Investigating the Feasibility to Estimate System Performance Based upon Limited Data of the Taipei Metro System

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Abstract—**Data analysis may yield information regarding the system performance. In this study, we analyze the maintenance data provided by Taipei Rapid Transit Corporation (TRTC); the data consists of limited maintenance records of the Taipei metro system. However, the accuracy to ascertain the system lifetime based upon limited maintenance records of a still young metro system is yet to be determined. Furthermore, the Taipei metro system is renowned for its good maintenance and performance, which further complicates the analysis with additional variable introduced by replaced new parts. Based on limited maintenance records, the research objective is to assess the feasibility of extracting reliable information indicative of the current stage of life, and, the remaining lifetime of the metro system.**

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

I. INTRODUCTION

The Mass Rapid Transit (MRT) system of Taipei Rapid Transit Corporation (TRTC) began operation on March 28, 1996; it has been operating for 22 years [1]. Most of the equipment has not yet been replaced. In this research, we investigate the feasibility of extracting information from the Taipei MRT maintenance records. 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 the maintenance data indeed contains such information of the current system status, our goal is to assess the current stage of life of the Taipei MRT system and determine the remaining lifetime.

The performance and degradation of metropolitan metro systems have been the focus of general public. Various studies have been reported, including technical issues of the MRT. Rail track condition monitoring is an important technical concern of the MRT system [2]. However, constant monitoring of the MRT system is not available; typically the usual maintenance is performed once a month or less. The track condition has attracted much attention since it is a potential threat to the railway system. Studies to prevent such threats have been reported [3]-[5]. To improve the reliability of a mass rapid transit system is the general goal of such research and technical modifications.

Analysis of information regarding other metropolitan mass transport systems may be helpful. As reported in [6], train model R36 of the New York City subway serviced from 1964 to 2003, a total of 39 years. R160s were used to replace 45-year-old trains. In another news report about old trains [7], the oldest trains for New York City Subway were planned to serve for 58 years. Now, this type of train is considered too old, has very high failure rate and is not appealing to passengers. 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. Thus, the actual wear-out period of a metro system, assuming they are similar, may roughly lie between 20 years (the oldest TRTC asset), and 40 years (New York City Subway). However, all of these metropolitan metro systems are different in various aspects, such as: model, company, maintenance, management culture, etc. It is natural that the characteristics of these MRT systems are not the same and may even differ dramatically. With unknown number of variables involved, the accuracy of assessment may be very limited.

Determining the current system status may be essential. The degradation curve is commonly employed for estimation of the system current status. Analysis of the reliability is based on failure rate and maintenance records [8]. To study the maintenance and performance characteristics, various approaches have been reported [9]-[17], including the popular bathtub curve analysis [18]-[23]. Typically, the bathtub-shaped curve is employed for system performance analysis [24]. Analysis based upon the bathtub curve has been extensively applied to various problems; various modifications to improve applicability have been reported [11][25][26]. It is possible that the bathtub-shaped 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. However, few MRT systems in reality exhibit degradation behavior similar to the bathtub-shaped curve model [27]. It is possible such bathtub curve may not be the ideal model for analyzing the metro system performance.

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This paper is organized as follows. Section I consists of an introduction of the problem. The research method is discussed in Section II. Research findings are reported in Section III, and finally, a summary is presented in Section IV, followed by an acknowledgement.

II. METHOD

The bathtub-shaped curve model [24] is commonly employed to assess the system condition. 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, the bathtub-shaped degradation curve is a 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.

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 humans, the degradation curve may be influenced by human factors and fall short to follow a universal bathtub-shaped curve. By analyzing the maintenance data, our goal is to decipher the feasibility to assess the MRT current stage of life based on available data ranging over a limited time-span.

III. DATA ANALYSIS

In this study, we investigate the maintenance data of the Taipei metro system. Based on the maintenance data records provided by TRTC, we analyze the maintenance data of the escalator system, elevator system, and Electric Multiple Unit (EMU) air conditioner of the metro system. These three systems are essential components of the metro system. The elevator and escalator are used regularly by the commuting people.

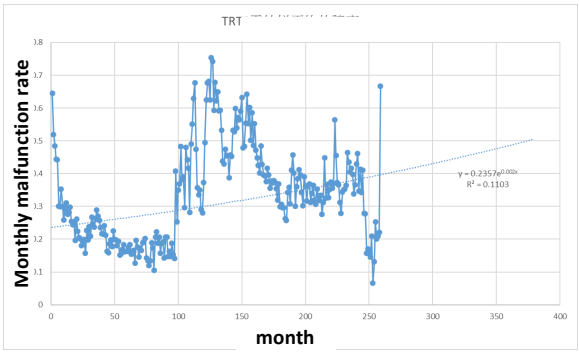

Figure 1. The reported average number of malfunctions each month of the Taipei metro station escalators.

The maintenance records of the elevator, escalator, and EMU air conditioner are analyzed. Figure 1 depicts the maintenance record of the escalator. We notice that the trend of the malfunction rate is irregular. Possibly because of the limited span of the maintenance data the specific stage of life-time is not apparent; further analysis is therefore required.

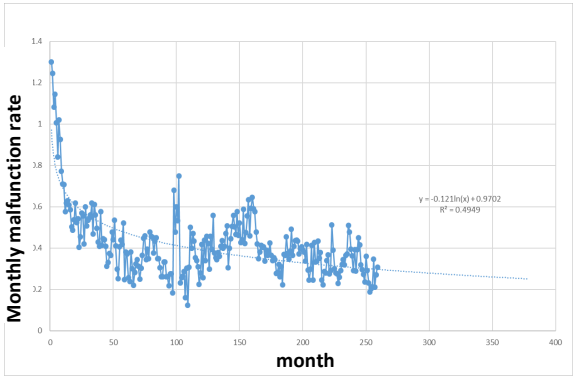

Figure 2. The reported average number of malfunctions each month of the Taipei metro station elevators.

Next, the maintenance records of the elevator system is shown in Figure 2. The maintenance records decrease with time. Trend of the maintenance records monotonically decrease with time. The monotonic decrease trend appears to be easier to match with the ideal bathtub-shaped curve.

Lastly, the maintenance records of the EMU air conditioner are shown in Figure 3, also exhibiting the malfunction rate decreasing over time. However, compared to the smooth trend of Figure 2, the EMU air conditioner maintenance data is more volatile. Though the maintenance data of the three systems differ, they all roughly decrease with time, suggesting that the system is still young whereas the performance is still improving. Or, the system is being well-maintained such that the malfunction rate does not reflect the system performance accurately.

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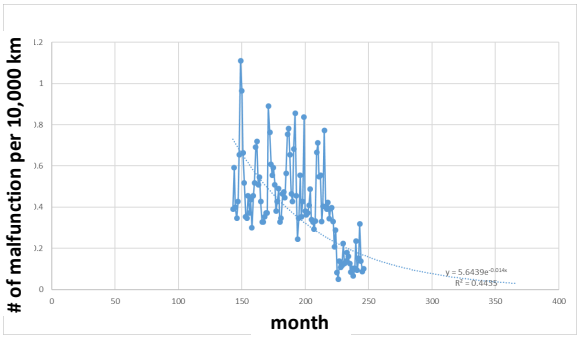

Figure 3. The reported average rate of malfunctions (per 10,000 km of operation) of the Taipei metro EMU air conditioners.

The maintenance records provided by TRTC consists of only the number of malfunctions per month. However, the severity of each malfunction may be drastically different, from as simple as the replacement of light bulb, up to power combustion resulting in system complete breakdown. Yet, in the available maintenance records, there is no information describing the severity of the malfunction event. The statistical analyses of these three systems (escalator, elevator, and EMU air conditioner) exhibit no apparent degradation of the system. Trends of the maintenance records suggest that the system condition improves with time, which is not the typical of a withering system.

IV. Conclusion and Future Work

The objective of this research is to determine the current condition of the metro system, and, furthermore, if possible, to estimate the remaining lifetime. 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. However, the desired information may not be fully contained in the provided dataset and therefore limiting the accuracy of system lifetime assessment. Research findings show that the accuracy to assess the system lifetime based upon the provided maintenance records of a still-young metro system is limited.

Data analysis of the Taipei metro system maintenance records revealed the general trend and characteristics of the system condition and performance. Yet, information regarding the total lifespan of the system, current stage-of-life, and remaining lifetime he not been ascertained. Possible reasons include: 1) the system being still young, 2) the regular maintenance altered the natural deterioration trend, 3) the available data being far from complete to make meaningful estimations of lifetime information. Further analysis to help answer these questions are in pursuit.

Based on the available maintenance records of the Taipei metro system, the statistical analysis suggests that the maintenance of the Taipei metro system is well conducted; no signs of deterioration or withering. The data analysis falls short to yield information regarding the total lifespan, the current stage of life, and the remaining lifetime. If data with longer span and more variables is available, it is possible that such information can be ascertained.

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References

[1] "Taipei Metro," https://english.metro.taipei/News_Content.aspx?n=07DAD5F7351B8882&sms=2190547C60526D6B&s=FD5C094216AE77AB.

[2] X. K. Wei, F. Liu, and L. M. Jia, "Urban rail track condition monitoring based on in-service vehicle acceleration measurements," *Measurement,* vol. 80, pp. 217-228, Feb 2016.

[3] M. Molodova, M. Oregui, A. Nunez, Z. L. Li, and R. Dollevoet, "Health condition monitoring of insulated joints based on axle box acceleration measurements," *Engineering Structures,* vol. 123, pp. 225-235, Sep 2016.

[4] G. Lederman, *et al.*, "Track-monitoring from the dynamic response of an operational train," *Mechanical Systems and Signal Processing,* vol. 87, pp. 1-16, Mar 2017.

[5] R. Jiang *et al.*, "Network operation reliability in a Manhattan-like urban system with adaptive traffic lights," *Transportation Research Part C-Emerging Technologies,* vol. 69, pp. 527-547, Aug 2016.

[6] Metropolitan Transportation Authority. (2017). *New York City Transit - History and Chronology*. http://web.mta.info/nyct/facts/ffhist.htm

[7] D. Rivoli. (2015). *Ancient subway trains on C and J/Z lines won't be replaced until 2022, documents say*. http://www.nydailynews.com/new-york/ancient-subway-trains-won-replaced-2022-article-1.2323289

[8] H. Yin, K. Wang, Y. Qin, Q. Hua, and Q. Jiang, "Reliability analysis of subway vehicles based on the data of operational failures," *EURASIP Journal on Wireless Communications and Networking,* journal article vol. 2017, no. 1, p. 212, Dec. 2017.

[9] Z. G. Li, J. G. Zhou, and B. Y. Liu, "System Reliability Analysis Method Based on Fuzzy Probability," *International Journal of Fuzzy Systems,* vol. 19, no. 6, pp. 1759-1767, Dec. 2017.

[10] A. Z. Afify, G. M. Cordeiro, N. S. Butt, E. M. M. Ortega, and A. K. Suzuki, "A new lifetime model with variable shapes for the hazard rate," *Brazilian Journal of Probability and Statistics,* vol. 31, no. 3, pp. 516-541, Aug 2017.

[11] T. Kamel, A. Limam, and C. Silvani, "Modeling the degradation of old subway galleries using a continuum approach," *Tunnelling and Underground Space Technology,* vol. 48, pp. 77-93, Apr. 2015.

[12] D. Brancherie and A. Ibrahimbegovic, "Novel anisotropic continuum-discrete damage model capable of representing localized failure of massive structures: Part I: theoretical formulation and numerical implementation," *Engineering Computations,* vol. 26, no. 1-2, pp. 100-127, 2009.

[13] R. Tahmasbi and S. Rezaei, "A two-parameter lifetime distribution with decreasing failure rate," *Computational Statistics & Data Analysis,* vol. 52, no. 8, pp. 3889-3901, Apr. 2008.

 ISBN: 978-1-61208-696-5

[14] C. F. Daganzo and N. Geroliminis, "An analytical approximation for the macroscopic fundamental diagram of urban traffic," *Transportation Research Part B-Methodological,* vol. 42, no. 9, pp. 771-781, Nov 2008.
[15] C. Kus, "A new lifetime distribution," *Computational Statistics & Data Analysis,* vol. 51, no. 9, pp. 4497-4509, May 15 2007.
[16] C. D. Lai, M. Xie, and D. N. P. Murthy, "A modified Weibull distribution," *IEEE Transactions on Reliability,* vol. 52, no. 1, pp. 33-37, Mar 2003.
[17] O. O. Aalen and H. K. Gjessing, "Understanding the shape of the hazard rate: A process point of view," *Statistical Science,* vol. 16, no. 1, pp. 1-14, Feb 2001.
[18] S. K. Maurya, A. Kaushik, S. K. Singh, and U. Singh, "A new class of distribution having decreasing, increasing, and bathtub-shaped failure rate," *Communications in Statistics-Theory and Methods,* vol. 46, no. 20, pp. 10359-10372, 2017.
[19] Q. H. Duan and J. R. Liu, "Modelling a Bathtub-Shaped Failure Rate by a Coxian Distribution," *IEEE Transactions on Reliability,* vol. 65, no. 2, pp. 878-885, Jun 2016.
[20] W. J. Roesch, "Using a new bathtub curve to correlate quality and reliability," *Microelectronics Reliability,* vol. 52, no. 12, pp. 2864-2869, Dec 2012.
[21] J. Navarro and P. J. Hernandez, "How to obtain bathtub-shaped failure rate models from normal mixtures," *Probability in the Engineering and Informational Sciences,* vol. 18, no. 4, pp. 511-531, 2004 2004.
[22] S. Rajarshi and M. B. Rajarshi, "Bathtub distributions - a review," *Communications in Statistics-Theory and Methods,* vol. 17, no. 8, pp. 2597-2621, 11988.
[23] M. V. Aarset, "How to identify an bathtub hazard rate," *IEEE Transactions on Reliability,* vol. 36, no. 1, pp. 106-108, Apr. 1987.
[24] K. L. Wong, "The bathtub does not hold water any more," *Quality and Reliability Engineering International,* vol. 4, no. 3, pp. 279-282, 1988.
[25] H. T. Zeng, T. Lan, and Q. M. Chen, "Five and four-parameter lifetime distributions for bathtub-shaped failure rate using Perks mortality equation," *Reliability Engineering & System Safety,* vol. 152, pp. 307-315, Aug 2016.
[26] D. N. P. Murthy and R. Jiang, "Parametric study of sectional models involving two Weibull distributions," *Reliability Engineering & System Safety,* vol. 56, no. 2, pp. 151-159, May 1997.
[27] G. A. Klutke, P. C. Kiessler, and M. A. Wortman, "A critical look at the bathtub curve," *IEEE Transactions on Reliability,* vol. 52, no. 1, pp. 125-129, 2003.

 ISBN: 978-1-61208-696-5