Setting Standards on Remote Monitoring & Diagnostic for lifts – A Singapore Context

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Abstract. The use of Internet of Things (IoT) with remote monitoring capability or Remote Monitoring & Diagnostics (RM&D) to carry out maintenance of lifts has been gathering momentum in recent years. The advantage of this over the traditional time-based maintenance is that it allows continuous tracking of lifts' operating condition for diagnosis of early fault detection, thus preventing unnecessary breakdowns and raising safety, reliability, and productivity levels. Recognising the importance of these benefits, the Building and Construction Authority of Singapore (BCA) had formulated the "Code of Practice for the Design and Performance of Remote Monitoring & Diagnostics Solution for Lifts" which aims to provide guidelines for RM&D solutions to be deployed in Singapore. This paper will first briefly discuss the structure of the code before moving to the 2 key areas of the code: "Monitoring Outcomes" and "Performance Indicators" which aim to provide a framework on the required monitoring areas and the evaluation of the effectiveness of the RM&D solutions respectively. Finally, there will be a brief discussion of the results of a local RM&D trial which was based on the code.

1 INTRODUCTION

In a densely built-up city State like Singapore, lifts are a vital mode of vertical transportation in buildings. Hence, proper and sufficient maintenance is essential to keep this equipment safe and reliable. Today, lifts in Singapore are required to be checked and serviced (where necessary) once every month, by skilled and trained technicians. For compliance, a properly maintained lift must meet the statutory requirements stipulated in the relevant legislation[1].

There are many different types of maintenance strategies used in the lift industry. Some common practices are as follows:

- Corrective maintenance. A category of maintenance carried out only when the lift experiences a breakdown.
- Preventive Maintenance. A maintenance method carried out at regular intervals to reduce the likelihood of premature asset failure. This includes TBM, CBM and PdM.
- Time Based Maintenance (TBM). Maintenance works are carried out at a planned interval. This may be based on manufacturer's recommendation or performed on a regular basis. In Singapore, monthly servicing is required by law.
- Condition Based Maintenance (CBM). This strategy requires condition monitoring and involves fixing the equipment before the conditions start to deteriorate beyond certain thresholds or boundaries.
- Predictive Maintenance (PdM). This maintenance method uses condition monitoring data and forecasts of failures using Artificial Intelligence techniques and repair or replacement will be carried out before the failure happens.

[1] Building Maintenance and Strata Management (Lift, Escalator and Building Maintenance) Regulations 2016

In recent years, Internet of Things (IoT) technology, which is basically the concept of connecting physical devices embedded with sensors, software and other technologies to the internet and having them to communicate and exchange data between themselves and with the cloud network (Oracle, 2022; Amazon Web Services, 2022), has advanced at a rapid pace. This helps to proliferate the use of CBM or PdM in many industries such as aviation, oil & gas, semi-conductor and sectors that involve the use of high capital cost equipment (Lai, et al., 2019). Such IoT enabled maintenance has the following advantages: (i) reduction in unnecessary maintenance leading to increased equipment availability, (ii) greater efficiency for maintenance personnel due to targeted maintenance, (iii) better planning for part replacement, (iv) lowering maintenance cost and (v) increased visibility of asset activities (Janelle, 2018; Lin, et al., 2002).

Given the above benefits, major lift companies such as Schindler, KONE, TK Elevator and Otis have started to roll out their IoT enabled CBM solutions in recent years (Schiller & Falge, 2018; Bourgeat, 2018; Beebe, 2016). At the same time, the Building and Construction Authority (BCA), a government agency in Singapore, is responsible for regulating the safety of lifts and escalators, has identified the use of IoT for lift maintenance as a long-term solution for manpower crunch issues and is encouraging companies to import this technology or develop them for use locally. For the purpose of this paper, we refer to IoT enabled CBM solution as Remote Monitoring & Diagnostics solution or RM&D solution in short.

In 2016, BCA convened the inaugural meeting of International Panel of Experts (IPE) on Lifts & Escalators to seek inputs on key issues relating to lifts and escalators. One of the topics covered was on Remote Monitoring & Diagnostics (RM&D). Following the IPE, BCA started to look in depth into the RM&D technology and how the lift industry could benefit from it. We also embarked on learning trips to countries where RM&D solutions had already been established. Through the process, we identified the lack of standards as one of the challenges in proliferation of RM&D technology. To address this, it is necessary and important for BCA and the local lift industry to set certain minimum requirements to level the playing field and ensure that it is effective. This then led to the publication of a code in August 2022 for the development and usage of RM&D solutions in Singapore's lift industry, which is the "Code of Practice for the Design and Performance of Remote Monitoring & Diagnostics Solution for Lifts"[2]. For this paper, we will first discuss the structure of the code before moving to describe the system architecture of an acceptable RM&D solutions. In this same section, we will also focus on 2 key areas of the code: "Monitoring Outcomes" and "Performance Indicators" which aim to provide a framework on the required monitoring areas and the evaluation of the effectiveness of the RM&D solutions respectively. Finally, there will be a brief discussion of the results of a local RM&D trial which was based on the code.

2 STRUCTURE OF THE CODE

The structure of the code is similar to lift related standards such as EN81-20/50 and Singapore standards SS 550. Like these standards, the code on use of RM&D solutions in lifts starts with the scope as well as key definitions that are extensively mentioned in the subsequent clauses. Following this, the code will then define the minimum requirements for lifts connected to RM&D solutions vis-à-vis the following sections: (i) System Architecture (ii) Data

[2] The code of practice can be downloaded from the URL: https://www1.bca.gov.sg/docs/default-source/docs-corp-regulatory/lifts-and-escalators-legislation/code-of-practice-for-design-and-performance-of-remote-monitoring-and-diagnostics-solution-for-lifts-(final).pdf?sfvrsn=cf5164cb_0

Visualisation (iii) Remote Testing, Intervention and Control and (iv) Cyber Security Requirements. At the end of the code, there are informative annexes on the Performance Indicators and Technical and Non-Technical Faults.

3 SYSTEM ARCHITECTURE

A review of available literature shows that there are no standards related to RM&D for lifts. However, there have been extensive research carried out on the theory, methodology and application of CBM. To define the system architecture, these were studied and references from available CBM standards such as ISO 17359, Condition monitoring and diagnostics of machines - General guidelines were used. ISO 17359 outlines the condition monitoring procedure for a general manufacturing process, factors influencing condition monitoring, a list of issues affecting equipment criticality (e.g., cost of machine down-time, replacement cost), and a table of condition monitoring parameters (such as temperature, pressure, and vibration) for various machine types. ISO 17359 also presents multiple examples of tables showing the correlation of possible faults (e.g., air inlet blockage, seal leakage, and unbalance) with symptoms or parameter changes. Furthermore, ISO 17359 shows an example of a typical form for recording monitoring information. The basis is that such system developed for CBM should be similar as after all, lifts are also electro-mechanical systems. The result is that we will require the system architecture to consist of the following combinations:

a) Data Acquisition
b) Data Pre-processing
c) Data Analytics

4 DATA ACQUISITION

Just like any other CBM system, the first step in the RM&D solutions is the data acquisition process. Conditioning monitoring data which can either be in the form of information from the lift controller such as fault signals and error codes or sensors data are acceptable. In this code, we did not attempt to define the list of conditioning parameters because there are several methods to obtain monitoring data and technologies may progress eventually and as such it would not be ideal to prescribe the specific monitoring points. From a regulatory and safety perspective, our approach would be to focus on defining the desired outcomes to be achieved by the RM&D solutions (this will be covered in more details in the monitoring outcomes later).

5 DATA PRE-PROCESSING

With a large amount of data being collected from the lifts, we learnt that there may be a need to pre-process the data before transmission to the cloud server to minimise the load on the network bandwidth. An example would be in the form of edge computing. That is to perform preliminary analysis on the data collected, segregating them based on the criticality of information and only transmit the data to the cloud that require urgent attention. It is included as a recommendation in the code because this is a desirable feature for the RM&D solutions.

6 DATA ANALYTICS

This is the most important step in the RM&D solutions where condition monitoring data are passed over to the central server i.e. cloud for analytics purposes. There are various models or techniques available to detect anomalies during the lift operations as well as to predict potential failures and future breakdowns of the lift. For example, model-based approach (construction of accurate model of the lift system) and/or data driven approach (use of artificial intelligence or machine learning algorithms) can be used to estimate the remaining useful life of the system or component before a fault or failure happens (Tung & Yang, 2009; Eisinger, 2021). However, for the code's purposes, we felt there was no need to specify the type of analytics approach that are acceptable. Instead, we choose to specify the "monitoring outcomes" or the desired outcomes that ought to be fulfilled by the RM&D solutions.

6.1 Monitoring Outcomes

In deriving these outcomes to be achieved by the RM&D solutions, a Failure Mode and Effects Analysis (FMEA) is being used. FMEA is a methodology used at design stage to analyse the possible points of failure in a system, product or process and the impact of that failure. This method is suitable because the same reasoning used for identification of component or system failures at design can also be applied similarly for the downstream RM&D solutions since they are designed to diagnose lift issues and prevent lift breakdowns before they occur.

The first step of the design FMEA is to identify the "item" which is the subsystem or component. The list of principal components or subsystems are generated using various references and our understanding of lift technology (The Chartered Institute of Building Services Engineers, 2020; Andrew & Kaczmarczyk, 2011; Janovsky, 2017). Next, we then list down the function, failure mode and the effect of the failure on the user or system. Failure occurrence and detection were excluded from the FMEA matrix. The former was due to the lack of comprehensive data for all the subsystem or component. Furthermore, the failure probability is also dependent on many variables such as environment, material use, usage and design. The latter is not meaningful as the purpose of RM&D solutions is to help in enhancing failure detection. Thus, the focus of the FMEA will be primarily on the severity of the failure if it occurs. Items high on the severity index should be monitored and diagnosed. Once these are done, we then rank each failure mode, based on the criteria from a severity level as shown in Table 1. In this FMEA, we not only consider the safety aspect, but also consider operational reliability when deciding the severity. For example, it is a well-established fact that doors are often the biggest contributor to lift breakdown. 30% or more of the breakdowns in a lift are due to door issues (Park & Yang, 2010). Therefore, the door systems are assigned a score that is high on the scale. Table *2* shows the severity level used for this FMEA.

After the severity values are assigned, we then apply a cut off level of 5 to decide the items for the monitoring outcomes. The final list of monitoring outcomes can be found in

*Table **3***.

Another requirement of the data analytic section is to necessitate the provision of output of the data analysis. System recommendations need to be provided to maintenance personnel to carry out part replacement, repair, or maintenance on the lift before a breakdown occurs. They can either be immediate in nature if breakdown or fault is imminent or scheduled to be carried out in the coming days or during the next planned maintenance for issues that are less critical. This will help to provide maintenance companies with greater operational flexibility and better optimisation of their manpower deployment.

Last but not least, the requirement to provide feedback into the IoT platform to improve the accuracies of the data analytics model is also included because this is an important feature to help the RM&D solutions to refine the accuracy of future diagnostics and be increasingly effective in the long run.

7 DATA VISUALISATION

The code also included the requirements for data visualisation platform to be included as part of the RM&D services. The rationale for this is transparency – by having information on the performance and status of the assets readily available to the lift owners. This could be done via a web-based interface and/or mobile application which helps to provide the flexibility and accessibility for lift owners to have a better overview of the equipment status. There is also a list of specifications recommended to be included in the data visualisation such as lift manufacturer, lift speed, rated capacity etc.

8 REMOTE INTERVENTION AND CYBERSECURITY

At the end of the code, we included two sections on remote intervention and cybersecurity. The first is because we are aware that there are systems out there which are capable of remote intervention to minimize mantraps and reduce rescue duration. This is not specifically prohibited as long as such function does not interfere with the safety of the lift nor compromise the safety of the users who are using the lifts. The section on cybersecurity was written with the intent to address the vulnerability of RM&D to cyberattacks and compromising the safety of the lifts. While we understand that there are number of cybersecurity standards around, ISA/IEC 62443 (Industrial network and system security) is the most applicable for RM&D solutions. Also, a new cybersecurity standard for lifts and escalators, ISO 8102-20 (Electrical requirements for lifts, escalators and moving walks – Part 20: Cybersecurity) is currently under development and takes reference from the IEC 62443. Hence, it is more than appropriate for RM&D solutions to meet IEC 62443 for cybersecurity standards in the interim and eventually to follow ISO 8102 once it is released.

Table 1: FMEA of Monitoring Outcomes of RM&D Solutions

S/N	Item	Function	Failure Mode	Effect	Severity	Critical for RM&D solutions
1	Traction Machine	Provide power to move the lift car up and down the shaft.	Overheating, bearing fault or short circuit etc leading to functional loss	Lift cannot move - breakdown	7	Yes

2	Brakes	Electro-mechanical devices capable of stopping the lift car when required.	Malfunctioning due restriction in movement or failure to engage	Injuries, or death due to overspeed of lift car	9	Yes
3	Controller	The brain of the lift system necessary to control and monitor the operation of lift.	Printed Circuit failure, loose connection, short circuit etc	Lift cannot move - breakdown	7	Yes
4	Suspension Ropes	Wire rope used to raise and lower the lift car	Wire rope breakage	Plunging of lift car	9	Yes
5	Car	Part of the lift that carries the users and/or other loads	Dents or damages caused by objects hitting the wall	Loss of aesthetics appeal	3	No
6	Alarm Bell	A device used for calling of attention and assistance	Loose connection or speaker failure	Unable to call for help when required	2	No
7	Intercom	A device used for communication between the user in the car and maintenance personnel	Loose connection, microphone and speaker failure	Unable to communicate with rescue team when required	2	No
8	Car and Landing Door	A means for users to enter and exit the lift car when the lift car is at the landings and protect users from entering the lift shaft when lift car is not at the landings	• Interlock failure – car move while doors are open • Dents or damage to door panels	• Injury or death due to crushing of passengers or falling of users into the lift shaft • Breakdown	9	Yes
9	Overspeed Governor System	Safety device to stop the lift car in the event of descending car or when the lift exceeds a predetermined speed	• Excessive Elongation of ropes • Malfunctioning of governor mechanism	Fail to hold the governor rope to trigger the safety gear	9	Yes
10	Guide System (guide rails, guide shoes and roller guides)	Help the lift car to maintain its travel in the vertical direction. Affects ride quality as well.	Wear and tear of the guide system	Affect ride quality	7	Yes
11	Safety Gear	Safety device used to grip the guide rail in the event of uncontrolled descent of the car due to breakage of suspension ropes	Malfunctioning of governor mechanism	Plunging of lift car	9	Yes
12	Signal Fixtures (buttons and indicators)	Used for the hall and car calling purpose and indication of the lift position.	Malfunction caused by vandalism or overuse	Inconvenience to the users	3	No

13	Levelling Devices	To move the lift car, when it is the door zone, at a reduced speed and eventually stop at the landing	Misaligned levelling devices, malfunction levelling switches etc	Mis-levelling of lift car at landings leading to trips and fall	7	Yes
14	Buffers	Resilient stop at the end of travel, and comprising a means of braking	Oil leakage, aging polyurethane buffer, cracked or corroded spring	Fail to arrest the free fall of the lift car in the event it happens	7	Yes
15	Travelling Cable	To provide electrical connection to lift car	Loose connection or cable breakage	No power in the lift car, inconvenience to users	3	No
16	Compensation system	To reduce power requirement for the traction machine and ensuring sufficient traction	Compensation chain/wire rope breakage	Increased power requirement and affects traction	6	Yes
17	Emergency backup power supply	To provide backup power to the lift system in the event of power supply	Batteries failure	No power for the lift system during power failure, inconvenience to users	2	No

Table 2: Severity Scale for FMEA

Severity of Effect	
10	May result in safety issue or regulatory violation without warning
9	May result in safety issue or regulatory violation with warning
8	Primary function is lost or seriously degraded
7	Primary function is reduced and customer is impacted
6	Secondary function is lost or seriously degraded
5	Secondary function is reduced and customer is impacted
4	Loss of function or appearance such that most customers would return product or stop using service
3	Loss of function or appearance that is noticed by customers but would not result in a return or loss of service
2	Loss of function or appearance that is unlikely to be noticed by customers and would not result in a return or loss of service
1	Little to no impact

Table 3: List of Monitoring Outcomes

Lift system and their sub-system	Monitoring Outcomes
1. Traction Machine	Provide recommendation on possible rectification works for the traction machine and indicate when they are required.
2. Brakes	Provide recommendation on possible rectification works for the brakes and indicate when they are required.
3. Suspension Means	Provide recommendations on possible rectification works for the suspension means and indicate when they are required.
4. Guide system (i.e. guide rail and guide shoes or rollers)	Provide recommendations on the possible rectifications for the guide system and indicate when they are required.
5. Car and Landing Doors (including door protective devices)	Provide recommendations on possible rectification works for the car and/or landing door system and indicate when they are required.
6. Levelling Devices	Provide recommendations on possible rectification works for potential occurrences and instances of mis-levelling and indicate when they are required.
7. Fault Diagnosis including the following components: a) Overspeed Governor b) Safety Gear c) Controller and Inverter Drive d) Buffer e) Compensation System	Indicate if one or more of the following fault(s) is/are possible cause(s) for the stoppage of the lift: • Overspeed Governor Activation • Safety Gear Activation • Controller and Inverter Drive Failure • Buffer Activation • Compensation System Activation • Ascending Car Overspeed Protection Activation • Unintended Car Movement Protection Activation • Fire Emergency • Power Failure

9 PERFORMANCE INDICATORS

In the Annex of the code, we define the performance indicators to evaluate the effectiveness of the RM&D solutions. There are a total of seven performance indicators as shown in Table 4. These indicators aim to objectively measure the performance of the RM&D solutions in 2 main areas: the performance of the lift as well as productivity indicators and to provide a harmonized method of evaluating across the different types of RM&D solutions in the market. We will look at some of these indicators in detail.

9.1 Average Uptime

Common to all industrial systems and processes, the availability of the equipment is a key indicator of reliability. Any equipment downtime would result in loss of production and all operators would like to maximise the uptime of their equipment. Therefore, availability is a factor of MTBF, also known as mean time between failures, and MTTR, or mean time to repair (Torell & Avelar, 2004). As mentioned earlier, one advantage of having RM&D is proactive maintenance resulting in greater equipment availability. Therefore, the average uptime of the lift provides an indication of the effectiveness of the RM&D solutions. At this juncture, we would like to highlight that the uptime formula is calculated without the inclusion of planned maintenance downtime. There are two reasons for this. Firstly, such maintenance is usually performed when the lift is not required to be functional. Secondly, maintenance contractors would be discouraged to carry out pre-emptive maintenance if this time is included in determining the performance of the RM&D.

9.2 Diagnostics Accuracy

A confusion matrix consisting of parameters such as true positives, false negatives, false positives and true negatives is often used to evaluate the effectiveness of the analytics engine. There are inherent difficulties in determining whether a positive prediction is true or false. Unless the predicted fault is not rectified and left for it to manifest, it will be difficult to confirm if the positive prediction is indeed true or false. Hence, we focus only on recommendation as a mean of assessing if the RM&D solutions are accurate in its prediction. A true intervention case is where the RM&D solutions recommend a visit to the lift location and the prediction matches the fault or failure on site.

Table 4: List of Performance Indicators

S/N	Indicators	Formula
1	Technical Fault per Equipment (TFE)	$\frac{\text{Total Number of Technical Faults}^{3}}{\text{Total Number of Equipment}}$
2	Fault per Equipment (FPE)	$\frac{\text{Total Number of Faults}^{4}}{\text{Total Number of Equipment}}$
3	First Time Fix Rate (FTFR)[5]	$1 - \frac{\text{Total Number of the Repeated Technical Faults}}{\text{Total Number of Technical Failures}}$
4	Mean Time To Repair (MTTR)[6]	$\frac{\text{Total Downtime of Technical Faults}^{7}}{\text{Total Number of Technical Faults}}$
5	Average Monthly Uptime (UT)	$\frac{\text{Maximum Possible Running Hours - Total Downtime of Technical Faults}}{\text{Maximum Possible Running Hours}^{8}}$
6	Diagnostics Accuracy (DiA)	$\frac{\text{Total Number of Intervention Cases marked as True (T)}^{9}}{\text{Total Number of Intervention Cases}^{10}}$
7	RM&D Device Availability	$\frac{\text{Total Number of RM\&D Units That Are Online}}{\text{Total Number of RM\&D Units}}$

[3] A list of technical faults is given in Annex A
[4] Faults is sum of technical faults and non-technical faults. A list of non-technical faults is given in Annex A.
[5] Technical failures that happen within the next 30 days after they have been rectified are to be considered for the calculations.
[6] MTTR exclude the following: (1) major repair/overhaul that takes more than 1 day (refer to the list of exclusion cases in Annex B; (2) waiting time for spare parts arrival; and (3) additional time needed to do hot-testing.
[7] Total downtime of technical faults is the sum of all time spent to rectify all technical faults in hours.
[8] Maximum possible running hours is the number of days in the month multiplied by 24 hours for each lift.
[9] A True (T) Intervention Case is when the RM&D prediction matches diagnosis/faulty component on site.
[10] Intervention cases are defined as cases prompted by RM&D solutions whereby a visit to lift by maintenance personnel is required.

10 TRIALS

These trials were conducted on 174 lifts with RM&D solutions from lift manufacturers European OEMs and sensors based IoT solution providers (3rd party solution providers). The lifts were located across Singapore, and they cover offices and light industrial use.

The focus of the trials would be on the proof of concept of the RM&D solution. The solution would be tested on whether lift faults can be accurately picked up, diagnosed and predicted under a monthly maintenance regime. It also aims to provide the technician an opportunity to be familiar with the technology and its usage. One example would be for the technicians to provide feedback on system-generated diagnostics which would help close the machine learning loop and refine the accuracy of future diagnostics. This is particularly important for 3rd party solution providers because an effective feedback loop between the 3rd party solution provider and the maintenance company is essential to improve the accuracy of fault predictions. This phase therefore also allows the owner to understand the dynamics of this relationship and learn how to manage the coordination effectively in the future.

The results have been promising so far. We have also seen improvements in some of the indicators. For example, there was an improvement of about 2% for the Average Monthly Uptime and decrease in Failure per Equipment from a value of 0.2. Details of the results of the performance indicators can be found in Table 5.

Table 5: Results from Local Trials

Performance Indicators (per lift/month)	**Values**
Average Monthly Uptime (UT)	99.5~99.7%
Faults per Equipment (FPE)	0.06~0.09
Technical Faults per Equipment (TFPE)	0.05~0.08
First Time Fix Rate (FTTR)	89~93 %
Mean Time to Repair (MTTR)	16 ~19%
Diagnostics Accuracy (DiA)	85~94%
RM&D Device Availability	96~99%

11 MOVING FORWARD

The trials have provided validation on the improvements in lift performance and safety with assessment based on the code. Further trials would have to be conducted with the use of the code to gain more insights into the impact of RM&D solutions with reduced maintenance frequency (once every 3 months or more) on the performance and safety of lifts.

12 CONCLUSIONS

In this paper, we briefly describe the code of practice for RM&D solutions developed for usage in Singapore and some of their considerations. The code covers the following key areas: (i) Data Acquisition (ii) Data Pre-processing (iii) Data Analytics (iv) Data Visualisation (v) Remote Intervention and (vi) Cybersecurity. For data acquisition, there is no specified list of monitoring parameters. Instead, we introduce the concept of monitoring outcomes which aims to define the desired outcomes to be achieved by any RM&D solutions. There is also a growing concern with such system on whether cyberattacks may compromise safety of the lift and users Therefore, the code has a section on remote intervention and cybersecurity.

At the end of the code, an informative annex on performance indicators is provided. A total of 7 performance indicators is listed down which aims to allow us to evaluate the effectiveness of various RM&D solutions in the market. Using them, we can quantify the outcome of local trials of RM&D solutions in Singapore and based on these indicators, we assess those RM&D solutions have been effective so far. This will provide us further confidence to continue to pursue the CBM and PdM approach with the use of RM&D solutions to achieve a more productive workforce.

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ANNEX A – LIST OF TECHNICAL FAULTS AND NON-TECHNICAL FAULTS

S/N	**Technical Faults**	**Non-Technical Faults**
1	Motor [Thermal/Voltage/Current]	Noise
2	Machine brake [Brake Switch]	Display Indicators/LCD
3	Electrical Components [Switches/Contactors/Relays/PCBs]	Faulty buttons [Car/Landing]
4	Main Drive Unit/Frequency Inverter	Card reader
5	Landing Doors	External Element Blocking Doors [Object/Human]
6	Car Door	Car Interior [False Ceiling/Cladding]
7	Buffers	Fire Homing/Power Failure Mode
8	Speed Control System [Shaft/Motor Encoder]	Natural Disaster/Incident leading to component failure [Water ingress]
9	Overspeed Governor & Governor Rope	Oil Pots Leakage
10	Levelling Accuracy	
11	ACOP/UCMP/Rope gripper	
12	Batteries Failures [ARD/EBOPS]	
13	Suspension Ropes	
14	Bearings Worn-out	
15	Load Measuring Devices [Overload Signal]	
16	Compensation Devices [Chain/Rope] –	

ANNEX B – LIST OF EXCLUSION

S/N	Examples of Special Events (non-exhaustive)
1	Hoisting motor replacement/repair
2	Ropes replacement
3	Main/Diverting sheave replacement/repair
4	Major lift components, e.g. governor, safety gear
5	Total failure of Frequency Inverter
6	Water ingress situation
7	Building power failure

BIOGRAPHICAL DETAILS

Mr Hashim Bin Mansoor is the Director of Engineering and Technology Department (ETD), Building and Construction Authority (BCA), Singapore. He is a professional engineer in mechanical engineering and Specialist Professional Engineer in the fields of lift & escalator. As the Director of Engineering and Technology Department, he is responsible in looking at innovations and digital improvements that can be made to further improve the safety and reliability of lifts and escalators.

Mr Justin Tai is currently the Director of Regulation and Process Transformation Department (RPTD) at BCA, which has regulatory oversight of amusement rides, lifts, and escalators. His professional experience includes performing design reviews and conducting investigations involving amusement rides, lifts, and escalators as well as contributing to the education and safety committees on vertical transportation in Singapore.

Mr Yao Hui Chee is currently a Senior Engineer in ETD at BCA with about 10 years of experience in lift and escalator. Beside actively involving himself in inspections and investigations of lifts, escalators and amusement rides in Singapore, he also represents BCA as a member of the Working Group on Lifts, Escalator and Passenger Conveyors, which is involved in regular review of the prevailing standards for lifts and escalators. He is currently pursuing an MSc in Lift Engineering with University of Northampton and is in the final year of his studies.

Mr Kenneth Ong is currently a Senior Engineer in ETD at BCA. His experience includes performing design reviews, inspections and investigations involving lifts, escalators and amusement rides in Singapore. He was working in the oil and gas industry for 13 years before joining BCA 2 years ago.

Mr Yih Perng Khoo is an Executive Engineer in Investigation and Enforcement Department (InED) at BCA. During his three years tenure in BCA, he performed regulatory works, design reviews, inspections and investigations involving amusement rides, lifts, and escalators. Prior to joining BCA, he was in the rail transport industry for 2 years.

Ms Jody Tan is a Senior Engineer in InED at BCA and has been in the L&E industry since year 1997. She evaluates and reviews design and conformance to safety standards of lift, escalator, and amusement ride in Singapore. She participates in incident investigation that involves lift, escalator, and amusement ride in Singapore.

Mr Andy Goh is currently an Executive Engineer with BCA, which regulates the amusement rides, lifts, and escalators in Singapore. His professional experience includes conducting incident investigations & inspections for lifts and escalators. He is actively involved in the development of lifts' Remote Monitoring & Diagnostics (RM&D) scene in Singapore.