Failure's Severity Affecting Railway Operation Based on Sensitivity Analysis: A Case Study of Addis Ababa Light Rail Transit (AALRT)

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Abstract

Operation delays and trip cancelations affect the reliability of the operation and customer's satisfaction. This review work adopts a case study of AALRTS operation system employing operation data and incident records of AALRTS. The purpose of this paper is assessing the failures frequency and the time it takes to get back to its operation aiming that how sensitive it is for the reliability of the operation. An extensive literature review has been used to approach the problem in which the sensitive failure`s analysis methods have been identified. The method that has been used to investigate the failure`s magnitude was sensitivity failure analysis by considering the case study of AALRTS. The method has been implemented to identify different failure modes through the analysis of the case how sensitive the failures are to the normal operation. The results that have been discovered from the analysis are: - the safety incidents and equipment failures are the major groups that affect the normal operation of AALRTS. When we go to the depth level-crossing incidents and power outages are the major sensitive failures (from safety incidents and equipment failures) that can reduce the reliability of the operation dramatically. Finally the researcher would like to recommend that giving a due attention for those sensitive failures might improve the reliability of the railway operation.

Keywords: Train delay incidents, operation reliability, failure`s severity, failure modes and sensitivity analysis.

1 Introduction

A railway transportation system is the finest transportation mode comparing to other transportation modes, when it is reliable. A bit failure in railway system may result a huge damage on the infrastructure or the rolling stock. It can also cause casualties. There is no transportation mode which is out of failure, but by improving the quality of the transportation system, we can improve the safety of our passengers and make reliable our transportation system. Railway transportation needs a huge investment for construction whereas the life cycle of the system will depend on the Reliability, availability, maintainability and safety (RAMS) of the system. Railway system is composed out of the infrastructure and the rolling stock (train).

Failure consequences of the railway system are:-

- causalities and operational shut-down
- Derailment
- Financial losses and
- Lots of maintenance works

Failures on railway system, that can affect the normal operation, can be triggered by three different causes, i.e.:-

- Safety incidents
- security incidents and
- Equipment failures

Safety incidents: - Safety incidents consist of significant accidents like: - People seriously injured and killed, Suicides and attempted suicides, Overall workforce safety, Workforce safety on track or trackside.

Security incidents: - security incidents can be caused by: - thefts, bombing and any actions performed and that can affect the security of passengers and the infrastructure as well.

Equipment failures: - Equipment failures entail: - Signaling failures, Telecommunication failures, Power supply failures, track Failures, structure failures, rolling stock failures and other failures. Some commonly observed equipment failures can be caused by: - ageing, wear on the rail, damages of equipment's and insufficient maintenance works.

Since the AALRTS operation has been started recently, the truck structures aren`t exposed to ageing whereas the other causes might be the real causes of equipment failures.

There are various methods that can used to predict failures in railway operation system; it is believed every method has its own purpose and drawback. This paper presents a new way of failure analysis technique based on the failure`s sensitivity to predict on what percent railway operation has been affected.

A failure mode, effects and criticality analysis (FMECA) [1] is a widely used failure analysis method which has a little difference with that of FMEA (Failure Mode and Effects Analysis) method. The failure data can be gathered either from the system`s field data or by the use of statistical data. [2] Criticality of risks in railway projects can be identified based on fuzzy and sensitivity analysis methods (Jelena M. Andrić, Jiayuan Wang, and Ruoyu Zhong, Published: 1 March 2019). Studying the causes of accidents and mitigating strategy is also one way of tackling failures. [3] There are some researchers who conducted their research on causes of train delays. This issue is also the concern of this paper. The number of delayed trains and corresponding probability are evaluated by MLE estimation, Railway Disruptions and Their Impact on Delayed Traffic in Chinese High-Speed Railway has been analyzed by a regression model, the model gives a detail description how Railway Disruptions is related to the number of delayed trains it can be assessed by using statistical analysis. (Peijuan Xu, Francesco Corman, Qiyuan Peng 2016). [4] [5] Sensitivity analysis has been employed for railway projects to analyze their effect on financial reliability. [6] FMEA (Failure Mode and Effects Analysis) has been used to assess the failures on different railway infrastructure equipment's and rolling stock components. I.e. switches and turnouts, door system of rolling stock, and so on. All of The failure modes aim to reduce maintenance cost by adapting preventive maintenance and eliminating corrective maintenance. Maintenance based approaches are also the ways that reduce the frequent occurrences of failures by improving the maintenance quality. The way suggested can be improving preventive maintenance or condition based maintenance. [7] [8]

Different researches have been conducted to improve the maintenance trend in order to improve the reliability of the system. Condition based maintenance (CBM) has been applied to minimize life cycle cost of the freight car components. [9] Bayesian methods could also use as a fault diagnostic method, it is quite important since it give a clear way to identify the accident occurrence on the specified structure by combining the empirical knowledge and statistical data. [10][11] the reliability of railway system will also be improved by improving our maintenance trend. Implementing preventive maintenance will improve the safety of the equipment's and as the same time minimize exaggerated costs of maintenance. Reliability centered maintenance (RCM) has been also applied in railway networks. [12] [13] (FMECA) has an extra advantage on (FMEA) since it can assess and provide the critical failures with their causes and effects. The critical failures on turnouts can be also addressed by expert approach [14]. FMEA (Failure Mode and Effects Analysis) is one of the most commonly applicable methods in different engineering applications including railway system. It bears reliability and safety analysis. [15] - [19]

Most researchers have also used a fault tree analysis method to predict the occurrences of failures. Fault tree analysis method can be a timed fault tree analysis (Zhaoguang Peng, Yu Lu, Alice Miller, Chris Johnson and Tingdi Zhao, 2014) or event tree analysis. A timed fault tree analysis method can define which faults need to be eliminated instantly, and it can also predict how much time has been left at least to eliminate the root failure in order to prevent accidents. [20-23]

"Probabilistic defect based risk assessment approach" for railway failure analysis uses defects as a cause. [24] Sensitivity analysis has been also applied to analyze effects of critical speed in railway vehicle dynamics. We can observe that the other researchers have used Sensitivity analysis method for the purpose of assessing financial reliability on railway projects, effects of critical speed in railway vehicle dynamics. But the researcher of this paper on the other way has used Sensitivity analysis method to identify how failures are sensitive concerning railway operation. Train delay incidents have a major effect on the reliability of the operation system, so that it has been analyzed on its effect on transit service reliability and on customer satisfaction by Barron, A., P.C. Melo, J.M.Cohen, and R.J. Anderson. (Barron, A., P.C. Melo, J.M.Cohen, and R.J. Anderson 2012) Rail accident investigation for railway safety improvement and risk management of railway infrastructure; have got a wide coverage in the research areas of railway technology. [25-30]

Failure analysis models and methods have been developed chronologically. Recent publications deeply analyze the methods by gathering different failure modes and studying their effects. Some researchers have used this Failure Mode and Effects Analysis as a means of railway risk assessment and hazard identification. [30-33]

Whenever there come research results it is an intellectual attitude to investigate the reason why and how the results have been achieved.

Gaps identified are:-

There are lots of models and methods which have been used for fault analysis of railway system, but most of them aim to predict faults at component level i.e. signaling system or door system, switches and crossings and so on, but not at operational level. This research paper aims to assess the criticality of failures in the aspects of affecting railway system operation. The normal operation of railway system could be affected by different kinds of failures that result in: - train delays, canceled trips and Part (short) routes. But which failures in what percent is affecting the operation are not clearly defined yet. So that filling this gap was my intention by tackling this problem systematically and giving a clear justification on the targeted case.

2 Analysis

2.1 Preparation

Reliability, availability, maintainability and safety (RAMS) of railway operation system are highly affected by the internal and external failures of the system and the time taken to recover the failures. Common consequences of failures are: - trip cancellations, Part (short) routes, Damages, Operation Delays and so on. Sensitivity analysis has an imperative significance in an extensive range of engineering uses. The method which has been used in this paper is sensitivity analysis approach. The method helps to recognize the most sensitive failures that can affect the normal operation of railway system. The sensitivity of the failure is also dependent on the time of recovery and the frequency of occurrences. The case study has been taken for the year of 2019. The figure below tries to indicate the major Failures affecting railway operation versus their consequences.

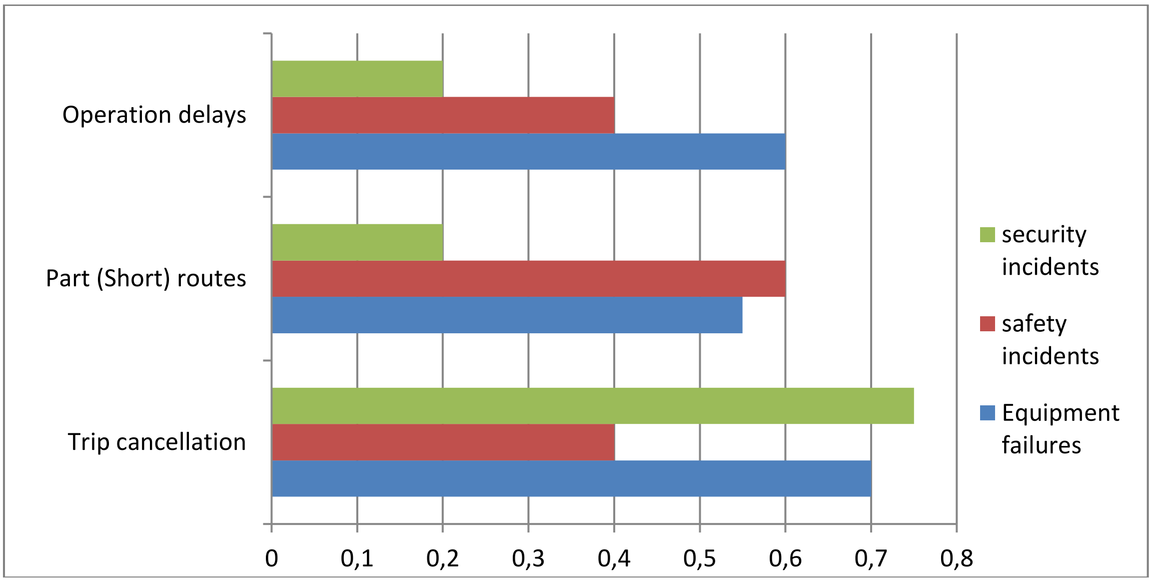

Figure 1: Major Failures affecting railway operation versus their consequence

2.1.1 Frequency Analysis of failures

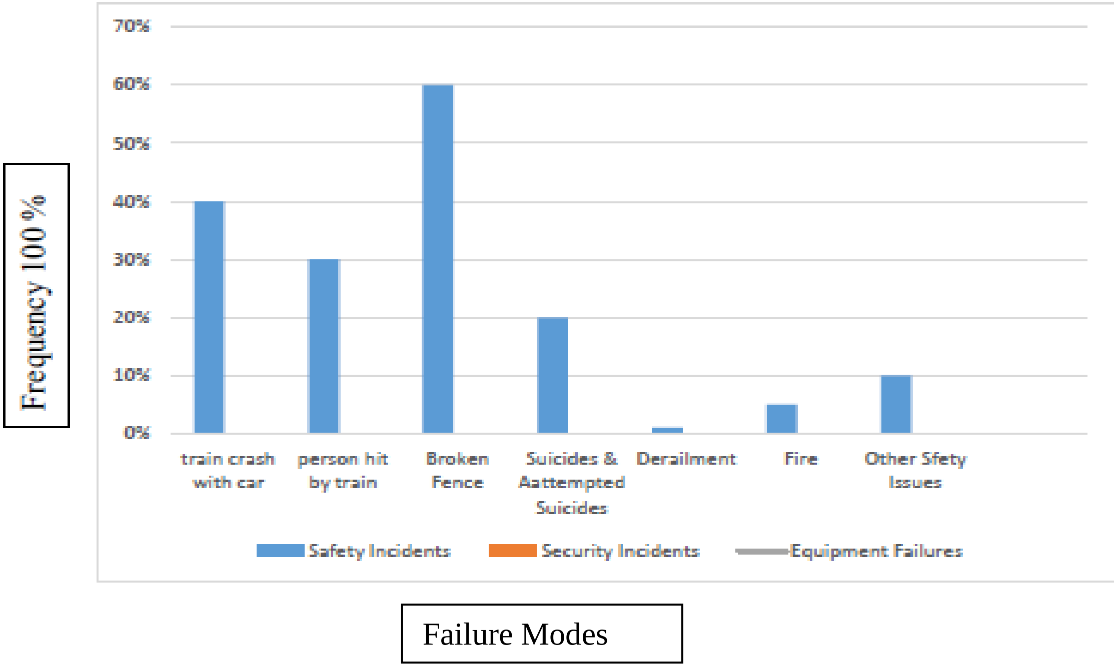

Figure 2: Frequency Analysis of Safety incidents

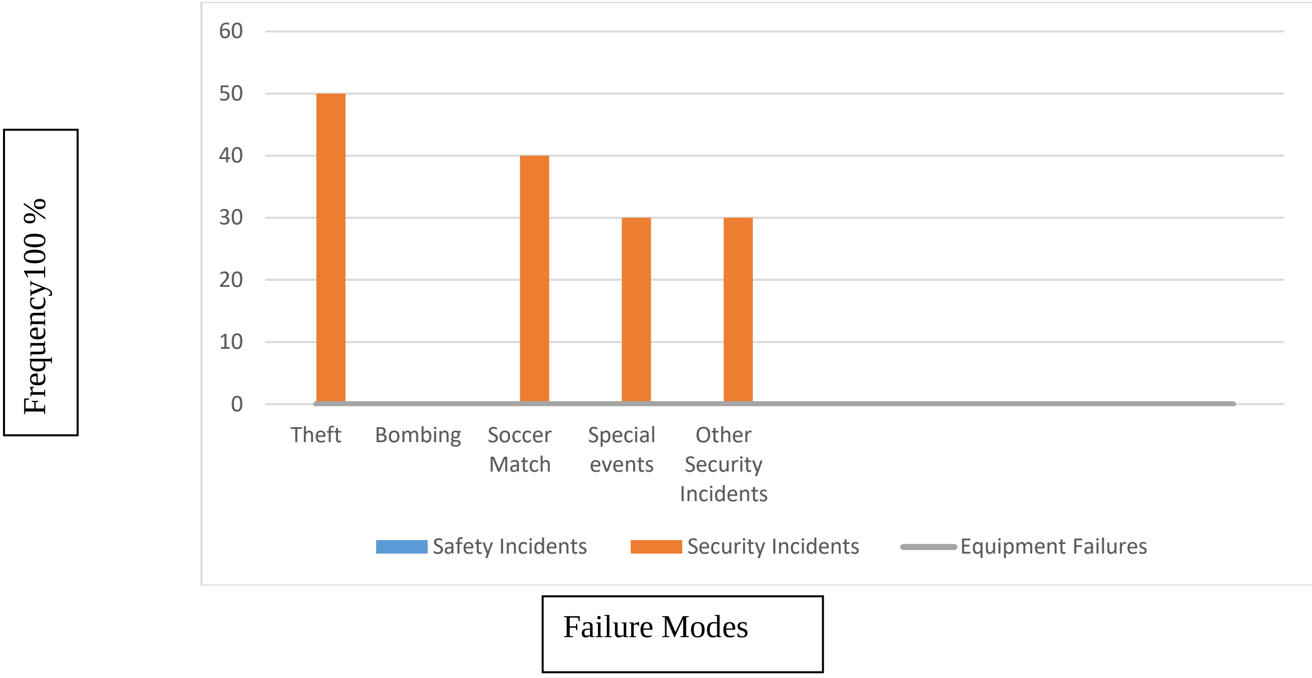

Figure 3: Frequency Analysis of Security incidents

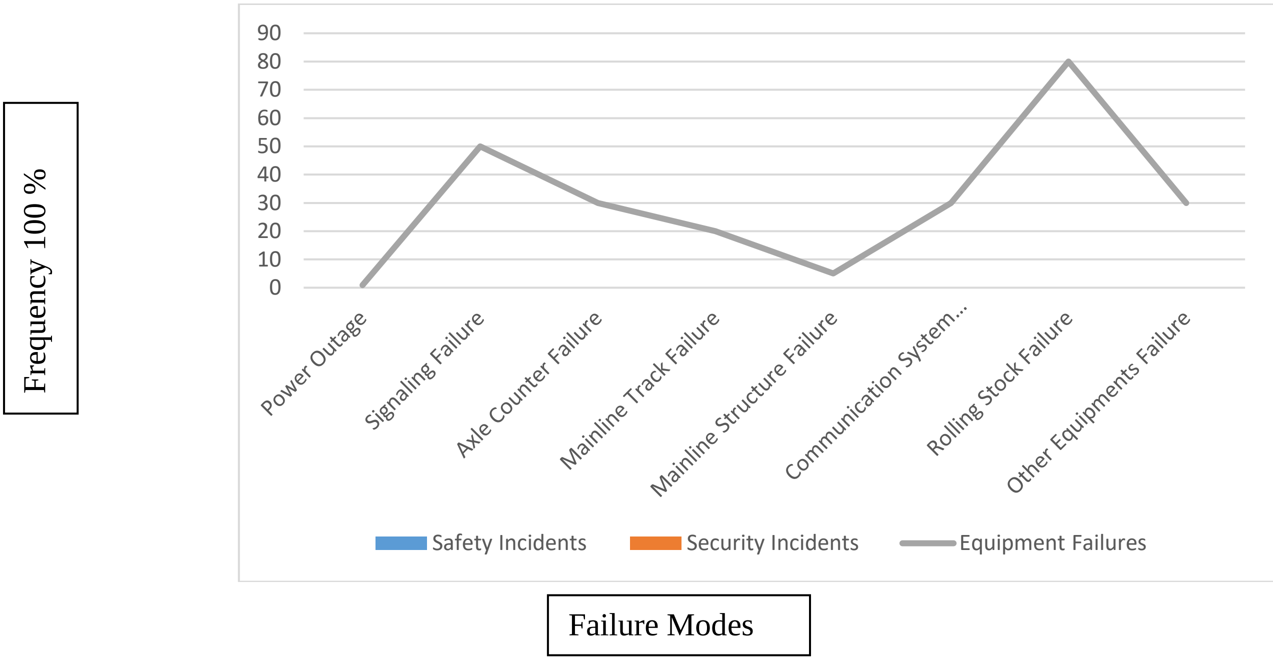

Figure 4: Frequency Analysis of Equipment Failures

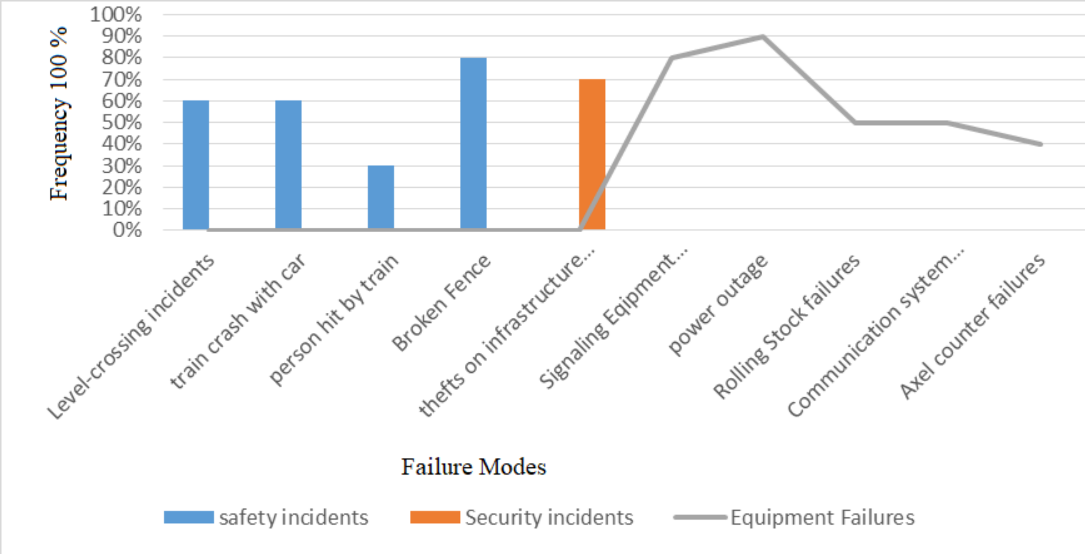

Figure 5: Frequency Analysis of All Failures

2.2 Details

2.2.1 Sensitivity Analysis of failures affecting the normal operation of railway system

Table 1: Sensitivity analysis of Safety incidents on railway operation

Sensitivity Out of 100%	**Train crash with cars**	**Person hit by train**	**Broken Fence**	**Suicides and attempted suicides**	**Derailment**	**Fire**	**Other Safety issues**
train delay hours	30%	10%	30%	10%	8%	2%	10%
number of trip cancellations	10%	10%	40%	10%	0%	5%	25%
number of part routs	15%	5%	60%	3%	0%	2%	15%
Time taken for recovery	35%	35%	10%	8%	0%	2%	10%

Table 2: Sensitivity analysis of security incidents on railway operation

Percent of Sensitivity Out of 100%	**Thefts (thefts of power cables and other equipment's from the infrastructure)**	**bombing**	**Football Match**	**Other Security incidents**
train delay hours	35%	0%	35%	30%
number of trip cancellations	25%	0%	50%	25%
number of part routs	25%	0%	50%	25%
Time taken for recovery	25%	0%	50%	25%

Table 3: Sensitivity analysis of Equipment Failures on railway operation

Sensitivity Out of 100%	**Power Outage**	**Signaling Failure**	**Axel Counter Failure**	**mainline Track failure**	**mainline Structure failure**	**Communication system Failure**	**Rolling Stock Failure**	**Other Equipment failures**
train delay hours	35%	6%	6%	2%	0%	6%	30%	15%
number of trip cancellations	60%	8%	0%	4%	0%	0%	20%	8%
number of part routs	60%	10%	0%	0%	0%	0%	25%	5%
Time taken for recover	40%	10%	5%	5%	0%	10%	20%	10%

2.3 Results and Discussion

The results that have been discovered from the analysis of the data indicate the percentage of sensitivity of failures on the normal operation of AALRTS. I have tried to analyze the issue by grouping in three major categories:-safety incidents, security incidents and equipment failures. Concerning the frequency of failures, safety incidents particularly level-crossing incident is the major failure happening frequently, while within Security incidents theft is the major failure happening frequently relative to other incidents. Finally power outage among the group of equipment failures is the major failure happening frequently. But it is not wise enough to conclude that "a failure happening frequently is a failure highly affecting the operation"; because in-order to affect the operation the failure should have a direct effect in the operation.

Concerning the sensitivity analysis, power outage is the first failure that can be able to stop the operation automatically; secondly signaling failures take the second portion; then it is possible to observe Communication system Failures and rolling stock failures will take the next portion of affecting the operation. The other failures will exhibit less effect in the operation one after the other. Safety incidents depending on their severity will affect the operation accordingly. Among the Safety incidents level-crossing incidents take a wider coverage of sensitivity. The sensitivity of Security incidents is very low comparing to other groups; because they don`t have a direct relation to the normal operation.

2.4 Conclusion and Recommendation

Finally the researcher would like to conclude her argument based on the results of the analysis. Power failure is the major failure that can reduce the reliability of the operation; whereas safety incidents particularly level crossing accidents take the next coverage. Within the equipment failures signaling equipment's failures take the next level in the contribution of interruption of the operation. Rolling stock failures and other equipment failures will exhibit less effect in the operation one after the other.

Finally the researcher would like to recommend that the maintenance center should give a high attention to the identified equipment failures which are categorized according to their level of sensitivity. They can improve their trend of maintenance by increasing the level of preventive maintenance and preparing spare parts for frequently damaged spare parts i.e.:- axel counter and signaling equipment's. Some spares which are not compatible to the system might fail frequently so that preparing genuine and compatible spare parts will dramatically improve the maintenance efficiency.

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