ISSN 2278-3091
Volume 9, No.1.4, 2020
International Journal of Advanced Trends in Computer Science and Engineering
Available Online at http://www.warse.org/IJATCSE/static/pdf/file/ijatcse3591.42020.pdf
https://doi.org/10.30534/ijatcse/2020/3591.42020

Fault Detection Tool for Maintenance of Signalling and Communication: A Case Study of the Urban Railway in Malaysia

Norhafiza Samion[1], Hairulazwan Hashim[2], Nazwa Hidayah Mohamad[3], Nor Aziati Abdul Hamid[4], Mohd Ismarul Azhar Ismail[5]
[1] Centre for Diploma Studies, Universiti Tun Hussein Onn Malaysia, Malaysia, hafiza@uthm.edu.my
[2, 3]Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, Malaysia, azwan@uthm.edu.my; nazwahidayah85@gmail.com
[4]Faculty of Technology Management and Business, Universiti Tun Hussein Onn Malaysia, Malaysia, aziati@uthm.edu.my
[5]Department of Signalling and Communication, Kelana Jaya Line, Rapid Rail Sdn. Bhd, Malaysia, mohdismarul@prasarana.com.my

ABSTRACT

The Kelana Jaya Line (KJL) of the leadin urban metro train operator in Malaysia, Rapid KL is the oldest unmanned train service run by the automatic train-controlled system (ATCS). The system provides the highest reliability of any aspect of the signalling system that equips them with sensors, electronics, and communication tool along the wayside. The key issue for KJL Department of Signalling Maintenance team are digging big data and filtering through manual screening of data logger for maintenance purposes leads to time constraint and data redundancy. To address this issue, the current study aims to propose an interactive tool made instant visibility of signaling status and assist the maintenance team to capture the trend failure of a signaling system. The tool begins with raw data processing using *AWK* programming which typically used as data extraction and reporting tool and loaded into a designated dashboard using *Microsoft Excel 2013*. To validate the whole modelling process, the tool was tested by the maintenance team and the survey is gathered. The result from the usability survey shows the score is 70.7 which is 1.04% above the global average. The study benefits the organization for decision making and scheduling is expected to reduce the cost of maintenance as well as a contribution to systematic maintenance.

Key words: dashboard, fault detection tool, maintenance, signaling and communication, urban rail.

1. INTRODUCTION

Kelana Jaya Line (KJL) has been one of the urban metro operators in Klang Valley for over 20 years, owned by Rapid Kuala Lumpur (KL). They are facing the degradation of the infrastructures such as track, electrical units, and signaling system. KJL is among the early railway line in the world which utilize the Automatic Train Control System (ATCS) applying the Transmission Base Train Control (TBTC) technology, which is the early stage the Communication-Based Train Control (CBTC) [1] since 1998 [2]. Acknowledging the CBTC system has overcome signaling issues of accurate, reliable and safe, it's less prone to failure than conventional train control systems [2], [3]. The CBTC system is easy to maintain as there has fewer wayside equipment and improved its diagnostic and monitoring tools. However, operators such as Rapid KL should be aware of the inevitable failure of the train, and sometimes the train might be operated in manual mode. As the contingency plan, they will provide multifunctional staff or mobile technician [4] as well as the efficient maintenance team in dealing with fault [5]. The KJL implements the Automatic Train Control System (ATCS).

This ATCS is applying the CBTC concept with the principle of moving block signaling. The moving block signaling allows more trains to safely occupy the same amount of track so that more trains can be used to provide a service. It also provides better headway (safely separated between two trains on a track) control, more flexibility in operation and bidirectional operation. The safe train separation is based on maximum operating speed, braking curve and location of trains. Figure 1 visualizes the basic principle of moving block [6]. In order to make this train control system works, there are about five reciprocal of integrated controller blocks (see Figure 2); System Management Centre (SMC), Vehicle Control Centre (VCC), Station Controller (STC), Inductive Loop and Vehicle On-Board Control (VOBC) [6].

According to the previous studies, maintenance management required to plan all maintenance activities such as equipment lifespan [7]–[9], downtime and high maintenance cost issue. Transit ridership affected by the operation and maintenance that contributes to the factor of cost-effectiveness [10] also faces by the KJL. In recent years, the growth of technology in the information, control, and communication provide a big opportunity for the signaling and telecommunication field to open their scope of engineering. These engineering activities and innovation will be focusing on exploring available data on railway operation that readily and accurate [11].

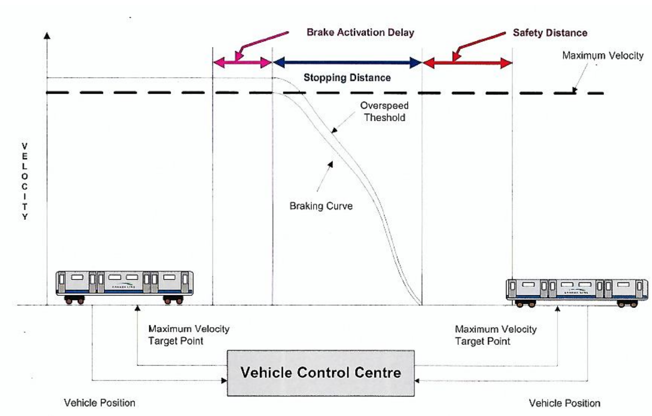


Figure 1: The principle of the moving block [6]

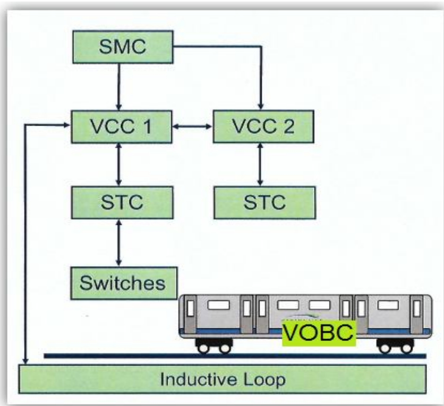


Figure 2: Integrated controller block of the moving block application [6]

Data from the transportation system will feed into applications that will help in decision making [12]. These applications then enhance through the IoT (Internet of Things) orientated transportation system supported by the technical skill and expert in programming and database management [13] lead to the success factor transportation technology.

KJL is facing problems related to the big data in the logging of the system operation. In 2018, there were at least five times service interruptions of the KJL during the peak time of revenue hours reported by the local media [14]–[18] as stated in Table 1. From the table, the major contributor was caused by the fault of the signaling system. Meanwhile, all these disruptions could affect the passengers' confidence while selecting a KJL as their main public transport. So, as the railway operator, they were very welcoming to the researcher on exploring their data logger for the benefits of future maintenance works.

The interruption might due to lack of a monitoring system of the infrastructures and facilities intermittent fault behavior that leads to an unplanned event. The situation has become worse if the maintenance team could not solve the problems within the stipulated duration.

Table 1: The service interruptions reported in 2018 [14–18]

Date	Operation Delay	Fault Causes
23/01/2018	An hour	Signalling fault between Damai and KLCC Station.
19/04/2018	About 25 minutes	PIES activated by fallen commuters from the platform.
31/07/2018	Intermittent 2-5 minutes delay	Vandalism on signalling devices.
22/08/2018	About 20 minutes	Malfunction train door (mechanical).
25/09/2018	2- hour	Signalling fault between Damai and Dato' Keramat Station.

The current situation faced by the maintenance team of Rapid KL was long-winded of screening lines from the data logger that affected the man-hour, higher downtime and may lead to data redundancy tracking upon alarm triggered from the System Management Centre (SMC).

Hence, the purpose of this study is to introduce an interactive tool to assist the maintenance team in capturing the trends of historical data and failure records for the signaling system. This tool is known as a dashboard to replace the traditional method for maintenance works. The dashboard can be a reporting tool that instantly can capture the trend of signaling status. The benefits of this tool are providing a better managerial decision for the maintenance department to deal with resources, revenues, and planning.

2. METHODOLOGY

The aim of this project is to develop a dashboard that can visualize the complex data without neglecting important information for the maintenance team of Signalling and Communication (S&C) of the KJL.

2.1 Process Flow Chart

Reference [19] defined a dashboard as an easy to read real-time user interface, showing graphical presentation of the current status (snapshot) and historical trends of an organization's Key Performance Indicators to enable decisions. On top of that, the developer dashboard should be satisfied with overall stakeholders' needs through interviews and a field test survey. Figure 3 shows the whole process of the project flow and every step details according to Table 2.

Table 2: Detailing of Labelled Project Process

Label	Step Process
A	Interview with experts, study on literature review and participate in training.
B	Study of data characteristics and process the raw data.
B & C	Design and develop the dashboard
D	Design and develop the manual instruction of using the tool.
E	Expert survey of usability (SUS) and experiences (UEQ) analysis.

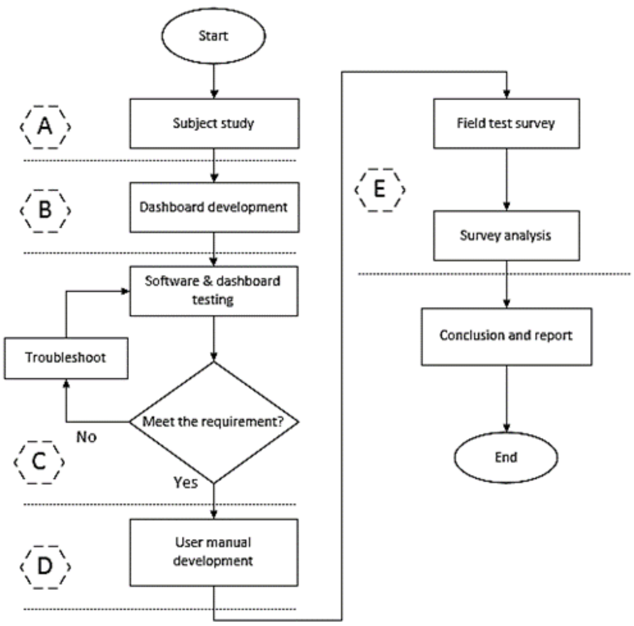


Figure 3: Flowchart of project

2.2 Dashboard Design Requirement

The designing of the dashboard connecting more data sources and data sets that are represented as in Figure 4. The pre-development process involved two steps in which the first step is processing the raw data from the SMC data logger by conducting the filtering and cleansing process. The other is loading the clean data into *Microsoft Excel* for the development of the visualization process.

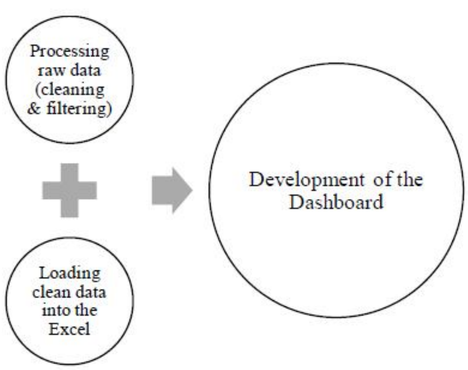


Figure 4: Dashboard design sketch

2.3 Processing Raw Data

The KJL team was handed over the raw data extracted from the SMC and the VCC data logger to be studied. The SMC is logging the entire KJL operation without segregating the region that makes them too huge to explore. KJL consists of 4 VCC under SMC to operate ATCS along the line. Each VCC caters their own region. VCC1 ranging from Kelana Jaya Station to KLCC Station continues from Ampang Park Station to Gombak Station is under VCC2 control. VCC3 has specifically controlled for Lembah Subang Depot, while VCC4 ranging from Lembah Subang Station until Putra Height Station. The main objective to select VCC1 as the main sample is because the file size and the regional area are the most compact ridership compare with the other VCC area. Once the data successfully filtered, it will load into the automated screening tool, the rest of the VCC can be replicated.

Figure 5 shows the general flow of raw data processing. The features of the VCC raw data compiled in one folder comprise of all four VCCs logging activities. The file is an individual daily compressed file for each VCC in a text file version. These text files appear quite scattered as in Figure 6. The cleaning process works using *AWK* programming language in Command Prompt platform.

AWK is a programming language designed for text processing and typically used as data extraction and reporting tool. The basic function of *AWK* is to search files for lines (or other units of text) that contain certain patterns. Programs in *AWK* are different from programs in most other languages because *AWK* programs are data-driven that suitable to load table format data and convert into a different script [20]. Then, *AWK* programming is used for the data cleaning process in Figure 7 and the syntax as shown in Figure 8. This programming also allows .txt file to be converted into .csv file type. Once the programming successfully running the command line, the successes file will be loaded into the appropriate folder. After the cleaning and filtering process, the appearance of the data as shown in Figure 9 which looks more organized. Then, it's ready for the next stage of data visualization.

2.4 Developing Tools

The process of acquiring the tools for visualizing the data is actually by screening thoroughly the characteristic of the data. Then choose the simple and easy platform to represent the data so that users could explore the tools with less effort. After deciding the platform for a dashboard is using Microsoft Excel, their much effort to know what this software can do's and don'ts.

Figure 5: The general flow of raw data processing

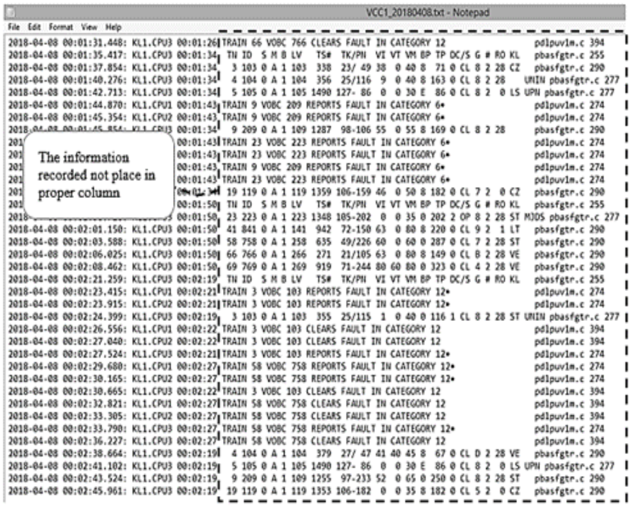


Figure 6: Data contains in a text file

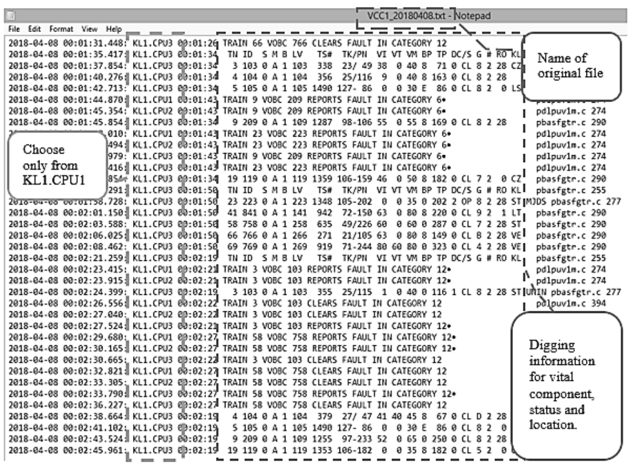
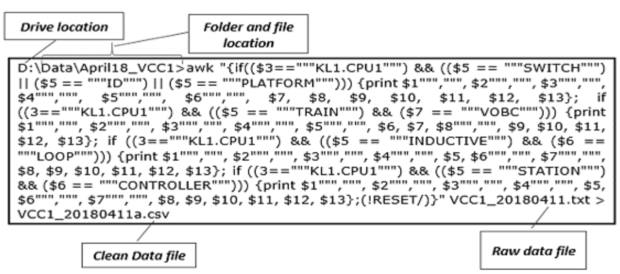
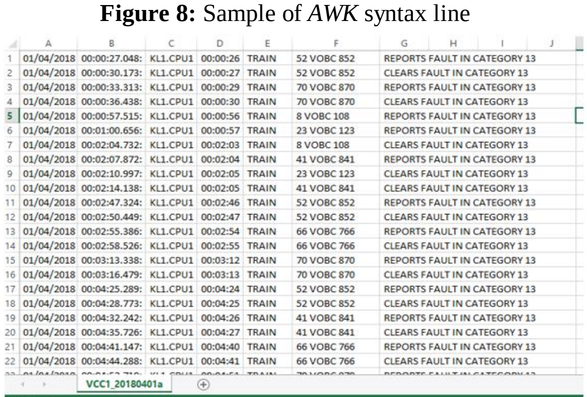


Figure 7: Cleaning process items




```
D:\Data\April18_VCC1>awk "{if(($3=="""KL1.CPU1""") && (($5 == """SWITCH""") || ($5 == """ID""") || ($5 == """PLATFORM"""))) {print $1""","""", $2""","""", $3""","""", $4""","""", $5""","""", $6""","""", $7, $8, $9, $10, $11, $12, $13}; if ((3=="""KL1.CPU1""") && (($5 == """TRAIN""") && ($7 == """VOBC"""))) {print $1""","""", $2""","""", $3""","""", $4""","""", $5""","""", $6, $7, $8""","""", $9, $10, $11, $12, $13}; if ((3=="""KL1.CPU1""") && (($5 == """INDUCTIVE""") && ($6 == """LOOP"""))) {print $1""","""", $2""","""", $3""","""", $4""","""", $5, $6""","""", $7""","""", $8, $9, $10, $11, $12, $13}; if ((3=="""KL1.CPU1""") && (($5 == """STATION""") && ($6 == """CONTROLLER"""))) {print $1""","""", $2""","""", $3""","""", $4""","""", $5, $6""","""", $7""","""", $8, $9, $10, $11, $12, $13};(!RESET/)}" VCC1_20180411.txt > VCC1_20180411a.csv
```

Figure 8: Sample of *AWK* syntax line



	A	B	C	D	E	F	G	H	I	J
1	01/04/2018	00:00:27.048:	KL1.CPU1	00:00:26	TRAIN	52 VOBC 852	REPORTS FAULT IN CATEGORY 13			
2	01/04/2018	00:00:30.173:	KL1.CPU1	00:00:27	TRAIN	52 VOBC 852	CLEARS FAULT IN CATEGORY 13			
3	01/04/2018	00:00:33.313:	KL1.CPU1	00:00:29	TRAIN	70 VOBC 870	REPORTS FAULT IN CATEGORY 13			
4	01/04/2018	00:00:36.438:	KL1.CPU1	00:00:30	TRAIN	70 VOBC 870	CLEARS FAULT IN CATEGORY 13			
5	01/04/2018	00:00:57.515:	KL1.CPU1	00:00:56	TRAIN	8 VOBC 108	REPORTS FAULT IN CATEGORY 13			
6	01/04/2018	00:01:00.656:	KL1.CPU1	00:00:57	TRAIN	23 VOBC 123	REPORTS FAULT IN CATEGORY 13			
7	01/04/2018	00:02:04.732:	KL1.CPU1	00:02:03	TRAIN	8 VOBC 108	CLEARS FAULT IN CATEGORY 13			
8	01/04/2018	00:02:07.872:	KL1.CPU1	00:02:04	TRAIN	41 VOBC 841	REPORTS FAULT IN CATEGORY 13			
9	01/04/2018	00:02:10.997:	KL1.CPU1	00:02:05	TRAIN	23 VOBC 123	CLEARS FAULT IN CATEGORY 13			
10	01/04/2018	00:02:14.138:	KL1.CPU1	00:02:05	TRAIN	41 VOBC 841	CLEARS FAULT IN CATEGORY 13			
11	01/04/2018	00:02:47.324:	KL1.CPU1	00:02:46	TRAIN	52 VOBC 852	REPORTS FAULT IN CATEGORY 13			
12	01/04/2018	00:02:50.449:	KL1.CPU1	00:02:47	TRAIN	52 VOBC 852	CLEARS FAULT IN CATEGORY 13			
13	01/04/2018	00:02:55.386:	KL1.CPU1	00:02:54	TRAIN	66 VOBC 766	REPORTS FAULT IN CATEGORY 13			
14	01/04/2018	00:02:58.526:	KL1.CPU1	00:02:55	TRAIN	66 VOBC 766	CLEARS FAULT IN CATEGORY 13			
15	01/04/2018	00:03:13.338:	KL1.CPU1	00:03:12	TRAIN	70 VOBC 870	REPORTS FAULT IN CATEGORY 13			
16	01/04/2018	00:03:16.479:	KL1.CPU1	00:03:13	TRAIN	70 VOBC 870	CLEARS FAULT IN CATEGORY 13			
17	01/04/2018	00:04:25.289:	KL1.CPU1	00:04:24	TRAIN	52 VOBC 852	REPORTS FAULT IN CATEGORY 13			
18	01/04/2018	00:04:28.773:	KL1.CPU1	00:04:25	TRAIN	52 VOBC 852	CLEARS FAULT IN CATEGORY 13			
19	01/04/2018	00:04:32.242:	KL1.CPU1	00:04:26	TRAIN	41 VOBC 841	REPORTS FAULT IN CATEGORY 13			
20	01/04/2018	00:04:35.726:	KL1.CPU1	00:04:27	TRAIN	41 VOBC 841	CLEARS FAULT IN CATEGORY 13			
21	01/04/2018	00:04:41.147:	KL1.CPU1	00:04:40	TRAIN	66 VOBC 766	REPORTS FAULT IN CATEGORY 13			
22	01/04/2018	00:04:44.288:	KL1.CPU1	00:04:41	TRAIN	66 VOBC 766	CLEARS FAULT IN CATEGORY 13			

Figure 9: Sample of the data in **.csv* file

In Figure 10 visualized the process of dashboard development. In planning the layout, it led into account of what users want to know, or what they necessitate to look forward. The dashboard must look interactive which makes them felt the tools are easy to handle and yet giving a piece of useful information as they want. Then, the software itself assists the designing work much easier because of the auto-generated by what requested in the Pivot Table. The rest is about the presentation of the layout. Figure 11 represents the elements that contributed to the designing process.

3. RESULT AND DISCUSSION

Testing of the software held by the cycling process as in the project flowchart in order to meet the maintenance team's needs. Every progress had a continuous discussion between both parties to meet project objectives.

3.1 Results of the Dashboard Visualization

Table 3 is a list of the descriptions, labels (A to G) as states in the dashboard (see Figure 12). The dashboard consists of 4 inputs (A, B, C and D) which represent Date, Variables, Location and Status. While 3 outputs labelled as E, F and G show the visualization of plots between "Status and Date", "Location and Status" and "Status and Variables". At the initial condition, where all inputs were not selected, the outputs of the fault frequencies for selected month clearly showing as in Figure 12.

The daily status of signalling activities in April 2018 is shown in Figure 13. The result shows the trend configured two-day of the non-working day at a low total of fault as opposed to another five days of working days of a week.

For the *Status of Variables* in Figure 14, it is giving the big picture of all variable faults recorded the whole month. The six variables being filtered that closely relates to the train signalling faults can be seen appearing in this status.

Figure 10: Development of the dashboard

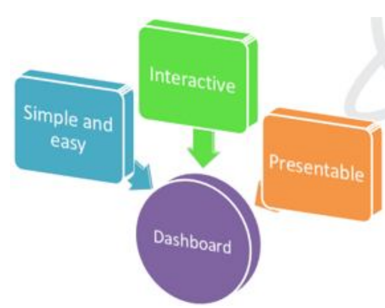


Figure 11: The elements of the designing process

Table 3: Label description of the dashboard

Label	Description
A	Menu for Date
B	Menu for Variables
C	Menu for Location
D	Menu for Status
E	Plot of Status vs. Date
F	Plot of Location vs. Status
G	Plot of Status vs. Variables

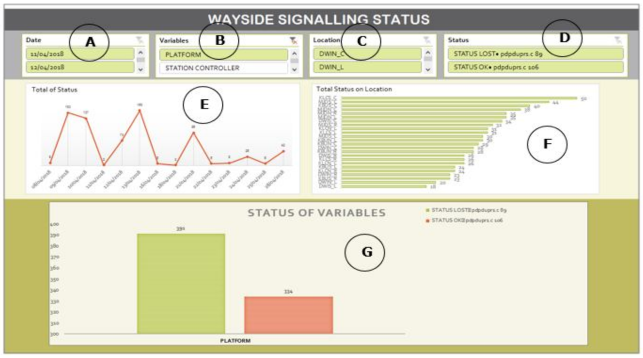


Figure 12: The layout of the dashboard

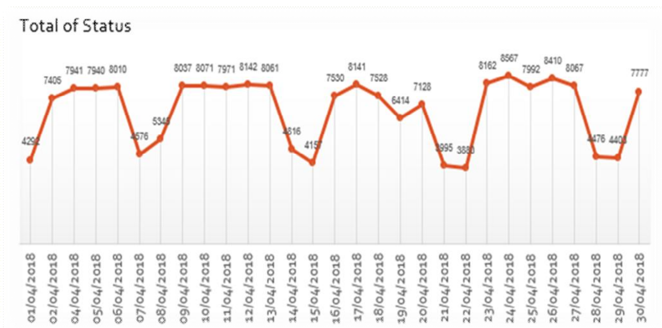


Figure 13: Total of fault status in a month

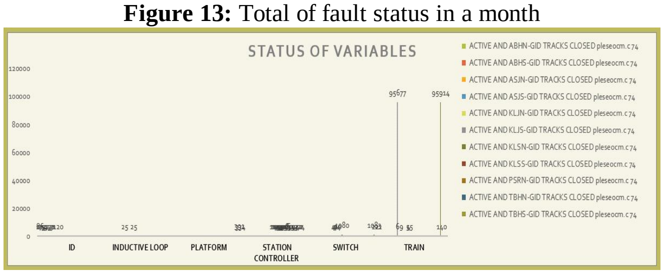


Figure 14: Fault status of each variable

Obviously, "TRAIN" had the highest total of status recorded for the entire month by comparing it with the rest of the variables. The experts of the Rapid KL maintenance team also surprised by the status but assured them as not totally true faults. The maintenance team has to further investigate on every fault status appears for declaring them as true faults. Nevertheless, the legends considerably assist in monitoring each type of "fault" for all variables.

3.2 System Testing and Validation

The testing process has been executed by investigated one of the data samples and how the dashboard may help to expedite their decision-making process for the maintenance specialist.

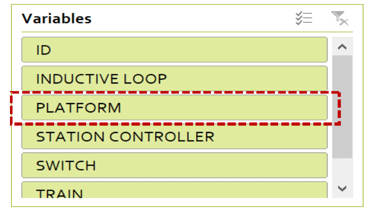


Figure 15: Platform screen door system is known as Platform in the dashboard.

The selected data sample known as a "Platform" is the Platform Screen Door System (PSDS) appears in the variables slicer as shown in Fig. 15. In KJL the PSDS was installed at 3 underground stations DWI, KLC and KBU. This data accuracy is referring to the degree of data correctly represents the "real-life" situation.

3.3 Case Study: Platform Screen Door (PSDS) Failure

The PSDS is a series of automatically controlled sliding doors arranged as a screen. The PSDS doors will remain closed until a vehicle has fully stopped at the platform. The vehicle will signal to the station that it has arrived, and once it has been confirmed that the vehicle has stopped in the correct position both vehicle and PSDS doors will receive a signal which enables them to open. Each station platform consists of 24 automatic sliding doors (also known as bi-parting doors) which have a pivoted emergency door on either side. This bi-parting door is arranged in sets of three, left (L), centre (C) and right (R) to match with vehicle door arrangements. In Fig. 16 shows the platform in the variables slicers has been selected as case study samples.

The graph showing the overall PSDS alarms, which 391 was alarms lost and 334 has been cleared. It indicates that there are 57 alarms require technical maintenance specialists to rectify manually. Based on Figure 17 is the trend of alarm status in April 2018. By looking at the trends below, is shows that the most dominant alarm occurred was on 13th April which 160 alarms appeared. The 160 alarms appeared has been cleared (Status OK) automatically by the system and the remaining alarm lost was 6 alarms (see Figure 18).

Hence, the lost status in detail can be traced by referring to the location of the alarms on the dashboard as in Figure 19. The PSDS alarms were occurring at the KLC station. To figure out which PSDS door to be rectified manually by the technical specialist, each of the locations to be selected in the dashboard slicer. If the status of the lost and OK is similar it means that the alarm was fully cleared as in Figure 20. Unfortunately, if the total loss of the alarms were not similar to status OK, it requires further action by the maintenance specialist.

In summary, the dashboard is able to fulfil the user's requirements which can assist them in fast decision making by speeding up the sorting and filtering process of the huge historical data for further corrective action on maintenance works.

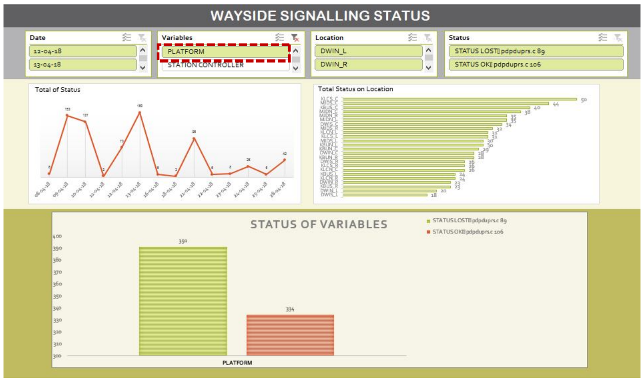


Figure 16: Platform variables to be selected

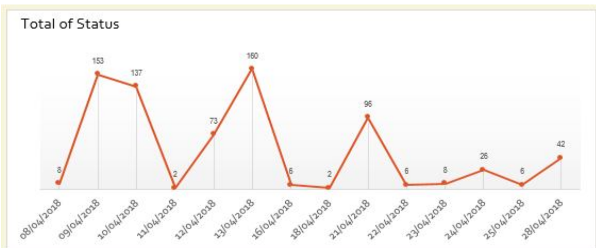


Figure 17: Trends of PSDS alarm

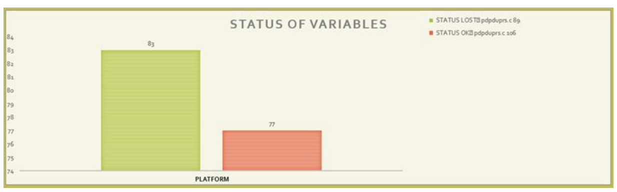


Figure 18: Status of alarm Lost and OK

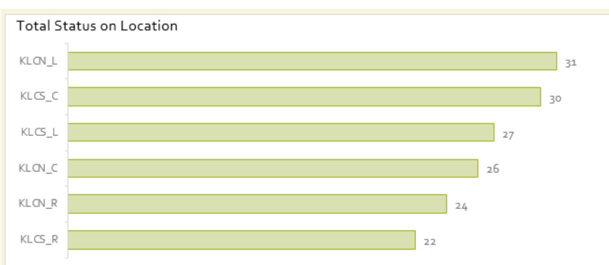


Figure 19: Status of alarm location

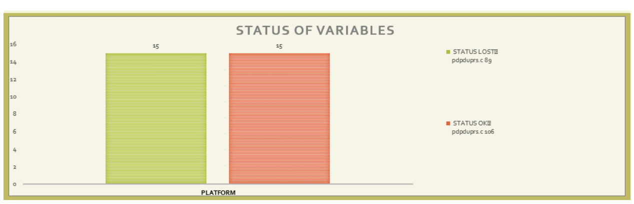


Figure 20: Status of the lost and OK is similar

4. CONCLUSION

The continuous drive for increased efficiencies within the railway industry necessitates the need for a greater understanding of the system performance, along with the ability to integrate to plan and prioritize maintenance works. As the rate of recording large volumes of data has rapidly grown, tools that allow for this data to be visualized and interpreted in an integrated, interactive manner become more and more crucial. The need for analyzing and visualizing the data in a succinct and at the same time understandable manner becomes more and more important. Data visualization and the ability to summarize and display the huge historical data are generally very effective known as dashboards. The dashboard is useful not only for decision making for enhanced visibility of the signalling historical data but also for the middle and lower executive to track daily activities and plan tasks. The dashboard was developed using a pivot table in Excel allows to create an intergroup, summarize large amounts of data into a meaningful format, and interactively drill down into details. The reason a pivot table to be used is that the user may be spending less time to operate and maintain as well as having more time doing the other useful things rather than the conventional method of screening and tracing huge data of failure records manually.

ACKNOWLEDGMENT

This work was supported by the UTHM TIER-1 research grant (H113).

REFERENCES

1. J. Farooq and J. Soler, **Radio Communication for Communications-Based Train Control (CBTC): A Tutorial and Survey,** *IEEE Commun. Surv. Tutorials*, vol. 19, no. 3, pp. 1377–1402, 2017.
2. D. Fernández- *et al.*, **Semi-automatic, Driveless and Unattended Operation of Train**, *IRSE International Technical Committee*, no. 150, pp. 8–10, 2009.
3. A. Rumsey *et al.*, **Communications Based Train Control**, *IRSE Semin.*, February, 2011.
4. T. J. Nicholson, **Total automation: Impacts & Systems**, in *IET Professional Development Course on Railway Signalling and Control Systems (RSCS 2012)*, 2012, pp. 259–268.
5. Z. Zhang, C. Q. Wang, and W. Zhang, **Status Analysis and Development Suggestions on Signaling System of Beijing Rail Transit**, *Urban Rail Transit*, vol. 1, no. 1, pp. 1–12, 2015. https://doi.org/10.1007/s40864-015-0004-y
6. Rail Academy, **Signalling & Communication of Rail Division**, Rapid Rail Sdn Bhd., 2018.
7. S. Mathew, **Optimal inspection frequency: A tool for maintenance planning/forecasting**, *Int. J. Qual. Reliab. Manag.*, vol. 21, no. 7, pp. 763–771, 2004.
8. H. Shang, **Maintenance Modelling, Simulation and Performance Assessment for Railway Asset Management**, Phd. thesis, universite de technologie Troyes, 2015.
9. I. Durazo-Cardenas *et al.*, **An autonomous system for maintenance scheduling data-rich complex**

infrastructure: Fusing the railways' condition, planning and cost, *Transp. Res. Part C Emerg. Technol.*, vol. 89, pp. 234–253, 2018.

10. P. A. Ehrhardt, D. J. Vozzolo, E. S. Riklin, and P. McMahon, **Evaluating Effeciency of Transit Alternatives in Griffin Line Corridor, Hartford, Connecticut**, *Seventh National Conference on Light Rail Transit: Baltimore, Maryland, November 12-15, 1995*, 1995, pp. 142–152.
11. F. How, **Signalling the future**, in *IET Professional Development Course on Railway Signalling and Control Systems (RSCS 2012)*, 2012, pp. 1–5. https://doi.org/10.1049/ic.2012.0039
12. S. EL Mendili, Y. EL Bouzekri, and N. Hmina, **Big Data Processing Platform on Intelligent Transportation Systems**, *Int. J. Adv. Trends Comput. Sci. Eng.*, vol. 8, no. August, pp. 1099–1109, 2019.
13. W. N. Hussein, L. M. Kamarudin, H. N. Hussain, M. R. Hamzah, and K. J. Jadaa, **Technology Elements that Influence the Implementation Success for Big Data Analytics and IoT- Oriented Transportation System,** *Int. J. Adv. Trends Comput. Sci. Eng.*, vol. 8, no. 5, pp. 2347–2352, 2019.
14. T. A. Yusof, **Kelana Jaya LRT delayed over technical issues**, *News Strait Times*, Jan-2018.
15. A. E. Azman and F. Rahman, **Kelana Jaya LRT line delays due to safety precautions**, *News Strait Times*, Jul-2018.
16. A. Gooi, **LRT passengers stuck at SS18 station due to malfunctioning train doors**, *The Star Online*, Kuala Lumpur, 22-Aug-2018.
17. H. H. M. Noor, **Pregnant woman rescued after falling onto tracks at Damai LRT station**, *News Strait Times*, Apr-2018.
18. **RapidKL apologises for temporary disruption on Kelana Jaya line**," *The Star Online*, Dec-2018.
19. M. Staron, **Dashboard development guide -How to build sustainable and useful dashboards to support software development and maintenance**, Göteborg, Swe, 2015.
20. R. A. and O. N. A. Yamanaka, M. Mizuno, **Low Cost and Flexible Data Analysis System to Find Approprite Corrective Action for Yield Deterioration in LSI Manufacturing**, in *International Symposium on Semiconductor Manufacturing*, 1995, pp. 103–106.