FAULT DETECTION TOOL FOR MAINTENANCE OF WAYSIDE SIGNALLING AND COMMUNICATION

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ABSTRACT

The Kelana Jaya Line (KJL) is the leading urban metro train operator in Malaysia and the eldest unmanned train operation system service use the automatic train-controlled system owned by Rapid KL. The system provides the highest reliability on the signalling aspect system which equips with sensors, electronics, and communication tool along the wayside. The key issue for KJL Wayside Signalling Maintenance Department team is facing a huge historical data and retrieving data failure records from the KJL Wayside Signalling data logger by manual screening method for maintenance purposes. This issue leads to time constraint and data redundancy. Therefore, this study aims to propose a tool known as a dashboard which may provide to retrieve failure data records by using Microsoft Excel software. The dashboard facilitates the team with the visualization of four selections inputs and three graphical outputs. This interactive tool made instant visibility of signalling status and assist the maintenance team to capture the trends of signalling activities. The tools begin with raw data processing using AWK programming for filtering and data cleansing for six significant variables of wayside equipment (i.e. Inductive Loop, Switch, Train, ID, Station Controller, and Platform). The result from the SUS shows the usability survey score 70.7 which is 1.04% above the global average. The study is beneficial for the organization on maintenance work in reducing time-consuming as per screening data and decision making for planning and scheduling.

ABSTRAK

Laluan Kelana Jaya (KJL) yang dikendali oleh Rapid KL iaitu penyedia khidmat kereta api pandu tanpa-orang tertua bagi kereta api metro bandar di Malaysia mengaplikasikan sistem kereta api yang dikawal secara automatik. Kebolehpercayaan sistem isyarat ini adalah tinggi dengan kelengkapan penderia-penderia, peranti-peranti elektronik serta alatan komunikasi di sepanjang laluan. Isu utama pasukan Jabatan Penyenggaraan Isyarat KJL adalah kaedah menggali data yang besar dan menyaringnya menggunakan penapis manual daripada data rakaman untuk aktiviti-aktiviti isyarat menyebabkan pembacaan data yang berulang kali dan memakan masa yang panjang. Oleh yang demikian, kajian ini mengusulkan satu alat yang dapat menyediakan pemeriksaan dan pengesanan status gangguan melalui papan pemuka yang dibangunkan menggunakan Microsoft Excel. Papan pemuka memudahkan pasukan penyelenggaraan dengan menvisualisasikan empat input pilihan serta memberi output melalui tiga output grafik. Alat interaktif ini pantas menyediakan gambaran bagi status gangguan isyarat dan membantu pasukan penyelenggaraan melihat arah aliran status. Alat cadangan ini perlu dimulakan dengan memproses data mentah untuk dibersihkan menggunakan pengaturcaraan *AWK* yang dapat menyaring enam pembolehubah penting dalam peralatan pada laluan ini (iaitu *Inductive Loop*, *Switch*, *Train*, *ID*, *Controller Station*, dan *Platform*). Data yang telah bersih, dimuatkan ke dalam papan pemuka di platform Microsoft Excel 2013. Bagi pengesahan keseluruhan proses pemodelan, alat ini diuji oleh pasukan penyelenggaraan dan maklum balas diambil untuk mengukur kebolehgunaan alat dan mengukur pengalaman semasa menggunakan alat ini. Hasil dari SUS menunjukkan skor tinjauan kebolehgunaan 70.7 iaitu 1.04% di atas purata global. Kajian ini memberi manfaat kepada organisasi mengenai kerja-kerja penyelenggaraan dalam mengurangkan masa memakan masa seperti data penyaringan dan membuat keputusan untuk perancangan dan penjadualan.

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LIST OF SYMBOLS AND ABBREVIATIONS

ATCS	-	Automatic Train Control System
ATO	-	Automatic Train Operation
ATP	-	Automatic Train Protection
CBTS	-	Communication- Based Train Control
CCOT	-	Central Control Operator Terminal
CCTV	-	Closed Circuit Television
CESB	-	Central Emergency Stop Button
CM	-	Corrective Maintenance
CTS	-	Central Transmission System
EFID	-	Entry Feed - In Devices
ERL	-	Express Rail Link
ESD	-	Emergency Stop Equipment
FID	-	Feed- In Devices
GLC	-	Government- Link Company
KJL	-	Kelana Jaya Line
KLIA	-	Kuala Lumpur International Airport
KTMB	-	Keretapi Tanah Melayu Berhad
KVIR	-	Klang Valley Integrated Rail
Lamp	-	Line Amplifier
LRT	-	Light Rapid Transit
MRT	-	Mass Rapid Transit
PA	-	Public Address
PI	-	Passenger Information
PIES	-	Platform Intrusion Emergency Stop
PM	-	Preventive Maintenance
PSDS	-	Platform Screen Door System
QRF	-	Quick Response Force

RAMS	-	Reliability, Accessibility, Maintainability and Safety
RLB	-	Remote Loop Boxes
S&C	-	Signalling and Communication
SCADA	-	Supervisory Control and Data Acquisition
SMC	-	System Management Centre
STC	-	Station Controller
SUS	-	System Usability Scale
TBTC	-	Transmission Based Train Control
TFR	-	Transnet Freight Rail
UEQ	-	User Experience Questionnaire
UTO	-	Unattended Train Operation
VCC	-	Vehicle Control Centre
VOBC	-	Vehicle On- Board Control

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CHAPTER 1

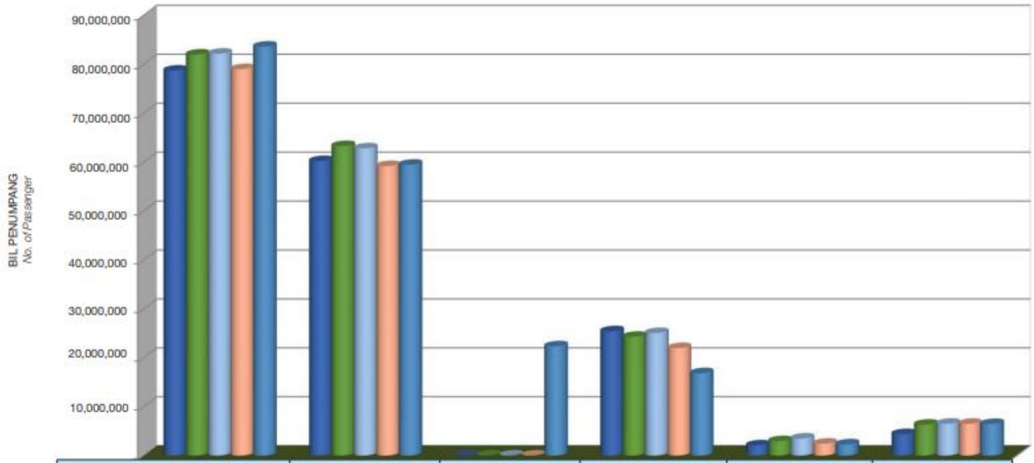
INTRODUCTION

1.1 Background Study

Maintenance is a necessity mainly in engineering involves of industries including the railways. The needs is to ensure confidence for the largest land's public transportation that provides availability, safety, and comfort of its users [1]. Filho *et al*. [2] added, maintenance should be maximized the availability (uptime) at a lower cost and also gives impact to the environmental integrity, energy efficiency and product. Thus, the procedures of maintenance to be used in railway must be followed the specification and demonstration of Reliability, Availability, Maintainability and Safety (RAMS) guides from the standard of the international agency, i.e. the EN 50126-1 (1999) [3].

In Malaysia, Kelana Jaya Line (KJL) is the one of urban metro operators in Klang Valley for over 20 years which owned by Rapid KL. They are facing the degradation of the infrastructures such as track, electrical units, and signalling system. KJL leads the ridership of the whole railway industries in Malaysia with a growth up to 83.6 million in 2017 compared to 17.2 million in early operation in 1999 which showing the statistic of ridership rise up to 380% [4]. Figure 1.1 shows the ridership records by MOT among the light rail transit (LRT) operators in the Klang Valley from 2013 until 2017.

KJL is among the early railway line in the world which utilise the Automatic Train Control System (ATCS) applying the Transmission Base Train Control (TBTC)



	LALUAN KELANA JAYA	LALUAN AMPANG	LALUAN MRT SBK	KL MONORAIL	KLIA EKSPRESS	KLIA TRANSIT
2013	78,702,931	60,207,397	0	25,437,621	2,063,419	4,374,219
2014	81,971,322	63,270,432	0	24,303,465	2,928,302	6,310,323
2015	82,144,674	62,809,412	0	25,067,866	3,470,710	6,496,617
2016	79,002,829	59,192,907	0	21,990,242	2,419,883	6,485,272
2017	83,585,412	59,462,032	22,350,508	16,841,630	2,275,650	6,443,667

Figure 1.1: The statistic of light rail transit in the Klang Valley from 2013 to 2017 [4]

technology, which is the early stage the Communication- Based Train Control (CBTC) [5] for signalling system with no person aboard (UTO- unattended train operation) since operated in 1998 [6].

Acknowledging the CBTC system has overcome signalling issues of accurate, reliable and safe, it's less prone to failure than conventional train control system [6], [7]. The CBTC system is easy to maintain as there has less 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, sometimes may cause to be operated in manual mode. As the contingency plan, they will provide multifunctional staff or mobile technician [8] as well as the efficient maintenance team in dealing with fault [9].

According to the previous studies, maintenance management required to plan all maintenance activities such as equipment lifespan [10]–[12], downtime and high maintenance cost issue. Transit ridership affected by the operation and maintenance that contributes to the factor of cost-effectiveness [13] also faces by the KJL.

In recent years, the growth of technology in the information, control, and communication, provide a big opportunity for the signalling 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 [14]. KJL is also having a big data related with operations system and they are very welcomed to the researcher to explore their data logger for the benefits of the future maintenance works.

1.2 Problem Statement

There were at least five times service interruptions of the KJL during the peak time of revenue hours reported by the local media in 2018 and major contributor are caused by failure of signalling system. All these disruptions could affect the passenger's confidence while selecting a KJL as their main public transport. Table 1.1 shows the reports described all year round.

Table 1.1: The service interruptions in 2018 reported by renowned local media [15]–[19]

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 commuter 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 interruption might due to lack of monitoring system of the infrastructures and facilities intermittent fault behaviour that leads to an unplanned event. The situation has become worse if the maintenance team could not solve the problems within stipulated duration. Mr. Mohd Ismarul Azhar bin Ismail, representative of the KJL confessed that they are still using manual method to retrieve the failure records from the data logger in order to find the root cause for further maintenance works. The downtime is counting from the moment of the failure occurred, until the repairing or troubleshooting progress and it is relatively impact to the high cost due to limited time for maintenance works as the railway operations is involved of public needs.

The current situation faced by the maintenance team of Rapid KL was long-winded of screening lines from the data logger that affected to the man-hour, higher down-time 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 that offers input selection by the user and instantly provides visualisation of three graphical outputs. This tool known as a dashboard of the wayside signalling status which propose to replace traditional method for maintenance works. The graphical status of the dashboard will also to assist the maintenance team capturing the trends of signalling activities and failure records.

1.3 Research Objectives

The objectives of this study are as follows:

(i) To filter and process raw data from the wayside signalling data logger.

(ii) To develop dashboard for the visualisation of fault status for maintenances team.

(iii) To validate the usability of the developed dashboard.

1.4 Scope of Study

This study is focusing on wayside signalling data of Light Rapid Transit (LRT) of KJL. The data studies limited to the following condition:

(i) Wayside signalling data were loaded from the Vehicle Control Centre (VCC) 1 which range from the Kelana Jaya station until the KLCC station between Mac 2018 and August 2018.

(ii) The filtering and processing raw data intended to be loaded into Microsoft Excel 2013 in a Windows environment.

(iii) The dashboard developed using Excel 2013 by licenced Microsoft Office Professional Plus.

(iv) Number of samples for analysis of the usability and the experiences study is at least from seven experts.

1.5 Significant of Study

The purpose of this study is to introduce a dashboard as an interactive tool that offers selection inputs and instantly provides data visualisation. Six variables inputs have been selected as the main significance with signalling system to assist the maintenance team to visualize the historical data. The dashboard can be as a reporting tool which instantly can capture the trend of signalling status. The benefits of this tool are providing a better managerial decision for the maintenance department to deal with resources, revenues, and planning. The Rapid KL's team would be very much appreciating for the tool development as it is beneficial for them to track impropriates status which may lead to any system failure as well as to reduce downtime on manual data screening

CHAPTER 2

LITERATURE STUDY OF MAINTENANCE REQUIREMENT IN RAILWAY APPLICATION

2.1 Introduction

The Institution of Railway Signal Engineering highlighted in 2015, the major challenges of the signalling engineer of the railway in a near future were about signalling systems moving from ground to trains which these two fields, signalling and telecommunication are becoming more integrated. Integration of the trains with the infrastructure (i.e. signalling, telecommunication and power system) can be more complex and accurate in achieving the optimization of the system performances [20]. Although the system performances refer to the safety and the availability which closely related to the railway passenger, reliability and maintainability may also affected them [21].

This chapter is bringing the perspective of maintenance concepts that emphasizes from the standard of RAMS to apply to the railway signalling system with the assistance of the information technology. There is also the background of the adopted signalling system in KJL and basic features of public transportation in Malaysia landscape.

2.2 Maintenance Overview

The studies of maintenance that aim to minimize costs and overcomes challenges has been produced a number of process maintenance models and the majority of them focus on information provision and information flow in maintenance [22]. Their argument in line with [23] who convinced the reliable information have to be provided to implement optimal maintenance on decision-making.

In context of railways, International Railway Industry Standard (IRIS, 2013) mentions that maintenance activities divided into four types:

(i) **Containment maintenance**: not planned, but with immediate action (safety related, accident, vandalism, failure)

(ii) **Corrective maintenance (CM)**: not planned, but with action done during the next scheduled intervention (train functions, not safety related issues for operations, to sustain a containment action)

(iii) **Preventive maintenance (PM)**: planned action (maintenance plan)

(iv) **Predictive maintenance**: output of analysis (Return of Experience, statistical analysis, physical caption of data).

Besides, there are brake down into another five level of activities which includes action monitoring, audits, test, replace, revision on procedure and upgrade production operations [1]. Maintenance after failure or unplanned maintenance may be costly not only for per equipment, but also include labour costs as compared to planned maintenance [10], [24], [25]. Although PM and CM are more relevant and widely implement in many industries to be included in maintenance management, there are still limited knowledge finding for predictive maintenance implementation in railway industry specifically. Predictive maintenance seems to be more actively discuss in the research studies, but the implementation among railway player has not yet been exposed.

Interestingly, predictive maintenance gave benefits of 35% reduction maintenance work to the Finnish state-owned railway company in 2013. The company developed a system via a mathematical model that recognise part that need to be replaced to avoid unplanned down-times [26]. These benefits encourage this research that may lead to overcome the down-times faced by the KJL especially during revenues hours.

2.2.1 Failure or Fault

There are always found in complex systems, data reported as faulty, but at the time investigate into that matter, "no fault" is found [11], [27]. But at other times, as an item being replaced, this item has "no fault" found in next investigation and then returned to service [28]. On the other hand, upon the fault occurrence, the centralized supervising system sent the warning message to the person in charge but the specific information about signalling equipment gone missing [29]. The action taken is send authorized personnel to the event location to investigate and to restore the signalling equipment. These two situations bring us up to some issues. Relevant issues highlight could be the safety of the personnel, time taken or down time, and also the reliability of the information data.

Maintenance engineering teams always deal with fault and failure. Many studies carried out to analyse the trend of failure of the railway assets and also to evaluate the impact of the transport operation. Down time during system fails made by two intervals; one from the time of failure occur until the time failure detected and the other interval is the time spent in repairing [30]. In practice, the recorded information such as the time of failure occur, repair cost and down time can be used for analysis the failure and forecasting failure trend [31]. The usage of sensors to monitor equipment by generating alerts on critical elements of the train that need to be cared [26].

Furthermore, the repeated failures pile up by a repairable system become harder to diagnose and to find the solution [3]. The contribution factor is from the operational, the human and the technical. The examples of the factors in sequence were at the time dealt with the environment such as temperature, the incompetent maintenance personnel because lack of training and lastly, the incorrect contact with wiring.

Railway British Standard define failure, fault and error based from the EN 50126-1 as follows [32]:

(i) **Failure**: loss of ability to perform as required.

(ii) **Fault**: abnormal condition that could lead to an error in a system.

(iii) **Error**: discrepancy between a computed, observed, or measured value or condition and the true, specified or theoretically correct value or condition.

From these definitions, system developers and all the maintenance engineering personnel should have a formal procedure that follows the standard in the specific field to win over reliable information. In KJL cases, the most prominent appeared is the fault resulted as intermittent status.

2.2.2 RAMS for Railway

EN 50126-1 is a standard for railway application fields, namely Command, Control and Signalling, Rolling Stock and Fixed Installations, that the specification and demonstration of RAMS [32]. A railway system must accomplish a characteristic of rail traffic in a given time under safe conditions and emphasized to considering RAMS for railway applications [33]. Table 2.1 shows the definition of RAMS which acronyms for Reliability, Availability, Maintainability and Safety presented by [33], is needed for train operation apply those indicators to system efficiency and increase service performance [34]. For service attainment availability targets are going to be achieved by optimising reliability & maintainability while considering the influence of maintaining safety.

The requirements of four elements interrelated can be met and controlled by a mixture of style and implementation measures and through the continued, long run maintenance and operational activities, all in line with the system surroundings [35]. British Standard in EN 50126-1:2017 explain the failures in a system operating within the bounds of an application and environment will have an impact on the system's reliability, availability and safety, with the level of impact being determined by the system functionality and design. The environment and the operational rules can also influence these effects. The effects of failure within a railway system illustrate in Figure 2.1. Meanwhile, Calle-Cordon using RAMS analysis to evaluate system performance using historical corrective and preventive maintenance data described maintenance for the infrastructure use [36]. The increasing of requirements for reliability and safety by the European rail engineering in recent years make the RAMS analysis become an essential tool in the railway industry.

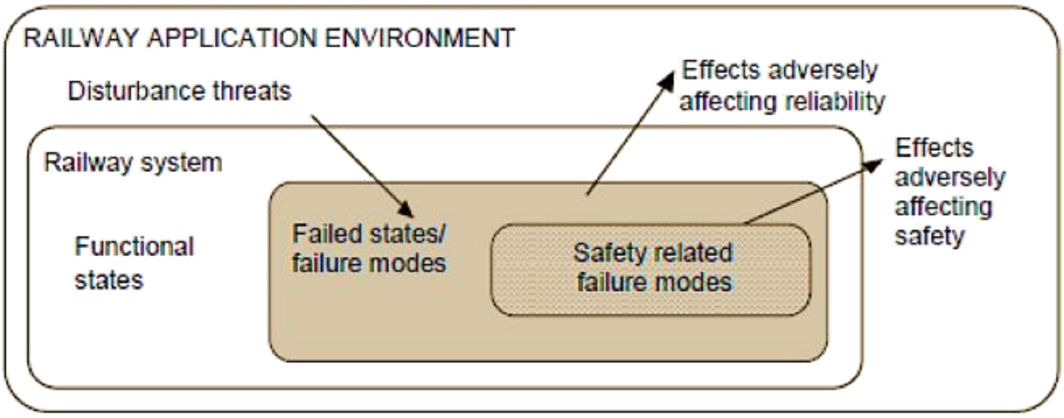


Figure 2.1: Effects of failure within a system [35]

Table 2.1: Summary of RAMS definition [36]

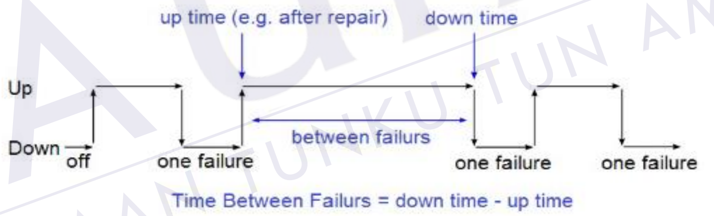
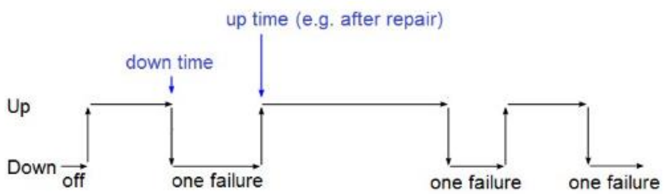
Definition	Description
R **Reliability** Probability that an item can perform a required function under given conditions for a given time interval.	 $\text{MTBF} = \frac{\sum(\text{start of downtime} - \text{start of uptime})}{\text{number of failures}}$ **Reliability** is quantified as Mean Time Between Failures (MTBF). The MTBF can be calculated as the arithmetic mean (average) time between failures of a system.
A **Availability** Ability of a product to be in such a state to perform a required function under given conditions at a given time interval	 $A = \frac{\text{MTBF}}{\text{MTBF} + \text{MDT}}$ $\text{MDT} = \frac{\sum(\text{start of uptime} - \text{start of downtime})}{\text{number of failures}}$ **Availability**, expressed as A, is the ratio of the total time a system is capable of being used (MTBF) during a given interval which includes both the operational periods (MTBF) and all downtimes (MDT).

Table 2.1 (Continued)

<table>
<tr><th>Definition</th><th>Description</th></tr>
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M

Maintainability

Probability that a given active maintenance action, for an item under given conditions of use can be carried out within a stated time interval.

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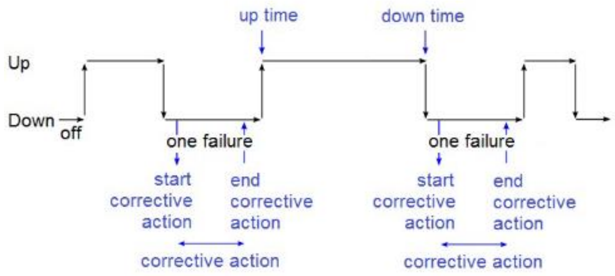

$$\text{MTTR} = \frac{\sum(\text{end of corrective action} - \text{start of corrective action})}{\text{number of corrective actions}}$$

Maintainability is quantified as the Mean Time To Repair (MTTR).

MTTR is the basic measure of the maintainability of repairable items and represents the average time required to repair a failed component or device.

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S

Safety

Freedom from unacceptable risk of harm.

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Safety can be described by means of the Safety Integrity Level (SIL).

The assignment of SIL is an exercise in risk analysis where the risk associated with a specific hazard to be protected against is calculated .

The Tolerable Hazard Rate (THR) is a figure which guarantees that the resulting risk does not exceed the target risks

SIL 4 = $10^{-9} < THR < 10^{-8}$ **per hour and per function**
SIL 3 = $10^{-8} < THR < 10^{-7}$
SIL 2 = $10^{-7} < THR < 10^{-6}$
SIL 1 = $10^{-6} < THR < 10^{-5}$

</td></tr>
</table>

In Malaysia, railways operators are facing a challenge to improve their reliability and speed in order to offer competitive services to the public and enhance their importance as a road alternative [34]. However, from the interview with maintenance team of KJL, most of the workers (the engineers, foremen and technicians) unaware of what is RAMS is all about. It is believed Malaysian railway operators awarded the contract based to renowned companies in handling signalling and communication such as Bombardier, Thales and Siemens. These companies have decent reputation and recognition of applying good standards should certain in work ethics without compromised to follow the RAMS. Insomuch, the operators have to put on trust to the contracted company and respect the operation guidelines. Nevertheless, the Land Public Transport Commission (SPAD) then named as Land Public Transport Agency (APAD) has appointed an independent technical auditor for the first time for auditing the RAMS elements to both LRT Lines (Ampang Line and KJL) as well as Kuala Lumpur Monorail to identify the reason for the breakdowns and suggestions on how services can be improved in the urban rail lines [37].

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