Investigating the Feasibility to Acquire System Performance Information of a Complex System from Limited Maintenance Data

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***Abstract*—We investigate the feasibility to extract system performance information based upon limited maintenance record of the Taipei Rapid Transit Corporation (TRTC). The maintenance record consists of malfunction incident rate per month of the Taipei metro system. It is desired to estimate the system lifetime from the maintenance record. However, whether such information is contained in the maintenance record, and furthermore, if the information can be extracted is to be determined. Moreover, the problem is further complicated by the regular maintenance, which further tampers the embedded information. The research goal is to assess the feasibility to acquire the desired information from the available dataset.**

Keywords-degradation; maintenance; metro; MRT; performance analysis.

I. INTRODUCTION

It is desirable to obtain system information from the maintenance data. In this research, we investigate the Mass Rapid Transit (MRT) system of Taipei Rapid Transit Corporation (TRTC), which began operation in 1996 for 23 years [1]. By analyzing the Taipei MRT maintenance records, we further explore the possibility to acquire information indicative of the system performance. The research objective is to determine whether it is possible to acquire reliable information of the system performance from the limited time-span maintenance records. If such information can be extracted, it may be helpful to diagnose the condition of the Taipei MRT system.

The performance and degradation of metropolitan metro systems play a crucial part in the civilians daily life and have attracted much attention of general public. The performance, malfunction, or maintenance all have huge impacts on the daily life of the passengers and civilians. Assessment and quantification of the system current status is essential to enhance performance. The performance of such complex system is commonly analyzed using the degradation curve model; analysis of the reliability is based on failure rate and maintenance records [2]. By assessing the condition of the system, improvement of the maintenance and performance can be recommended.

The performance record of various metropolitan metro systems in the world are studied. For example, the subway system in New York City, USA, has a long history. As reported in [3], train R36 serviced from 1964 to 2003, a total of 39 years. R160s were used to replace 45-year-old trains. In another news report about the old trains [4], the oldest trains for New York City Subway were planned to serve for 58 years, and now this type of trains are actually found too old with very high failure rated. From the limited reference that we can access, an estimate of the subway train lifetime is estimated to be around 40 to 50 years. For example, some lines of Singapore Mass Rapid Transit (SMRT) have been operating since 1987, 30 years from today. On the other hand, TRTC operated from 1996, which is only 21 years ago. There is a difference of 9 years. The assets' actual wear-out period may lie somewhere between 20 years (the oldest TRTC asset), and 40 years (New York City Subway). All these metropolitan metro systems are different in various aspects, thus, the performance of such MRT systems are not the same. Research attempts to establish a degradation curve model from the maintenance data has not been satisfactory.

The metro system is a complex system consisting of various components. For example, the rail track condition monitoring is an important technical concern of the MRT system [5]. However, it is infeasible to constantly inspect track conditions; an inspection once a month or less is the common maintenance. Severe track condition degradation is a potential threat to the railway system. Hence, more attention has been devoted to monitoring track condition via in-service vehicles [6]-[8]. The general goal of the research and technical modifications is to improve the performance and reliability of a mass rapid transit system.

Various approaches to analyze system performance have been reported [9]-[18], including the popular bathtub curve analysis [19]-[24]. The Bathtub curve model is widely used to assess system performance analysis [25]. Analysis based upon the bathtub curve has been extensively applied to various problems [11], [26]-[29]. Our research goal is to investigate the feasibility and validity to assess the performance of the Taipei MRT system based upon limited maintenance record.

We investigate and analyze the Taipei MRT data. We have data from Taipei MRT consisting of 11 systems: Electric Multiple Unit (EMU) propulsion, EMU Air Conditioner, EMU Communication, Switcher, Platform door, 22kV switchboard, Automated Fare Collection (AFC) door, Wenhu Line traffic control computer, Transmission system, elevator, and escalator. Specifically, we search for characteristics and

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compare with the bathtub degradation curve; the research objective is to acquire status information of the equipment and identify possible tendencies or features that may be indicative of the system performance.

This paper is organized as follows: Section I: Introduction with a description of the goal of this research project. Section II: Method. Section III: Data Analysis. Finally, Section IV: Conclusion and Future Work, followed by an acknowledgement.

II. METHOD

System condition analysis using the bathtub-shaped curve model [25] is commonly employed. It consists of a break-in trend as the system condition improves, followed by a plateau regime where the system condition is stable. After this stable regime, the system condition withers with increased malfunction rate, followed by a steep increase of malfunction rate where the malfunction rate increases with time rapidly whereas the system breaks down. Together, the bathtub-shaped curve represents the various stages of an ideal system.

However, not all system status can easily be compared to the bathtub-shaped degradation curve; it is an idealized theoretical model used in many problems. It is an idealized trend that depends on various factors. The feasibility of applying such bathtub-shaped curve may depend on the specific application and the various factors involved. Specifically, the system condition may not follow the same degradation curve, also, each equipment system may exhibit different characteristics depending on the specific application.

It is proposed that the maintenance data would yield a simple bathtub-shaped degradation curve for an equipment that is operated under normal condition. For systems that are affected by other factors, this theoretical degradation curve may be affected. Most cases do not follow the same degradation curve. For a complex system involving various brands, various models, and systems of various ages, the exhibited characteristics shall be different. In addition, as maintenance decisions involve human decision factors, such uncertainty further complicates the degradation curve, causing the exhibited characteristics further derailing from the possible universal bathtub-shaped curve.

Furthermore, each equipment in the Taipei metro system consists of various brands and various models that may possess different intrinsic characteristics. Since each equipment is maintained by human, the degradation curve is tampered with human factors and may exhibit characteristics differ from the original degradation curve without human influence. The research objective is to decipher whether such complex information can be extracted from the maintenance data of a limited time span.

III. DATA ANALYSIS

Maintenance data provided by TRTC is analyzed. We employ linear regression and various regression models to identify the trend. Through each method, our goal is to ascertain the general behavior of the dataset. The limited dataset showed diverse characteristics which is inconclusive. The recorded number of malfunction incidents of the MRT transmission system per month as a function of age is shown in Figure 1. The data is sporadic and gradually decrease with time.

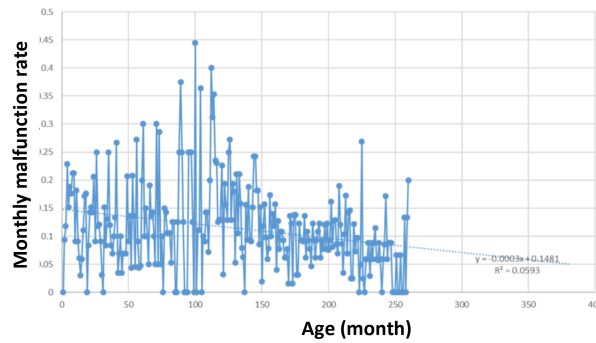

Figure 1. Average malfunction rate per month as a function of transmission system age (month).

As shown in Figure 1, the decreases with time is apparent. This could be due to the regular maintenance. in this mostly likely is due to the improvement of MRT maintenance. On the other hand, since the age of each equipment and the number of samples for each equipment are not consistent, the degradation curve exhibits mixed information of various complex factors.

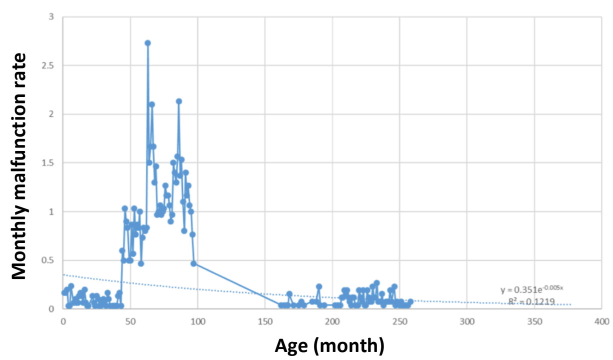

Figure 2. The average malfunction rate of the Wenhu Line central computers as s function of age (month).

The average malfunction rate of the Wenhu Line central computers as a function of age is shown in Figure 2. Due to incomplete record, there are some maintenance data is missing. Thus, the degradation trend may not be conclusive.

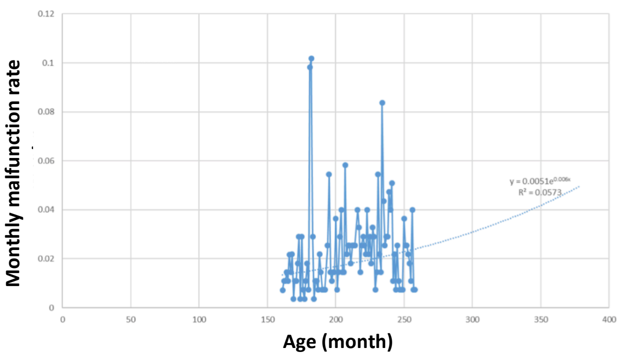

Figure 3. The average malfunction rate of the Muzha Line screen door as s function of age (month).

As shown in Figure 3, the average malfunction rate of the Muzha Line screen door as a function of age exhibits a gradual increase with age. The data span only covers short period of time, but it clearly increases with age. A more complete dataset may be required for conclusive results.

IV. Conclusion and Future Work

The goal of this paper is to assess the feasibility to extract status information of various Taipei MRT systems based upon the maintenance data. The maintenance data is limited and only consists of a single parameter: count of the number of malfunction incidents per month. By means of data analysis, our goal is to identify characteristics indicative of the current status of the metro system, remaining lifetime, and estimate its future trend. Yet, the system information may not be fully contained in the provided maintenance record. The validity of the estimation based upon incomplete data, may be limited.

The bathtub degradation curve could be affected by human factors; for example, if the asset retired in its early stage, the curve may not rise up during the wear-out period and may even descend. If properly maintained, the curve may not rise in the wear-out period, similar to the situation in airline industry. However, few MRT systems in reality exhibit degradation behavior similar to the bathtub curve model [30].

The degradation curve acquired from data analysis of the provided Taipei metro maintenance record has be assessed. however, the trend of each degradation curve exhibits various characteristics. By comparing with the bathtub curve model, we tried to assess the status of each system. However, the assessment is inconclusive. Possible factors include:

1) Each system has not reached the steady state.

2) Human factor such as maintenance tampers the natural trend.

3) More data, longer temporal span of maintenance record is required to reveal a degradation trend.

Based on the available maintenance records provided by TRTC, statistical analysis findings indicate that the Taipei metro is stable with no significant indication of degradation. Degradation curve acquired via statistical analysis is not conclusive. More data may be required to establish the general trend.

If the maintenance data contains severity information of each malfunction incident, data analysis may potentially yield more information to assess the status of the system. On the other hand, it is not ascertained that the desired status information is embedded in the malfunction incident record, which is further tampered by the regular maintenance. On a broader perspective, a fundamental question to be asked: Is the required information contained in the dataset? If it isn't, or perhaps only partial information is contained in the dataset, then even the most elaborate analysis approach cannot legitimately extract information that is not contained within the dataset.

For future work, we recommend the maintenance record consists of more than a single-parameter, such as the severity of the malfunction, the cost of the malfunction, maybe mileage of operation between each malfunction incidents. The maintenance record will be a resourceful dataset for assessing the status of a complex system. Such information may provide more direct information regarding the system status. We believe such approach may be more sensitive and indicative, and potentially be indicative of the system status and system lifetime.

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