Research Assessment Exercise 2020
Impact Case Study

University: The Education University of Hong Kong
Unit of Assessment (UoA): 11 Mathematics and statistics

Title of case study: Improving safety and efficiency for Hong Kong Mass Transit Railway through advanced statistical models for lifetime prediction

(1) Summary of the impact

Hong Kong Mass Transit Railway Corporation (MTR) spends over HK$ 6 billion on maintaining and renewing rail assets every year to sustain high quality railway service. Advanced statistical modelling by Dr LING Man Ho, which enables engineers and users to better estimate the probability of failure, has caught the attention of the MTR. An applied research that uses his models for predicting failure of bearing systems in its locomotives has being hosted by the MTR. In addition, his works can improve the safety and efficiency of a wide range of products, namely, LEDs, re-chargeable batteries and one-shot devices, and associated economic benefits for industry and society.

(2) Underpinning research

Dr Ling, assistant professor in the Department of Mathematics and Information Technology, has developed a series of statistical models to predict the longevity and failure of products with long operating lifetimes, namely LEDs, re-chargeable batteries and one-shot devices, which underpinned the reliability analyses conducted in the Department.

Many products are designed to function for a long period of time, presenting a challenge for experiments that can accurately demonstrate their life characteristics. Inaccurate lifetime predictions present significant risks to safety, as well as economic losses from inaccurate maintenance and replacement scheduling. Engineers have sought to overcome this challenge by using accelerated life tests that shorten products' lives or hasten the degradation of product performance by incorporating stress factors. Dr Ling applied his reliability models and statistical expertise to the improvement of such predictions, by extrapolating data from accelerated life tests already conducted; making statistical inference on the life characteristics of products; and evaluating the risk for maintenance and replacement scheduling [**See Section 3, R2, R5**].

In research conducted in 2013, Dr Ling considered accelerated degradation models [**R2**] that incorporate various levels of electrical current to model light intensity of LEDs. Subsequently, a two-phase degradation model [**R5**] was developed to model system performance that incorporated physical and chemical changes and provided a more accurate prediction of the failure time of the LED based on its current light intensity. This information based on current system performance could be invaluable for maintenance policies to reduce maintenance cost, while maintaining a high level of product usage availability.

A second series of research, led by Dr Ling between 2009 and 2018, applied the methodology to one-shot devices that cannot be used again after the function is triggered. Without actual lifetime data, estimating the reliability of such devices becomes a greater challenge. Dr Ling developed parametric and semiparametric models to analyse one-shot device testing data from constant-stress accelerated life tests (CSALT) [**R1, R3**]. He used advanced statistical techniques, such as expectation-maximization algorithms, to cope with the models' complexity. Moreover, in investigation of the

model mis-specification analysis, a new statistic was introduced for testing the validity of a fitted model and its estimates [**R4**]. Dr Ling built on this research in 2017 in an investigation of the use of step-stress accelerated life tests (SSALTs) for one-shot devices. The outcomes enabled him to suggest stress levels, inspection times, and sample allocation that could minimize the standard error of an estimate based on data collected from SSALTs. This statistical approach will enhance the efficiency of product testing, because SSALTs require fewer samples and shorter testing durations than CSALT [**R6**].

The above applications reflect the uniqueness of Dr Ling's models, and their potential for a wide range of engineering applications. They have been communicated in reliability engineering journal articles, including key publications of the Institute of Electrical and Electronic Engineers (IEEE) for engineering professionals and academics and research students engaged in product and system reliability disciplines [**Section 4**]. Dr Ling's contribution to the field was recognised in 2017, when he won a Faulty-level Research Prize for his work on one-shot device testing. The awarding panel commented on the high practical value of his model.

(3) References to the research

[R1] Balakrishnan, N., **Ling, M.H.** Gamma lifetimes and one-shot device testing analysis, *Reliability Engineering & System Safety*, **126**, 54-64, 2014. [SNIP: 2.403; SJR: 1.665; number of citations: 23]

[R2] Ling, M.H., Tsui, K.L., Balakrishnan, N. Accelerated degradation analysis for the quality of a system based on the gamma process, *IEEE Transactions on Reliability*, **64**, 463-472, 2015. [SNIP: 1.986; SJR: 1.444; number of citations: 49]

[R3] Ling, M.H., So, H.Y., Balakrishnan, N. Likelihood inference under proportional hazards model for one-shot device testing, *IEEE Transactions on Reliability*, **65**, 446-458, 2016. [SNIP: 1.986; SJR: 1.444; number of citations: 4]

[R4] Ling, M.H., Balakrishnan, N. Model mis-specification analyses of Weibull and Gamma Models based on one-shot device test data, *IEEE Transactions on Reliability*, **66**, 641-650, 2017. [SNIP: 1.986; SJR: 1.444; number of citations: 2]

[R5] Ling, M.H., Ng, H.K.T., Tsui, K.L. Bayesian and likelihood inferences on remaining useful life in two-phase degradation models under gamma process, *Reliability Engineering & System Safety*, **184**, 77-85, 2019.

[R6] Ling, M.H. Optimal design of simple step-stress accelerated life tests for one-shot devices under exponential distributions, *Probability in the Engineering and Informational Sciences*, **33**, 121-135, 2019.

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(4) Details of the impact

Dr Ling's research has had significant impact in reliability engineering, with associated economic and safety benefits. It has had practical use for subsequent applied engineering research and practice. His unique contributions resulted in him being invited in 2016 to join the collaborative Theme-Based Research project, *Safety, Reliability, and Disruption Management of High Speed Rail and Metro Systems*, led by City University of Hong Kong, as a Co-Investigator [**C1**]. This project, which aims to support Hong Kong's development by establishing it as a centre of expertise in the safety, reliability, and efficient management of complex networking systems, is using his modelling in on-going applied research to more accurately predict the failure of ball bearings of Mass Transit Railway Corporation (MTR) trains, working with MTR engineers. This has benefited the MTR to identify the degradation pattern of axle bearing and to establish predictive maintenance regime prior to the axle bearing failure, thus improving the efficiency of its maintenance schedule, with an associated positive economic impact for the MTR, while enhancing the reliability and safety of the network for the 5.8 million passengers using it each week.

MTR Acting Asset Information and Development Manager Dr. CM Zhao affirmed the significance and practical value of Dr Ling's modelling for the MTR's engineering operations [**C2**]: "Dr Ling's ability will be benefit for our development of predictive maintenance in railway engineering. Dr Ling devoted great effort to explore the data pattern for the axle bearing failure study and generated good ideas to classify the degradation condition using his research works, which is particularly innovative for such complex engineering problem…We expect long-term collaboration with Dr Ling to explore the degradation patterns from his critical data insight and establish appropriate mathematical models to estimate the remaining life for the key critical components such as vehicle axle bearing, point detection unit, etc." This involved a significant improvement on the current system. "The traditional method by temperature threshold is always too late to alert the maintenance team to prevent the axle bearing failure. With Dr Ling's expertise in statistical analysis, we have learned the new data exploration methods and tried to employ his statistical models into the other applications."

In addition, Dr Ling's research has had impact on research practice in Hong Kong and other countries, as evidenced three emails [**C3, C4, C5**] from post-graduate students in Hong Kong, Iran and France. They have all showed their interests in Dr Ling's research works on degradation data analysis and one-shot device testing data analysis. Moreover, two requests [**C5, C6**] for Dr Ling's algorithm codes have been received. Mesfin Said wrote: "I would be very grateful if you share me the MATLAB code used for MLE based parameters estimation (scale and shape parameter) so that I will be able to try with my experimental data" **[C5**]. Nadare Matoirichaibati described Ling's paper [R5] as "very excellent" and also requested the code used **[C4]**. Ling shared the codes, which were employed to analyze the doctoral students' own data.

(5) Sources to corroborate the impact

[C1] Safety, Reliability, and Disruption Management of High Speed Rail and Metro Systems Theme-Based Research project http://www.cityu.edu.hk/csie/TBRS/
[C2] Letter, CM ZHAO, Acting Asset Information and Development Manager, MTR Corporation
[C3] Email, Habib CHARCKAZI, Master Student, Ferdowsi University of Mashhad, Iran
[C4] Email, Nadare MATOIRICHAIBATI, PhD Student, Angers University, France
[C5] Email, Mesfin Seid IBRAHIM, PhD Student, The Hong Kong Polytechnic University, Hong Kong
[C6] Email, John MORTON, Veterinary Epidemiological Consultant, Australia