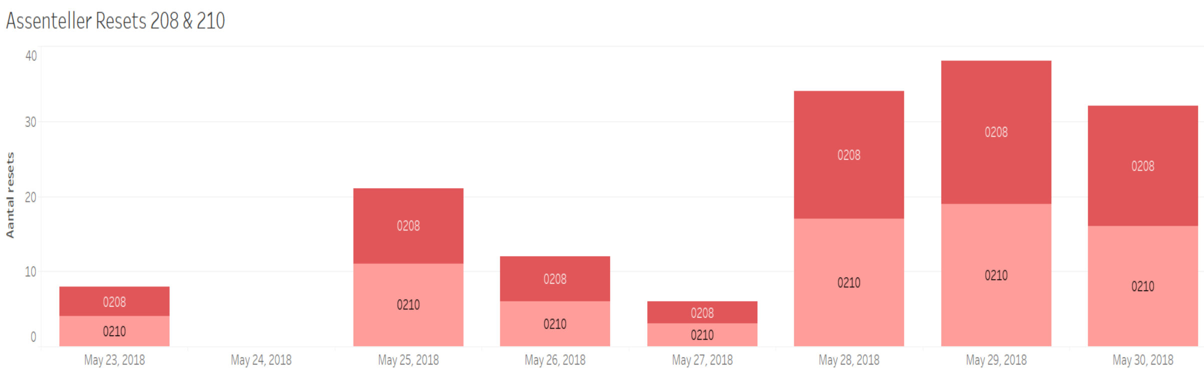

Figure 11. Example of data visualization: number of axle counter reset on section 208/210.

4 CONCLUSION

In this study, an analysis approach have been established for the root cause analysis of the disturbance in Randstad Rail, using the data collected by different systems. The identification of the sections prone to TOBS and the related vehicles is purely data-driven and thus the main challenge resides in extracting the useful data from different systems.

A follow-up investigation of the data analysis has shown that on sections which have the most false notification of section occupancy, the two main root causes were the cable connection between the axle counter and the IXL, as well as the failing interaction between vehicle and axle counter. The deviated positioning of the wheel prevented the axle counter from receiving the magnetic field, resulting in the axle counter missing wheels of the vehicle.

5 DISCUSSION

As discussed in Section 3.2, the main challenge of the whole analysis procedure is to gain the useful information from the substantial amounts of data. Understanding the raw data and correlating different data sources play a crucial role in reaching the correct conclusion that represents the reality. The first important step is to define 'what information are we looking for?' at the initial stage of the data engineering, which leads to an efficient and successful analysis.

One highlight of the current research of Randstad Rail is the digitalization of the data, including data visualization and developing degradation model of the field elements to improve the maintenance schedule, etc. More efforts are being made to realize the ultimate goal of improving the performance of the whole Randstad Rail.

6 REFERENCES

1. R.Burger, Randstad Rail cursus HTM, 04-10-2016.
2. Emilio Tuinenburg, Junior Marte Garcia, Melvin Agten, RCA Onderzoek TOBS– fase 1 – infrastructuur gerelateerde TOBS – RandstadRailtraject, 09-10-2017.
3. Emilio Tuinenburg, Edwin Vijverberg, Junior Marte Garcia, Lawrence v.d. Berg, RCA Onderzoek TOBS– fase 2 – voertuig baan interactie gerelateerde TOBS – RandstadRailtraject, 27-07-2018.
4. http://www.railsystem.net/axle-counter/