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FOREWORD

It is with great pleasure that we present the proceedings of the 12th Symposium on Lift and Escalator Technologies, 22-23 September 2021, organised by The Lift and Escalator Symposium Educational Trust. The Covid 19 pandemic has necessitated the Symposium to take place on-line for a second year. There intentionally are less papers than normal as we were able to plan for a short on-line conference rather than in 2020 when we had to migrate the planned in person conference online. We hope to have full in-person conference in 2022 and will send out a call for papers as soon as this can be confirmed.

The objective of The Lift and Escalator Symposium Educational Trust is to advance education in lifts, escalators and related technologies. The Trust is a Registered Charity No: 1170947 and is supported by The University of Northampton, The Chartered Institution of Building Services Engineers (CIBSE) and The Lift and Escalator Industry Association (LEIA).

Proceedings from the full conference series (since 2011) are available to download from www.liftsymposium.org. The proceedings are indexed in Scopus as "Symposium on Lift and Escalator Technologies", starting from the 2015 Symposium. Scopus is the world's largest abstract and citation database of peer-reviewed literature (scientific journals, books and conference proceedings), see https://blog.scopus.com/about.

The Lift Engineering programme offered at The University of Northampton includes postgraduate courses at MSc/ MPhil/ PhD levels that involves study of the advanced principles and philosophy underlying lift and escalator technologies. The programme aims to provide a detailed, academic study of engineering and related management issues for persons employed in lift making and allied industries.

The CIBSE Lifts Group is a specialist forum for members who have an interest in vertical transportation. The group meets regularly to promote technical standards, training and education, publications and various aspects of the vertical transportation industry. The CIBSE Lifts Group directs the development of CIBSE Guide D: Transportation systems in buildings, the de facto reference on vertical transportation.

LEIA is the UK trade association and advisory body for the lift and escalator industry with a membership covering some 95% of the lift and escalator industry. LEIA members supply passenger and goods/service lifts, stairlifts, homelifts, lifting platforms, escalators, passenger conveyors and a range of component parts for such products. LEIA members undertake the maintenance and modernisation of more than 250,000 products falling within the scope of the Association. LEIA provides advice on health, safety and standards matters, promotes education and training especially through its distinctive distance learning programme.

The Symposium brings together experts from the field of vertical transportation, offering an opportunity for speakers to present peer reviewed papers on the subject of their research. Speakers include industry experts, academics and post graduate students.

The papers are listed alphabetically by title. The requirement was to prepare an extended abstract, but full papers were accepted from the invited speakers where they preferred to offer them. The submissions are reproduced as they were submitted, with minor changes in formatting, and correction of obvious language errors where there was no risk of changing meaning.

Professor Stefan Kaczmarczyk, and Dr Richard Peters
Co-Chairs and Proceeding Editors

CONTENTS

The Two Modes of Failure of Escalator Braking Systems

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Keywords: escalator braking systems, runaway condition, escalator kinematics, passenger falls, intelligent braking systems deceleration, jerk.

Abstract. The braking system in an escalator is the most critical safety component. Failure of the escalator braking system can lead to passenger injury and even fatalities. Escalator braking systems can fail in two modes: In the first mode of failure, the braking system fails to arrest the descending load and slow it down when it is not correctly adjusted or completely out of adjustment. This leads to a runaway situation. The second mode of failure is when the escalator braking system is too tightly adjusted such that it leads to a severe stop of the escalator and consequential passenger falls. Passenger falls on escalators are one of the major causes of accidents including cuts, bruises, finger entrapment and in certain cases crushing leading to suffocation. The paper provides an overview of these two types of failures, their causes and possible solutions. One of the technical solutions previewed is the use of intelligent escalator braking systems in order to control the deceleration of a stopping escalator. Two technologies exist for control the escalator braking systems: electrical and hydraulic.

1 INTRODUCTION

The braking system in an escalator is the most critical component. Failure of the braking system on an escalator can lead to passenger injuries and even fatalities.

This paper attempts to review the failure of the braking system that leads to passenger injuries. There are two modes of failure for escalator braking systems. The first mode of failure of the braking system is when it fails to slowdown and stop the loaded escalator. This leads to a dangerous increase in speed and the consequential passenger injuries caused by the formation of a 'human pile' at the lower landing of the escalator. The second mode of failure of the escalator braking system is when the braking system applies too harshly when it is lightly loaded, causing passenger to lose balance and fall, with consequential injuries in the form of cuts, bruises and even finger entrapments.

It could be argued that these two types of failures are not failures in the classical sense of the work (e.g., a classical failure is when a component is damaged, or a sensor is not sending a signal). While this is true, these two failures are basically forms of maladjustment leading the inability of the braking system to perform its function. Hence, they have been classified as failures in this paper.

It is worth noting that the first mode of failure is easily reversible if detected in good time. It is also worth noting that there are other failure modes in the escalator that are irreversible. A better understanding of the contents of this paper can be gained by understanding the status of safety regulations for major escalators in the world.

This paper reviews the research and practical work carried out to date in all the areas above. The paper provides some necessary background information about escalator braking in terms of the passenger accident causation model (section 2), the anatomy of an escalator stop (section 3), the standard requirements regarding escalator braking system performance (section 4) and the requirement for weight testing in public service escalators (section 5). The problem of escalator runaway accidents is reviewed in section 6 including suggested new methodology for testing the escalator braking system without the use of weight to avoid this failure mode. Section 7 examines the experimental work done in finding a relationship between the kinematics and mechanics of the stopping escalator and the risk of passengers falls. The work done in this area provides a recommended value for the maximum value of deceleration that should not be exceeded during an escalator stop. Section 8 reviews two types of intelligent braking system that are used to prevent the deceleration of the stopping escalator exceeding these recommended values: hydraulic braking systems and electrical braking systems. Conclusions are drawn in section 9.

2 THE ESCALATOR PASSENGER ACCIDENT CAUSATION MODEL

It is useful at this stage to discuss the passenger causation model in escalators. Previous research has identified three categories that lead to passenger accidents on escalators [1]:

1. Design: During the design phase of the escalator braking system, the risk of brake failure can be reduced or eliminated.
2. Inspection and maintenance: Inspection is critical in identifying problems in the braking system early on and addressing them via maintenance.
3. Passenger behaviour: Passenger awareness is important in avoiding accidents. Good awareness could avoid the risk of passenger falls (e.g., holding onto the handrail and facing the direction of travel).

This model provides a guidance framework for the prevention of passenger accidents (Figure 1). By analysing the three categories above (or a combination thereof), it is possible to identify the root causes of an accident and prevent it. More on passenger accidents on escalators can be found in [2] and [3].

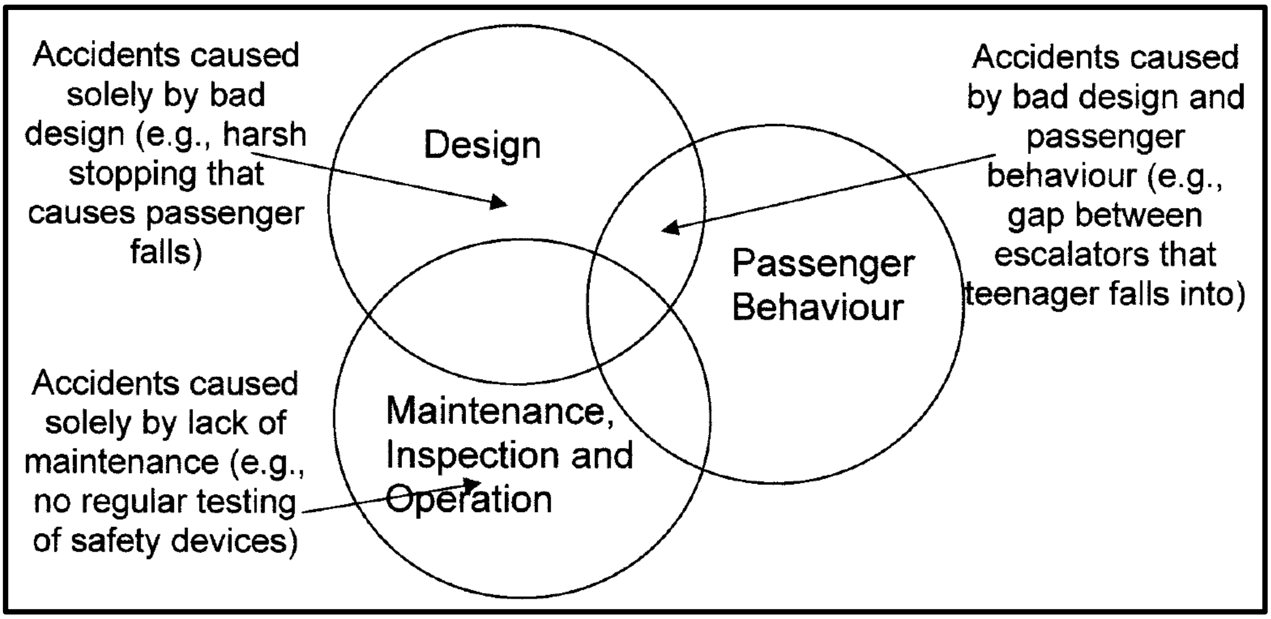

Figure 1 Venn Diagram of Escalator Accidents Causation [1]

3 ANATOMY OF AN ESCALATOR STOP UNDER THE INFLUENCE OF THE BRAKING SYSTEM

Another useful tool that can be essential in understanding brake operation and thus brake failure is the speed-time profile of the escalator step-band during a stop. The speed-time profile is a plot of the speed of the step-band of the escalator against time.

Figure 2 shows the speed-time profiles for a public service escalator. The braking systems comprises two parts: An operational brake and an auxiliary brake (using EN 115-1:2008 terminology). Both brakes are hydraulically lifted and spring-applied (for obvious safety reasons).

As can be seen, the stopping time (from the time that the stop-switch is pressed until the escalator comes to a complete standstill) is around 2 seconds. This stopping time includes the electrical delay (around 350 ms), the mechanical delay (around 360 ms), the brake torque build-up (around 890 ms), and the final stopping time under full brake torque (around 400 ms).

The figure also shows the comparison with a frictional stop (where the escalator stops under the effect of friction only without any braking torque). This is useful for providing an indication of the mechanical status of the step-band.

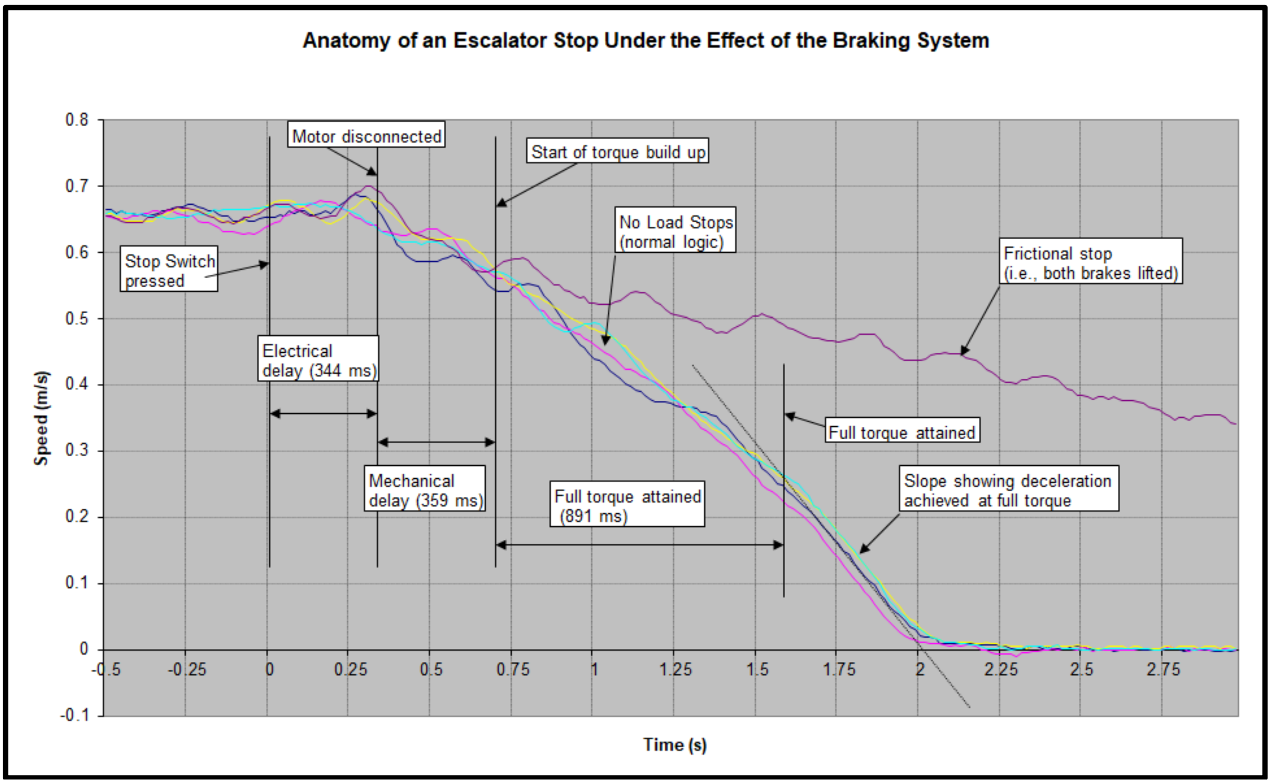

Figure 2 The speed-time profiles for a public service escalator under the influence of the braking system

4 BRAKE PERFORMANCE REQUIREMENTS

The brake performance requirements as set out in the European Standard EN115 only stipulate maximum and minimum stopping distance. The maximum stopping distance relate to the fully loaded escalator running in the down direction. The minimum stopping distance relates to empty stopping escalator (see Table 1).

The rationale for this is that the escalator should not stop too abruptly when empty, so that it does not cause passenger falls when passengers are travelling on it. When fully loaded it should be able to stop within a reasonable distance to protect passengers from a runaway situation.

Table 1 Stopping distance in accordance with EN115.

Rated speed	Stopping distance
0.50 m/s	min. 0.20 m; max. 1.00 m
0.65 m/s	min. 0.30 m; max. 1.30 m
0.75 m/s	min. 0.35 m; max. 1.50 m

The American Standard (ASME A17.1-2010/CSA B44-10) specifies the maximum value of deceleration of the escalator, as 0.91 m/s^2.

The stopping distance on its own is a poor indicator of brake performance. Based on several pieces of research, there is strong evidence to suggest that the maximum value of deceleration is the best indicator of the passenger stopping comfort and the risk of passenger falls [4]. It is believed that the maximum value of the deceleration during an escalator stop is inversely proportional to the risk of passenger falls. EN115 has been re-drafted to specify an additional maximum deceleration requirement of 1 m/s^2 in addition to the stopping distances.

5 WEIGHT TESTING REQUIREMENTS ON PUBLIC SERVICE ESCALATORS

Prior to discussing the mode of failure where the braking system fails to slowdown the loaded escalator and bring it to standstill, it is useful to look at the weight testing that is carried out on public service escalators to mitigate the risk of such a failure.

The function or the braking system on the escalator is to ensure that the fully loaded escalator is brought safely to a standstill when required to do so following the tripping of a safety device or the activation of the passenger emergency stop switch. Recent developments have introduced the use of electrical braking systems to complement the mechanical braking systems [5].

It is generally a requirement that full load weight testing be carried out for new, refurbished and partially refurbished escalators to prove that the braking system is capable of (and has been set up to) arresting the fully loaded escalator running in the down direction at rated speed and bringing it to a standstill within the distances stipulated by EN115-1:2008.

Weight testing is a very lengthy and costly process. It is carried out when an escalator has been replaced or refurbished or where the braking system has been altered. This is especially critical on public service escalators. Public service escalators are subjected to high level of passenger traffic which makes the safety of the brakes even more critical.

A value of 150 kg per step is generally assumed in order to calculate the motor or inverter size for public service escalators. The 150 kg is equivalent to two passengers per step each weighing 75 kg, and is over and above the requirement of EN115-1: 2008

Much research has been carried out on the energy drawn by escalators [6] that have shown that that the power drawn by an escalator in kW can be calculated as follows (and is central to the weightless weight testing methodology that is discussed later in this section: by finding the no load power drawn by the escalator, it then becomes possible to find the frictional torque in the escalator):

$$P_{NL} = 0.47 \cdot r + 1.74$$

Where:
P_{NL} is the power drawn by the escalator at rated speed and no load in kW
r is the escalator rise in m

A previous paper [7] presented a measurement-based-model that allows the prediction of the stopping distance of an escalator under loaded conditions in order to obviate the need for the full load weight testing. Such a model will enhance the level of safety in escalators and allow a more scientific approach to the subject of weight testing and proofing of the brakes.

If the relationship between the steady-state speed, deceleration, and stopping distance is clarified under the regulatory standards, physical information that leads to the status of accident countermeasures can be obtained.

6 RUNAWAY CONDITIONS ON ESCALATORS

Runaway situations are one main source of serious passenger injuries on escalators. A runaway situation takes place when a heavily loaded escalator accelerates downwards exceeding its rated speed and causing a passenger pile at the lower landing. An example of a runaway situation was the accident at the CN Tower in Toronto that took place in 1988. The following is an excerpt from the news item in the press (shown from Elevator World December 1988 below):

> *"Nine children were taken to the hospital after being in a human pile-up on an escalator at the base of Toronto's CN Tower, but were quickly released. Staff-Sergeant Doug Ecklund of the Metro Police said witnesses reported that the escalator seemed to accelerate before halting after the emergency stop button was pushed. He said an adult pushed the button after becoming concerned about congestion at the base of the escalator."*

Runaway situations take place when the braking system of the escalator is not properly adjusted and cannot bring the loaded escalator to rest. When the escalator stops unloaded or lightly loaded, the friction in the escalator is sufficient to stop it. However, when the escalator is heavily loaded with passengers (as is the case during rush hours or following major events such as football matches or concerts) the braking system is unable to stop the loaded escalator when the stop button is pressed. Passengers are reported as saying: "I pressed the stop switch a number of times, but the escalator did not stop!" Tests carried out after the accident do not reveal the problem, as the escalator is stopped with no load on it, and friction is sufficient to bring it to rest.

What happens during a runaway situation is outlined here. A down-moving heavily loaded escalator is given a command to stop (either by someone pressing the stop switch or by a spurious safety device trip). The motor is then disconnected from the source of supply by the tripping of the main contactors. By taking the power away from the motor, the escalator is left to move freely under gravity. As the braking system is ineffective the escalator and its load start accelerating downwards. Attempts by passengers to stop it by pressing the stop switch are futile, as the escalator is already 'electrically' stopped; and is in fact mechanically under gravity. The escalator accelerates to dangerously high speeds (speeds as high as 2 m/s have been reported). Passengers get to the lower landing falling on each other and forming a 'human pile'. Once a significant number of passengers have been 'thrown' off the escalator, the escalator starts slowing down until it stops under friction.

In cases where the heavily loaded escalator is moving upwards, the escalator slows down to a standstill and then reverses direction and accelerates downwards in the same sequence of events discussed above for the case of the down moving escalator.

In certain cases, the cause of the runaway is not a defective braking system, but a mechanical shearing of the top shaft of the escalator. The sequence of events however is similar.

If the problem is not detected by operational staff, what happens sometimes is that the escalator is left in service (in a stationary condition) following the accident. New passengers arriving find the escalator stationary and think that it is in service as a fixed staircase. Once sufficient passengers have boarded the stationary defective escalator it starts moving downwards under gravity, repeating the sequence of events above.

The following are examples of runaway incidents:

- Toronto CN Tower, December 1988 (down).
- MARTA (Metropolitan Atlanta, Rapid Transit Authority), Atlanta, Georgia, U.S.A. Escalators locked off to prevent free-wheeling during crowded conditions (Elevator World 1997).
- London Underground, London, United Kingdom, Oxford Circus Station, Escalator number 4, August 1999 (sheared top shaft).
- 18th January 2000, Nashville International Airport, U.S.A.
- Newcastle, England, United Kingdom, Metro escalator, May 1st, 2001 (up).
- Newcastle, England, United Kingdom. Metro escalator, February 9th 2002 (down).
- London Underground, London, United Kingdom, Waterloo Station, 2002.
  Anaheim, California, baseball fans May 7th 2002, 15 passengers with minor injuries (down).
- Coors Field Stadium (Denver, Colorado, U.S.A.) 9/7/2003, 20 injured.
- Raffles City Shopping Centre, Singapore, May 2003, (up), 1 person hospitalised.
- Escalator reversed direction, Xinzhuang Station, Shanghai, China, number one subway line, 38 people injured (up).

A recent paper by David Cooper more comprehensively covers this type of failure [8]. The current status of risk control for escalators can be grasped by describing the diffusion rate of safety measures after the revision of EN115-1:2008.

7 RESEARCH INTO THE EFFECT OF THE KINEMATICS OF A STOP ON PASSENGER FALLS

The other mode of failure is the escalator stopping harshly when lightly loaded and causing passengers to fall. Passenger falls on escalators can be caused by escalator stops. It has been shown that 2.5% escalator unplanned stops can lead to passenger falls. Passenger falls on escalators can lead to a range of injuries, starting from cuts and bruises upon impacting the steps, finger entrapment between the steps and the skirts and as severe as crushing at the lower landing due to other passengers falling on each other with the risk of suffocation [9].

Three studies have been carried out into the relationship between the risk of passenger falls on a stopping escalator and the kinematics of the stop. The methodology is based on asking volunteers to assess the quality of the stop either in words [4] and [10] or on a numeric scale from 1 to 10 [11].

The work in [4] and [11] concludes that a value of 1 m·s-2 for the value of acceleration during an escalator stop seems to be a reasonable limit to impose on the maximum value of acceleration during a stop.

This method is based on the use of human subjects who would ride the escalators during the stop and provide a subjective assessment of the quality of the stop and their assessment of the risk of falling. An example of this empirical approach can be found in [10] where experimental tests on subjects were used to find their perception threshold of movement in relation to age and other factors.

The research in this area can be summarised as follows:

1. General research on the risk of passenger falls [12, 13, 14].
2. The qualitative relationship between passenger falls and the kinematics of a stop [11, 4, 10].
3. The quantitative relationship between passenger falls and the kinematics of as stop using analytical models [15].

The outcome of all these pieces of research (both quantitative and qualitative) shows that:

1. The most important factor in causing passenger falls during an escalator stop is the maximum value of the deceleration.
2. Placing an upper limit on the value of deceleration of a stopping escalator of 1 m/s^2 would ensure that most passenger falls caused by the escalator stop are eliminated.

This value would be the recommended target design and testing value that would be used as a testing criterion for the acceptability or otherwise of the performance of the escalator braking system. Such a criterion would eliminate the risk of passenger falls caused by the escalator unplanned stoppage. The next section discusses how the use of intelligent braking systems is applied in achieving this requirement.

8 INTELLIGENT BRAKING SYSTEMS

As discussed in the earlier sections, a limit must be placed on the maximum value of the acceleration of a stopping escalator in order to ensure that passenger falls are avoided when a lightly loaded escalator stops (especially in response to a safety device tripping or a manually operated stop switch).

The maximum allowable value of the deceleration of the stopping escalator can be used as the control variable in the intelligent braking system. An intelligent braking system is a system that controls the stopping speed profile of the escalator in order to achieve the required stopping distance or speed. A block diagram of a generic intelligent braking system is shown in Figure 3 below.

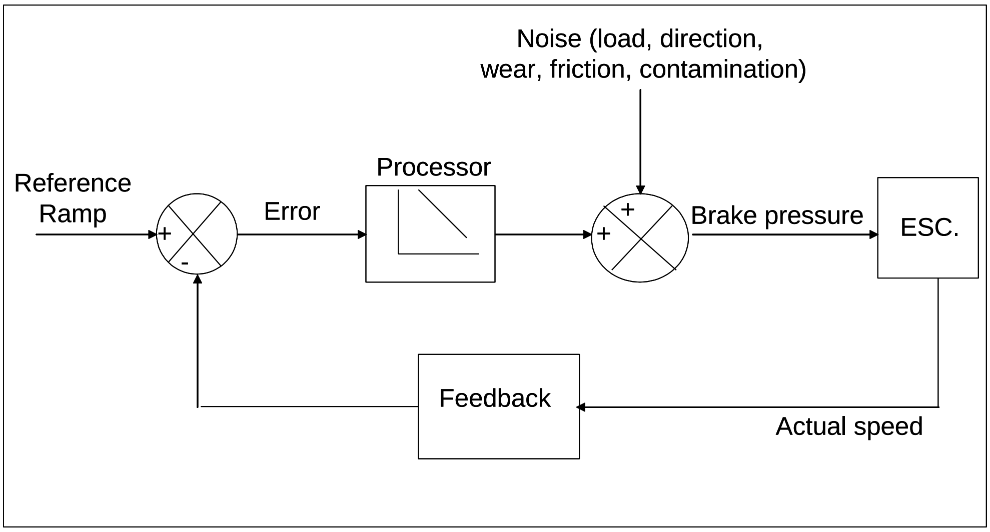

Figure 3 Block diagram of an intelligent braking system (with a negative feedback loop)

It is now possible with the use of modern escalator braking systems (electrically or hydraulically based intelligent braking system) to continuously monitor the value of speed and acceleration of the escalator in real time and adjust the electrical braking effort in order to avoid the deceleration exceeding the target value. This is outlined in detail in [5] and [16].

<u>*Hydraulically based systems:*</u> Hydraulically based systems require that one of the conventional brakes be hydraulically lifted. Hydraulic systems control the hydraulic pressure lifting the brake pads off the disk. This can either be done by the use of a linearly proportional valve or using on/off modulation by varying the duty ratio (i.e., on/off ratio). Hydraulically based intelligent braking systems are discussed in more detail in [16].

<u>Electrically based systems</u>: Modern escalator control systems are equipped with variable speed drives that are used for starting the escalator and running it at different speeds during the day. This drive can also be used to implement the intelligent braking function. Electrically based systems employ the variable speed drive (usually a VF drive) to bring the escalator to a standstill and then apply the mechanical brakes as holding devices. In this case the mechanical brakes that are used for conventional braking become merely parking brakes applied once the escalator has come to a standstill. The inverter used on this system does not employ closed loop feedback and it relies on the fact that the motor will follow the speed that is set by the frequency sent by the drive.

An example of the performance of an electrically based intelligent braking system is shown in Figure 4. It is clear from the figure how the braking system achieves the same deceleration regardless of the load on the escalator [5].

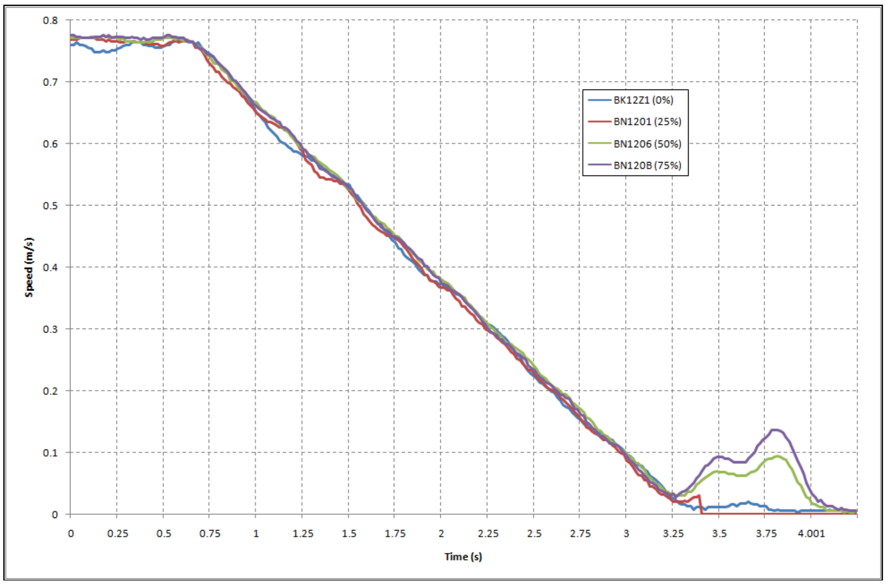

Figure 4 Graph showing the speed-time profile of the stopping escalator under the influence of the variable speed drive under 3 loading scenarios.

Generally, the electrically based intelligent braking system is now becoming more widely used compared to the hydraulically based systems. A comparison is shown below:

1. The electrical braking system is generally found to be faster in responding to the changes in the speed of the escalator, and thus achieves a much closer control on the speed profile.
2. In general, the cost of the electrical braking system is lower than the hydraulically braking system as many of the modern escalators already contain a variable speed drive. In order to implement a hydraulic based intelligent braking system, a special controller is needed as well as a pulse width modulation (PWM) feature in order to control the operational brake valve.
3. The implementation of the electrical braking system contravened older version of the EN115, but this has now been addressed in the latest revision of EN115-1:2008.

9 CONCLUSIONS

There are two modes of failure of escalator braking systems. The first mode of failure is when the escalator braking system is badly adjusted or worn, that is fails to slowdown and stop a fully loaded escalator. This can lead to serious passenger injuries (e.g., suffocation) where the downward speed of the escalator significantly exceeds the rated speed of the escalator. This risk of failure is mainly prevented by regular inspection and maintenance. To avoid the need for weight testing on public service escalators, modern modelling techniques can be used to predict the performance of a fully loaded escalator from deceleration measurements on unloaded escalators.

The second mode of failure is when the braking system causes a harsh stop for the lightly loaded escalator, such that is causes passenger falls. Passenger fall can cause a number of injuries such as cuts, bruises and even finger entrapments between the step side and the skirting.

It is worth noting that the first mode of failure is easily reversible if detected in good time. It is also worth noting that there are other failure modes in the escalator that are irreversible.

Research has been carried out into the relationship between risk of passenger falls and the kinematics of the stop. It has been found that there is strong correlation between the deceleration of the stopping escalator and the risk of passenger falls. Kinematic modelling has also found that a restriction of 1 m/s^2 must be placed on the value of the deceleration of a stopping escalator to prevent passenger falls on a stopping escalator. This value of deceleration can be used in intelligent braking systems.

Intelligent braking systems can be used on escalators in order to control the stopping distance and speed of an escalator, regardless of the fluctuations in the load on the escalator and the direction of travel. Two types of such systems can be used: electrically based and hydraulically based. The electrically based system uses the variable speed drive that is part of the electrical control system of the escalator. The hydraulically based system employs an operational brake hydraulic system with a pulse width modulated valve. The electrically based system has been used with good results and shows accurate control of the stopping speed profile regardless of the load.

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N.B. Reference has been made to the older EN115 standard 2008, rather than the latest standard 2017.

BIOGRAPHICAL DETAILS

Lutfi Al-Sharif is currently the Dean of Engineering Technology and Professor of Electrical Engineering at Al-Hussein Technical University in Amman/Jordan and jointly Professor of Building Transportation Systems at of the Department of Mechatronics Engineering, The University of Jordan. He received his Ph.D. in elevator traffic analysis in 1992 from the University of Manchester, U.K. He worked for 10 years for London Underground, London, United Kingdom in the area of elevators and escalators. He has over 50 papers published in peer reviewed journals and conferences in the area of vertical transportation systems and is co-inventor of four patents and co-author of the 2nd edition of the Elevator Traffic Handbook, and the author of the "indoor transportation" chapter in the Elsevier Encyclopaedia of Transportation.

Uplifting the Safety of Aged Lifts in Hong Kong

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Keywords: Electrical and Mechanical Services Department, Hong Kong, lift safety, aged lifts, regulator, facilitator, promoter, lift modernisation subsidy scheme, special maintenance

Abstract. Hong Kong is one of the most densely populated cities. There are around 70,000 lifts in operation to transport millions of people in the built environment of the territory. The safety of lifts is dependent on proper periodic examination and maintenance. With rapid technological advancement, modern lifts are equipped with more comprehensive safety devices than the aged ones. Lift modernisation could transform aged lifts to deliver more versatile services with enhanced safety, reliability and ride comfort. The Electrical and Mechanical Services Department ("EMSD") of the Government of Hong Kong Special Administrative Region ("HKSAR") of the People's Republic of China acts as the "regulator", "facilitator" and "promoter" for electrical and mechanical safety in the HKSAR. The EMSD has been actively introducing multidimensional measures for uplifting the safety of aged lifts, thereby enhancing public safety. While paying attention to the progress of lift modernisation works, the EMSD has stepped up the surveillance of aged lifts and requested the responsible persons and registered lift contractors to step up the maintenance of aged lifts. At the same time, the Government has made available financial assistance with appropriate professional support to building owners in need to modernise or replace their aged lifts. In the long run, the EMSD will consider mandating measures for lift modernisation by making reference to relevant experience in other jurisdictions, the enactment and enforcement of similar ordinances in Hong Kong as well as taking into account the impact on the community and the trade. This paper will share the experience, effectiveness and challenges faced when implementing measures to enhance the safety of aged lifts in Hong Kong.

1 LIFT SAFETY IN HONG KONG

Hong Kong is a densely populated city packed with skyscrapers and high-rise buildings, where the social activities rely much on its sound and reliable vertical transportation. There are around 70,000 lifts operating diligently to transport millions of people from floor to floor among buildings of which 8,500 blocks are high-rise and about 500 are skyscrapers [1].

1.1 Lifts and Escalators Ordinance in Hong Kong

The safety of lifts in Hong Kong is regulated by the Lifts and Escalators Ordinance (Chapter 618) ("LEO"), which was put into operation on 17 December 2012, to replace the repealed Lifts and Escalators (Safety) Ordinance (Chapter 327). The EMSD, as the regulator, enforces the LEO through various means, such as conducting risk-based audit inspections, carrying out prosecution and disciplinary proceedings, promulgating codes of practice as well as registration of contractors, engineers and workers. In addition to being a regulator, the EMSD also acts as "Facilitator" and "Promoter" for improving lift safety in Hong Kong.

1.2 "Guidelines for Modernising Existing Lifts"

When a lift is put into service for the first time, its design must comply with relevant safety standards prevalent at the time of installation. The latest design requirements are stipulated in the Code of Practice on the Design and Construction of Lifts and Escalators 2019 Edition ("Design Code") adopting the requirements of EN81-20/50. Since the roll-out of the Design Code in 1993, several amendments of the Design Code were made to uplift the safety requirements in line with the prevailing international safety standards and meet with technological advancements to make lifts safer. In view of this, the EMSD promulgated in 2011 the "Guidelines for Modernising Existing Lifts" to facilitate owner of lifts to implement enhancement and modernisation solutions to make their existing lifts safer, more efficient and reliable, and with better ride comfort. The Guidelines adopted requirements from EN81-1:1998+A3:2009 [4], introduce seven application solutions for enhancing existing lifts. The first four solutions (namely installation of (i) double brake system, (ii) unintended car movement protection device, (iii) ascending car overspeed protection device, and (iv) car door mechanical lock & door safety edge) were considered essential and were recommended to be taken with priority, whereas the remaining three solutions (namely (v) installation of intercom & CCTV system, (vi) obstruction switch to protect suspension ropes, and (vii) automatic rescue devices) were recommended to be considered according to the actual situation or individual need (Figure 1).

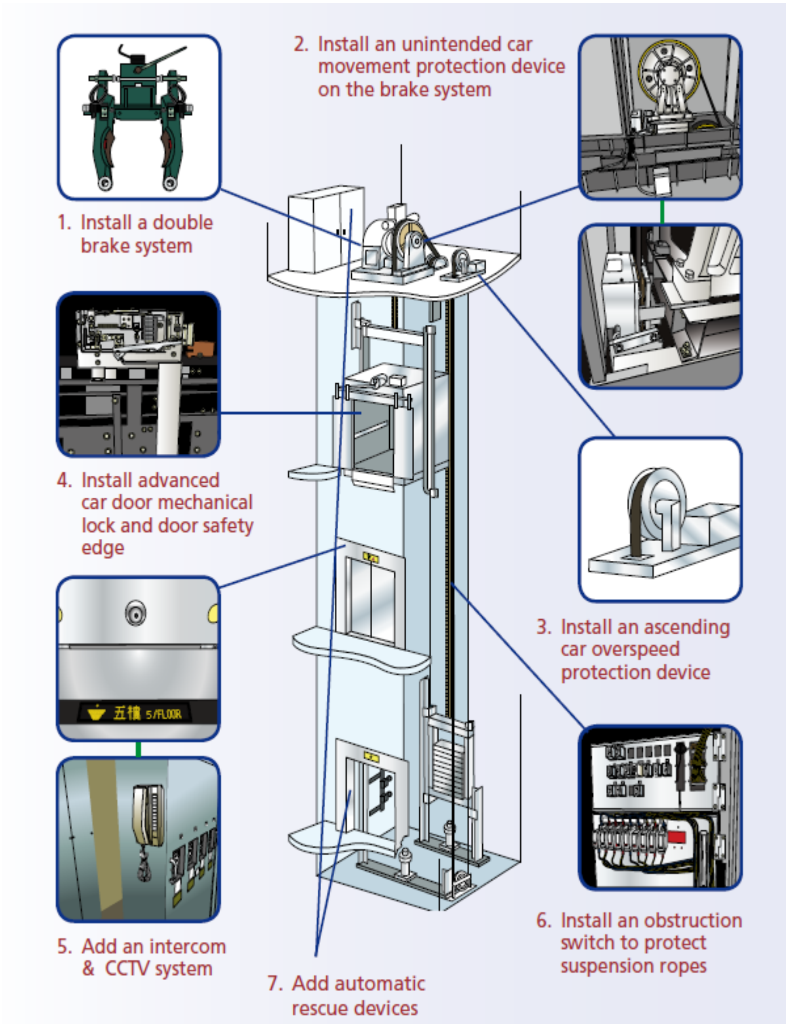

Figure 1 Applicable Solutions for Enhancing Requirements of Existing Lifts

1.3 Aged Lifts and Incidents

As the end 2020, there were about 70,000 lifts in Hong Kong, with over 41,000 lifts (about 60%) aged over 20 years and about 45,000 lifts (about 65%) were not equipped with all four essential modern safety devices (i.e. double brake system, unintended car movement protection device, ascending car overspeed protection device, and car door mechanical lock & door safety edge). Reported lift incident records in Hong Kong revealed that most of the lift incidents were related to passenger behaviors (Table 1) [2]. For those few incidents related to lift equipment fault, most of them were due to poor levelling.

Table 1 Reported Lift Incident Records in Hong Kong (2016 - 2020)

Main Cause of Incidents	Number of Incidents				
	2016	2017	2018	2019	2020
Passenger Behavior	411	449	387	358	225
Lift Equipment Fault	11	8	15	6	11
Injuries to Lift Worker	6	5	2	3	2
	430	462	404	367	238

However, there were a few lift incidents causing serious injury to passengers or even fatality[1]. All of those lifts were installed over 20 years ago and the serious incidents could well be avoided if those lifts had been equipped with the four essential modern safety devices mentioned before.

In response to the above, especially for the two serious lift incidents involving Unintended Car Movement that resulted in serious passenger injury and death in 2018, the Government rolled out a series of measures to enhance the safety of aged lifts in June 2018.

2 STEP UP THE MAINTENANCE WORKS OF AGED LIFTS

The LEO requires that lifts must undergo periodic maintenance by registered lift workers ("RWs") at least once a month[2] and be examined by registered lift engineer at least once a year to ensure the safe operation of the lifts. As short-term measures to uplift the safety level of aged lifts, the EMSD stepped up the surveillance checks of relevant maintenance items to ensure the quality of the inspection and maintenance works carried out by the registered contractors and introduced special maintenance for the aged lifts in June 2018.

2.1 Surveillance Inspections of Maintenance Works

The EMSD increased its manpower to step up the surveillance checks on the maintenance and examination of aged lifts which have not yet been modernised, i.e. not yet equipped with the four essential safety devices. The number of inspections increased from the earlier level of 11,000 inspections per year to about 29,000 inspections per year and about 55% of the inspections were concerned about maintenance works.

2.2 Special Maintenance

The EMSD revised the "Code of Practice for Lift Works and Escalator Works" [3] in 2018 to require aged lifts, which have not equipped with unintended car movement protection device, ascending car overspeed protection device, or double braking system, to have "special maintenance" conducted twice a year, unless alternative requirements have otherwise been specified by the manufacturers.

The scope of special maintenance of aged lift includes:

a. Disassembly maintenance of the braking mechanism for the lift machine brake.
b. Measure the braking distance by performing no-load brake test to ensure compliance with the lift manufacturer's requirements.

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[1] There was a fatal case in 2018 due to uncontrolled car movement of an age lift.

[2] In actual practice, most responsible persons require registered lift contractors to organize RWs to perform periodic maintenance for their lifts twice a month.

c. Check grooves of traction sheave in the lift traction machine to ensure they are in accordance with the lift manufacturer's specifications.
d. Perform no-load traction test for the lift and measure the leveling accuracy to ensure the traction and leveling accuracy are in compliance with the lift manufacturer's requirements.
e. Check the mechanical locks and electrical contacts of all lift landing doors to ensure they are in safe working order.

The special maintenance is meant to enhance the reliability of the critical components of aged lifts which have yet undergone modernisation. To ensure the works quality, the EMSD conducted over 5,000 inspections for the special maintenance works done by registered contractors in 2020.

There was obvious improvement in the performance of aged lifts following adoption of special maintenance and the stepped up inspections. The irregularities found per inspection dropped by about 50% from the third quarter of 2018 to the first quarter of 2021. On the other hand, the EMSD took the initiative to share statistics and summary of inspection findings regularly with the trade to enhance awareness and drive for continuous improvement in uplifting lift safety. The transparency and facilitation have brought greater collaboration with the trade to tackle the safety concerns of aged lifts for the common good of the society.

3 LIFT MODERNISATION SUBSIDY SCHEME

The EMSD always takes on the role of "Promoter" to publicise improvement and enhancement options and solutions for better lift safety. In 2011, "Guidelines on Modernising Existing Lifts" was published and distributed to lift owners, the trade and other stakeholders, recommending owners to modernise their aged lifts. For further expediting lift modernisation, the Government launched a HK$4.5 billion Lift Modernisation Subsidy Scheme ("LIMSS") over seven years starting from the financial year 2019-20 to provide financial incentives and appropriate professional support to building owners in need to carry out lift modernisation works, thereby enhancing the safety of their aged lifts.

3.1 Needs of Aged Lifts Owners

Whilst it is always the primary responsibility of lift owners to upkeep and improve the safety of their lifts and to comply with the legal requirements, lifts installed in buildings would commonly be used by visitors and the general public and so enhancing lift safety would benefit the community at large. From publicity events and communications with aged lift owners, the EMSD recognised that some owners may face difficulties in carrying out modernisation works due to problems of finance, technical knowledge, organisation ability, etc. In view of these difficulties, the EMSD has partnered with the Urban Renewal Authority ("URA") to implement the LIMSS, where the URA in Hong Kong, allows a very experienced statutory body to undertake, encourage, promote and facilitate urban renewal of Hong Kong, with a view to addressing the problem of urban decay and improving the living conditions of residents in old districts.

3.2 Core Elements of LIMSS

The LIMSS is a new initiative in Hong Kong. The development of LIMSS has directed to the correct focus. The LIMSS comprises the following five core elements:

a. **Care-based:** In view of the rateable values reflect the condition of buildings and lifts, the LIMSS focuses on providing subsidies to building owners in need by targeting aged lifts at private residential or composite buildings with relatively low average rateable values.

b. **Safety-based:** Priority is accorded to lifts with higher risk, such as lifts having statutory improvement orders or lifts which have not been installed with the safety devices of the prevalent safety standards.

c. **Resource-based:** Having struck the balance between the availability of resources and attractiveness of the financial incentive to building owners, the LIMSS subsidies 60% of the cost of the modernisation works / replacement works, subject to a cap of HK$500,000 per lift. Additional subsidies are to be provided for elderly owner-occupiers aged 60 or above, subject to a cap of HK$50,000 per domestic unit of buildings having had the lift modernisation.

d. **Capacity-based:** Having regard to the capacity of the industry to avoid inflating market prices and affecting works quality due to the additional lift modernisation works, the LIMSS would roll out in an orderly manner to modernise about 8 000 lifts in batches over seven years starting from 2019-20.

e. **Streamlined procedures:** As the URA is now undertaking various subsidy schemes for building rehabilitation and fire services improvement works, the Government has partnered with the URA in delivering the LIMSS to maximise synergy and facilitate participation by the public.

3.3 Scope of LIMSS

Figure 2 Examples of work scope covered by LIMSS

a. Retrofitting of the following "Essential Safety Devices" under the scheme (the first 4 solutions in the Guidelines for Modernising Existing Lifts).
   i. Double brake system;
   ii. Unintended car movement protection device;
   iii. Ascending car overspeed protection device; and
   iv. Car door mechanical lock and door safety edge.

b. Addition of the following "Optional Safety Devices" (the last 3 solutions in the Guidelines for Modernising Existing Lifts)
   i. Intercom and CCTV system;
   ii. Obstruction switch; and/or
   iii. Automatic rescue device.

c. Lift drive replacement and associated works where it is technically necessary or more cost-effective in order to install the "Essential Safety Devices" and "Optional Safety Devices" specified above (Figure 2).

d. Owners are granted with the flexibility to opt for installation of specified safety devices or carrying out complete replacement of their lifts.

e. Subsequent follow-up services during defect liability period for the related safety devices above, but exclusive of routine maintenance services (it is emphasized that the LIMSS is not intended to subsidise lift maintenance services as which should be the sole responsibility of the owner to ensure that lifts are in a proper state of repair and in safe working order).

Free consultancy services would be assigned to the Applicant. If the Applicant opts to appoint their own consultant to co-ordinate the lift modernisation works, relevant consultancy fee will be subsidised.

3.4 Technical Assistance and Other Associated Support

Consultants are assigned to participating buildings for pursuing lift modernisation works and technical advice services. The services include scope assessment, cost estimation for budgeting purpose, tender document preparation based on standard tender document templates, tendering through e-tendering platform, tender evaluation, works supervision and contract management associated with the lift modernisation works.

It is inevitable that building owners' access would be affected during lift modernisation works, especially for buildings with single lift or with floors served by one lift only. As such, under the LIMSS, the URA has also engaged non-government organizations to provide outreach social services to the needy residents, such as the aged and the disabled, of these buildings in order to minimise inconvenience caused to them by the lift modernisation works. Such outreach social services include delivery of meals, procurement of daily supplies and provision of stair-climber services, temporary accommodation etc.

Two rounds of applications for the LIMSS were launched in Mar. 2019 and Jan. 2020. Very encouraging results of applications for more than 8,200 lifts were received, meaning that the launch of LIMSS has correctly addressed the need of building owners.

4 FACILITATION AND PROMOTION OF LIFT MODERNISATION

Equal weight has been given to coordination of the trade and industry, and promotion to the public for smooth implementation of the lift modernisation scheme, such as LIMSS.

4.1 Attraction of New Blood to the Industry

In accordance with the LEO, all lift works are required to be carried out by RWs or any person under the supervision of a RW. RWs are specialised technicians for carrying out lift works including installation, commission, maintenance and repair works. It was foreseeable that launching of the LIMSS might increase the demand for RWs.

In order to alleviate manpower shortage in the trade, the EMSD partnered with the Construction Industry Council ("CIC") to expand the coverage of the Intermediate Tradesman Collaborative Training Scheme ("ITCTS") launched in 2017 to training of lift technicians. Under the scheme, trainees are recruited on a first-hire-then-train basis and primarily trained on-site. This is a 6-month training, jointly provided by the CIC and lift companies, consisting of two parts. The two parts are respectively a 12-day initial training, giving trainee general knowledge of background and skills required for performing lift works, and an on-site practical training where trainee will perform actual works under the guidance of their employers. To ensure the quality and progress of the training, the CIC regularly conducts site visits to the workplace and inspects training progress of trainees by prior arrangement with the trainers. Towards the end of the scheme, trainees will have to complete a certification test in order to ensure their knowledge and skillsets are up to the requirements before granting certification test bonus. Employers will also receive an employer completion bonus after that.

Trainees, who have completed the ITCTS, will be eligible to join the Advanced Construction Manpower Training Scheme – Pilot Scheme (ACMTS – Pilot Scheme) and proceed on with their career path in the trade. The scheme has successfully helped attract young newcomers to join the industry, alleviating the manpower demand.

4.2 Promotion of Lift Modernisation

Since the release of the "Guidelines on Modernising Existing Lifts" in 2011, the EMSD has started promoting lift modernisation via various means for lift owners to uplift the safety standard of aged lifts. To synergise with the launch of LIMSS in 2018, EMSD conducted a series of publicity activities. As revealed in the announcement of public interests, the proper safeguard for aged lifts is not personal protection equipment, but lift modernisation (Figure 3). The message of lift modernisation, delivered in a laymen's tone, was direct and easily understood by the general public.

Figure 3 API of Lift Modernisation Subsidy Scheme in 2019[3]

In addition to the television and radio announcements, posting advertisements on newspapers and bus bodies, etc., the EMSD has also delivered and participated in numerous public briefings, seminars, owner's meetings, district council meetings, etc. (Figure 4 and 5), to promote the lift modernisations and lift safety.

Figure 4 and 5 Mass briefing and Online briefing for promoting Lift Modernisation

[3] Full API of LIMSS available online at https://www.isd.gov.hk/eng/tvapi/19_eg91.html

4.3 Facilitation to Upkeep Lift Safety with Technology

As one of six smart areas under the "HKSmart City Blueprint" induced by the Government since 2017, the "Smart Government" concept has guided the EMSD to have more initiatives on adoption of technology for enforcement of legislative requirements as well as facilitating the trade to use innovation technologies on their daily works. The EMSD launched the E&M InnoPortal[4] (F6) which lists the service wishes of various government departments, public organisations and the electrical and mechanical trades, and invites the I&T sector, including start-ups and universities to propose relevant I&T solutions for matching. Up to June 2021, more than 750 I&T solutions and 350 I&T wishes were collected for matching, and over 130 trial projects were started and completed in the past few years. One of the successful matching between the I&T solutions and wish items on the portal is the development of e-log book of lifts and escalators.

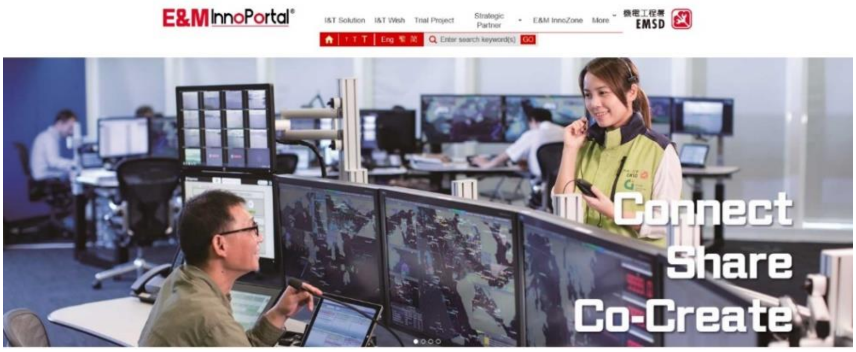

Figure 6 E&M InnoPortal Website

In Hong Kong, it is a statutory requirement for responsible persons[5] to keep and maintain a log-book for their lifts. The log-book must be in the specified form, containing information such as: (i) description of the lift, (ii) name and contact details of registered contractors who undertake maintenance works, and (iii) particulars of every incident of the lift concerned. Responsible persons are required to keep track of the entries of the log-book to ensure works by registered contractors are accomplished and on schedule.

There are approximately 26,000 conventional paper-bound log-books in Hong Kong. Some responsible persons may pay less attention to the statutory requirements for the upkeep of log-books, leading to unnecessary sanctions or warnings, while other responsible persons may find paper-bound log-books cumbersome to trace and summarise different maintenance logs and occurrences for monitoring and ensuring timely execution of lift works. Thus, a new way of logging and analysing these data has been proposed by the EMSD.

To facilitate stakeholders to better manage, analyse and monitor lift works, the EMSD has proposed to develop a common electronic platform, viz. digital log-book, to replace the paper-bound log-books. The digital log-book will be accessible on both mobile devices and desktop computers, adopting a newly designed user-interface, offering user-friendliness and easy information access to responsible persons and trade personnel. It can also strengthen the Government's monitoring/regulatory control as well as encouraging compliance and enhancing works quality. The system, capable of uploading of images, audios and videos of lift works carried out will aid incident investigations and equipment fault analysis. The works and entries recorded for each lift generated every day will be analysed for insights leading to setting of performance indicators for quality assessment, better strategic regulatory moves and policies for healthy trade developments. Automatic alerts will be dispatched to

[4] The E&M InnoPortal https://inno.emsd.gov.hk/en/home/

[5] According to the Lifts and Escalators Ordinance (Chapter 618) in Hong Kong, the responsible person for a lift is defined as (1) the owner of the lift; or (2) any other person who has the management or control of the lift.

responsible persons and registered contractors, reminding statutory activities and the relevant submissions are due, safeguarding stakeholders from contravening the legislative requirements. All in all, the digital log-book combining with big data analysis will facilitate all trade parties to work hand-in-hand to enhance lift safety.

5 Conclusion and the Way Forward

Looking into the long run for addressing the safety issues of aged lifts, the EMSD has been studying the feasibility of mandating measures for lift modernisation. The EMSD will make reference to relevant experience in other jurisdictions, the enactment and enforcement of similar ordinances in Hong Kong as well as taking into account the impact on the community and the trade in formulating the resolution proposal. In this connection, EMSD will consult the public, legislators and the trade in due course.

Recently, the EMSD has conducted a benchmarking study to review 10 overseas jurisdictions (i.e. Germany, Belgium, France, UK, New York City, California, Tokyo, South Korea, Singapore and Shenzhen) on regulatory measures over aged lift modernisation. The study results reveal that financial subsidy and mandatory risk assessment of modernisation are two major measures to drive for upgrading or replacement of aged lifts. The EMSD would further explore the possibilities of adopting similar measures in Hong Kong.

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BIOGRAPHICAL DETAILS

Ir Vincent H.K. CHOW is the Chief Electrical and Mechanical Engineer of the EMSD, Government of the HKSAR. He have diversified managerial experience in the regulation of lift, escalator, amusement ride, fuel gas and electrical systems as well as implementing government policy and schemes. He is currently overseeing the stepped-up inspection of aged lifts, the implementation of LIMSS as well as the feasibility study and proposal of long term mandatory measures of aged lifts in Hong Kong. Ir CHOW is a Chartered Engineer in the Engineering Council of the United Kingdom, a Member of the Institution of Mechanical Engineers, a Member of the Institution of Gas Engineers & Managers and a Corporate Member of Hong Kong Institution of Engineers.

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Brake Failures on Lifts

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Keywords: Lift, runaway, rollback, accident, passenger safety, brake, overtravel, uncontrolled movement.

Abstract. Brake failures affect many types of equipment and whilst many efforts have been made in standards to improve the outcome of a brake failure they still occur. The consequences of a failure can range from a near-miss to one or more fatalities. Many service technicians take the view that with the introduction of variable frequency drives into the lift and escalator industry that the brake no longer needs maintaining. This paper will demonstrate that this opinion is incorrect. The paper will look at what happens when a brake fails, the causes of brake failure, examples of brake failures and how recent standards have developed to reduce the risk of brake failure.

1 THE FUNCTION OF THE BRAKE

The function of a lift brake has changed over recent years with developments in drive systems.

Older systems such as single speed and two speed designs relied on the brake itself to bring the lift to a stop during an ordinary journey and the levelling accuracy would be dependent upon the condition of the brake pads, the load in the lift car relative to balance and the position of the lift in its shaft. With these drive systems the brake was also used to bring the lift to a safe stop in the event of a power supply fault or a control system situation (such as a high speed lock tip). The regular maintenance of the brake in this situation is vital.

Older but more sophisticated drive systems such as the DC Ward Leonard system or the DC static converter drive were designed such that the motor would bring the lift to a stop at a landing and then the brake would apply to hold the lift car for loading and unloading. Similarly these drive systems were required to bring the lift to a safe stop in the event of a power supply fault or control circuit situation previously described.

Modern drive systems such as the AC VV and the variable frequency drives are similar to these however maintenance is still required as situations such as high speed lock tips can still occur and cause premature wear of brake pads.

2 WHAT HAPPENS WHEN A BRAKE FAILS?

A lift can be compared to a set of scales with the heaviest side of the balance equation between the car and counterweight being the side that descends when left to gravity.

In many cases when a brake fails the lift car will run upwards due to the counterweight being heavier than a lightly loaded lift car.

As the counterweight descends, where no compensation exists, the lift car ascent increases in speed as the suspension ropes pay out onto the counterweight side.

Modern lifts are fitted with uncontrolled movement devices that will detect and arrest a runaway condition such as previously described but many lifts were installed prior to this recommendation in the standards and do not have such a facility. It should be remembered that uncontrolled movement may be caused by other situations other than a brake failure.

In addition, many older lifts using single speed or two speed drive systems rely on the brake for stopping and the accuracy of the car to landing threshold is reliant on the condition of the brake, position of the lift in the shaft and the load in the car.

3 EXAMPLES OF BRAKE FAILURES

There are many ways that a brake can fail and these include electrically and mechanically.

Examples include:

1. Brake solenoid going open circuit (single solenoid)
2. Brake solenoid going open circuit (twin polarised type)
3. Physical wear of brake pad
4. Rivets coming loose on brake pad
5. Lubricant on brake pad
6. Stuck in open position – release mechanism failure
7. Stuck in open position – other mechanical failure (such as a single line component e.g. a split pin)
8. Held in open position – residual magnetism
9. System overloaded
10. Poor adjustment
11. Overheating

The failures at 1 & 2 can allow the lift to drive through the brake and if not detected early enough can lead to physical wear and ineffectiveness of the brake as at 3.

In some cases one or more of these situations can come together to create an uncontrolled movement scenario.

For instance lubricant on a brake pad plus physical wear may lead to the uncontrolled movement scenario occurring earlier than it would have done had the pad been in good order. It is, in this situation, an external influence i.e. the lubricant probably leaking from a gearbox shaft causing the failure.

Physical wear on brake pads on modern variable frequency drive lifts should not be a problem in theory but in reality uncontrolled movement has been seen when a variable frequency drive is able to drive through brake pads which is particularly prevalent when a lightly loaded lift car is in the upper reaches of the lift shaft and the suspended masses are heavier on the counterweight side.

It is difficult to cite specific cases where brake failures have occurred especially where they were the subject of legal investigations and even more so where fatal injury was sustained however there are some reports in the public domain that can be referenced [1].

There are still a number of brake release mechanisms around that can leave the brake in the open position thus allowing the lift car to move uncontrollably.

Photograph 1 Example of a brake release that can permanently jam open

4 MECHANICAL FAILURES

An early failure of a lift brake was recorded following the Markham Colliery failure on 30th July 1973 where a single line component failed. This was a significant case in that it highlighted issues around single line components and yet many years later EN81-80 (2019) 8.1 [2] acknowledges that inadequate braking systems are an issue. Interestingly the EN81-80 (2003) [3] edition did not acknowledge this.

CONCLUSIONS

70. I conclude that:

(i) the disaster was caused by the complete failure of the mechanical brake of the winding engine because the spring nest centre rod which was a 'single line' component, broke. The design of the trunnion did not take account of the high pressures due to the spring nest, and the main lever could not rotate freely about the trunnion axle which had no practicable means of lubrication. Consequently, operation of the brake produced bending forces and induced fluctuating stresses in the rod which it could not sustain. Cracks developed in the rod and one of them extended until failure occurred;

Source 1 Markham Colliery Report [1]

The requirement to eliminate single line components has been part of the philosophy of ongoing standards for many years which is looked at later in this paper.

'Single line' components

54. The centre rod in the spring nest is an example of a 'single line' component as the safety of the men in the cage was completely dependent upon it. Such components should either be eliminated or so designed as to prevent danger, for example, failure of any 'single line' component in a braking system should cause the winding system to be brought safely to rest. Overspeed and overwind protection should not rely on single components, but where this is not possible they should be reliable and monitored to give warning of failure, or, alternatively, they should fail safe. All winding engines which are dependent upon only one brake path should be modified as should those where automatic application of the brakes is dependent on a single solenoid. Furthermore, there should be indication of any electrical fault in a safety circuit which could render it ineffective or, alternatively, the winding engine should be automatically brought to rest if a fault occurs in a safety circuit which would give rise to danger.

Source 2 Markham Colliery Report [1]

An example of a single line component failure could be experienced on a typical lift brake as below and components including the plate at G being retained by a split pin, or the rod at H failing.

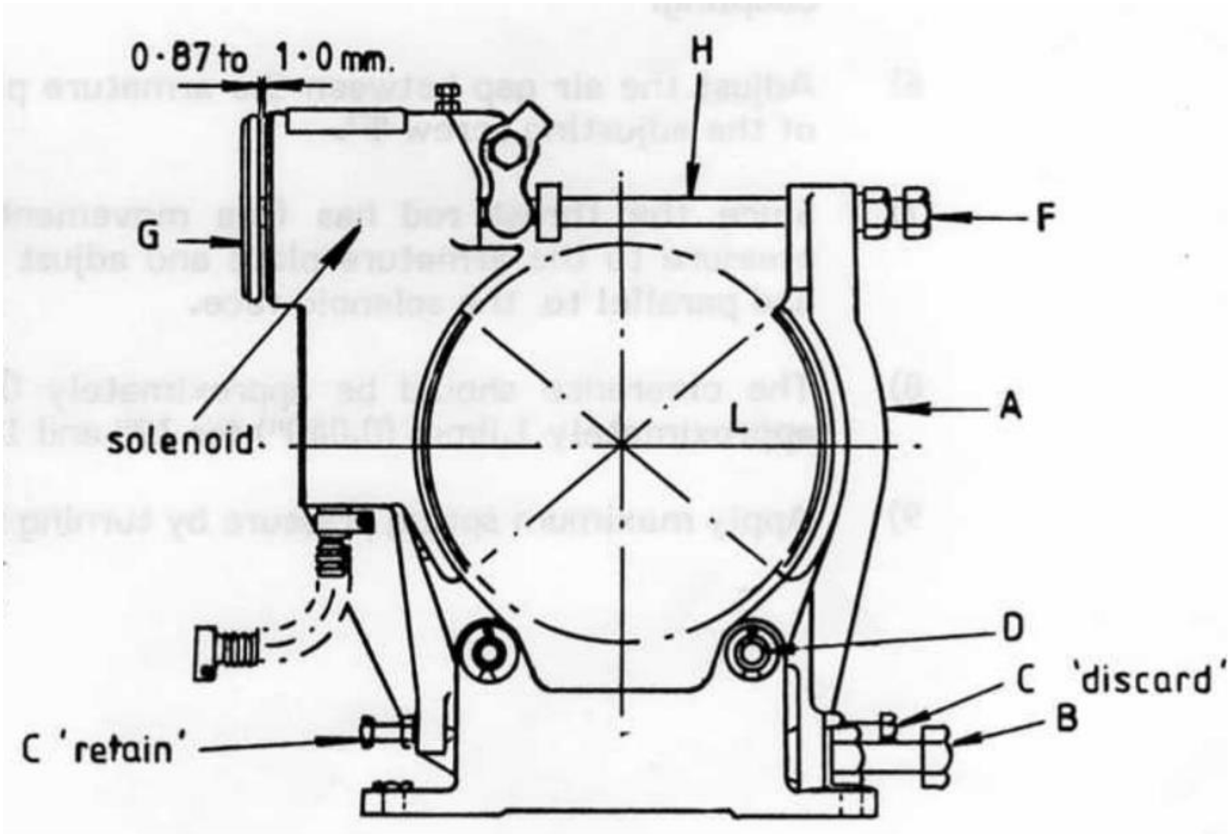
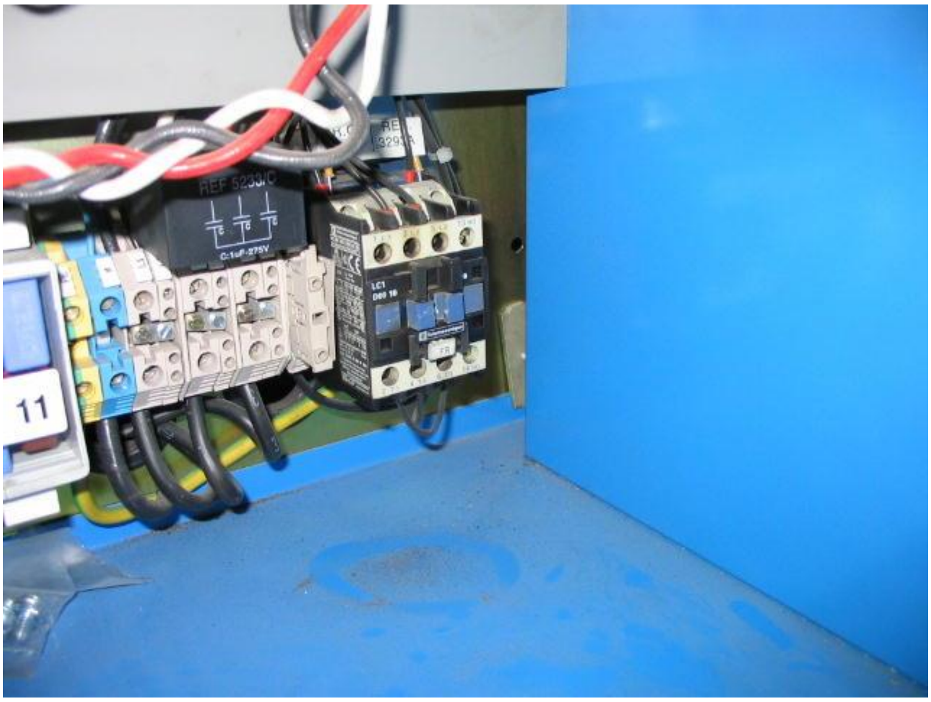


Figure 1 Typical Old Style Lift Brake [4]

5 ELECTRICAL FAILURES

Electrical failures, including the single solenoid going open circuit in the diagram above could result in a brake failure but other contributory factors could be present including high resistance on brake contactors meaning that the brake only lifts partially making it easy for a variable drive system to drive through the brake thus accelerating wear until eventual failure and lift car uncontrolled movement (runaway) occurs.

The photograph below shows a brake contactor that was involved in an uncontrolled movement incident as a result of the brake contactor not having been replaced in a timely fashion. The lift industry more often than not waits for something to fail as the impulse to initiating component replacement [5].



Photograph 2 Build up of carbon dust under the brake contactor indicating oncoming problems.

In another industry technical information notice [6] thermal fuses were fitted to lifts where the brake shoe temperature became excessive.

4. Field Solution:

To fit thermal fuses to the brake shoes that will trip when the brake shoe temperature exceeds 71 C. This will render the lift out of service when it reaches its destination. The lift will be unable to go back into service until the thermal fuse is replaced before which the cause of the overheating should be investigated and rectified

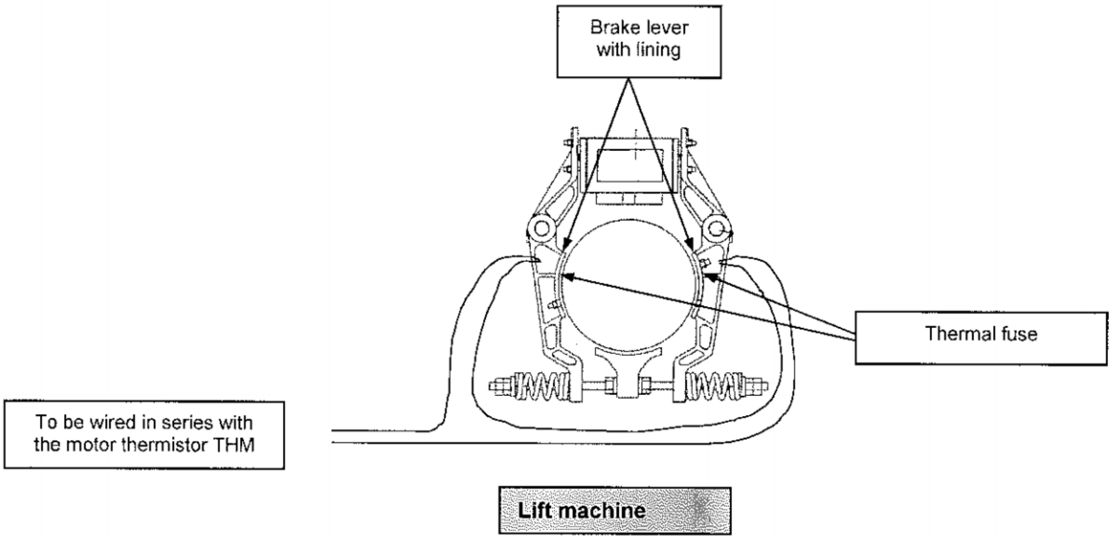


Figure 2 Industry manufacturers technical information sheet [6]

6 DEVELOPMENT OF STANDARDS

Over the years there have been many improvements in braking systems for lifts including the introduction of the A3 amendment for uncontrolled movement however this dealt with the symptom of brake failure rather than the cause.

The current edition of EN81-20 [7] includes uncontrolled movement detection and also the requirement for brake components to be in two sets this offering redundancy and monitoring of the brake itself for correct operation.

5.6.7.2 The means shall detect unintended movement of the car, shall cause the car to stop, and keep it stopped.

5.6.7.3 The means shall be capable of performing as required without assistance from any lift component that, during normal operation, controls the speed or retardation, stops the car or keeps it stopped, unless there is built-in redundancy and correct operation is self-monitored.

5.9.2.2.2.1 This brake on its own shall be capable of stopping the machine when the car is travelling downward at rated speed and with the rated load plus 25 %. In these conditions the average retardation of the car shall not exceed that resulting from operation of the safety gear or stopping on the buffer.

All the mechanical components of the brake which take part in the application of the braking action on the braking surface shall be installed at least in two sets. If one of the brake sets is not working due to failure of a component a sufficient braking effort to decelerate, stop and hold the car, travelling downwards at rated speed and with rated load in the car and upward with empty car shall continue to be exercised.

As has already been mentioned the EN81-80 (2003) [3] standard didn't mention inadequate braking systems however the 2019 version [2] has been expanded to include this situation.

7 CONCLUSIONS

The author is of the opinion that:

- Older lifts with single line components in the braking system need to be assessed.
- All brakes should be fitted with lift detection switches.
- Where modernisation takes place and an old style brake is retained and a variable frequency drive is fitted to replace an older system such as single speed, two speed etc there is a real risk that the lift can drive through a closed brake.
- Prevention is better than cure and methods of detecting the depletion of braking efficiency should be developed so as to detect rather than respond to a failure situation. The potential for uncontrolled movement should be detected before it actually happens.
- Checking of brake condition and adjustment is still an essential part of the maintenance regime as extraneous situations such as high speed lock tipping can affect braking performance.

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BIOGRAPHICAL DETAILS

David Cooper is the Managing Director of UK based lift consultants LECS (UK) Ltd. He has been in the lift & escalator industry since 1980 and is a well-known author and speaker. He holds a Master of Philosophy Degree following a 5-year research project into accidents on escalators, a Master of Science Degree in Lift Engineering as well as a Bachelor of Science Honours degree, Higher National Certificate and a Continuing Education Certificate in lift and escalator engineering. He is a co-author of "*The Elevator & Escalator Micropedia*" (1997) and "*Elevator & Escalator Accident Investigation & Litigation"*. (2002 & 2005) as well as being a contributor to a number of other books including CIBSE Guide D. He is a regular columnist in trade journals worldwide including Elevation, Elevator World and Elevatori. He has presented at a number of industry seminars worldwide including 2008 Elevcon (Thessaloniki), 2008 NAVTP (San Francisco),1999 LESA (Melbourne), 1999 CIBSE (Hong Kong), 1999 IAEE (London), 1998 (Zurich), 1997 CIBSE (Hong Kong), 1996 (Barcelona) and 1993 (Vienna) as well as numerous presentations within the UK. He is also a Founding Trustee of the UK's Lift Industry Charity which assists industry members and/or their families after an accident at work. In 2012 David was awarded the silver medal by CIBSE for services to the Institution. David Chairs the Charitable Trust that runs the Lift Symposium and is an Honorary Visiting Professor in Lift Engineering at The University of Northampton.

A Brief History of Lift Safety Devices 1835-1935

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Keywords: history, safety devices.

Abstract. The history of lift technology is, essentially, the history of lift safety devices. Passenger safety has always been a primary focus of the lift industry and all aspects of lift technology are typically designed with regard to safety. For over 175 years the invention of safety devices has followed a developmental pattern predicated on an assessment of risk, the needs of different lift types, lessons learned from actual lift operation, and changes in lift systems and technologies. Critical safety concerns have included rope failure, overspeed, access to lift cars and shafts, automatic door operation, and leveling. This paper will offer a chronological outline of the development of lift safety devices and will, when possible, link the appearance of a given safety device to a specific cause, determining factor, perceived problem, or change in use. This paper examines the first 100 years of lift safety devices and will reveal that the development of these systems followed both logical and (occasionally) somewhat illogical paths.

1 INTRODUCTION

The following outline of the history of lift safety devices from 1835 to 1935 touches on some of the key developments that occurred in England and the United States during the period under investigation. The primary materials examined for this study include the American patent record and scholarship produced by the author over the past twenty years. This paper does not attempt to present a comprehensive history of lift safeties. The goal is to provide an outline that highlights key moments in this important story.

2 1835: THE TEAGLE

The design of William Strutt's North Mill at Belper, England, built in 1803/04, included the installation of one of the first mechanized lift systems [1]. The machine, which became known as a "Teagle," was a belt driven platform lift used for transporting goods and workers in the five-story mill. A description of the lift published in 1835 revealed that between 1804 and 1835 several safety systems were added to the original lift. These included a shaft safety gate and safety stops. The safety gate was designed to prevent the gate from being opened if the lift platform was not present at the landing. The safety stops were balls placed on the shipper rope such that, if the car passed the upper or lower landing it would strike a ball, which would move the shipper rope and stop the lift's movement (Fig. 1). The origin of these safeties is unknown. They were likely developed in response to lift accidents that occurred in the mill.

3 1854: SAFETY HATCHES

The first patent for a lift safety device appeared in 1854 and concerned a design for automatically operating shaft hatches, which were located at each floor [2]. Invented by Daniel Tallcot, the safety was designed to ensure that unwary factory or mill workers could not fall down the lift shaft. As the lift platform moved through the shaft it encountered a cam and spring system that opened and closed the hatches (Fig 2.) In his patent text Tallcot reported that, although many lifts employed shaft doors, these were often left open and thus accidents occurred.

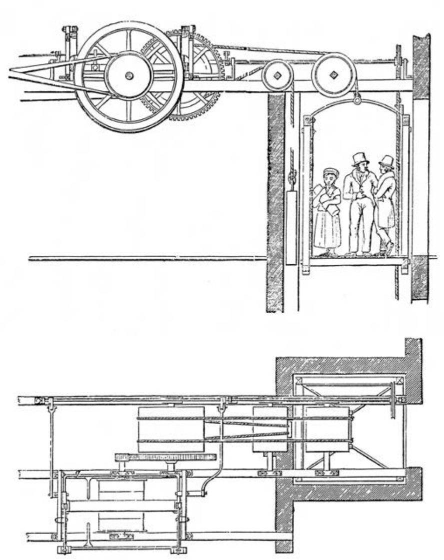

Figure 1 The Teagle, William Strutt's North Mill, Belper, England (1835)

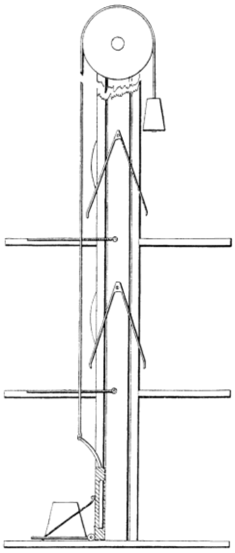

Figure 2 Safety Hatch, Daniel Tallcot (1854)

4 1854: THE RATCHET & PAWL SAFETY DEVICE

In 1854 Elisha Graves Otis exhibited his ratchet & pawl safety device at the New York Crystal Palace (Fig. 3) [1, 3]. Otis was the first to propose integrating a safety into the design of the lift platform. His device was intended to ensure that the platform would not fall if the hoisting rope failed. His exhibition also marked the first (and possibly only) public exhibition of the operation of a lift safety device. Although he initiated the process to patent his design in 1854, Otis later withdrew this application [1].

5 1856: THE FIRST RATCHET & PAWL SAFETY DEVICE PATENT

In 1856 Hugh Baines, an architect practicing in Manchester, England, received a patent for a ratchet and pawl safety device that resembled Otis' design in its proposed operation, whereby if the hoisting rope broke ratchets would be released and engage racks, thus stopping the lift platform (Fig. 4) [4]. Baines claimed that his invention represented:

> a novel method of stopping or retaining the ascending or descending room, chamber, or box employed in "hoists" in warehouses, mills, factories, pits, etc., for conveying persons and goods from one floor or height to another, in the event of the rope breaking, or the occurrence of any other equivalent accident, which would cause or allow the room or chamber to fall to the bottom of said shaft, thereby endangering life and property [4].

While the inventor's rationale focused on the most common cause of lift accidents – rope failure – he also alluded to other unspecified causes of accidents.

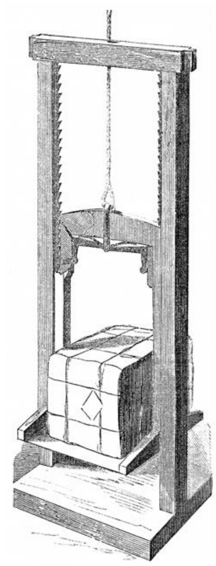

Figure 3 Elisha Graves Otis safety exhibited at the New York Crystal Palace (1854)

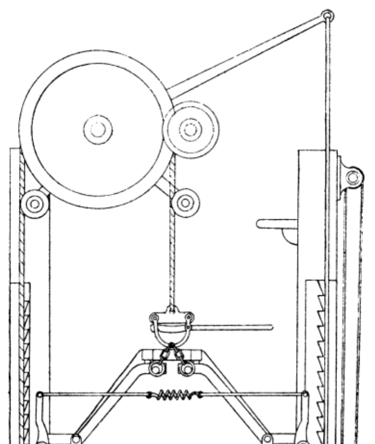

Figure 4 Hugh Baines, Ratchet and pawl safety patent (1856)

6 1857: THE FIRST SAFETY DEVICE TEST ACCIDENT

In addition to receiving the first patent for a ratchet and pawl safety device, Baines has the unfortunate distinction of beging the first to be involved in a safety test accident [5]. In April 1857 he had his safety installed on an existing lift in Pender & Co.'s Warehouse in Manchester. The lift, carrying four passengers (including Baines), was raised to the top floor, and the hoisting ropes were "disconnected." The safety failed to act and the car fell 60 feet to the bottom of the shaft, resulting in one fatality, two serious injuries, and the inventor receiving a "severe laceration of one foot" [5]. The cause of the safety's failure is unknown (Baines alleged that previous tests had been successful). This tragic event reveals an aspect of safety development that remains unexplored: the history of lift safety testing.

7 1859: THE FIRST AIR CUSHION SAFETY DEVICE

In 1859 Albert Betteley patented the first "air cushion" safety device [6]. The lift platform featured a tapered "parachute" like structure that, when it entered a reservoir at the base of the shaft would compress the air in the reservoir, which would be slowly released around the edges the platform (Fig.5). Betteley's rationale was that there was a clear need to supplement existing rachet and pawl safeties because of their "inefficiency in preventing the fall of the car in many cases, as for instance when some part of the machinery gives way beyond the rope, or where, as may be the case, the rope breaks and is subject to sufficient friction to keep the pawls from falling into the rack until the car acquires such a momentum as to destroy the racks and pawls when they act" [6].

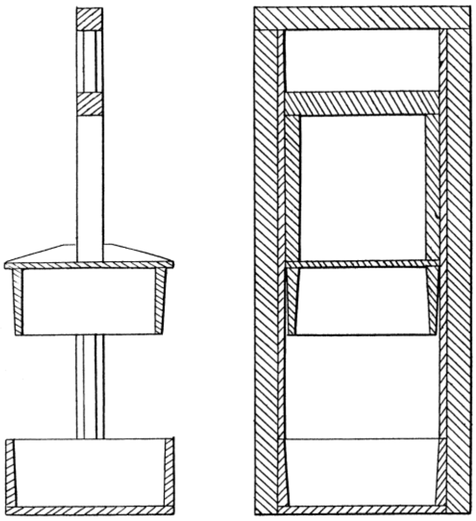

Figure 5 Albert Betteley, Air cushion safety device (1859)

8 1859: THE VERTICAL RAILWAY

In 1859 Otis Tufts patented his "vertical railway" elevator that replaced hoisting ropes with a screw-shaft that extended the height of the building with the car traveling along the shaft (Fig. 6) [7]. His goal was to avoid the "extreme and ordinary dangers of suspension upon chains, ropes, or cords of any kind, in the safety of which, every additional experience has led me to place less and less reliance" [7]. In addition to eliminating hoisting ropes, Tufts provided other safeties, including a speed governor, an automatic safety stop (located at the top of shaft) and a buffer (located at the bottom of shaft). He was also the first lift designer to propose using an enclosed car to carry passengers (in order to ensure their safety), and he was one of the first to place the controller or shipper rope inside the car.

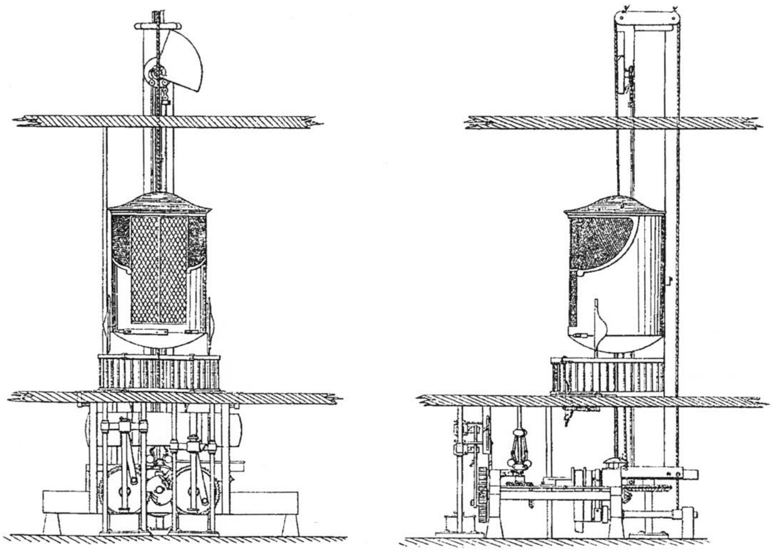

Figure 6 Otis Tufts, Vertical railway elevator (1859)

9 1859: THE FIRST INTERLOCK DOOR SAFETY DEVICE

In 1859 Albert Betteley patented the first interlock door safety system that featured interlocking shaft and car doors [8]. It employed a device operated by a series of cams and springs such that, when the car door was open, the safety automatically "grasped" the shipper rope and prevented its use, thereby holding the car stationary (Fig. 7). Betteley's use of ordinary hinged-doors followed the established door-type used on lifts at this time.

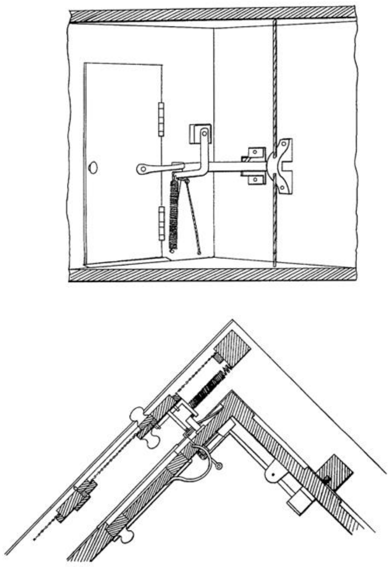

Figure 7 Albert Betteley, Interlock door safety device (1859)

10 1859: THE FIRST SAFETY LIFT

In a December 1859 advertisement for his lift company, Elisha Otis stated that "not a single" accident had occurred to one of his "improved safety elevators" [9]. This marked the first use of the phrase "safety elevator" in the United States. From this date forward, most manufacturers referred to their products as "safety elevators" or "safety lifts."

11 1861: THE SECOND RATCHET & PAWL SAFETY DEVICE PATENT

In 1861 Elisha Otis finally patented his ratchet and pawl safety device (Fig. 8) [10].

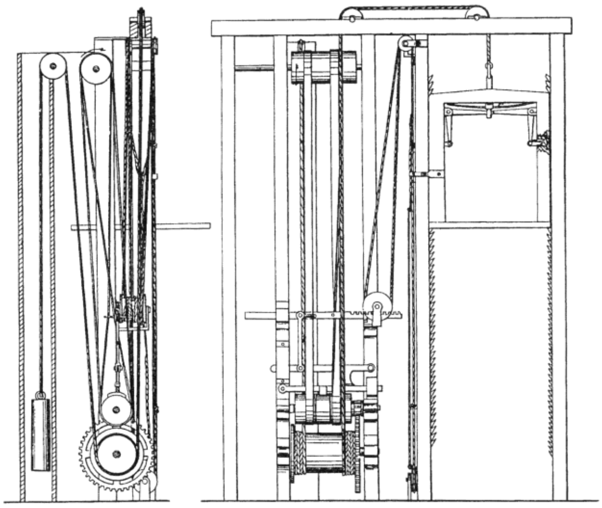

Figure 8 Elisha Otis, Ratchet and pawl safety device patent (1861)

12 1861: AN EARLY OTIS ELEVATOR ACCIDENT

On February 1, 1861 an accident occurred involving one of Otis' improved safety elevators [11]. Following routine maintenance (which involved replacing the hoisting rope) on an Otis lift in Struelens & Palmer's factory in New York, the lift traveled to the fifth floor here it was loaded with goods. As the lift began to descend the hoisting rope, which had not been properly secured, came loose and the car fell. The safety did not engage until the lift reached the second floor. The resulting "force of concussion" killed an employee on the lift and injured Nazaire Struelens, who had been standing near the second-floor lift entrance [11]. Following an investigation, Elisha Otis reported that the car's framework "had been racked out of shape in such a manner as to prevent the operation of the safety spring" [12]. Otis also stated that he had "never warranted elevators to be *perfectly safe*, as their safety depends in some measure upon their reasonable care and usage by the operator, over whom I can have no control" [12]. This was one of the first public acknowledgements that safe lift operation was not solely dependent on the efforts of lift manufacturers. The tragedy of this accident was compounded in March 1861 when Struelens, while reaching for the shipper rope, slipped and fell down the unguarded shaft to his death [13].

13 1864: THE FIRST OVERSPEED SAFETY (DIRECT ACTION HYDRAULIC LIFT)

In 1864 Easton, Amos & Sons designed a speed regulator for use on the direct-action hydraulic lift installed in the Brighton Hotel (Fig. 9) [14]. The regulator was described as:

> a cast iron box or chamber, through which the water passes on its way to and from the cylinder, and in which is suspended on a center a brass quadrant, the face of which fits accurately the face of both the inlet and outlet passages … When the velocity of the water, in either direction, does not exceed that decided upon, the swinger hangs

> in a vertical position without moving, but the instant the velocity increases beyond that point … the swinger rises and closes the passage to such an extent as to reduce the speed to the normal velocity [14].

The safety was unusual in addressing the possibility of overspeed in a hydraulic lift. This device was also the first to address overspeed in the "up" direction.

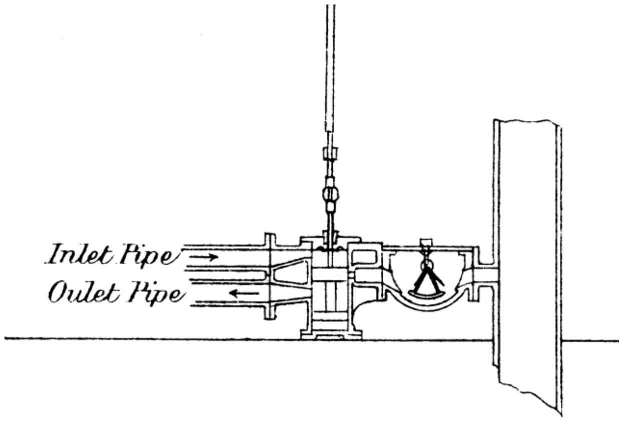

Figure 9 Easton, Amos & Sons, Overspeed safety for a direct-action hydraulic lift (1864)

14 1865: THE FIRST OVERSPEED SAFETY (STEAM POWERED LIFT)

In 1865 Charles R. Otis patented the first overspeed safety designed for use on steam powered, winding drum lifts (Fig. 10) [15]. The design employed a safety drum located at the top of the shaft, which used a flyball governor to control the action of a brake. The safety was attached to car such that the car's speed determined the governor's rotational speed. If the car exceeded a predetermined speed the governor would activate the brake. Charles Otis, acknowledging earlier criticisms of his father's original safety device, stated that the overspeed safety was needed in the event of an accident where the action of the falling car failed to trigger the ratchet and pawl safety.

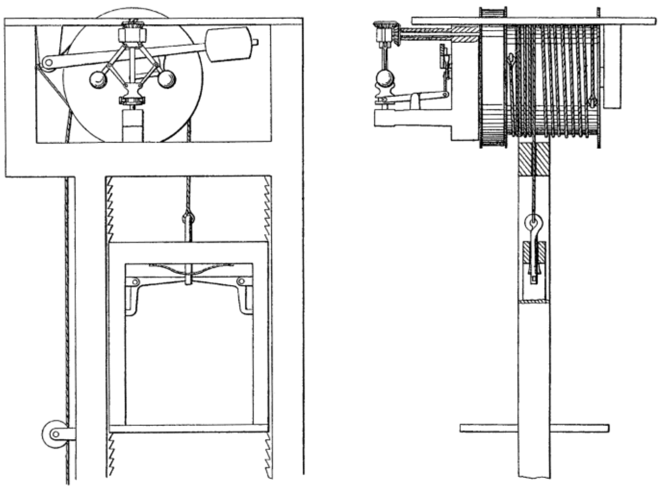

Figure 10 Charles R. Otis, Overspeed safety for a steam powered lift (1865)

15 1879: THE SECOND AIR CUSHION SAFETY DEVICE

In 1879 Albert C. Ellithorpe patented the second "air cushion" safety device (Fig, 11) [16]. His rationale and design were similar to Betteley's, with the primary difference between the two designs being the addition of an automatic air valve that opened to admit air into shaft as car ascended and closed as the car descended. Ellithorpe also recommended the use of sliding doors to keep the shaft as "air tight" as possible. The critical difference between these inventions was the fact that, unlike Betteley, Ellithorpe was able to successfully market his safety device across the United States.

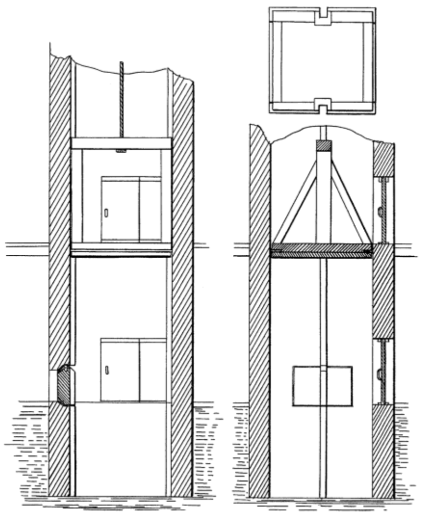

Figure 11 Albert C. Ellithorpe, Air cushion safety device (1879)

16 1884: (ANOTHER) OVERSPEED SAFETY

In 1884 Adolphe Gallinant patented an overspeed safety that consisted of a series of fan blades attached to a mechanism mounted at the of the shaft (Fig. 12) [17]. The mechanism was attached to the top of the car via a rope such that the car's movement caused the fan blades to rotate. The blades were designed to close as the car ascended and open as it descended, and chains were used to prevent the blades from opening too far. The car's speed was allegedly controlled by moving the blades on their supports. Nothing is known about Gallinant other than the fact that he immigrated to the United States from France in 1872/73 and that he apparently had no connection to the vertical transportation (VT) industry. This safety is representative of hundreds of devices patented during the 19th century by people outside the VT industry. These patents represent another unexplored topic: in spite of their idiosyncratic and often impractical nature, they serve as an important indicator of the public's general awareness of the need to ensure safe lift operation.

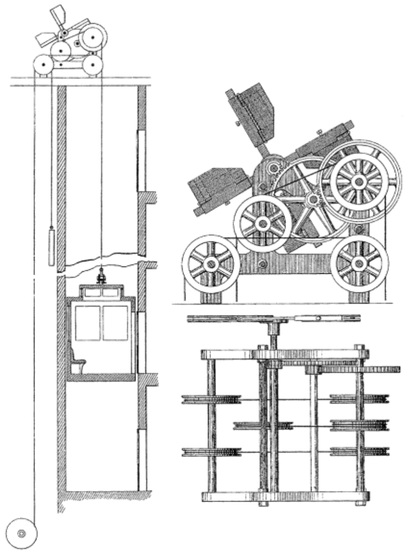

Figure 12 Adolphe Gallinant, Overspeed safety device (1884)

17 1897: THE FIRST UNDER-CAR OVERSPEED SAFETY

In 1897 Charles R. Pratt patented one of the first under-car overspeed safety devices [18]. Pratt's design was, in many ways, made possible by the development of modern steel guide rails in the early 1890s [19]. Earlier car mounted safeties were typically located atop the car and were designed to engage wooden guide rails. The presence of narrow steel guide rails allowed Pratt to propose using spring activated clamps that grasped the sides of the rails (Fig. 13). The action of his safety was controlled by a flyball governor whose speed was determined by the car's movement.

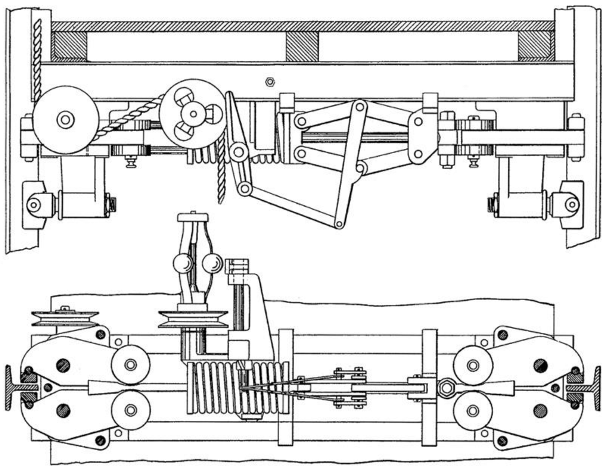

Figure 13 Charles R. Pratt, Under-car overspeed safety device (1897)

18 1899: THE FIRST IN-CAR COMMUNICATION SYSTEM

The Park Row Building in New York, completed in 1899, utilized the first lift cars that employed an in-car communication system; the cars were equipped with telephones that allowed lift operators to immediately report operational problems to the building's engineer [20].

19 1903: (ONE OF) THE FIRST ELEVATOR THRESHOLD SAFETY DEVICES

The absence of automatic elevating systems inspired inventors to devise safety devices to help passengers enter and exit cars that were not perfectly level with their landings [21]. Once such safety, developed by George Hail, involved placing lights either inside the car or on the landing that were directed at the threshold to help passengers to see if the car was level (Fig. 14) [22, 23].

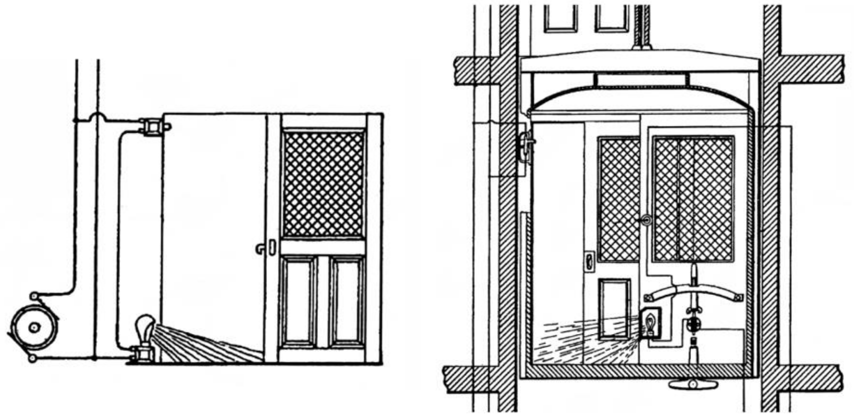

Figure 14 George Hail, Elevator threshold safeties (1903)

20 1900-1915: AUTOMATIC LEVELING SYSTEMS

Designing an effective automatic leveling system was defined in terms of solving two related problems [24]. The first problem concerned the design of a cost-effective means of automatically slowing the car speed to approximately 15 feet per minute as it approached the landing. The second problem involved designing a means by which the car, now moving at a slow speed, would automatically stop level with a given landing and automatically "inch" back to a landing should it go past level [25]. In 1903 Harold Rowntree patented a design that solved the first problem. He proposed to switch from the main motor to an auxiliary slow speed motor as the car approached a landing [26]. In 1913 August Sundh patented a solution to second problem [27]. His design employed a controller mounted on the car that was connected to a chain that ran from the top to the bottom of the shaft. As the car traveled through the shaft the chain rotated sprocket wheels in the car controller that in turn rotated contact points that governed the flow of current to the hoisting motor and controlled the activation of the brake. The mechanical movements within the controller were determined by the height between individual floors, which was keyed to the number of chain links that passed over the sprockets. If the car traveled past the landing the controller would detect this movement and the car would automatically reverse its motion and level itself.

21 1931: THE FIRST DOOR REVERSAL SAFETY DEVICE

The development of interlocking, automatically operating sliding lift doors in the 1920s created a new safety hazard: the possibility of passengers being injured by the closing doors [28]. In 1931 two Westinghouse engineers, Luther J. Kinnard and James Dunlop, patented an automatic door reversal safety device [29]. They described the need for their invention and its basic operational characteristics as follows:

> In operating an elevator having a power-controlled gate, it is desirable to provide some means for preventing the passengers from being injured by a premature closing of the gate while they are entering or leaving the car. Therefore, we have devised a means for preventing the gate from closing until the doorway, or entrance, to the car is clear. This means comprises … a photoelectric cell and a cooperating source of light …

> mounted in the entrance to the car for operating a safety relay, the contact members of which are included in the circuit for the door-operating mechanism [29].

The inventors also stated that it was an "object of our invention to provide for reopening the door or gate and retaining it in such open position for a predetermined length of time when anyone steps into the entrance to the elevator while the door is in the act of closing" [29]. Their design employed two pairs of lights and photoelectric cells, one mounted in the car and one the landings, that could be used to detect passengers' movements in and out of the car (Fig. 15).

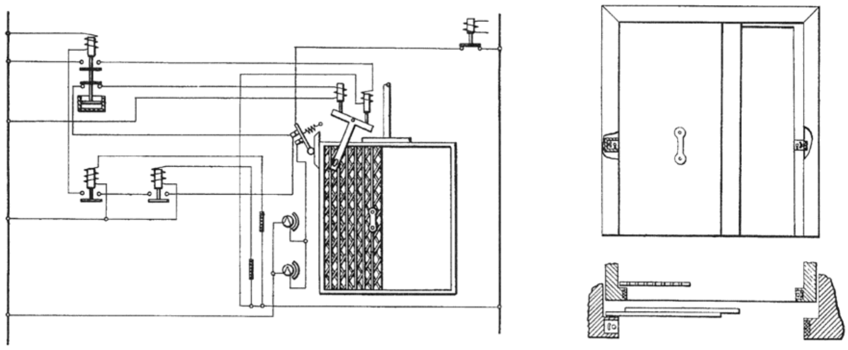

Figure 15 Luther J. Kinnard and James Dunlop, Door reversal safety device (1931)

22 CONCLUSION

This brief examination of the history of safety devices reveals the need for a comprehensive study of lift safeties. Such a study would involve a careful examination of the patent record in the United States and Europe, the relevant technical literature, accident reports, lift codes and regulations, and manufacturer's catalogs. The product of such an investigation would be a comprehensive history of lift development. While several lift histories have appeared over the past 50 years, none of them offers readers a work that encompasses all of the topics referenced above (1, 30, 31).

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BIOGRAPHICAL DETAILS

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Challenging Our Thinking Regarding Lift Incidents

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Keywords: Class I, Class II, Class III, taxonomy, energy.

Abstract. The purpose of this paper is firstly to present an understanding of the elevator fatality problem. Fatalities will then be presented in the context of the overall burden of personal damage. Damage to people can be classified as multiple fatality, single fatality, non-fatal permanent damage, temporary, and minor damage. The patterns or taxonomies associated with each class of damage are generally quite different from one another. The paper will suggest that the damage class of non-fatal permanent damage represents 80% of the cost of all damage (by any measure) and yet data with respect to elevators is seriously lacking on this class of damage. If we cannot describe the non-fatal permanent damage problem, we form hypotheses as to whether or not it is simply a subset of another level of damage. For example, a hypothesis could be "non-fatal permanent damage is a subset of fatalities. Therefore, manage fatalities and you will manage non-fatal permanent damage".

If the hypothesis is true, the overall size of the problem will alter. If the hypothesis is not true, we do not impact a critical class of damage. The proposition that will be put before the conference is that we cannot describe the size and nature of the problem associated with non-fatal permanent damage associated with elevators. Herein lies an opportunity, but the beginning point is the recognition of the gap.

Additionally, the paper will present a model for thinking about the timeline of an elevator fatality event, suggesting there is still much more to do in the engineering space versus the procedural/training space. For example, Engineers need to be challenged to think about elevator equipment and the elevator shaft more strongly as an information detector, information processor, and decision maker. This will allow for controls to be found in the metastable and unstable time zones of an incident. Several elevator fatalities will be presented to illustrate.

1 INTRODUCTION

The objective of Health and Safety activity should be the elimination of permanent damage to people. This objective when applied to the lift industry has application to the manufacture, installation, operation, maintenance, and eventual decommissioning. If we are to manage future potential damage to people, we must first be able to describe which Classes of damage we are wanting to eliminate or minimize. We must then be able to describe the patterns of damage (the taxonomies) associated with that Class of damage. Then we can use appropriate models to challenge how we understand the damage that occurs and devise effective controls. This paper suggests that there is still much to do with respect to lifts and escalators.

2 DAMAGE TO PEOPLE

In engineering terms, damage to people, equipment or the environment can be considered to be a consequence of an energy exchange wherein that energy exchange exceeds the tolerable limits of the structure. In this paper we are interested in the human structure. The energy exchange can occur in milliseconds (such as a fall where the head strikes a hard surface) or it can be a series of moderate energy exchanges which occur over a timeframe of seconds or minutes and are separated in time (such as heavy lifting tasks). Additionally, it can be a very low-level energy exchange which requires months and years of exposure time (such as chemical absorption through the skin, or respiratory inhalation of particulate/ mists/ fumes). The reality is that to confine our discussion of damage such that we only classify it as an injury has the lift industry potentially missing two of the three types of energy/time relationships described above. If one does not embrace the above time dependency notion of an energy exchange, it becomes more difficult to move closer to the overall objective that safety and health activity should be the elimination of permanent damage. So often, safety activity has focused on those energy exchanges measured in milliseconds and health activity has focused on those energy exchanges measured in months and years, which has left those series of moderate energy exchanges in *no man's land*. That observation combined with the mythologies such as "*lift correctly, use the knees and not the back"* has partly contributed to the epidemic of musculoskeletal damage.

3 CLASSES OF DAMAGE

To achieve the objective of the elimination of permanent damage to people in the lift industry, it is necessary to couple the notion that damage is a consequence of an energy exchange (with a time dependency relationship for the various types of damage) with the idea that there are different Classes of Damage.

Damage to people can be usefully classified as Class I (permanent), Class II (temporary damage/full recovery) or Class III (minor irritation).

Class I damage involves permanent alteration of life and includes three sub-categories of:

i. multiple fatalities,
ii. single fatalities, and
iii. non-fatal permanent damage.

Non-fatal permanent damage includes an upper level wherein a person does not return to work, and a lower level wherein the person returns to work but in a limited capacity, time, or skill.

It is necessary to understand the relative importance of the cost of Class I, II and III damage. There are direct costs and there are indirect costs associated with the person's damage. As one examines the Class I damage, it becomes increasingly clear that the majority of the cost is borne by the community, the individual and their family, and not by the employer and the insurer. Australian National Studies [1,2,3,4] clearly demonstrate that the majority of the cost of Class I damage is associated with the non-fatal but permanent damage category of Class I and the cost is borne by the worker, their family, and the community. In the main, this is because these people either:

i. do not return to work and are eventually separated from the insurance system. Their income and standard of living decreases, or
ii. cannot return to the same wok but are engaged in a reduced-income situation, or
iii. are supported by a government -funded social security system.

The reader is referred to the source documents for a more detailed explanation.

With respect to Class II damage, it is borne by the insurer and the employer for those countries that have established compensation systems. With respect to Class III damage, the cost is borne by the employer as the damage is managed totally *in-house.*

Australia is one of the few countries that has attempted to establish the true cost of the different Classes of personal damage. The insights gained over some 30 years of study by federal government departments reveals dramatic insights.

The big picture is presented as per the following Table 1 [1,2,3,4].

Table 1 Percent distribution of the quantity of personal damage

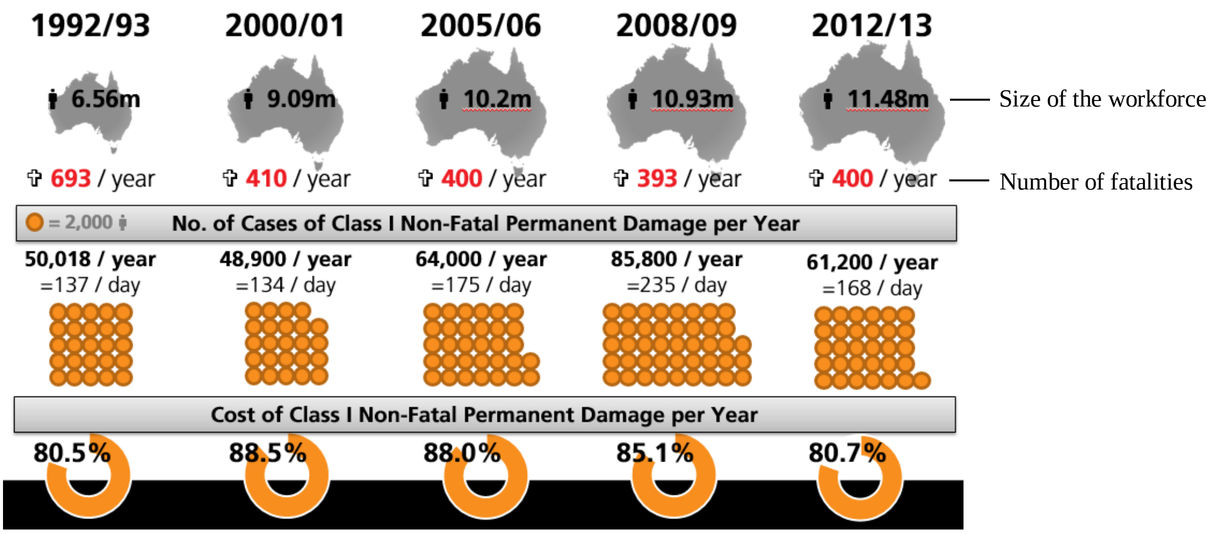
	1992-93	*2000-01*	*2005-06*	*2008-09*	*2012-13*
Class I Fatal	1.5	3.5	3.3	5.3	6.6
Class I Non-fatal	80.5	88.5	88.0	85.2	80.7
Class II	18.0	8.0	8.7	9.5	12.7
Cost $ billion *	**$20**	**$34.3**	**$57.5**	**$60.6**	**$61.8**
2000-01 Goods and Services Exports $132.8 billion **2008-09 Goods and Services Exports $198 billion**					

***Without pain, suffering and early death costed**

In Australia's legal system, there is a cost attributed to pain and suffering and early death. The above relative costs do not include those parameters for the Class I non-fatal and fatal damage and so understate the importance of Class I damage.

The following Table 2 [1,2,3,4] gives further insight.

Table 2 Class of Damage - Number of people involved



It is recommended that the reader study this table and be staggered by not only the numbers involved but the very high cost associated with Class I non-fatal permanent damage. It is proposed to this audience that Class I non-fatal permanent damage often slips under the radar and that the Class I non-fatal permanent damage which is of current interest to employers is the one involving a hard, sharp energy exchange producing traumatic damage e.g., amputation/crushing.

The data in the tables above is supported by individual studies by workers compensation authorities of the various states of Australia.

The following Figure 1 and Figure 2 [5] show that it is the 10% of Class I non-fatal permanent damage cases which represent the majority of the cost. These people are not malingerers but have suffered permanent impairment to the musculoskeletal system as measured by such objective measures as the American Medical Association Degrees of Impairment Tables.

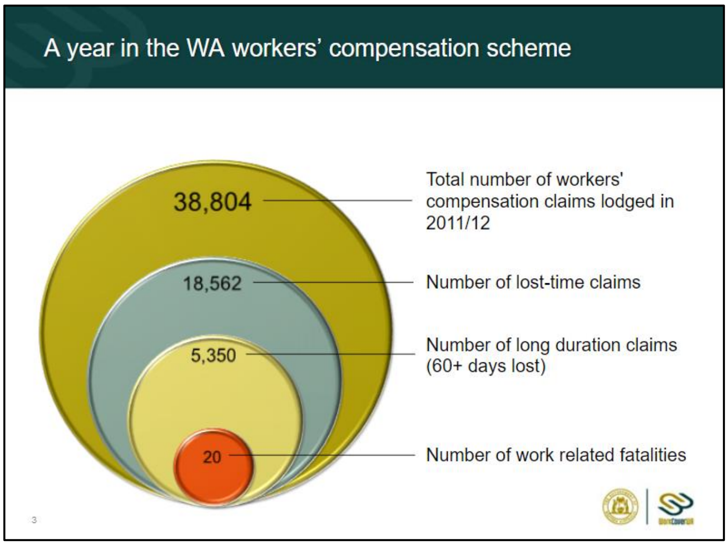


Figure 1 A year in the WA workers compensation scheme

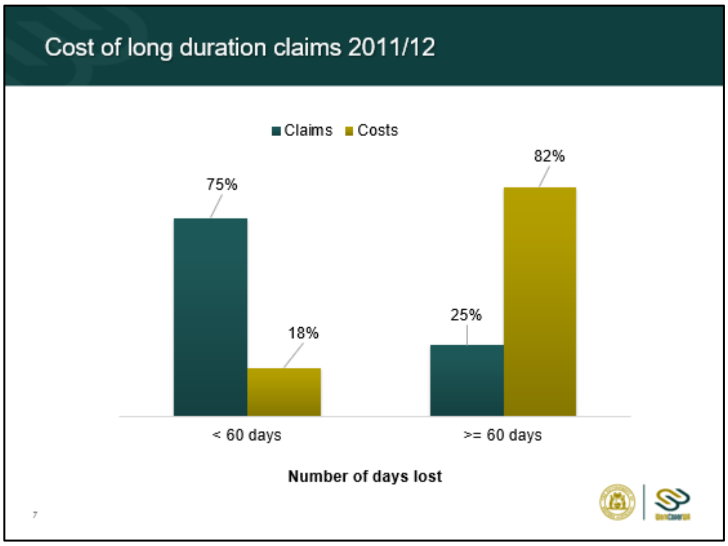


Figure 2 Number of Days Lost

The 80/20 rule will be known to the audience. It has its origins in Europe from that famous Italian Alfredo Pareto. The application of the 80/20 rule to the various Classes of Damage reveals — without a shadow of doubt — that Class I non-fatal permanent damage is the class of damage that costs the most by any measure. However, for ethical, moral, and legal reasons - and a genuine love for people - fatalities must be avoided. This is the other category of Class I damage.

With this preamble, the Health and Safety objective is restated as the "*Elimination of Class I Damage*". It is then absolutely beholden upon the lift and escalator industry to be able to describe the pattern of Class I damage for the various activities of manufacture, installation, usage etc. if the objective is to be reached. Being driven by data is essential.

4 WHAT DATA IS REQUIRED?

The medical profession has made the advances that it has because it has progressively moved away from an egocentric/human error centred model to recognising that there is a complex interplay between a host, an agent, the environment, and a vector. The following Figure 3 illustrates the model.

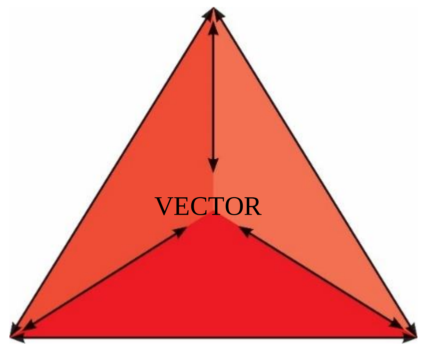


Figure 3 Medical Model

The model is supported by epidemiological work so that the patterns and the incident rates can be clearly described, and research effort strongly directed. We suggest that the lift industry cannot strongly and succinctly communicate the pattern of Class I fatal and Class I non-fatal permanent damage, remembering that Class I damage is the *Pareto Class of Damage* by any measure. The oldest of the scientific tools is taxonomy or pattern analysis which, when it matures, becomes epidemiology. The lift industry needs to '*start the walk*' of developing taxonomies for the different sub-classes of Class I damage and then watching for the effect of change over time upon that pattern — be it positive or negative.

In Australia, patterns or taxonomies do exist for many industries e.g., mining and construction. The taxonomies that give significant insight are those that are completed by the energy involved in the damage and taxonomies which go into sufficient detail to observe the relative importance of taxons (sub-groups) within the taxonomy. The critical learning from previous taxonomic work is that the pattern or taxonomy of Class I multiple fatalities is similar to - but essentially different from - the pattern of Class I single fatalities. The pattern of Class I non-fatal permanent damage is similar to - but essentially different from - the pattern of Class I single fatalities. The authors suggest that in the absence of information for the lift industry that the above hypothesis holds true.

This is not to say that there have not been studies completed for the lift industry or a desire by the industry to eliminate Class I damage at any level. Much good work has been done. Standards continue to evolve.

Just a few of the many injury data documents include *Deaths and Injuries Involving Elevators and Escalators* [6], *Journal of Forensic Sciences* [7], and *ThyssenKrupp Newsletter* [8]. There are studies completed which give some useful insights, but the data analysis needs to be elevated to the next level. The current information surrounding lift and escalator fatalities generally appears to be more insightful than the information surrounding Class I non-fatal permanent damage. When one examines the data of non-fatal damage (classified as *injuries*) it does not focus on the Class I non-fatal permanent damage but focuses on serious injury. The definition of *serious* in studies involving compensation data typically include claims involving greater that 5 days' work. This level of damage (>5-10 days lost) is not necessarily the predictor of the Class I non-fatal permanent damage. This > 5 days lost data will include a significant amount of Class III (temporary) damage. It is only when one studies data sets > 60 days lost that the pattern matches the Class I non-fatal permanent damage problem. It is being suggested that the current studies of *injury* are useful and helpful but not sufficiently focused, and that the Class I non-fatal permanent damage is camouflaged in the *injury* datasets.

The following tables and figures [9] are useful with respect to the fatality story:

Table 2 Deaths related to work on or near elevators, by cause, 1992-2009

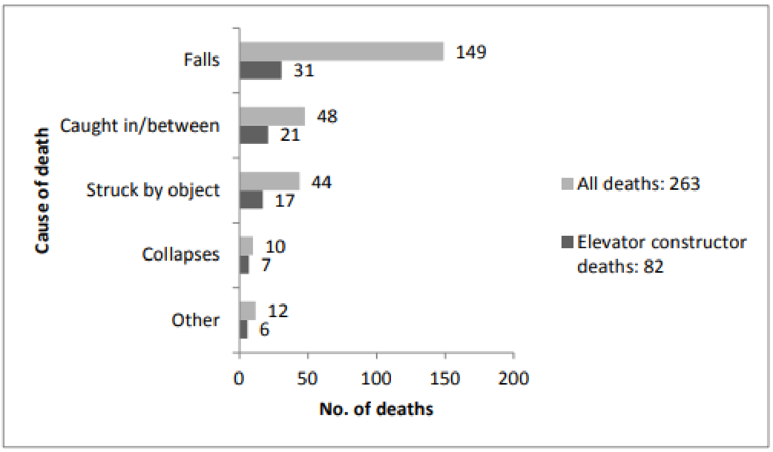


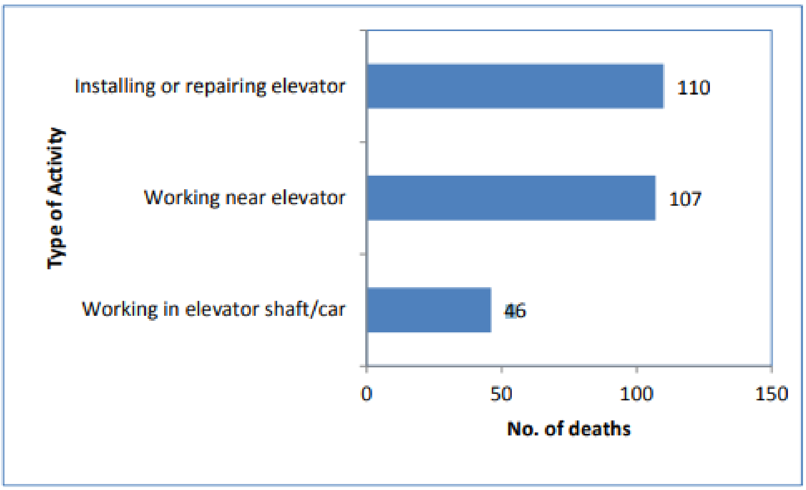
Table 3. Work-related deaths among construction workers involving elevators, by cause and activity, 1992-2009

	Activity			Total	
Cause	**Installing & repairing**	**Other work in elevator shaft/car**	**Working near elevators**	**No.**	**Percent**
Falls	38	23	88	149	57%
Caught in/between	32	8	8	48	18%
Struck by object	24	10	10	44	17%
Collapse	8	--	--	10	4%
Other causes	8	--	--	12	5%
Total	110	46	107	263	*

- - Data do not meet BLS criteria.

* Does not add to 100% due to rounding

Table 4. Deaths related to work on or near elevators, by activity, 1992-2009



Total number of deaths: 263

The following Figure 4 is the authors' attempt to develop the taxonomy from the 110 people described in Tables 3 and 4 who died installing and repairing elevators between 1992 and 2009.

It is necessary to show meaningful patterns with associated describers. This type of analysis is the starting point. The industry must be able to accurately describe the Class I problem and then come to understand the phenomena involved in the various taxons so that health and safety resources are appropriately directed.

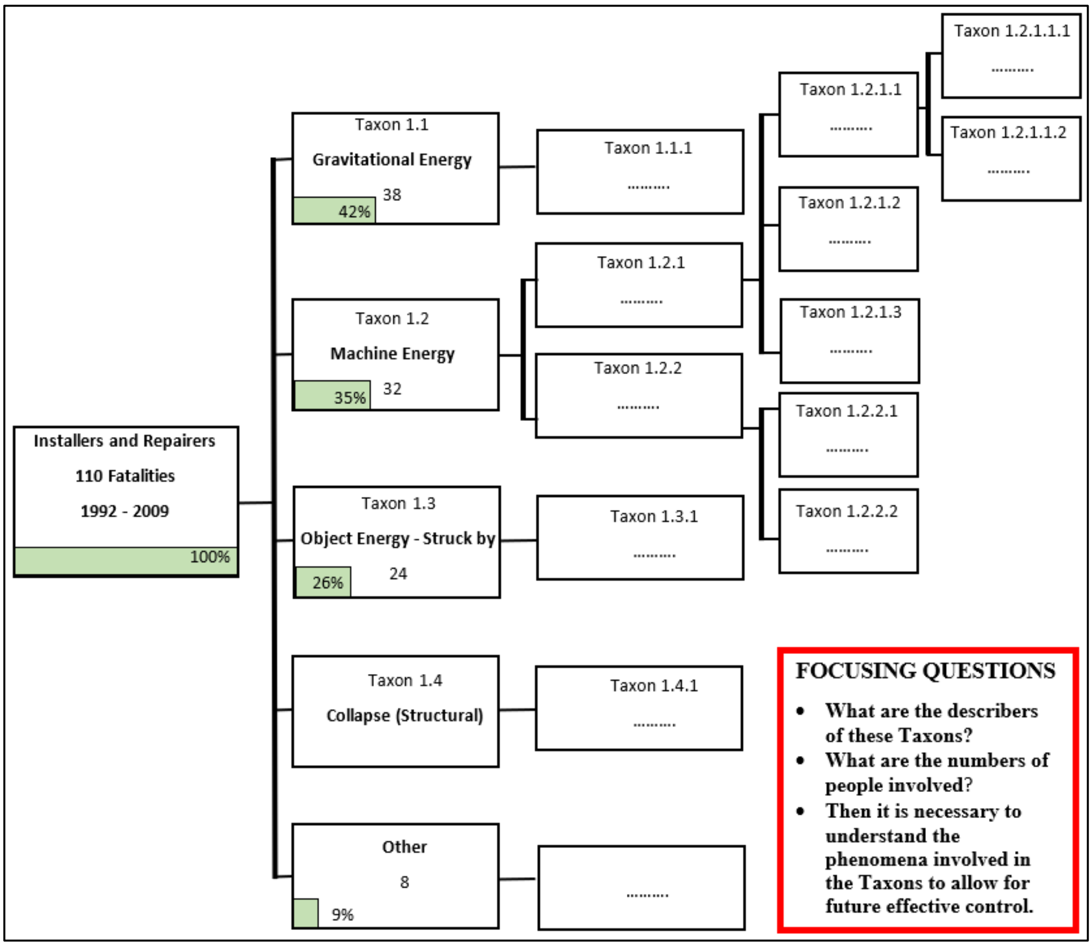


Figure 4 Attempt at a Taxonomy of Lift Fatalities

Quality descriptive data (supported by codified data, e.g., occupation) of individual events is critical to building a meaningful taxonomy to show that there is a desperate need for quality taxonomic information in the first instance to be able to understand the patterns and the relative importance of the mechanisms by which various energies are damaging people.

Similar comments can be made when one looks at publications with respect to injury because they do not filter out the Class I non-fatal permanent damage. The current *injury* studies are useful in that they show the involvement of falls of people, musculoskeletal damage from manual tasks etc. However, there is not sufficient insight in the data analysis to strongly direct health and safety activity.

4.1 Two Deaths

Our own experience with two escalator fatalities is useful in that it gives the authors' insights into one aspect of the mechanism of death and the associated controls, but those deaths do not get captured in a dataset that assists the industry in understanding the relative importance of the energies and mechanisms involved in fatal incidents.

The following Figure 5 [8] illustrates where the pathway of movement beyond the edge commenced.

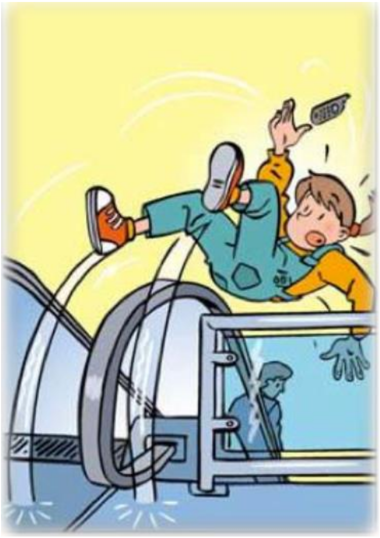


Figure 5 Where the pathway of movement beyond the edge commenced

Figure 6 Reinforcing the mythology

There is a common notion that such fatalities are due to bad behaviour, lack of attention and carelessness. Figure 6 [8] reinforces that mythology. Figure 5 shows the movement pathway of two deaths that the authors' investigated. In one case a child grabbed the rising part of the handrail and was lifted up and carried over and fell to their death. The second involved a young lady being embarrassed as her boyfriend went to give her a kiss in a public environment and she stepped back, and her clothing interacted with the rising part of the escalator handrail to lift her up and carry her beyond the handrail, falling to her death. In both incidents a common feature was the exposed and rising part of the handrail. Here in becomes the first point of challenge: Both people were behaving reasonably. The exposed section of the rising handrail was essential to the incident, and the absence of a barrier to prevent them moving beyond the edge was also essential. Probably some 15 years after investigating those two deaths, the industry in Australia commenced to use safety barriers, but we still do not address the rising part of the handrail. The authors are sure the two stories will create some disagreement but the point being made is that, as an industry, we are not building useful datasets that aid in understanding and give insight into the relative importance of the different mechanisms by which people lose their lives or are permanently damaged with lifts and escalators.

The view is supported by Ruibal et al [10]:

> *There is a real need to collect reliable escalator accident data which could help identify potentially dangerous situations that can be sources of risk for users or technicians on escalators.*

5 CHALLENGE OUR WAY OF THINKING

As we think about Class I damage and come to better understand the pattern and relative importance of the different mechanisms of energy transfer, we will then need to challenge our thinking about individual damaging occurrences. It is not to say that some very significant thought and analysis of Class I damaging occurrences is not occurring, but we do not think it is sufficiently widespread. There is a strong belief in accident prevention and the desire to stop situations moving out of control. Many of the outcomes of investigations are administrative in nature and yet in the lift industry we do seek out controls that are operating as a situation commences to move out of control, is out of control, and damage is occurring.

The following Figure *7* illustrates the timeframes through which situations pass with the length of those time zones dependent upon the timeframe of the event under consideration. The timeline forms part of the InterSafe Essential Factors™ model.

Figure 7 Unscaled time diagram for an incident resulting in death or destruction of equipment. Incidents with less serious outcomes branch from this time diagram at any stage [11]

The lift industry has many controls that operate in the metastable, unstable and damage time zones of Figure *7*. Examples involve detecting the presence of the person in the pathway of closing lift doors. This is a control that operates in the metastable time zone.

When a lift is in freefall and the safety brakes apply, the rate of application of the safety brake can result in very significant jerk (rate of change of acceleration) which results in permanent damage to people but prevents fatalities. The safety brake is a damage reduction device. It is not an accident prevention device.

For the industry to make further progress, we must force our thinking into the *fast* timeframes of *unstable* and *damage* and learn to think in terms of the concept of meta-stability. This is the timeframe in which the participants in the incident often consider the situation to be stable when in fact it is moving out of control but recoverable. Perhaps the concept is best demonstrated by example: The following case study (Figure 8) is in the public arena [12]:

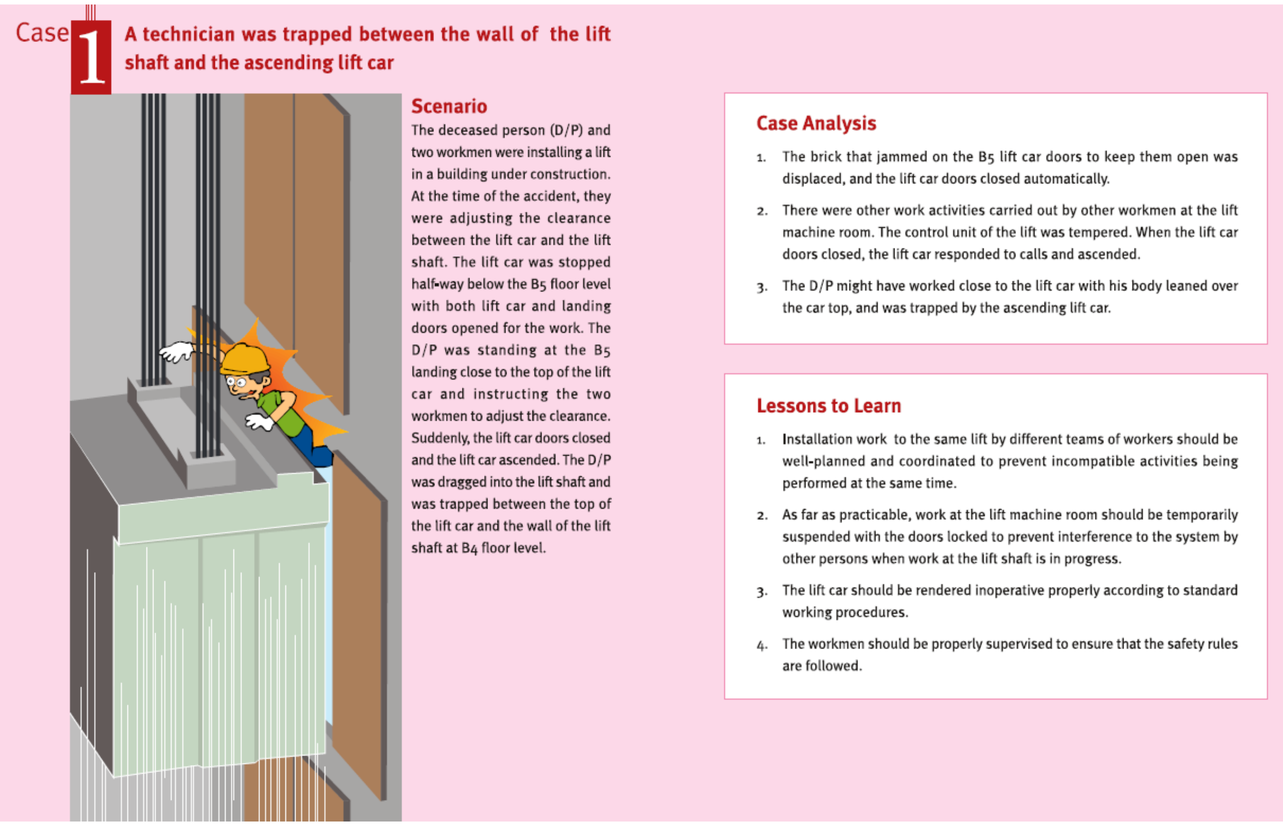


Figure 8 Case Study

If one were to read the *Lessons to Learn* (above), they are totally focused on keeping the situation under control and in the *stable* time zone of Figure *7*. As the situation progresses beyond stability, it is often necessary to have a very strong focus on the machine and the work environment of the lift shaft. These components can be considered as information detectors, information processors and decision-makers as the reaction times of people are often far too slow in the fast time frames of *unstable* and *damage*. Technology has made rapid advances in the last 15 - 20 years in which equipment and the work environment can be considered as an information detector, processor and/or decision-maker. The lift shaft environment is very unforgiving when a person is in the travel path of either the lift or the counterweight. Perhaps there is real opportunity going forward that either the lift, the counterweight, or the lift shaft itself can act as an information detector, processor, and decision-maker, in that it recognizes that an object is moving towards a susceptible structure e.g., a maintenance person and that there is a need to intervene. The concept may sound abstract but unless we are to apply increasing rigour with respect to personal damage, the stories depicted in the case study will continue with similar lessons learned and the taxonomy of fatalities will not alter.

Another example is provided to challenge our thinking: The *Hierarchy of Controls* could be rebranded *Control Options* and placed on the event timeline as follows:

- Elimination - operates in the Predisposing time zone of Figure *7*.
- Administrative – operates in the Stable time zone of Figure *7*.
- PPE - operates in the Unstable/Damage time zone of Figure *7*.
- Engineering – can operate in any of the time zones of Figure *7*.

The scientist’s models and language must be more neutral and objective. *Control Options* is neutral and objective. *Hierarchy of Controls* implies *good* and *bad*, *best*, and *least*, and invokes value judgements.

For the person who reads this paper and is interested in a more comprehensive range of control options, they are referred to the paper by William Haddon, *On the Escape of Tigers* [13] which lists 10 strategies for managing an energy exchange. What is fascinating is that the paper was written by a medical practitioner venturing into the province of energy and engineers. William Haddon's 10 strategies for managing an energy exchange effectively derive from the medical profession’s desire to intervene in the prevent phase of the disease, at multiple points of time in the event phase of the disease and then in the post event phase. We have much to learn from the medical profession.

Figure 9 illustrates Haddon’s 10 Energy Management Strategies overlaying the event timeline:

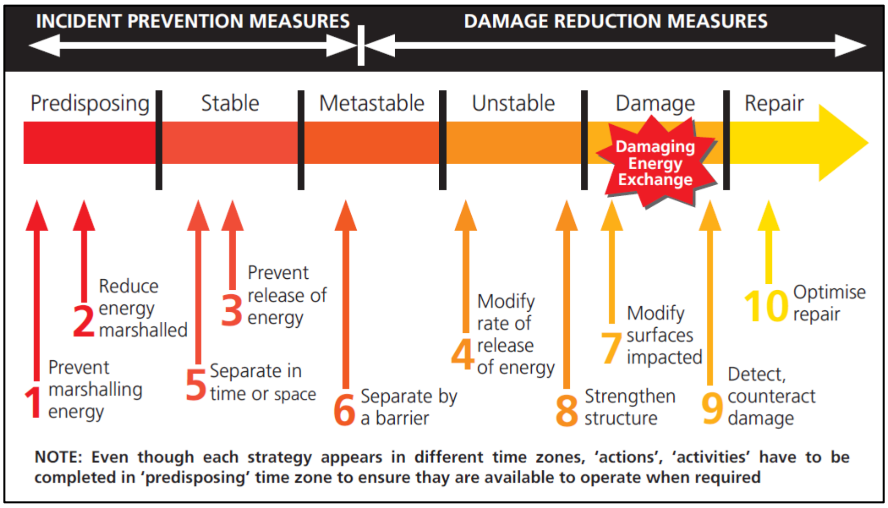


Figure 9: Haddon’s Energy Management Strategy

6 SUMMARY

This paper is not intended to denigrate or detract from the significant work and gains that are being made in the lift industry but to challenge some of the baseline thinking that allows opportunities to go unnoted as we study individual cases of personal damage.

The paper joins with others who have written on the same subject in the past that we are in desperate need of quality taxonomies of Class I damage associated with multiple fatality, single fatality, and non-fatal permanent damage.

The following recommendations are made for the industry with respect to a study of Class I damage:

Firstly, the industry association to collect descriptive and codified data of fatalities and non-fatal but permanent damage (traumatic and over-time damage) and > 60-days-lost cases[1] from:

- Insurers,
- Large and medium sized lift manufacturers and installers, and
- Government agencies.

This data to be collected for the various groups of:

- Manufacturing,
- Installation and commissioning,
- Repair, and
- Users (general population).

Aim for several thousand records over a 10 – 20-year period. This will be the most time consuming aspect of this study.

Secondly, complete 8 taxonomies using an agreed upon set of describers e.g., energy that damaged for each of the 4 groups (a fatal taxonomy and a non-fatal but permanent damage taxonomy for each group).

Thirdly, share the learnings and each recipient of the taxonomies to implement change within their sphere of influence.

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BIOGRAPHICAL DETAILS

Roger Kahler has, since 1983, specialized in: accident analysis, hazard studies, audits, implementation of occupational health and safety systems, strategic accident analysis, industry training, and advice to the legal profession.

Mr. Kahler has experience in the detailed investigation of over 5000 accidents for the legal profession, multinational and national companies. Detailed investigations and reports on those factors essential to accidents and their control have been completed.

Additionally, Mr. Kahler has led intensive training of industrial management, medical staff, and the workforce in the areas of accident investigation, ergonomics, slips, trips and falls to the same level, human perception, management of damage to the musculoskeletal system, predictive techniques for serious personal damage, design of mobile equipment access systems and problem-solving methodology.

Mr. Kahler has also completed literature surveys in the areas of biomechanical, epidemiological, psychophysical, and physiological research to understand the phenomena of work-related damage to the lumbar spine, cervical spine and upper limbs and has delivered expert advice on litigation in all of the above areas as well as appearances in the criminal court.

Nicholas Pierce is a mechanical engineer with twenty years industrial experience. His background is primarily in the field of design, construction and maintenance of fixed plant and equipment. As a specialist investigator, Mr. Pierce has investigated in excess of one hundred incidents involving fatalities, permanent damage to people and extensive damage to equipment. These include investigations in the mining, construction, manufacturing, transport, and energy industries using InterSafe's Essential Factors™ models. This has included elevator incidents involving workers in elevator shafts, passengers using elevators and people being rescued from elevators. Mr. Pierce has also undertaken studies of the patterns of fatal and non-fatal-permanent damage of people in the construction and mining industries to understand the dominant damaging energies and incident types to assist industries prioritise their risk management activities.

Future Modernizations

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Keywords: modernization, post-pandemic workplace, societal changes, innovation.

Abstract. Modernization has been a part of the lift industry for a very long time. There are buildings that are over 100 years old that have been modernized multiple times but continue to use the original direct current machine. Both societal changes and technical innovations will make the modernizations of the very near future different from the modernizations of the present.
The motivations for modernization, the societal changes, and the technical innovations will be reviewed. The benefits of the next generation modernization will also be explored.

1. INTRODUCTION

Buildings, like most other products, compete with other buildings for customers. In the case of buildings, the customers are the entities who lease or buy the space in the building. While there are many factors that affect the customer's decision, some of the most important factors are location, price, and building features.

New buildings have all the latest features. Existing buildings must upgrade their systems or accept lower rents. It is for this reason that buildings have modernized their lifts in the past. However, that was before COVID-19.

The post-pandemic commercial real estate market will also see changes in building use and building specifications. These changes will affect lift requirements and create new lift modernization opportunities, even for relatively new buildings that were completed before and during the pandemic.

Future modernizations will need to address the following two requirements,

1. Post-pandemic workplace requirements.
2. New technologies.

The pool of existing buildings that must modernize to compete with new buildings is large. The following are three examples:

1. At the end of 2020, the average commercial building in the USA was 52.67 years old [1].
2. In Europe, 80% of existing commercial buildings were built before 1990 [2].
3. China's period of reform and reopening began in 1978. Many of the of buildings built in the first 20 years of this period will need to be modernized [3].

2. THE POST-PANDEMIC WORKPLACE

2.1 Societal Change, Working Remotely

Businesses have learned that people can work productively from remote locations such as home offices. However, teamwork, collaborative efforts, mentoring, and the development and maintenance of corporate culture requires people to work together in the same location.

The question that the real estate industry is trying to answer is, "How many people will ultimately continue to work remotely and how many people will return to the office?" Industry leaders are forecasting that between 60% to 80% of the work force will return to the office [4] [5]. However, many people will utilize a hybrid solution of working some days of the week in the office and some days of the week from a remote location.

If 80% of the workforce returns to the office, it would appear there will be a very large surplus of office space and, consequently, vacancy rates will increase. However, it also appears that the workforce wants to continue to exercise social distancing. Additionally, workers have found open office spaces are less productive because it is difficult to concentrate in such an environment.

Because working remotely will create some level of surplus office space. It is possible that some office buildings will be converted to residential buildings. In fact, the author has been informed by a lift consultant that his firm is working on two projects where an office building is being converted to a mixed-use building that includes both office space and residential units.

2.2 Touchless

Contacting a contaminated surface is one way that COVID-19 and many other bacterial and viral diseases can be transmitted. Touching a lift push button or grabbing an escalator handrail are correctly perceived to be good ways to spread disease. As a result, many lift companies are offering touchless solutions for lifts and handrail sanitizing devices for escalators [6].

Destination Dispatch systems inherently are more “touchless” than conventional control systems with up and down buttons because one must only enter their destination. Using smart devices such as mobile phones, ID badges and facial recognition systems make it possible to have a completely touchless lift.

It is often not necessary to replace a control system to upgrade to a touchless Destination Dispatch system. Many companies are offering Destination Dispatch overlay systems [7].

One can therefore expect there will be an increase in control system modernizations or upgrades to touchless Destination Dispatch systems.

For safety, escalator users are encouraged to hold the handrail. Since a touchless handrail is not possible, two solutions are currently being offered: Ultra-violet C sanitizers and handrails with anti-microbial coatings [8]. It is logical to expect that many escalators will be upgraded by installing these devices.

2.3 Cabin Space

Personal space has always defined the number of passengers that a lift car could transport. A value of $0.21m^2$ per person is commonly used. However, in the post-COVID-19 world, it is anticipated that this value will increase.

The combination of reduced passengers per floor, increased personal space in cabins, and the use of contactless destination dispatch controls will have an impact on the traffic handling capacity of a lift system.

The overall impact of these factors can be evaluated using simulation. The following examples compare the traffic handling performance of a hypothetical building designed before COVID-19 and the same building with features designed post-COVID-19.

The two systems were evaluated using ELEVATE® simulation software.

2.3.1 Example 1, Before COVID-19

The building has 18 stops, 58 people per floor, 6 lifts with a capacity of 1350 kg, and a speed of 3 m/s. The control system is Group Collective.

Using the Enhanced UP Peak calculation, the system had a 31.4 second interval at an arrival rate of 12%.

Simulations using the Peters Research Modern Office Lunch Peak 2015 template and the Peters Research Modern Office Up Peak template with a Passenger Area of 0.21 m² per person. Table 1 summarizes the results:

Table 1 Simulation results, Passenger Area: 0.21 m² & 100% occupancy

	Waiting Time	Transit Time	Time to Destination
Lunch	24.3	64.4	89.7
Up Peak	9.3	70.0	79.4

It should be noted that with a passenger area of 0.21m², the maximum number of passengers transported per trip is 14.

2.3.2 Example 2, Post-COVID-19 Traffic

A second set of simulations was run using post-Covid parameters. The number of persons per floor was reduced to 43, which represents 80% of the 58 persons pre-COVID-19. Personal space was increased to 0.5 m² per person. This limits the maximum passengers per trip to 6. Additionally, touchless Destination Dispatch system (ACA) control system was used. Table 2, summarizes the results:

Table 2 Simulation results, Passenger area: 0.5 m² & 80% occupancy

	Waiting Time	Transit Time	Time to Destination
Lunch	26.8	35.4	62.2
Up Peak	19.0	36.0	55.0

One can see that the existing lifts with new controls, when applied with post-COVID–19 conditions, had improved traffic handling performance.

2.4 Ventilation

Traditionally, there have been two approaches to forced cabin ventilation:

1. Extraction. Ceiling fans extract air from inside the cabin and vent it into the hoistway.
2. Supply. Ceiling fans force air from the hoistway into the cabin.

In response to COVID-19, lift companies are offering supply type ventilation systems that pass the air either through an ionization chamber or an ionization chamber combined with a filter [8], [9]. Passengers can still spread disease by sneezing or talking, but these systems ensure that the air entering the cabin is sanitary and the air flow will prevent contaminates from lingering in the cab.

Another method of sanitizing Supply type ventilation systems is the use of UV-C lamps near the supply intake [10]. This approach works in the same manner as the UV-C systems used for escalator handrails.

3. NEW TECHNOLOGIES

There are two technologies that will create a demand for future modernizations or system enhancements. These technologies are Connectivity and Machine Learning.

3.1 Connectivity

Connectivity, as it relates to Information Technologies, is defined as "*the ability to connect to or communicate with another computer or computer system*" [11].

For the lift industry it typically signifies that the lift control system is connected to a remote computer using cloud technologies. The information sent from the controller can be used for many things including Machine Learning, interfaces to other building systems, applications (Apps) used by building managers and, and Apps used by lift passengers.

Connectivity systems that connect directly to the control system are available for most new or recently installed lifts.

Existing lifts can be connected using sensor packages with which have little or no connection to the control system. Using one of the many commercially available connectivity systems, virtually any lift can have some level of connectivity [12].

The data from the connectivity system can be processed and made available to other computer programs by way of an API.

An API is an Application Programming Interface [13]. A User Interface (UI) allows a person to communicate with a computer. An API lets a computer communicate with another computer.

The following are some examples of computer systems that may want to access a lift system's API:

1. A Building Management System (BMS) computer.
2. A security system computer.
3. A Facilities Management Company's computer.
4. A service robot that wants to use the lift.
5. A Government agency computer.

Apps are Applications that can be downloaded onto a mobile device such as a smartphone or a tablet [14]. Apps for lifts are used interfaces to permit service personnel, passengers, and building managers to access data about or communicate with lifts and escalators. The following are some examples of lift apps:

1. App to place calls in a destination dispatch system.
2. App to help service personnel diagnose lift problems.
3. App for facility managers and building engineers to receive performance data and alarms about their lifts and escalators.

Connectivity will only be possible if lifts and escalators are upgraded or modernized.

3.2 Machine Learning and Artificial Intelligence

The goal of Artificial Intelligence (AI) is to develop computers and software that mimic human intelligence. Machine Learning (ML) is one form of Artificial Intelligence (AI). Machine Learning involves making predictions based on properties learned from data [15].

There are many forms of ML. The following are two forms that can be used for lifts:

1. Classification and Regression Trees (CART).

    a. Description: These trees are decision trees that learn from what has occurred in the past and use that knowledge to make predictions about future outcomes [16].

    b. Example: The output of a lift remote monitoring system records what has happened in the past. Analyzing this data using CART might reveal a sequence of events and or error codes that almost always leads to a shutdown within two weeks.

2. Artificial Neural Networks (ANN)

    a. Description: ANN's are computing systems inspired by the biological neural such as human and animal brains [17]. These networks have the ability to learn.

    b. Example: An ANN is shown the vibration signature of a properly functioning lift component and told it is the signature of an undamaged component. It is also shown the vibration signature of a damaged component and told it is the signature of a damaged component. Many vibration signatures are shown to the ANN and in time the ANN learns to identify damaged components by their signature.

Because of its ability to learn and predict, Machine Learning will make possible tremendous improvements in reliability and maintenance efficiency [18]. Soon it will be possible to almost completely eliminate lift breakdowns except those caused by external factors such as misuse, abuse, vandalism or acts of God.

Building owners and managers want the improvement in up time that is made possible by Machine learning.

Machine learning generally requires connected lifts and escalators.

4. CONCLUSIONS

The modernizations of the future will be driven by societal changes and innovation.

The societal changes are the result of our experience with the COVID–19 pandemic. Society knows how to work remotely at least a portion of the time and that we are more comfortable with greater personal space and less contact with potentially contaminated surfaces.

Building owners, building managers, and building occupants what the benefits made possible by connectivity.

Even recently completed or modernized lifts are candidates for additional upgrades to deal with the changing workplace. The market for lift modernizations and upgrades has never been better.

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