

Identifying KPIs for Lift Maintenance Performance Evaluation

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Introduction

- A collaborative research project, titled “Establishment of Standard KPIs for Evaluation of Lift Maintenance Performance in Hong Kong”
- Jointly undertaken by the Building Services Operation and Maintenance Executives Society (BSOMES) and the Hong Kong Polytechnic University (PolyU)
- The project comprises **two parts**:
 - Part A (Stages 1 to 3)
 - Part B (Stages 4 to 5)

Introduction

- Aim
 - To develop standard key performance indicators (**KPIs**) for evaluation of **lift maintenance performance** in Hong Kong.
- Objectives
 1. To review and identify any **overseas or local KPIs** applicable to lift maintenance performance evaluation in Hong Kong.
 2. To **reveal the current practices** of lift maintenance performance evaluation in Hong Kong.
 3. To derive **KPIs tailored** for evaluation of lift maintenance performance in Hong Kong.
 4. To **shortlist KPIs** for evaluation of lift maintenance performance in Hong Kong.
 5. To **validate the applicability** of the shortlisted KPIs.

Part A

Stage 1: Literature review

- In **preparing the proposal** for this Study, a **search of publications** in the public domain has provided some reference materials.
- Upon official commencement of this Study, a further, comprehensive search and review of **relevant literature** was conducted.
- This review identified **KPIs applicable to lift maintenance performance evaluation in Hong Kong**.

Stage 1: Literature review

- Examples of such KPIs include (not limited to):
 - Maintenance downtime
 - Maintenance response time
 - Maintenance repair time
 - Availability
 - Passenger trap release time
 - Emergency call response time
 - Outsourced maintenance cost
 - In-house maintenance cost
 - Total maintenance cost
 - Number of statutory orders
 - Compliance percentage of statutory orders
- More KPIs were identified through the literature review.

Stage 2: Definition and derivation of KPIs

- For each of the KPIs obtained in the preceding stage, the corresponding **representation was defined**.
- Then, how each of the KPIs can be derived was worked out by devising an **appropriate formula**.
- To illustrate how such formulas can be used to derive the KPIs, **example data will be processed** and the **calculation results** of the KPIs will be obtained in the later stages.

Stage 3: Focus group study

- The focus group meeting was intended for participation **by lift maintenance professionals** (e.g. committee members of BSOMES).
- The meeting participants were given the **questionnaire** and facilitated by the convenor (i.e. the project team) to **exchange their views and experiences** on various aspects, such as:
 - **types of lift maintenance data logged**
 - **method used to log the data**
 - **how the logged data are retrieved for lift maintenance performance evaluation**

Stage 3: Focus group study

(continued)

- how useful are the performance evaluation results
 - any problem with the existing way of lift maintenance performance evaluation
 - any suggestion for improvements
-
- In this meeting, the **applicability of the identified KPIs** in real-world buildings in Hong Kong was discussed.



Stage 3: Focus group study

- In particular, **factors that may affect the definition and derivation** of the KPIs, such as the following, were considered and discussed:
 - different building types
 - different building grades
 - different lift types
 - different lift capacities
 - different lift operation days (e.g. weekdays, holidays)
 - different lift operation periods (e.g. up peak, down peak)
- **Deliberation** at the focus group meeting took the above factors into account → a **list of KPIs were identified**

Findings

Literature review

- Relevant publications were searched from four literature databases, namely, [Web of Science](#), [Scopus](#), [ScienceDirect](#) and [Emerald](#).
- In the first round of literature search, keywords including “[lift](#)”, “[escalator](#)”, “[elevator](#)”, “[maintenance](#)”, “[KPI](#)” and “[Performance indicator](#)” were used in combinations.
- A summary of the search results is shown in [Table 1](#), and a sample screenshot taken during the search process is shown in [Figure 1](#).

Literature review

Database	Search Results								
	lift + maintenance	escalator + maintenance	elevator + maintenance	lift + KPI	escalator + KPI	elevator + KPI	lift + performance indicator	escalator + performance indicator	elevator + performance indicator
Web of Science	908	33	161	4	0	1	6	0	2
Scopus	1274	99	440	38	0	1	78	1	13
ScienceDirect	220	1	21	2	0	0	11	0	4
Emerald	> 2000	207	659	83	12	23	557	49	126
Total Nos.	> 4402	340	1281	127	12	25	649	50	145

Table 1: First round of literature search results

Literature review

Web of Science™ Search Marked List History Alerts Sign In Register

Advanced Search > Results > Results > Results > Results > Results > Results > Results

908 results from Web of Science Core Collection for:

TS=(lift) AND TS=(maintenance) Analyze Results Citation Report Create Alert

Copy query link | Timespan: 2000-01-01 to 2021-10-31 (Publication Date)

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1 Human Factors Lead to Lift Accidents in High-Rise Residential Buildings
Tahari, MHA; Akasah, ZA and Nagapan, S
AWAM International Conference on Civil Engineering (AICCE)
2020 | PROCEEDINGS OF AICCE'19: TRANSFORMING THE NATION FOR A SUSTAINABLE TOMORROW 53 , pp.1139-1149 32 References

Lifts widely used as vertical transportation in high-rise buildings. Lift accident cases are increasing every year, giving a negative impact to building occupants in terms of their confidence in using lift system. To uncover the key lift accident factors, this paper identifies various human factors of lift system acc ... Show more

PolyU eLinks Full Text at Publisher Related records

Figure 1: Sample screenshot of first round of literature search

Literature review

- Over 5000 publications were identified from the first round of literature search; after screening, most of them were found to be peripheral to the context of the Study.
- Then, a second round of literature search was done using three groups of keywords, as shown in the Table 2.

Group 1	Group 2	Group 3
<ul style="list-style-type: none"> ● Lift ● Elevator ● Escalator 	<ul style="list-style-type: none"> ● Maintenance 	<ul style="list-style-type: none"> ● KPI ● Key performance indicator ● Performance indicator ● Performance index ● Performance score

Table 2: Keyword groups used in second round of literature search

Literature review

- Similar to the first round, the **second round** of literature search was made on the **four literature databases**, i.e., Web of Science, Scopus, ScienceDirect and Emerald, with the **three groups of keywords** used in combinations. The search results are summarized in **Table 3**.

Database	Search Results				
	Lift + Maintenance +				
	KPI	Key performance indicator	Performance indicator	Performance index	Performance score
Web of Science	0	0	0	0	0
Scopus	4	4	7	0	0
ScienceDirect	0	0	0	0	0
Emerald	34	95	185	18	16
Total	38	99	192	18	16

Table 3: Second round of literature search results

Literature review

Database	Search Results				
	Elevator + Maintenance +				
	KPI	Key performance indicator	Performance indicator	Performance index	Performance score
Web of Science	1	0	0	0	0
Scopus	1	1	1	0	0
ScienceDirect	0	0	0	0	0
Emerald	12	37	62	13	4
Total	14	38	63	13	4

Table 3: Second round of literature search results (continued)

Literature review

Database	Search Results				
	Escalator + Maintenance +				
	KPI	Key performance indicator	Performance indicator	Performance index	Performance score
Web of Science	0	0	0	0	0
Scopus	0	0	0	0	0
ScienceDirect	0	0	0	0	0
Emerald	8	18	27	3	2
Total	8	18	27	3	2

Table 3: Second round of literature search results (continued)

Literature review

- In the **second round** of literature search, around **500 publications** were found.
- After screening those publications, the following were found to be **of particular relevance** to KPIs for lift maintenance:
 - Elyna Myeda, N., Nizam Kamaruzzaman, S. and Pitt, M. (2011), "Measuring the performance of office buildings maintenance management in Malaysia", Journal of Facilities Management, Vol. 9 No. 3, pp. 181-199.
 - Lai, J.H.K. and Man, C.S. (2018), "Performance indicators for facilities operation and maintenance (Part 2): Shortlisting through a focus group study", Facilities, Vol. 36 No. 9/10, pp. 495-509

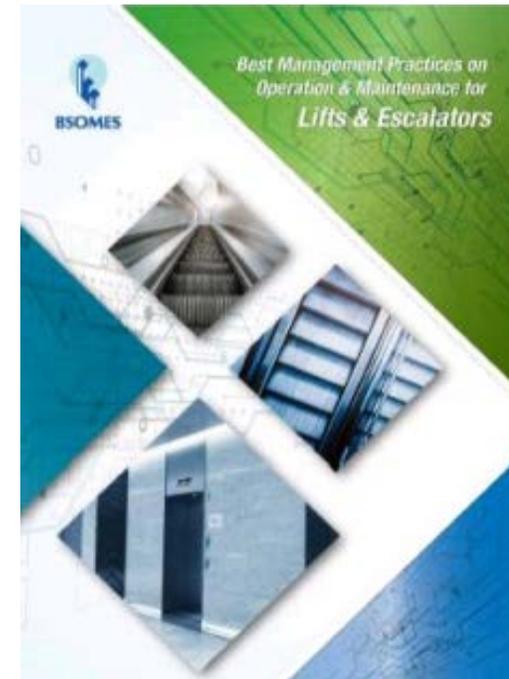
Literature review

(continued)

- Lai, J.H.K. and Yik, F.W.H. (2008), "Benchmarking operation and maintenance costs of luxury hotels", *Journal of Facilities Management*, Vol. 6 No. 4, pp. 279-289.
- Lai, J. and Yuen, P.L. (2021), "Identification, classification and shortlisting of performance indicators for hospital facilities management", *Facilities*, Vol. 39 No. 1/2, pp. 4-18.
- Zubair, M.U. and Zhang, X. (2020), "Hybrid Performance-Measurement Model of Elevators", *Journal of Performance of Constructed Facilities*, Volume 34, Issue 2

Literature review

- To **further identify** if there are suitable performance indicators in the local lift industry, **guidelines of professional bodies** (e.g. BSOMES) and **government websites** (e.g. EMSD) were searched and reviewed. Consequently, additional performance indicators were found.
- From the “**Best Management Practices on Operation & Maintenance for Lifts & Escalators**” (BSOMES, 2019), the following indicators are suggested for representing the quality and safety performance of lift maintenance services:



Literature review

- **Reliability** – Low rate of lift breakdowns, e.g. percentage of breakdown time, calculated as the breakdown hours divided by operational hours. (The period of planned maintenance or breakdown due to other external factors should be excluded in the calculation)
- **Safety** – No passengers injured during lift operation
- **Safety** – Lifts operated safely and reliably
- **Response** – Attendance of service calls for lift failures, i.e. passengers trapped, within 30 minutes
- **Response** – Attendance of service calls for lift failures i.e. no passengers trapped, within 60 minutes

Literature review

(continued)

- **Response** – Registered Contractor (RC) responded to enquiries from owners or management companies in a timely manner
- **Response** – RC submitted maintenance reports as required on time
(Any time)
- **Comfort** – No complaints about lift performance
- **Comfort** – RC is cooperative and understands the client's needs
- **Technical Support** – Spare parts or components can be delivered to the correct properties within the specified hours (e.g. 8 hours)

Literature review

- According to [BSOMES \(2019\)](#), KPIs are a quantitative measurement on contractor and equipment performance. The management offices of buildings can set up a yardstick objectively and grant the incentive to the RC. A list of recommended KPIs for breakdown or emergency calls are shown in [Table 4](#).

Key performance indicators	Description
Number of equipment failures	<p>Denotes the inability of a piece of equipment to perform its required function under specified conditions. Failures found during preventive maintenance are to be excluded from the calculation of performance measures.</p> $\frac{\text{Total number of failures per month}}{\text{Total number of lifts}}$

Table 4: KPIs for breakdown or emergency calls

Literature review

Key performance indicators	Description
Availability	<p>The probability that a piece of equipment is in an operable state at any random point in time when used under stated conditions.</p> $\frac{A - \sum \text{Service Down Time}}{A} \times 100\%$ <p>A = Total Scheduled Operating Time, excluding PM downtime</p>
Response time	<p>The time that elapses between the reporting of a fault and the RC arriving at where the faulty equipment is located.</p> $\frac{\text{No. of attendance met response time requirement}}{\text{Total number of Emergency Call-Outs}} \times 100\%$

Table 4: KPIs for breakdown or emergency calls (continued)

Literature review

Key performance indicators	Description
Service recovery time	<p>The time that elapses between the reporting of a fault and the affected equipment regaining its ability to perform all of its required functions.</p> <p>Service recovery time = (Maintenance Services Sign Off time – Fault reported time)</p> $\text{Mean service recovery time} = \frac{\sum(\textit{Service recovery time})}{\textit{Total number of failures}}$
Number of complaints	Used to measure the user satisfaction with the service provided by the RC

Table 4: KPIs for breakdown or emergency calls (continued)

Literature review

- **BSOMES (2019)** further recommends that the calculation of KPIs shall only count for **equipment breakdown**. Breakdown arising from malicious acts or caused by **external factors** (e.g. vandalism, misuse, water drenching or planned repair or maintenance, etc.) or any other events beyond the control of RC are excluded.
- Besides, the **classifications for lifts** shown in **Table 5** were found from the **EMSD's website** (EMSD, 2021a). While these classifications were used for maintenance contract pricing, they may be of reference value when setting lift KPIs in a later stage of this Study.

Literature review

Lift travel level	Rated speed of lift
1 to 15	$\leq 1.5\text{m/s}$
	$> 1.5\text{m/s}$
16 to 25	$\leq 2.0\text{m/s}$
	$> 2.0\text{m/s}$
26 to 35	$\leq 3.0\text{m/s}$
	$> 3.0\text{m/s}$
More than 35	$\leq 3.5\text{m/s}$
	$> 3.5\text{m/s}$

Table 5: Classification of lifts in private commercial buildings

Literature review

- An inspection on a **sample lift log book** found that the following lift **performance data** should be available from a properly-kept lift log book:
 - **Call Received by Contractor** (Date / Time)
 - **Contractor's Representative Arrived at Site** (Date / Time)
 - **Passenger Released** (Date / Time)
 - **Service Resumed** (Date / Time)

Literature review

- The sample log book also shows that there are **different types of work/event**:
 - Breakdown
 - Routine
 - Routine Suspended
 - Risk Assessment / Supervisory / Quality Check
 - Trapping
 - Special Maintenance
 - Routine Compensated

Literature review

The “Best Practices Operation and Maintenance Service of Lift and Escalator Installations” (EMSD, 2020a), which recommends a basic framework for 15 key attributes important to users such as facility management professionals and relevant stakeholders, covers the following guidelines that are related to lift maintenance services:



- For all emergency situations including failure and trapped passengers, the registered lift contractor shall arrive at the venue of incident within 1 hour (or within 30 minutes if trapped passenger is reported) upon being notified.

Literature review

(continued)

- Development and use of a reporting system shall ensure technical transparency of repair situations, should **the repair work duration extend to more than 8 hours.**
- If the lift or escalator involved in the incident **cannot resume operations within the specified 4-hour period**, the registered lift or escalator contractor shall notify all users by displaying a notice on the specified form describing the type of incident involved, and reason for suspension.

Literature review

- Under the **Quality Lift Service Recognition Scheme** (EMSD, 2020b), there are **three assessment criteria**:
 - A) Level of lift modernization
 - B) Record of lift operation
 - C) Performance of RPs in managing lift services
- Points scored under **Criteria A**, e.g. for the assessment item titled “installed double brake system”, reflect the level of **lift modernisation**. Such items, therefore, could **not be taken as applicable performance indicators** in the context of the present study.



Literature review

- On the other hand, **Criteria B**, which is highly relevant to the present study, comprises “duration of service suspension due to failure”, “average arrival time for failure related to passenger entrapment” and “average arrival time for failure unrelated to passenger entrapment”; collectively they represent a maximum of 50 points (**Table 6**) out of the total 150 points.
- The items of the checklist (**Table 7**) for measuring the performance of responsible persons in managing lift services, under **Criteria C**, represent another 50 points of the scheme.

Literature review

Average duration of service suspension due to failure	Points scored
0 - 20 hours	25 Points
21 - 40 hours	18 Points
41 - 60 hours	13 Points
61 - 80 hours	8 Points
More than 80 hours	0 Points

Table 6: Scoring table from the “Quality Lift Service Recognition Scheme”

Literature review

Average arrival time for failure related to passenger entrapment	Points scored
0 - 30 minutes	15 Points
31 - 40 minutes	10 Points
41 - 50 minutes	7 Points
51 - 60 minutes	4 Points
More than 60 minutes	0 Points

Table 6: Scoring table from the “Quality Lift Service Recognition Scheme” (continued)

Literature review

Average arrival time for failure unrelated to passenger entrapment	Points scored
0 - 1 hour	10 Points
1 - 1.5 hour	7 Points
1.5 - 2 hour	5 Points
2 -3 hour	3 Points
More than 3 hours	0 Points

Table 6: Scoring table from the “Quality Lift Service Recognition Scheme” (continued)

Literature review

Ensure compliance of lift maintenance and examination with legal requirements	Points scored
The registered contractor has conducted periodic maintenance for the lift at intervals of not more than one month.	2 Points
The registered engineer has conducted periodic examination for the lift at intervals of not more than 12 months.	2 Points
Examination with load has been conducted at intervals of not more than five years.	2 Points
All the above three maintenance and examination items have been completed.	1 Point

Table 7: Checklist for performance of responsible persons in managing lift services

Literature review

Frequently conduct inspections to oversee the condition of the lift	Points scored
Inspect the condition of the lift operation.	1 Point
Inspect the condition of floor displays.	1 Point
Inspect the condition of the buttons of each floor and lift car.	1 Point
Inspect the level of lift floor.	1 Point
Inspect the ventilation fan and lighting of the lift car.	1 Point
Conduct testing on the performance of CCTV.	1 Point
Conduct testing on the alarm.	1 Point

Table 7: Checklist for performance of responsible persons in managing lift services (continued)

Literature review

Properly manage the contractors' work	Points scored
Maintenance works have been carried out as scheduled.	1 Point
Notifications have been issued regarding lift suspension for conducting routine examination and annual examination, etc., and a mechanism for checking the identity documents of engineering workers has been established.	1 Point
Storage space has been provided for lift contractors.	1 Point
Request has been made to lift contractors for submission of documents relating to emergency repair.	1 Point
Follow-up action has been taken or written response has been made regarding contractors' comments and quotations, and a checklist for spare parts for repair has been kept .	1 Point

Table 7: Checklist for performance of responsible persons in managing lift services (continued)

Literature review

Verify the records in the log book	Points scored
No omission of signature.	5 Points
Maintenance schedule drawn up.	
Conduct maintenance as scheduled.	
Hold regular meetings with contractors	Points scored
Meet with contractors less than once in every six months over the past year.	0 Point
Meet with contractors no less than once in every six months over the past year.	2 Points

Table 7: Checklist for performance of responsible persons in managing lift services (continued)

Literature review

Appoint a professional lift consultant, a registered lift engineer or an in-house engineer employed by the property management company to examine the work of lift contractors	Points scored
Appoint a professional lift consultant, a registered lift engineer or an in-house engineer employed by the property management company to examine the work of lift contractors.	1 Point
Review the examination report and results with the contractors after examining their work.	1 Point
Follow up on the progress of the work mentioned in the report after examining the work of contractors.	2 Points

Table 7: Checklist for performance of responsible persons in managing lift services (continued)

Literature review

Ensure the cleanliness of the lift machine room, shaft and pit	Points scored
Cleanliness of the machine room.	1 Point
Cleanliness of the lift car.	1 Point
Cleanliness of the lift shaft.	1 Point
Cleanliness of the car top.	1 Point
Cleanliness of the lift pit.	1 Point

Table 7: Checklist for performance of responsible persons in managing lift services (continued)

Literature review

Immediately assist trapped lift passengers	Points scored
Display in the lift machine room guidelines for assisting trapped lift passengers.	1 Point
Keep documents containing the conversations made when pacifying trapped passengers.	1 Point
Keep records of drills.	1 Point
Provide training on assisting trapped lift passengers.	1 Point
Know about the records of trapping incidents and releasing trapped passengers in the log book.	1 Point

Table 7: Checklist for performance of responsible persons in managing lift services (continued)

Literature review

Properly handle users' complaints	Points scored
Draw up service indicators for handling complaints.	1 Point
Provide training on handling users' complaints.	1 Point
Conduct drills on handling users' complaints.	1 Point
Keep complete records of complaints.	1 Point
Keep records of follow-up on complaints.	1 Point

Table 7: Checklist for performance of responsible persons in managing lift services (continued)

Literature review

The comfort of lift passengers and quality of physical environment of the lift car	Points scored
No odour nuisance detected in the lift car.	1 Point
Good ventilation in the lift car.	1 Point
Good lighting in the lift car.	1 Point
Steady operation of the lift car.	1 Point
Cleanliness of the lift car.	1 Point

Table 7: Checklist for performance of responsible persons in managing lift services (continued)

Performance indicators

- Through the **above literature review process** and with reference to **specific guidelines** in the local O&M industry, a number of performance indicators were identified.
- For performance indicators to be useful, they need to be “**Specific**”, “**Measurable**”, “**Attainable**”, “**Relevant**”, and “**Time-Bound**” (SMART).
- Scrutinizing the above-identified performance indicators against this SMART principle, some of the indicators were found to be **not qualified**, for reasons such as: they are **not specific enough**, they **could not be quantified**, etc. Thus, the indicators (examples) shown in **Table 8** were excluded.

Performance indicators

Indicators

- | | |
|---|--|
| 1. Motor | 12. Ascending car overspeed protection device |
| 2. Gearbox | 13. Car operating panel |
| 3. Sheave | 14. Landing and final limit switches |
| 4. Controller | 15. Unintended car motion protection device |
| 5. Hoisting rope | 16. Landing and car doors |
| 6. Intercom | 17. Cage ceiling and sill |
| 7. Rollers and guide shoes mounted on car cage | 18. Automatic rescue device |
| 8. CCTV | 19. Guardrails |
| 9. Car and landing door opening and closing assembly | 20. Jerky cab motion |
| 10. Door interlock | 21. Levelling accuracy |
| 11. Door sensor | 22. Energy efficiency |
| | 23. ... |

Table 8: Performance indicators excluded for use

Identified performance indicators

- The remaining performance indicators were grouped into **four aspects**, namely “**Financial**”, “**Physical**”, “**Safety**” and “**Clients’ needs & satisfaction**”, as summarized in **Table 9**.

Aspect	Indicator	Sources
Financial	(F1) Maintenance cost per area	Lai, J.H.K. and Yik, F.W.H. (2008)
	(F2) Maintenance cost per lift	
	(F3) Outsourced maintenance cost per area	Research Proposal
	(F4) Outsourced maintenance cost per lift	
	(F5) In-house maintenance cost per area	
	(F6) In-house maintenance cost per lift	

Table 9: Shortlisted performance indicators

Identified performance indicators

Aspect	Indicator	Sources
Physical	(P1) Availability	Lai, J. and Yuen, P.L. (2021) / Lai, J.H.K. and Man, C.S. (2018)
	(P2) Maintenance downtime	Research Proposal
	(P3) Maintenance response time	
	(P4) Maintenance repair time	
	(P5) Percentage of attending service calls within 30 minutes	BSOMES (2019)
	(P6) Percentage of attending service calls within 60 minutes	
	(P7) Enquiries response time	
	(P8) Number of complaints from users	

Table 9: Shortlisted performance indicators (continued)

Identified performance indicators

Aspect	Indicator	Sources
Physical	(P9) Number of repair work with duration extended to more than 8 hours	EMSD (2022a)
	(P10) Number of incidents cannot resume operations within specified 4-hour period	
	(P11) Duration of service suspension due to failure	EMSD (2022b)
	(P12) Average arrival time for failure unrelated to passenger entrapment	

Table 9: Shortlisted performance indicators (continued)

Identified performance indicators

Aspect	Indicator	Sources
Safety	(S1) Passenger trap release time	Research Proposal
	(S2) Number of statutory orders	
	(S3) Compliance percentage of statutory orders	
	(S4) No. of passengers injured during operation	BSOMES (2019)
	(S5) Number of cases that the registered lift contractor not able to arrive at the venue of incident within 1 hours (or within 30 minutes if trapped passenger is reported) for all emergency situations.	EMSD (2022a)
	(S6) Average arrival time for failure related to passenger entrapment	EMSD (2022b)

Table 9: Shortlisted performance indicators (continued)

Identified performance indicators

Aspect	Indicator	Sources
Clients' needs & satisfaction	(C1) Implementation of preventive maintenance plan which includes monthly servicing	Elyna Myeda, N., Nizam Kamaruzzaman, S. and Pitt, M. (2011)
	(C2) Daily inspection on the lift buttons, cleanliness, appearance and also function of the lifts	
	(C3) All lifts provided are sufficient and in excellent condition to cater the capacity of the building end-users	
	(C4) RC submitted maintenance reports as required on time	BSOMES (2019)
	(C5) RC is cooperative and understands the client's needs	
	(C6) Spare parts or components can be delivered to the correct properties within the specified hours (e.g. 8 hours)	

Table 9: Shortlisted performance indicators (continued)

Identified performance indicators

- The shortlisted performance indicators, after further review and as far as possible, were each given a definition. Such **definitions**, together with the **formulas**/data needed for deriving the respective indicator, were shown in **Table 10**.

Group	Financial
Indicator	(F1) Maintenance cost per area
Definition	Ratio of the maintenance cost during the assessment period to the total internal floor area of the building.
Formula	$\frac{\text{Maintenance Cost}}{\text{Building Area}}$

Table 10: Shortlisted performance indicators – definitions and formulas

Identified performance indicators

Group	Financial
Indicator	(F2) Maintenance cost per lift
Definition	Ratio of the maintenance cost during the assessment period to the total number of lifts.
Formula	$\frac{\text{Maintenance Cost}}{\text{Number of lifts}}$
Indicator	(F3) Outsourced maintenance cost per area
Definition	Ratio of the outsourced maintenance cost during the assessment period to the total internal floor area of the building.
Formula	$\frac{\text{Outsourced Maintenance Cost}}{\text{Building Area}}$

Table 10: Shortlisted performance indicators – definitions and formulas (continued)

Identified performance indicators

Group	Financial
Indicator	(F4) Outsourced maintenance cost per lift
Definition	Ratio of the outsourced maintenance cost during the assessment period to the total number of lifts.
Formula	$\frac{\text{Outsourced Maintenance Cost}}{\text{Number of lifts}}$
Indicator	(F5) In-house maintenance cost per area
Definition	Ratio of the in-house maintenance cost during the assessment period to the total internal floor area of the building.
Formula	$\frac{\text{In-house Maintenance Cost}}{\text{Building Area}}$

Table 10: Shortlisted performance indicators – definitions and formulas (continued)

Identified performance indicators

Group	Financial
Indicator	(F6) In-house maintenance cost per lift
Definition	Ratio of the in-house maintenance cost during the assessment period to the total number of lifts.
Formula	$\frac{\text{In-house Maintenance Cost}}{\text{Number of lifts}}$
Group	Physical
Indicator	(P1) Availability
Definition	Ratio of uptime of lift to the sum of its uptime and downtime over the assessment period.
Formula	$\frac{\text{Uptime}}{\text{Up-time} + \text{Downtime}}$

Table 10: Shortlisted performance indicators – definitions and formulas (continued)

Identified performance indicators

Group	Physical
Indicator	(P5) Percentage of attending service calls within 30 minutes
Definition	Ratio of number of attending service calls within 30 minutes to the total number of service calls over the assessment period.
Formula	$\frac{\text{Number of attending calls within 30 mins}}{\text{Total number of service calls}}$
Indicator	(P6) Percentage of attending service calls within 60 minutes
Definition	Ratio of number of attending service calls within 60 minutes to the total number of service calls over the assessment period.
Formula	$\frac{\text{Number of attending calls within 60 mins}}{\text{Total number of service calls}}$

Table 10: Shortlisted performance indicators – definitions and formulas (continued)

Identified performance indicators

Group	Physical
Indicator	(P7) Enquiries response time
Definition	Average response time to enquiries from owners or management companies.
Formula	$\frac{\text{Total enquiries response time}}{\text{Total number of enquiries}}$
Indicator	(P8) Number of complaints from users
Definition	Number of complaints from users, owners or management companies over the assessment period.
Formula	$\text{Total number of complaints from users}$

Table 10: Shortlisted performance indicators – definitions and formulas (continued)

Identified performance indicators

Group	Physical
Indicator	(P9) Number of repair work with duration extended to more than 8 hours
Definition	Total number of repair work with duration extended to more than 8 hours over the assessment period.
Formula	Sum of repair works duration over 8 hours
Indicator	(P10) Number of incidents cannot resume operations within specified 4-hour period
Definition	Total number of incidents cannot resume operations within 4 hours over the assessment period.
Formula	Sum of incidents cannot resume within 4 hours

Table 10: Shortlisted performance indicators – definitions and formulas (continued)

Identified performance indicators

Group	Physical
Indicator	(P11) Duration of service suspension due to failure
Definition	Average duration of service suspension due to failure of each lift over the assessment period.
Formula	$\frac{\text{Total duration of service suspension due to failure}}{\text{Total no. of failure cases}}$
Indicator	(P12) Average arrival time for failure unrelated to passenger entrapment
Definition	Average arrival time for failure unrelated to passenger entrapment over the assessment period.
Formula	$\frac{\text{Total arrival time of failure cases (unrelated to passenger entrapment)}}{\text{Total no. of failure cases}}$

Table 10: Shortlisted performance indicators – definitions and formulas (continued)

Identified performance indicators

Group	Safety
Indicator	(S1) Passenger trap release time
Definition	Average passenger trap release time of lift over the assessment period.
Formula	$\frac{\text{Total passenger trap release time}}{\text{No. of incidents involving passenger trapping}}$
Indicator	(S2) Number of statutory orders
Definition	Total number of statutory orders issued by government departments over the assessment period.
Formula	Total number of statutory orders

Table 10: Shortlisted performance indicators – definitions and formulas (continued)

Identified performance indicators

Group	Safety
Indicator	(S3) Compliance percentage of statutory orders
Definition	Compliance percentage of statutory orders issued by government departments over the assessment period.
Formula	$\frac{\text{Total number of statutory orders cleared}}{\text{Total number of statutory orders received}}$
Indicator	(S4) No. of passengers injured during operation
Definition	Number of passengers injured duration operation over the assessment period.
Formula	Total number of passengers injured

Table 10: Shortlisted performance indicators – definitions and formulas (continued)

Identified performance indicators

Group	Safety
Indicator	(S5) Number of cases that the registered lift contractor not able to arrive at the venue of incident within 1 hour (or within 30 minutes if trapped passenger is reported) for all emergency situations
Definition	Number of cases that the registered lift contractor not able to arrive at the venue of incident within 1 hour / 30 minutes for all emergency situations over the assessment period.
Formula	$\frac{\text{Total passenger trap release time}}{\text{No. of incidents involving passenger trapping}}$

Table 10: Shortlisted performance indicators – definitions and formulas (continued)

Identified performance indicators

Group	Safety
Indicator	(S6) Average arrival time for failure related to passenger entrapment
Definition	Average arrival time for failure related to passenger entrapment over the assessment period.
Formula	$\frac{\text{Total arrival time of failure cases (related to passenger entrapment)}}{\text{Total no. of failure cases}}$

Table 10: Shortlisted performance indicators – definitions and formulas (continued)

Identified performance indicators

Group	Clients' needs & satisfaction
Indicator	(C1) Implementation of preventive maintenance plan which includes monthly servicing
Definition	-
Formula	Yes / No
Indicator	(C2) Daily inspection on the lift buttons, cleanliness and appearance and also function of the lifts
Definition	-
Formula	Yes / No

Table 10: Shortlisted performance indicators – definitions and formulas (continued)

Identified performance indicators

Group	Clients' needs & satisfaction
Indicator	(C3) All lifts provided are sufficient and in excellent condition to cater the capacity of the building end-users
Definition	-
Formula	Yes / No
Indicator	(C4) RC submitted maintenance reports as required on time
Definition	-
Formula	Yes / No

Table 10: Shortlisted performance indicators – definitions and formulas (continued)

Identified performance indicators

Group	Clients' needs & satisfaction
Indicator	(C5) RC is cooperative and understands the client's needs
Definition	-
Formula	Yes / No
Indicator	(C6) Spare parts or components can be delivered to the correct properties within the specified hours (e.g. 8 hours)
Definition	-
Formula	Yes / No

Table 10: Shortlisted performance indicators – definitions and formulas (continued)

Identified performance indicators

- Referring to EMSD (2021b), there are **indicators** relevant to the **energy use/performance** of lifts or escalators (**Table 11**).
- Apparently, these indicators are highly dependent on **design/construction** provisions (cf. maintenance effort), thus not included in the KPI list

Group	Energy & environmental
Indicator	(E1) Electrical power of the motor
Definition	The running active electrical power of the motor drive of a traction drive lift carrying a rated load at its rated speed in an upward direction should not exceed the corresponding maximum allowable value.

Table 11: Performance indicators relevant to lift energy use/performance

Identified performance indicators

Group	Energy & environmental
Indicator	(E2) Total power factor
Definition	The total power factor of the motor drive of a lift at the isolator connecting the lift to the building's electrical supply circuit should not be less than 0.85 when the lift is carrying a rated load at its rated speed and traveling in an upward direction.
Indicator	(E3) Lift Decoration Load
Definition	The decoration load in a lift should not exceed the corresponding maximum allowable value given.
Indicator	(E4) Lift Parking Mode
Definition	At least one lift of a lift bank should operate under a parking mode during low traffic period when the traffic demand on the vertical transportation system is low.

Table 11: Performance indicators relevant to lift energy use/performance (continued)

Identified performance indicators

Group	Energy & environmental
Indicator	(E5) Lift Ventilation and Air-conditioning
Definition	<p>The ventilation of a lift car after idling for 2 minutes should be shut off automatically until the lift is activated again by passenger call.</p> <p>The air-conditioning of a lift car after idling for 10 minutes should be shut off automatically until the lift is activated again by passenger call, and resume operation no earlier than 5 minutes after the shut-off.</p> <p>Power consumption of lift car ventilation fan at design air flow condition should not exceed 0.7 W per litre per second (L/s).</p>
Indicator	(E6) Lift Regenerative Braking
Definition	<p>Regenerative braking should be provided for each of a lift -</p> <p>(a) with rated speed of 2.0 m/s or above, and</p> <p>(b) rated load at 900 kg or above.</p>

Table 11: Performance indicators relevant to lift energy use/performance (continued)

Identified performance indicators

Group	Energy & environmental
Indicator	(E7) Lift Car Lighting
Definition	The lighting power density of lift car should not exceed the maximum allowable value. After idling for 10 minutes, the lift car lighting should reduce to 50% or less.
Indicator	(E8) Automatic Speed Reduction of Escalator
Definition	Switching provision should be made for each escalator to operate under automatic speed reduction mode when the traffic demand is low.
Indicator	(E9) Total Harmonic Distortion
Definition	When a lift is moving up with rated load at its rated speed, the total harmonic distortion produced by the motor drive at the isolator connecting the lift to the building's electrical supply circuit should be limited to the corresponding maximum allowable value

Table 11: Performance indicators relevant to lift energy use/performance (continued)

Identified performance indicators

Group	Energy & environmental
Indicator	(E10) Metering and Monitoring Facilities
Definition	Metering devices should be provided for the electrical supply circuit for the motor drive of each lift, escalator or passenger conveyor, for measurement of voltages (all phase-to-phase and phase-to-neutral), currents (three phases and neutral), total power factor, total harmonic distortion, energy consumption (kWh), power (kW) and maximum demand (kVA).

Table 11: Performance indicators relevant to lift energy use/performance (continued)

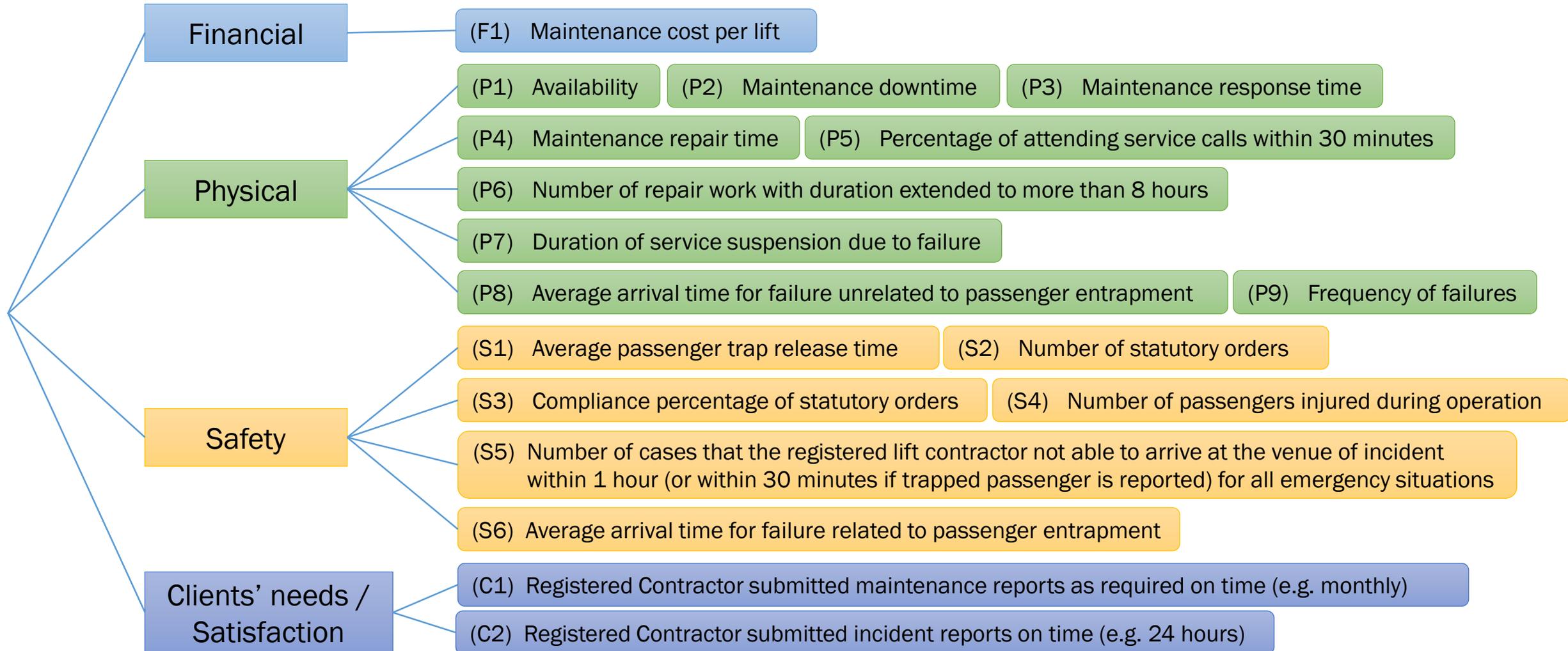
Break for 10 minutes (to complete a survey)

- Your help is needed
- A **survey** on “Establishment of Standard KPIs for Evaluation of Lift Maintenance Performance in Hong Kong”

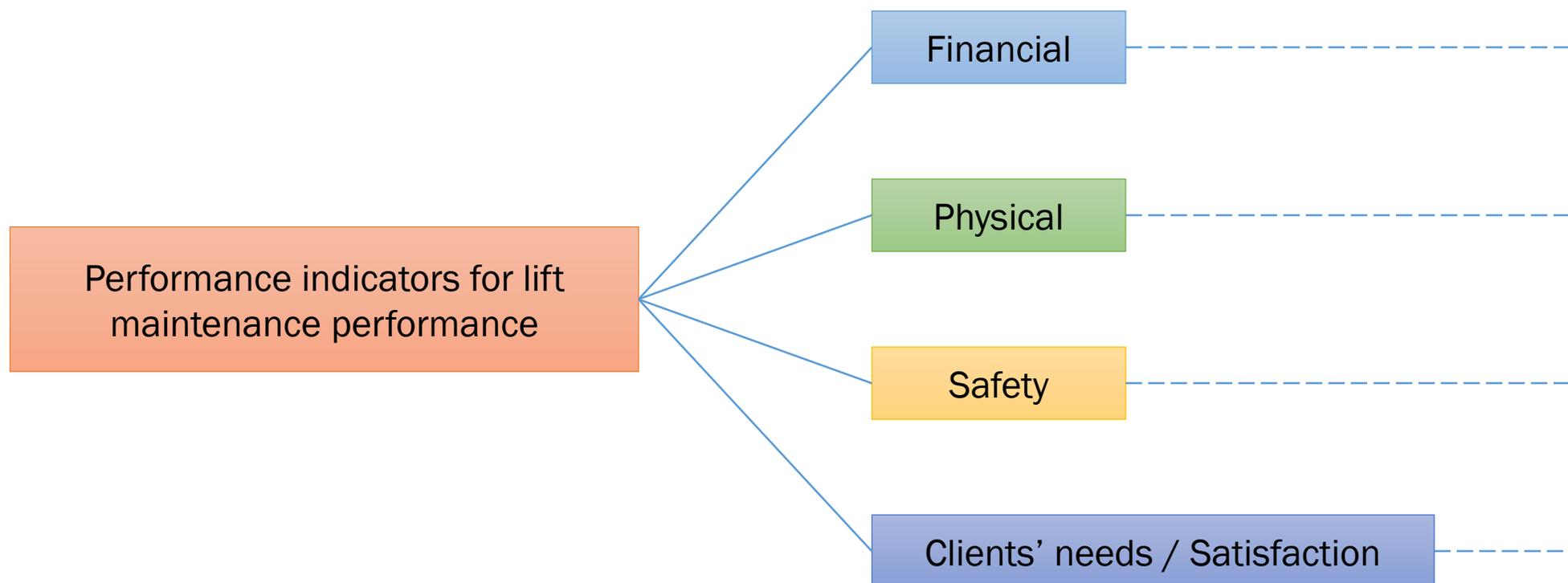
<https://forms.gle/85SYppy4PCUW6ppN6>



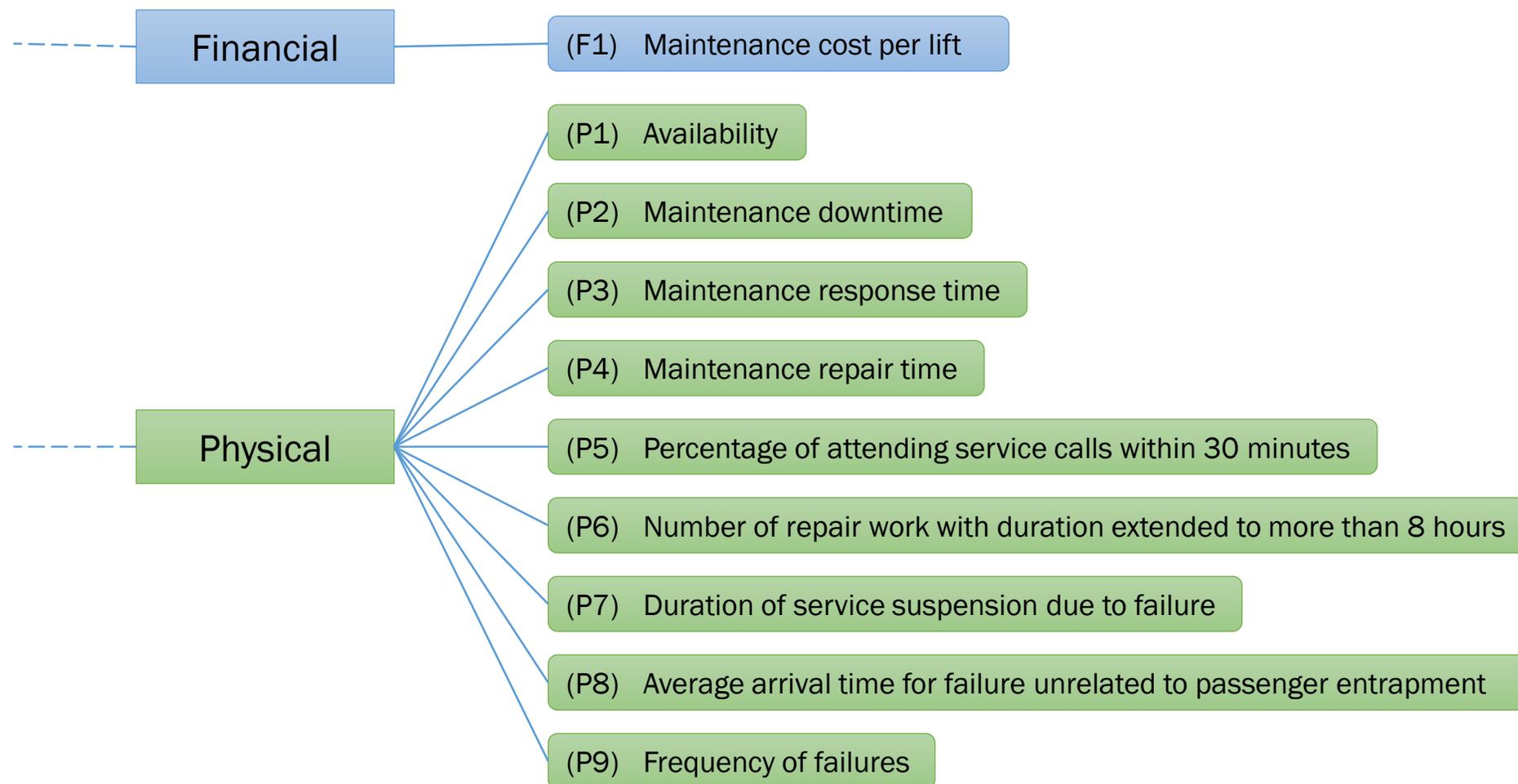
Performance indicators for lift maintenance performance



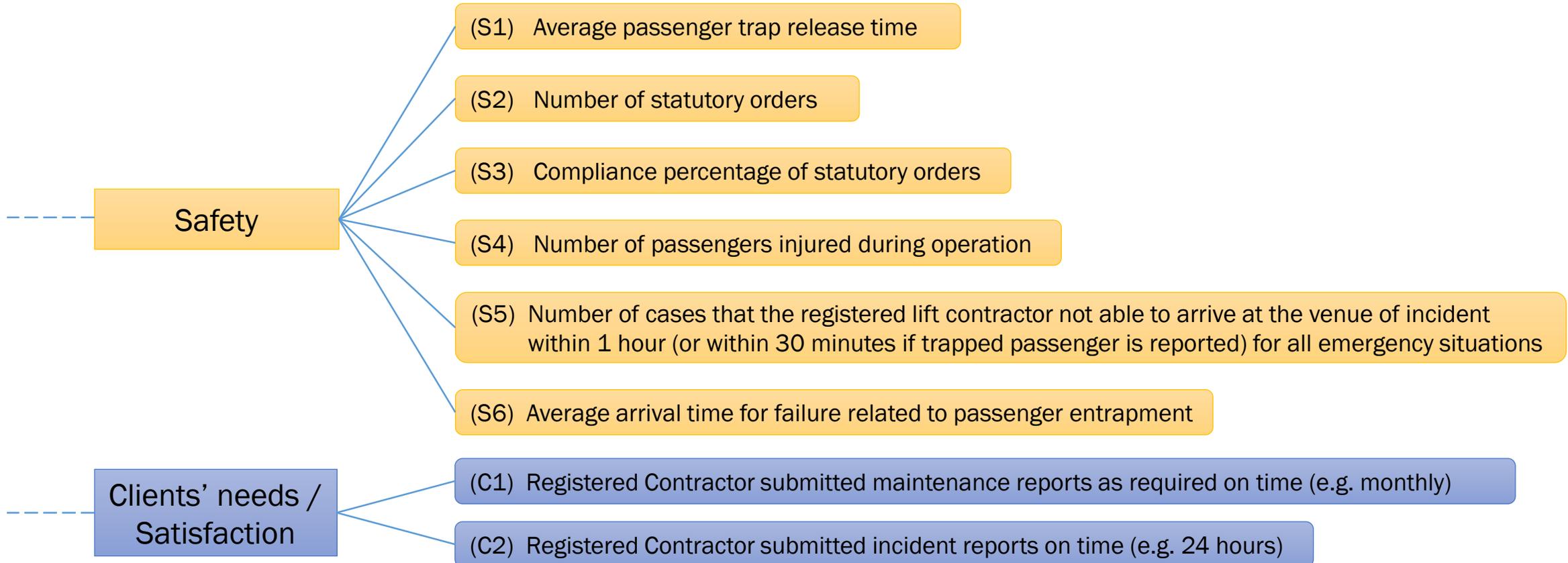
Performance indicators for lift maintenance performance



Performance indicators for lift maintenance performance



Performance indicators for lift maintenance performance



Break for 10 minutes (to complete a survey)

<https://forms.gle/85SYppy4PCUW6ppN6>



Establishment of Standard KPIs for Evaluation of Lift Maintenance Performance in Hong Kong

Dear Sir/Ms
The aim of evaluation

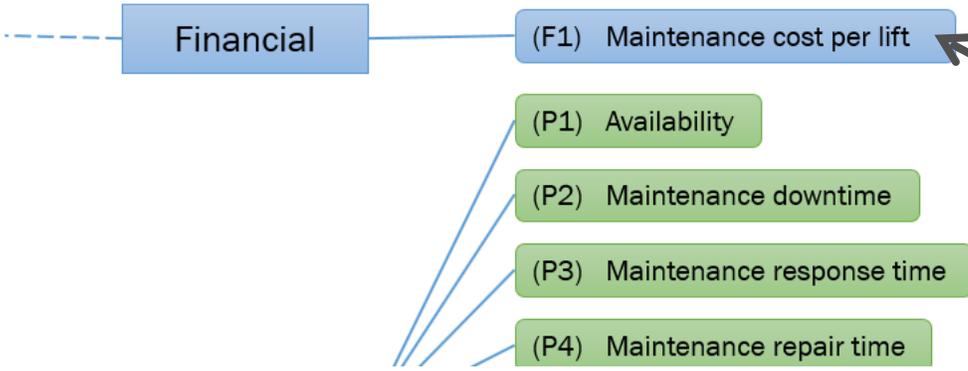
Section 3A: Please rate the importance for the following "FINANCIAL" lift maintenance performance KPI:



1. Maintenance cost per lift (F1) *

Ratio of the maintenance cost during the assessment period to the total number of lifts.

	1	2	3	4	5	
Very low	<input type="radio"/>	Very high				



Focus group meeting

- Executive Committee members including President and Office Bearers of BSOMES were invited to join a focus group meeting, of which the main purpose was to **shortlist** from the **performance indicators** (identified above) the **practicable and essential** ones.
- The meeting was conducted for **2 hours**
- A total of **10 professionals**, with work experience from **14 to over 30 years** joined the meeting.
- To facilitate the meeting discussion, a file of **slides** showing the **background of this study**, a set of **guiding questions** (to facilitate discussion) and the **performance indicators identified above** was provided to the participants for their advance information.

Focus group meeting

- In the first part of the focus group meeting, after a **briefing by the facilitator** (i.e. the study team) the participants referred to the guiding questions and **exchanged views** on the **applicability of the performance indicators** identified above.
- With the consent of the participants, the meeting discussion was recorded; the **recording was transcribed** after the meeting for **checking against the accuracies of the notes taken** during the meeting.
- Key notes drawn from the discussion include:
- **General:**
 - Assessment period for the KPIs: **1 year**
 - The KPIs are determined **per lift**

Focus group meeting

● Financial KPIs:

- Consider only lift maintenance cost **under contract** (i.e. contract maintenance cost or outsourced maintenance cost)
- Cost for cleaning lift pits, etc. is not counted, as it depends on whether the contract requires the contractor to cover such cleaning work and the **focus should be on lift cars** (not lift shafts, pits, etc.)
- **Normalize cost by number of lift** (i.e. per lift), not by area

● Physical KPIs:

- **P8*** - Hard to count complaints, disputes (some frequent and unreasonable complainers)

*Remark: Numbering here is for indicators before shortlisting

Focus group meeting

(continued)

- **P7*** – count the response time for the first reply to enquiry? The reply could be sloppy without addressing the enquiry properly, just for minimizing such an enquiry's response time.
- **P10*** – cannot resume operations in 4 hours – could be due to the need of some specific/expensive parts that can't be made available in 4 hours. Examples of such spare parts: lift motor and suspension ropes.
- **P3*** – users care very much the response time.
- **P13*** – not on the original list. “Number of repeated failures” (proposed by Participant J), then changed to “frequency of failures” (with consensus of the participants), which covers repeated failures (very annoying to users and often lead to complaints).

*Remark: Numbering here is for indicators before shortlisting

Focus group meeting

(continued)

- Mean time between failures (MTBF) and Mean time to repair (MTTR) – average values not good for fluctuating cases (e.g. some cases with long downtime, some others with short downtime. Cases with occasional long downtimes could still have MTBF within the limit required by client.)
- P2* to be superseded by P11*, which should not count the service suspension duration due to routine maintenance service (e.g. regular inspection).
- The ordinance requires monthly inspection for lifts, but in practice some are done every two weeks.

*Remark: Numbering here is for indicators before shortlisting

Focus group meeting

- **Safety KPIs:**

- Seldom to receive statutory orders. But in case there are such orders, it means the maintenance performance is poor.

- **Customer needs KPIs:**

- C4* is needed, with the typical maintenance report submission interval being 1 month.
- C4a* is added (upon consensus of the participants). Usually incident reports need to be submitted within 24 hours.
- C5* is descriptive and C6* varies with contracts and lifts (and some contractors outsourced spare parts from suppliers who are not the original equipment manufacturer (OEM)). So C5* and C6* are dropped.

*Remark: Numbering here is for indicators before shortlisting

Focus group meeting

- **Lift classifications (groupings)**

- “Lift travel level” does not reflect well the maintenance work demand, as, for example, a lift (executive) may serve only the boss from G/F to say 40/F, with only 2 stops.
- Instead, the **number of stops** can better reflect the maintenance work demand, as “more stops” means “more doors and associated accessories” and so bigger maintenance work demand.

Focus group meeting

- According to the focus group discussion, **some** performance indicators are **not specific, not measurable** and/or with **no actual data available** for assessment purposes, the list of performance indicators was revised as in **Table 13**:
 - some of the original indicators were **deleted**
 - some were **changed** to indicators with better representation/meaning
 - some **additional** indicators were suggested by the participants as essential

Focus group meeting

Financial		
	Original performance indicators	Revision after reviewed by participants (with reason)
(F1)	Maintenance cost per area	Deleted (Represented by F2)
(F2)	Maintenance cost per lift	Nil
(F3)	Outsourced maintenance cost per area	Deleted (Represented by F2)
(F4)	Outsourced maintenance cost per lift	Deleted (Represented by F2)
(F5)	In-house maintenance cost per area	Deleted (Represented by F2)
(F6)	In-house maintenance cost per lift	Deleted (Represented by F2)

Table 13: Revision of performance indicators

Focus group meeting

Physical		
	Original performance indicators	Revision after reviewed by participants (with reason)
(P1)	Availability	Nil
(P2)	Maintenance downtime	Nil
(P3)	Maintenance response time	Nil
(P4)	Maintenance repair time	Nil
(P5)	Percentage of attending service calls within 30 minutes	Nil
(P6)	Percentage of attending service calls within 60 minutes	Nil
(P7)	Enquiries response time	Nil
(P8)	Number of complaints from users	Nil
(P9)	Number of repair work with duration extended to more than 8 hours	Nil

Table 13: Revision of performance indicators (continued)

Focus group meeting

Physical		
	Original performance indicators	Revision after reviewed by participants (with reason)
(P10)	Number of incidents cannot resume operations within specified 4-hour period	Nil
(P11)	Duration of service suspension due to failure	Changed to: Average duration of service suspension due to failure
(P12)	Average arrival time for failure unrelated to passenger entrapment	Nil
(P13)	Frequency of failures	Proposed by focus group participants

Table 13: Revision of performance indicators (continued)

Focus group meeting

Safety		
	Original performance indicators	Revision after reviewed by participants (with reason)
(S1)	Passenger trap release time	Changed to: Average passenger trap release time
(S2)	Number of statutory orders	Nil
(S3)	Compliance percentage of statutory orders	Nil
(S4)	No. of passengers injured during operation	Nil
(S5)	Number of cases that the registered lift contractor is not able to arrive at the venue of incident within 1 hour (or 30 minutes if trapped passenger is reported)	Nil
(S6)	Average arrival time for failure related to passenger	Nil

Table 13: Revision of performance indicators (continued)

Focus group meeting

Clients' needs / Satisfaction		
	Original performance indicators	Revision after reviewed by participants (with reason)
(C1)	Implementation of preventive maintenance plan which includes monthly servicing	Deleted (Not specific)
(C2)	Daily inspection on the lift buttons, cleanliness, appearance and also function of the lifts	Deleted (Not specific)
(C3)	All lifts provided are sufficient and in excellent condition to cater the capacity of the building end-users	Deleted (Not measurable)
(C4)	RC submitted maintenance reports as required on time (e.g. monthly)	Nil
(C4a)	RC submitted incident reports on time (e.g. 24 hours)	Proposed by focus group participants

Table 13: Revision of performance indicators (continued)

Focus group meeting

Clients' needs / Satisfaction		
	Original performance indicators	Revision after reviewed by participants (with reason)
(C5)	RC is cooperative and understands the client's needs	Deleted (Too subjective)
(C6)	Spare parts or components can be delivered to the correct properties within the specified hours (e.g. 8 hours)	Deleted (Not specific, varies with contracts)

Table 13: Revision of performance indicators (continued)

Focus group meeting

- After confirming the performance indicators as above, the participants were facilitated by the study team to **vote on whether the indicators** should be taken for use in evaluation of lift maintenance performance. **Table 14** shows the voting result.

Financial		Agree (No.)	No. of participants	Percentage
(F2)	Maintenance cost per lift	10	10	100%
Physical		Agree (No.)	No. of participants	Percentage
(P1)	Availability	9	10	90%
(P2)	Maintenance downtime	6	10	60%
(P3)	Maintenance response time	7	10	70%
(P4)	Maintenance repair time	9	10	90%

Table 14: Voting result of the performance indicator

Focus group meeting

Physical		Agree (No.)	No. of participants	Percentage
(P5)	Percentage of attending service calls within 30 minutes	7	10	70%
(P6)	Percentage of attending service calls within 60 minutes	2	10	20%
(P7)	Enquiries response time	2	10	20%
(P8)	Number of complaints from users	1	10	10%
(P9)	Number of repair work with duration extended to more than 8 hours	9	10	90%
(P10)	Number of incidents cannot resume operations within specified 4-hour period	3	10	30%
(P11)	Duration of service suspension due to failure	10	10	100%

Table 14: Voting result of the performance indicator (continued)

Focus group meeting

Physical		Agree (No.)	No. of participants	Percentage
(P12)	Average arrival time for failure unrelated to passenger entrapment	8	10	80%
(P13)	Frequency of failures	10	10	100%

Safety		Agree (No.)	No. of participants	Percentage
(S1)	Average passenger trap release time	10	10	100%
(S2)	Number of statutory orders	6	10	60%
(S3)	Compliance percentage of statutory orders	5	10	50%
(S4)	No. of passengers injured during operation	8	10	80%

Table 14: Voting result of the performance indicator (continued)

Focus group meeting

Safety		Agree (No.)	No. of participants	Percentage
(S5)	Number of cases that the registered lift contractor is not able to arrive at the venue of incident within 1 hour (or 30 minutes if trapped passenger is reported)	9	10	90%
(S6)	Average arrival time for failure related to passenger	9	10	90%
Clients' needs / Satisfaction		Agree (No.)	No. of participants	Percentage
(C4)	RC submitted maintenance reports as required on time (e.g. monthly)	7	10	70%
(C4a)	RC submitted incident reports on time (e.g. 24 hours)	6	10	60%

Table 14: Voting result of the performance indicator (continued)

Focus group meeting

- In the second part of the focus meeting, the participants were facilitated to discuss the classification of lifts by “travel level”, “rated speed”, “age”, etc. Table 15 shows the voting result of lift classifications and Table 16 lists the classifications after deliberation among the participants.

Lift classification		Agree (No.)	No. of participants	Percentage
(G1)	Travel Level	4	10	40%
(G2)	Rated speed	8	10	80%
(G3)	Age	9	10	90%
(G4)	Size	8	10	80%
(G5)	No. of stops	8	10	80%
(G6)	Lift usage	9	10	90%

Table 15: Voting result of lift classifications

Focus group meeting

Lift classification		Revision after reviewed by participants (with reason)
(G1)	Travel Level	N.A. (only 40% participants agree)
(G2)	Rated speed	Same as EMSD's classification in Table 5
(G3)	Age	Up to 5 years, 6-25 years, >25 years
(G4)	Size	75-750kg, 751-1500kg, >1500kg
(G5)	No. of stops	2-10, 11-20, >20
(G6)	Lift usage	Passenger, passenger (fireman), service, goods, vehicle

Table 16: Recommended classifications by focus group participants

Part B (current & upcoming)

Stage 4: Shortlisting of KPIs

- Based on the findings from the focus group study, a **survey questionnaire** has been designed for **distribution to the lift maintenance industry** in Hong Kong.
- The questionnaire lists the KPIs identified above and requests the survey respondents to indicate the **importance levels of the KPIs**.
- Survey responses will be **analysed to yield** the importance levels and hence the **priority of the KPIs**, based on which the **most essential KPIs will be shortlisted**.

Stage 5: Validation and finalization of KPIs

- To ensure that the shortlisted KPIs are fit for evaluation of lift maintenance management performance in Hong Kong, **case studies** will be conducted.
- In these case studies, **empirical lift maintenance data** will be collected from **high-rise buildings in Hong Kong**.
- The data, to be collected through **interviews** with lift maintenance management professionals, will be used to **test whether the KPIs are effective** for the intended performance evaluation purpose.
- **Any modifications needed**, if found necessary from the validation process, **will be incorporated** before the KPIs are finalized.

References

- BSOMES (2019), Best Management Practices on Operation & Maintenance for Lifts & Escalators. Building Services Operation and Maintenance Executive Society, Hong Kong.
- Elyna Myeda, N., Nizam Kamaruzzaman, S. and Pitt, M. (2011), "Measuring the performance of office buildings maintenance management in Malaysia", Journal of Facilities Management, Vol. 9 No. 3, pp. 181-199.
- EMSD (2021a), Past Maintenance Price Figures for Lifts at Private Residential Premises, EMSD, the government of HKSAR. Retrieved from https://www.emsd.gov.hk/en/lifts_and_escalators_safety/responsible_persons_corner/maintenance_price_figures_for_lifts_at_private_res/past_maintenance_price_figures_for_lifts_at_priv/announcement_date_27_may_2021/index.html
- EMSD (2021b), Code of Practice for Energy Efficiency of Building Services Installation. EMSD, the government of HKSAR
- EMSD (2022a), Best Practices for Operation and Maintenance Service of Lift and Escalator Installations. EMSD, the government of HKSAR. Retrieved from <https://bestpractice.emsd.gov.hk/en/lift-and-escalator-installations/>

References

- EMSD (2022b), Quality lift service recognition scheme. EMSD, the government of HKSAR. Retrieved from https://www.emsd.gov.hk/en/lifts_and_escalators_safety/responsible_persons_corner/qlsrs/
- Lai, J.H.K. and Man, C.S. (2018), "Performance indicators for facilities operation and maintenance (Part 2): Shortlisting through a focus group study", *Facilities*, Vol. 36 No. 9/10, pp. 495-509.
- Lai, J.H.K. and Yik, F.W.H. (2008), "Benchmarking operation and maintenance costs of luxury hotels", *Journal of Facilities Management*, Vol. 6 No. 4, pp. 279-289.
- Lai, J. and Yuen, P.L. (2021), "Identification, classification and shortlisting of performance indicators for hospital facilities management", *Facilities*, Vol. 39 No. 1/2, pp. 4-18.
- Zubair, M.U. and Zhang, X. (2020), "Hybrid Performance-Measurement Model of Elevators", *Journal of Performance of Constructed Facilities*, Volume 34, Issue 2.

Thank you very much

Q&A

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