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FOREWORD

It is with great pleasure that we present the proceedings of the 10th Symposium on Lift and Escalator Technologies, 18-19 September 2019, organised by The Lift and Escalator Symposium Educational Trust.

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

A Template for an Undergraduate Elective Final Year Lift (Elevator) Engineering Course

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Keywords: lift; lift traffic engineering; lift electrical engineering; lift mechanical engineering; guide rails; ropes; safety devices; safety gear; speed governor; electrical logic controller; electrical speed controller; traction motor; drive system; sensors and transducers.

Abstract. Lifts offer an ideal final year engineering capstone course, due to the multidisciplinary nature of its potential content. This paper sets out to develop a template for planning and delivering such a course at undergraduate engineering level based on experience gained at the School of Engineering at the University of Jordan.

There are basically four streams within this course: traffic analysis and design; space and layout planning; mechanical lift engineering and electrical lift engineering. Thus, it is ideal as a final year undergraduate elective course for mechanical, electrical and mechatronics engineering programmes.

The traffic engineering stream introduces the students to the basic concepts of the round-trip time, the interval, the handling capacity as well as basic introduction to the concept of group control and dispatching. The space and layout planning stream introduces the concepts of shaft dimensions, pit depth and headroom, as well as structural forces in the pit. The electrical stream introduces the student to the concept of a safety circuit and safety devices, DC and AC motors, drive systems as well as electronic logic controllers. The mechanical stream introduces the students to the main mechanical components such as gearboxes, ropes, safety gears, speed governors, sheaves, guide rails and buffers.

Providing such an introductory course in elevator engineering allows the students to reinforce concepts that they had studied earlier in non-applied basic courses and provides an opportunity to develop multi-disciplinary integrated design skills. The long-term aim of this project is to build an open access repertoire of study material, assessment tools and question banks as well as software that can be used to deliver and study the course.

1. INTRODUCTION

There is great emphasis in modern engineering education on project-based learning (PBL) and multidisciplinary engineering. It has been well recognised that lifts offer an ideal subject for the application of such projects, especially for electrical, mechanical and mechatronics engineering.

This paper is the result of experience by the author in delivering a final year elective course in the Department of Mechatronics Engineering at the School of Engineering, The University of Jordan. The course is entitled: “Selected Topics in Mechatronics Engineering” and can contain any content that is relevant to mechatronics engineering. The course has been delivered around the area of lift engineering around 6 times over the period between 2013 and 2018.

Based on the author’s personal experience, the feedback from the students regarding these courses has been very positive. Students enjoy this type of course because they feel it is linked to a real-life system and that it addresses real-life problems. In addition, the students are expected to work in a group on a project within the course, which allows them to reinforce some of the concepts by applying them in practice.

Similar work has been carried out on the Mechatronics System Design course for final year undergraduate students ([1], [2], [3]). Final year courses usually include a capstone course which aims to encourage the student to use all the concepts that they have learnt in a design project ([4], [5], [6], [7], [8], [9], [10], [11], [12]).

Section 2 outlines the contents of typical course. Section 3 lists and discusses typical topics that can be discussed in class to stimulate debate and discussion. Three typical course projects are discussed in Section 4. The three advantages of using lift engineering as the basis for this course are discussed in Section 5. Conclusions are drawn in Section 6.

2. CONTENTS OF A TYPICAL COURSE

The course comprises four main streams: lift traffic engineering, lift space planning, lift electrical engineering and lift mechanical engineering.

The lift traffic engineering stream provides the students with a basic understanding of the methods of describing traffic in a building, the concept of the arrival rate (AR%) and the concept of handling capacity of the lift traffic system, the definition of the round trip time and how to find the suitable number of lifts to meet the required demand. A comprehensive set of resources that have been prepared especially for this course, entitled "Modern Elevator Traffic Engineering (METE) can be found in references ([13], [14], [15], [16]. [17], [18]. [19]), that have been adopted by others [20]. The students solve simple problems in finding the suitable number of lifts required for a certain building, establishing the interval as the index of the quality of service and the handling capacity as the index of the quantity of service. Student are also encouraged to use MATLAB to evaluate the Round-Trip Time using the Monte Carlo Simulation method [28]. A simple introduction to group control is given (an METE resource can be found in [21]), with some emphasis on sectoring as a tool for group control during incoming traffic. Graphical methods are also used to solve more advanced problems (the HARint Space [22]), in a way similar to the Root Locus Method developed by Evans used in control systems.

Under the lift space planning stream, the four critical dimensions of the lift shaft are explained: the shaft width, the shaft depth, the headroom and the pit depth. The use of the ISO 4190 standard is encouraged in order to find standard preferred sizes for car capacity, speed and shaft sizes. It is very appropriate at this stage to introduce the concept of preferred number and the concept of the Renard Series (R5, R10, R20 and R40) and the rationale for their use industry in general. An analysis of the forces that can occur on the pit floor are also discussed, based on the reaction force under the guide rails and the buffers.

In the lift electrical design stream, the general overview of the function of a logical controller is introduced. The concept of a safety device is discussed. The need to protect against one single failure taking place is presented practically by introducing possible failures in a control system and suggesting possible solutions to prevent them from causing a dangerous situation. An excellent resource for the concepts of safety in control systems can be found in [23] written by the Heath & Safety Executive (HSE). The whole system of a speed controller is also introduced with emphasis on the speed feedback device and associated concepts of stability and disturbance rejection. A good set of resources on drive systems and electrical machines can be found in ([24], [25], [26], [27]). The concept of cascade control is presented in the context of a closed loop feedback control of a dc motor drive lift. A detailed exercise on sizing an induction motor based on torque requirements and power requirements is carried out, based on achieving the required starting acceleration.

In the lift mechanical engineering stream, the students are introduced to the general mechanical arrangement of the traction lift, including the ropes, the sheave, the overspeed governor, the safety gear, the buffer system, the gearbox and the mechanical braking system. The main resource used for lift mechanical design was the textbook by Janovsky [29]. It is very useful at this point to get the students to gain a general appreciation of the integrated safety system that is made up of the mechanical brakes, the overspeed governor, the safety gear and the buffers and where each component's contribution is required. This allows the student to understand that engineering designs need to be safe as well as functional; that the engineering designer needs to consider faulty conditions in addition to normal functional conditions. Sizing the ropes would be a useful exercise in order to understand the concept of the safety factor (16 for one single rope; 12 for two or more ropes). This introduces the student to the concept of a safety margin in design, which is a central concept in engineering design in all engineering disciplines.

3. INTERESTING EXAMPLES OF LINKS TO ENGINEERING TOPICS

There are specific featured topics that attract a lot of interest and excitement from students and enrich the lecture environment by stimulating discussion. The following list includes some of these concepts that can be introduced or reinforced during the course:

Probability Calculations for the Traffic

Many of the important concepts of probability theory are encountered when deriving the basic equations for the round-trip time, such as the concept of the mean value of a random variable, independent events and conditional probability. These are needed when driving the expected number of stops (S) in a round trip and the expected value of the highest reversal floor (H). The use of Venn diagrams is a great tool for clarifying some of these concepts.

Using Queueing Theory to Calculate Waiting Time and Queue Lengths

The number of passengers waiting for a lift, the formation of queues and the operation of the lifts as servers are concepts ideally dealt with using queuing theory. A resource that explains the application of queueing theory to lift traffic systems can be found in [30]. Queuing theory has been used to find the value of the average waiting time and the average queue length under steady state conditions (i.e., when the lift system is subjected to a constant passenger arrival rate for a long period of time such that the system arrives at a steady state condition).

Kinematic Analysis Modelling

The development of the speed-time curve for a lift and the inclusion of the values of the rated jerk and rated acceleration can be introduced in a very interesting way when looking at the movement of the lift car. The students are encouraged to use MATLAB/Simulink to generate the curves and extract data from them. As will be seen later in the projects section, they can also use an accelerometer to measure acceleration from a real lift and extract the speed-against-time profile and the displacement-against-time profile.

Energy and Power Modelling of a Lift System

Energy modelling and simulation is also an interesting area that students can explore and research in more detail. For example, they calculate the amount of potential energy stored in the mechanical components such as the car and the counterweight, the translational and rotational kinetic energy stored in the masses and the inertias, respectively ([31], [32]). They can also calculate the frictional losses incurred in the shaft. They may also measure the actual power consumed and regenerated by the lift systems as it is moving upwards and downwards (and is the lift system is accelerating and decelerating).

The Space Lift and Rope Sizing for Lifts

One of the main components that needs to be sized in lift systems is the diameter and number of ropes that must be used. This takes into consideration yield stress of steel ropes, the masses of the counterweight and the lift car, the masses of passengers, as well as the required safety factors to account for dynamic forces. Once students have carried out the sizing of ropes for a lift, it is interesting to ask them to find the limitation of steel ropes (e.g., current limit is around 600m assuming the safety factors are adhered to). This often leads to the discussion of using carbon nanotubes in the proposed space lift (Figure 1) that have a higher yield strength and lower density compared to steel ropes. Students find this topic thought provoking and fascinating. The students start to have an appreciation for the limitation placed on conventional materials and how they can be overcome with modern materials.

Figure 1: The Space Lift (and the use of carbon nanotubes to connect it to earth). ***Accessed on: 29th June 2019:*** *https://spectrum.ieee.org/aerospace/space-flight/a-hoist-to-the-heavens*

Buckling in Guide Rails

When considering the distance between the fixing for guide rails, one of the items that must be considered is the risk of buckling. Buckling is a topic that is often included in Strength of Materials courses (Figure 2). Euler's formula is used to decide if buckling will take place, and if so, the critical distance between fixing points that will prevent buckling.

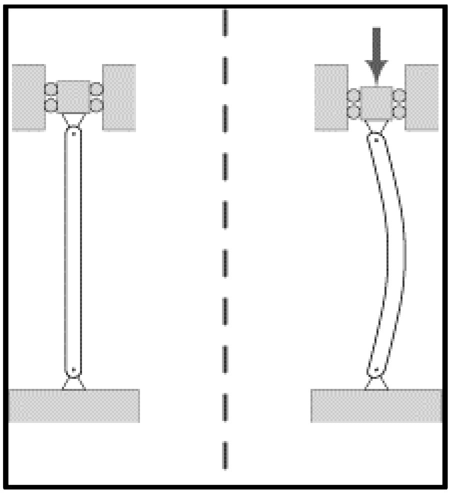

Figure 2: The concept of buckling in slender element subjected to compression.

4. POSSIBLE COURSE PROJECTS

As this course is usually run for final year students, it is ideally placed to include a project within it. Students are asked to work in groups of 2 or 3. A number of suggested projects are offered to students to work on. They are usually given a period of 4 to 6 weeks. More details about the application of project-based learning (PBL) in undergraduate engineering education can be found in [33]. Some of the more interesting projects are discussed in this section.

Lift Kinematics Measurement and Filtering

One of the most popular projects that the students enjoyed was measuring the lift kinematics from a real lift and processing the results. The students borrowed a dedicated accelerometer, or they install an application on their tablet or smart phone. This is then used inside a lift to measure the raw acceleration. The students then are taught how to design a suitable second order digital filter. The block diagram of a digital filter is shown in Figure 3.

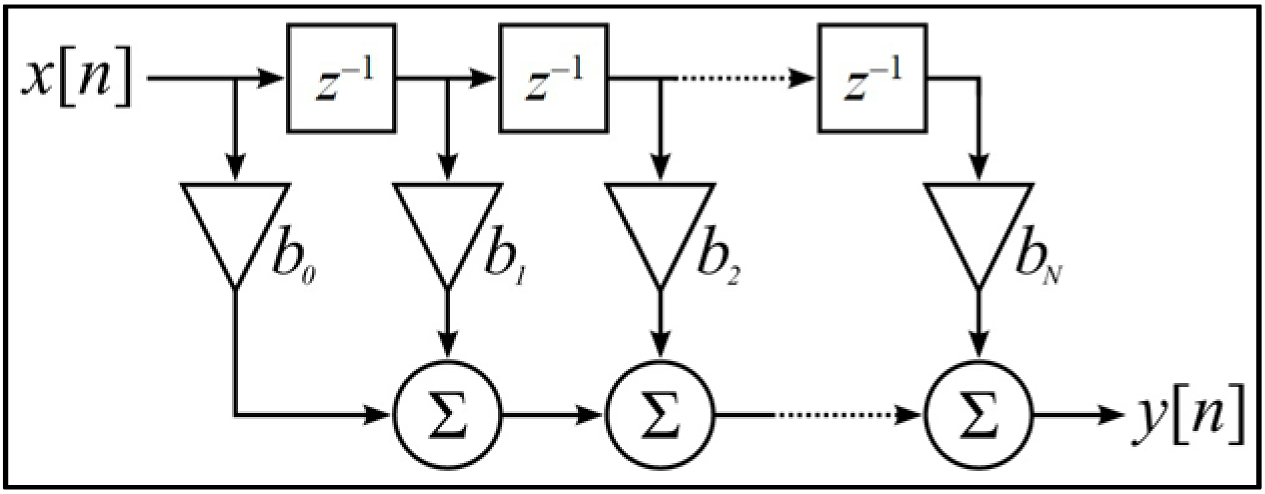

Figure 3: A block diagram of a digital filter.

Once the students have designed a suitable digital filter in MATLAB, they import the raw captured acceleration data. This is then passed through the second order digital filter for filtering the acceleration signal. One of the results obtained is shown in Figure 4. The figure shows the raw acceleration data before filtering the filtered acceleration signal. It can be clearly seen how the filter has removed the high frequency noisy signal and kept the low frequency acceleration signal.

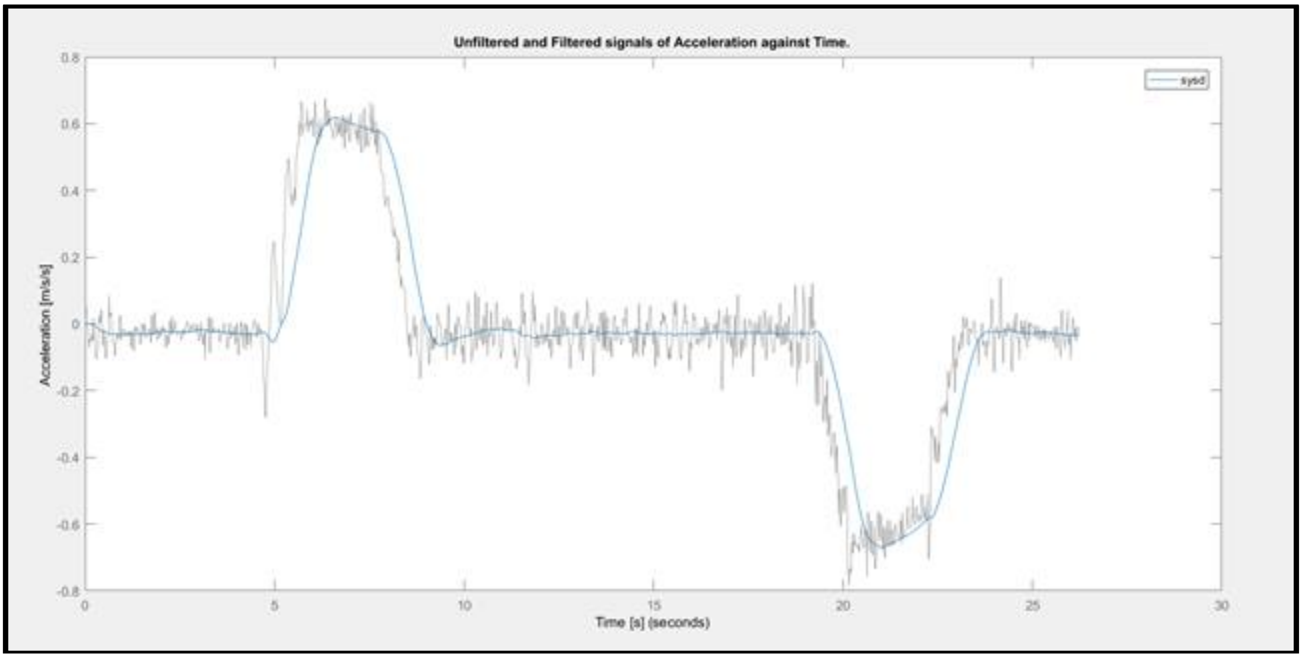

Figure 4: A digital filter used to filter the acceleration data captured from a lift.

Traction Motor Sizing and Selection
Another one of the popular projects is the sizing and selection of the traction motor for the lift. A set of equations are developed that include the masses and the inertias in the lift components, the speed reduction ratio of the gearbox, the diameter of the traction sheave and the details of the traction ropes [34]. These equations are then used in order to calculate the required torque from the motor that would achieve the required value of the starting acceleration. An overview of the motor, gearbox, sheave, traction ropes, car and counterweight is shown in Figure 5.

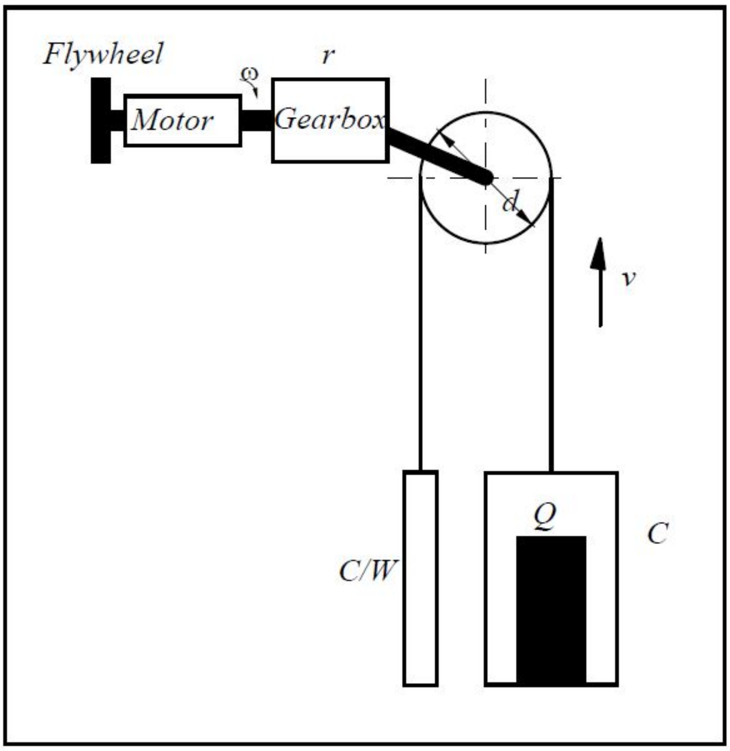

Figure 5: Sizing and selecting a suitable induction motor for the lift.

Passenger survey in a building
The group of students would arrange to visit a building and carry out a passenger survey. They work in a group and synchronise their watches. They have a special form prepared in which they enter the arrival time of each passenger. They also collect data about the number of occupants on every floor, and they carry out an accelerometer measurement in order to obtain the rated speed, rated acceleration and rated jerk of the lift as well as the floor to floor distance. Using all of the data obtained, they assess the passenger arrival rate (AR%) and then they reverse design the lift traffic system in the building.

5. ADVANTAGES OF THESE TYPES OF COURSES
There are three main advantages of using a lift engineering course to deliver certain concepts in engineering.

1. Students are always pointing out that they will be more engaged in their studies if they understood the real-life applications of the topics. Most of the topics and problems presented in this course represent real-life applications and problems. Thus, they are more appealing to students as they can better understand the need for analysing these applications and solving the associated problems.

2. The nature of lift engineering is ideal for project-based learning. Thus, students can be given a project that is very practical in nature. They can work on it in teams, solve problems, and learn by doing things.

3. Lift systems by their very nature are multidisciplinary. The students can thus deal with problems that straddle multiple disciplines, such as mechanical engineering, electrical engineering, control engineering, programming and operational research. This is much more representative of real-life problems and better prepares the students for the marketplace.

6. CONCLUSIONS

It is well established that courses that address real-life multi-functional systems are ideal and examples include but are not limited to: automotive systems, manufacturing systems, aircraft systems and robotic systems. These represent ideal capstone projects for students, due to their practical nature and the multiplicity of disciplines that they comprise.

This paper has outlined a template for using lift engineering as the basis for such a final year course as part of an undergraduate engineering degree (in mechanical engineering, electrical engineering or mechatronics engineering). Four distinct streams have been identified and detailed: lift traffic engineering, space layout and planning, lift electrical engineering (include logic control, safety devices and speed control) and lift mechanical engineering.

The paper has also highlighted specific topics and links that present excellent opportunities to present and/or reinforce many concepts that the students traditionally study in dedicated courses (such as strength of materials, mechanics, electrical machines). These topics always attract a lot of interest from students and stimulate interesting and thought-provoking debates in class. Examples include: rope sizing and the space lift; and buckling in guide rails.

Project-based learning (PBL) presents an excellent tool to encourage student to learn the topics by working practically on them and gathering real-life information. Three examples were given: measuring the acceleration of a lift and filtering the data using a second order digital filter, sizing and selecting the traction motor for a geared lift and carrying out a traffic survey in a building and reverse designing the traffic system.

It has been explained that there are three reasons why this approach is successful in encouraging students to better learn the engineering concepts: the fact that students understand *why* they are studying a topic because they can see its real-life applications, lift engineering is ideal for project based learning (as there are many lift systems that are everywhere and accessible) and the multidisciplinary nature of the lift engineering system that is ideal for preparing the students for real-life engineering.

The long-term aim of this work is to develop an open online repertoire of resources for delivering this course at any school of engineering around the world.

REFERENCES

[1] Al-Sharif, L. Twenty engineering principles for undergraduate mechatronics engineering students. 7th International Symposium on Mechatronics and its Applications, Sharjah, UAE, 2010.

[2] Al-Sharif L, Saleem A and Tutunji T A. Mechatronic system design: The ideal capstone course? 7th International Symposium on Mechatronics and its Applications, Sharjah, UAE, 2010.

[3] Al-Sharif L, Tutunji T A, Ragab D and Kayfi R. Using Elevator system modelling and simulation for integrated learning in mechatronics engineering. *15th International Workshop on Research and Education in Mechatronics (REM),* 2014; pp 1-8.

[4] de Silva C W. Mechatronics: An integrated approach. CRC Press, 2005.

[5] Jarrah M A. Teaching Mechatronics Design Course for Engineers. *IEEE Workshop on Advanced Robotics and Its Social Impacts*, 2005.

[6] Tutunji T, Saleem A and Abd Rabbo S. An Undergraduate Mechatronics Project Class at Philadelphia University, Jordan: Methodology and Experience. *IEEE Transactions on Education,* Vol. 52, No. 3 August 2009.

[7] Goldberg J R. Helping students recognize the value of capstone design courses. *IEEE Engineering in Biology and Medicine Magazine,* May/June 2009.

[8] Goldberg J R. Preparing students for capstone design. *IEEE Engineering in Biology and Medicine Magazine*, Nov/Dec 2009.

[9] Gruenther K, Bailey R, Wilson J, Plucker C and Hashmi H. The influence of prior industry experience and multidisciplinary teamwork on student design learning in a capstone design course. *Design Studies* 30, 721-736, 2009.

[10] Isomottonen V and Karkkainen T. The value of a real customer in a capstone project. *21st Conference on Software Engineering Education and Training, Proceedings*, Engineering Education and Training pages 85-92, 2008.

[11] Pieper J. Work in progress: A capstone course in practical control systems through mechatronics. *36th Annual Frontiers in Education, Conference Program*, Vols 1-4 – Borders: International, Social and Cultural, pages 18-19, 2006.

[12] Benaroya H. Lunar base design: A paradigm for the capstone design course. *Aerospace and Electronic Systems Magazine*, IEEE, Volume 21, Issue 7, pages 33-36, July 2006.

[13] Al-Sharif L. Introduction and Assessing Demand in Elevator Traffic Systems (METE I). Lift Report 2014; 40(4): 16-24. July/August 2014.

[14] Al-Sharif L. Calculating the Elevator Round Trip Time for the Most Basic of Cases (METE II). Lift Report 2014; 40(5): 18-30. Sep/Oct 2014.

[15] Al-Sharif L. Intermediate Elevator Kinematics and Preferred Numbers (METE III). Lift Report 2014; 40(6): 20-31. Nov/Dec 2014.

[16] Al-Sharif L. Four Special Cases in the Calculation of the Elevator Round Trip Time (METE IV). Lift Report 2015; 41(1): 22-36. Jan/Feb 2015.

[17] Al-Sharif L. Calculating the Elevator Round Trip Time for the General Case under Incoming Traffic Conditions (METE V). Lift Report 2015; 41(2): 24-37. Mar/Apr 2015.

[18] Al-Sharif L. Introductory Elevator Traffic System Design (METE VI). Lift Report 2015; 41(3): 32-44. May/Jun 2015.

[19] Al-Sharif L. The Average Waiting Time and the Average Travelling Time (METE VII). Lift Report 2015; 41(4): 34-45. July/August 2015.

[20] Drewer S. Development of tools for planning and comparison of elevators, Ph.D. Thesis. Karlsruhe Institute of Technology, November 2015.

[21] Al-Sharif L. Introduction to Elevator Group Control (METE XI). Lift Report 2016; 42(2):59-68.

[22] Al-Sharif L, Abdel Aal O F, Abu Alqumsan A M and Abuzayyad M A. The HARint Space: A Methodology for Compliant Elevator Traffic Designs. *Building Services Engineering Research & Technology*, 2015; 36(1): 34–50.

[23] HSE Books. *Out of Control: Why control systems go wrong and how to prevent failure*. Health and Safety Executive, United Kingdom, 2nd Edition, 2003, HSE Books.

[24] Wildi T. *Electrical Machines Drives and Power Systems*. 6th Edition, Pearson Prentice Hall.

[25] Crowder R. *Electric Drives and Electromechanical Systems*. Newnes, 2006.

[26] Shepherd D, Hully L N and Liang DTW. *Power Electronics and Motor Control.* Cambridge University Press, 2nd Edition, 1995.

[27] Chapman S J. *Electric Machinery Fundamentals.* McGraw Hill International Edition, 1991.

[28] Al-Sharif L. MATLAB CODE TO EVALUATE THE ELEVATOR ROUND TRIP TIME USING MCS The Use of In-Class Problem Based Learning for Final Year Engineering Students. Lift Report 2018; 44(1): 14-20.

[29] Janovsky L. *Elevator Mechanical Design*. 3rd edition

[30] Al-Sharif L, Abu Alqumsan A M, Ghanem W, Tayeh I and Jarrar A. Modelling of Elevator Traffic Systems Using Queuing Theory. 4th Symposium on Lift and Escalator Technologies 2014. Vol 4, pp 9-18. University of Northampton, September 2014. doi: 10.13140/RG.2.1.1392.0165.

[31] Al-Sharif L. Lift and Escalator energy consumption. *Proceedings of the CIBSE/ASHRAE Joint National Conference*, Harrogate 1996; 1: 231-239.

[32] Smith R S, Peters R D and Al-Sharif L R. Elevator system to minimize entrapment of passengers during a power failure. *US Patent Number US7967113*. Publication date: 28th June 2011.

[33] Al-Sharif L. Project Based Learning in Undergraduate Engineering Education. *Professional Accreditation Conference for Engineering (PACE),* Jordan Engineers' Association, 25th March 2015, Amman, Jordan.

[34] Al-Sharif L. Lift and Escalator Motor Sizing with Calculations & Examples. *Lift Report* 1999; 52(1).

BIOGRAPHICAL DETAILS

Lutfi Al-Sharif is currently Professor of Building Transportation Systems at of the Department of Mechatronics Engineering, The University of Jordan. He received his Ph.D. in lift traffic analysis in 1992 from UMIST (Manchester, U.K.). He worked for 10 years for London Underground, London, United Kingdom in the area of lifts and escalators. He has around 30 papers published in peer reviewed journals 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. He is also a visiting professor at the University of Northampton (UK), member of the management committee of the annual Symposium on Lift & Escalator Technologies and a member of the editorial board of the journal Transportation Systems in Buildings.

Accessible Goods Only Lifts (AGOLS):
The Law & Levels of Safety

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Keywords: Accessible, AGOL, safety gear, machinery directive, lift regulations.

Abstract. When a person enters a lift - whether to load it, unload it or just to travel in it - the question is whether they are entitled to believe that it offers an acceptable level of safety. Given that the function of the lift, whether manufactured to The Lift Directive or The Machinery Directive, is the same (i.e. to move goods from one level to another), would it not be reasonable to expect that the levels of safety would be the same? This paper will look at the different requirements against uncontrolled movement in the downward direction and will discuss the risks with reduced levels of protection, as well as the implications for persons in the car, including those who have to enter the car to maintain the said lift.

1 WHAT IS AN AGOL?

An AGOL is an "Accessible Goods Only Lift". This means that it was intended to transport goods only and was not intended to have passengers travel in it.

2 THE LAW AND LIFTING APPLIANCES

The Lifting Operations & Lifting Equipment Regulations 1998 (LOLER) states in Regulation 5(1)(c) *"Every employer shall ensure that lifting equipment for lifting persons has suitable devices to prevent the risk of a carrier falling*" [1].

The question that then arises is whether this clause applies to AGOL's as they are intended to move goods only and the clause specifically states *"for lifting persons"*.

Photograph 1: Typical Sign on a Landing

Following the introduction of the Supply of machinery (Safety) Regulations 1992 [2] , which enacted the 1992 Machinery Directive [3], the Essential Health & Safety Requirements (EHSR's) of these Regulations set out a clause (4.1.2.6), which required machinery such as lifts to be designed and constructed so that loads could not creep dangerously, fall freely or fall unexpectedly.

In December 2009, the Supply of machinery (safety) Regulations 2008 [4] replaced the 1992 version. Clause 4.1.2.6 remained similar but clause 4.1.2.8.2 required *"that where persons have access to the carrier, the machinery must be designed and constructed in such a way as to ensure that the carrier remains stationary during access, in particular whilst being loaded and unloaded"*.

In 2010, a harmonised standard was published for AGOL's (BS EN 81-31 [5]). This standard, whilst not law in itself, presumes conformity to the EHSR's of the Machinery Directive. This standard requires rope and chain suspended lifts to be fitted with means to prevent free fall and uncontrolled movement.

During the process of maintaining an AGOL the maintenance operative will be protected by the Provision & Use of Work Equipment Regulations (PUWER) [6].

This, amongst other things, requires that the employer conduct a risk assessment to identify the hazards and determine what the risks associated with the equipment and its use are. It is anticipated that such a risk assessment would identify the obvious risk of free fall on some designs.

3 WHAT ARE THE ISSUES WITH AGOLS WITHOUT SAFETY GEARS?

For many years, our industry was cautious about older designs of lifts that had no safety gear. These were generally goods only lifts with no car operating station but often had a call and send arrangement on the landings, to allow the operative to send the consignment of goods to wherever it was required. Then they would go to that floor and perform the unloading task.

The issue that was identified by the industry many years ago was that there was a risk to a person crossing the landing and car thresholds to load or unload the car, (described as a carrier in LOLER).

The industry reacted in a number of ways, including removing car operating stations where they existed on a lift with no safety gear, placing signs on the car roof advising operatives not to ride on the car roof, (where there would be no car top control anyway) and in some cases reduced height cars were introduced such that it was uncomfortable for an operative to enter the car and therefore the goods were loaded and unloaded by pushing them in from a distance on pallet trucks etc.

The issue arises when the passenger is across the threshold and there is uncontrolled movement.

Another issue that has arisen is that maintenance operatives have to travel in the lift and plug in a pendant in some cases to operate it.

The industry does not allow car top controls on lifts with no safety gear so why would should lifts with no safety gear be allowed to have a pendant?

The answer is very simple. They should not as the operative is a passenger being lifted, by definition.

4 WHAT ARE THE RISKS

The risks include:

- Uncontrolled movement whilst boarding or alighting
- Maintenance operative entrapment whilst undertaking maintenance
- Uncontrolled descent or ascent whilst a person is in the car

Additional risks arise as a result of some designs not having a car door and some having a car door but not a car door contact, allowing it to travel with the door open.

The HSE issued guidance on lifts with no car doors many years ago and it must therefore be considered a step backwards to allow cars to not have a car door or one with no means of proving that it is closed and locked. Given that these lifts are designed to move goods only and in an unaccompanied manner, the risk of the goods moving during travel need to be considered.

Uncontrolled movement whilst boarding or alighting is a risk on any lift with or without a safety gear. EN81-1 [7] & EN81-2 [8] amendment 3 (known in the industry as A3), dealt with uncontrolled movement and was intended to prevent the risk of shearing between the car and landing in the event of uncontrolled movement.

In the UK such incidents have occurred causing death including incidents in Woodford, Essex and in Broadgate in the City of London.

It is clearly a well-known risk which should to be eliminated by sound engineering design such as the addition of a safety gear.

CITY GIRL IS CRUSHED TO DEATH IN LIFT SHAFT

Plunge horror at posh gym

Figure 1: Newspaper coverage following fatality in London

The above example of a lift (although not an AGOL), moving with its doors open creating a shearing affect as a passenger was across the threshold, is a real example of what could happen.

A potential issue arises with maintenance operatives, as a result of having to travel in the lift car and on some designs having to remove panels for the car walls to access the guides, ropes or chains and limit switches. In the event of uncontrolled movement whilst a limb is through the window there is an obvious risk of entrapment which would potentially result in serious injury.

Even with a safety gear installed it is not considered safe to put limbs through a window to access components due to the obvious risk of shear, even in the distance dropped by the car until the safety gear engages.

5 THE ARGUMENT THAT SOME DESIGNS COMPLY

Arguments have been made that on some hydraulic designs there are two ropes over the ram head diverter and that one is slightly less tensioned than the other. This means the AGOL is being raised and lowered on a single rope which, if it snaps, transfers a dynamic load to the other rope, thus preventing free fall.

It is not unknown that ropes on lifts break either due to poor maintenance or an unusual event causing an unintended load to be applied to them.

Photograph 2: Failed hoist ropes after dynamic loading

6 CONCLUSION

It is concluded that all AGOL's designed to either the Supply of Machinery (Safety) Regulations, Machinery Directive, Lift Directive [9] or the harmonised standard EN81-31 should be fitted with means of protection against uncontrolled movement.

It is concluded that LOLER requires that protection against free fall be fitted to any lifting installation.

It is also concluded that an operative undertaking maintenance on an AGOL would be protected by PUWER and a risk assessment required by this statutory instrument should identify the risk of free fall and to seek the prevention of such an occurrence.

REFERENCES

[1] HM Government (1998) Lifting Operations & Lifting Equipment Regulations

[2] HM Government (1992), Supply of Machinery (Safety) Regulations

[3] Machinery Directive 1992

[4] HM Government (2008) Supply of Machinery (Safety) Regulations

[5] BSI (2010), BS EN81-31 Accessible Goods Only Lifts

[6] HM Government (1998) Provision & Use of Work Equipment Regulations

[7] BSI (2009) BS EN81-1 Amendment A3

[8] BSI (2009) BS EN81-2 Amendment A3

[9] Lift Directive

[10] LEIA Technical Warning Notice (Feb 2019)

BIOGRAPHY

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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 Charity that runs the Lift Symposium and is an Honorary Visiting Fellow at The University of Northampton.

Can Lift Traffic Simulators be Verifiable, Transparent, Repeatable and Reproducible?

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Keywords: Lift, lift traffic, calculation, simulation.

Abstract. A lift traffic design is carried out to determine the rated load, rated speed, number of lifts and number of other defining parameters of a lift installation, in order to meet the passenger demands made upon it. A calculation can be carried out using verifiable, transparent, reproducible and repeatable mathematical (statistical) theory. Should further information be required then a simulation is often carried out, but what is the veracity of the simulation results? This paper reviews the simulation results for the same project brief. The paper considers whether simulation results can be verifiable, transparent, reproducible and repeatable.

1 DEFINITIONS

Standards, whether British, European or International are required to be verifiable and secondly where calculations are included, they are required to be transparent, repeatable and reproducible.

Verifiable (able to be checked or demonstrated to be true, accurate), example:

> *Ventilation apertures shall be built or arranged in such a way that it is not possible to pass a straight rigid rod through the car walls from the inside.*

is not verifiable but:

> *Ventilation apertures shall be built or arranged in such a way that it is not possible to pass a straight rigid rod **10 mm in diameter** through the car walls from the inside.*

… is verifiable.

[Example from BS EN 81-20, 5.4.9.3.]

Transparent (easy to perceive or detect), example:

> *The values of acceleration and deceleration shall be calculated by applying a 10 Hz low-pass filter to the original un-weighted z-axis signal.*

is not transparent but:

> *The values of acceleration and deceleration shall be calculated by applying a 10 Hz low-pass filter to the original un-weighted z-axis signal …. **The 10 Hz low-pass filter shall be a 2-pole Butterworth filter** …*

… is transparent.

[Example BS ISO 18738:2003, 5.2.1]

Repeatable means:
A person carrying out a measurement, investigation or simulation can repeat the measurement, investigation or simulation and obtain the same results using the same simulator. There may be acceptable and understood random errors in the results.

For this paper it is assumed that each individual investigator can repeat their results.

Reproducible means:
A measurement, investigation or simulation is reproducible if when the measurement, investigation or simulation is repeated by another investigator using the same simulator or another simulator obtains the same results.

2 THE PROBLEM

Calculation and simulation methods are used to select lift systems to meet specified traffic design requirements and establish the main parameters of rated load, rated speed and number of lifts.

The calculation method

The calculation method takes the input parameters, applies a mathematical (statistically based) model and provides output results.

The mathematical model is represented by formulae and is defined precisely.

The calculation method is verifiable, transparent, repeatable and reproducible by the ordinary traffic designer.

The simulation method

The simulation method takes the input parameters, applies them to a simulator and provides output results.

The simulator runs a digital model. The details of how it operates are not fully known to the ordinary traffic designer.

A simulation should be repeatable by an ordinary traffic designer. But can the ordinary traffic designer confirm that the simulation method is verifiable, transparent and reproducible? The simulation method could be made more transparent if the simulator engine coding were available for review by the traffic designer. However, most designers would not have the skill or time to undertake this review.

This is why there are often different output results when using different simulators.

3 COMPUTER AIDED DESIGN OF LIFTS

The necessity for the computer aided design of lifts was foreseen by Jackson (1970) who wrote:

> *"a real need … is a computer program to simulate the likely performance of proposed lift systems . . . Different numbers, speeds and groups of lifts should be considered, as well as different control systems … the results would show designers the performance of several proposals . . . [and allow] . . . rational decisions".*

The computer simulation of engineering processes is particularly appropriate, where the study of the actual process is difficult or dangerous, too costly, would take too much time, or would be inconvenient. Existing lift systems fall into this category. In the case of a new lift, the installation does not even exist.

Digital computers are most suitable for the simulation of discrete (digital) systems, as their algorithms can be described by sets of logical equations. A lift system is a discrete system:

- Each passenger is a discrete entity.
- Each individual passenger arrival or departure are discrete events.
- Each floor is a discrete entity.
- Each lift is a discrete entity.
- Each lift car movement and door operation are discrete events.

Digital computer simulation programs can be either event based, ie: the model is updated every time something happens, or time based, ie: the model is updated at regular intervals. A lift system is relatively sparse in the number of events that occur, compared to some engineering systems. Most lift system events do not require immediate action, and some events initiate identical actions, making it efficient to service them at the same time. It is therefore better to select the time-based method, with an update interval chosen to contain a statistically significantly number of events.

Engineering design involves the appreciation of shape, form and relative values; thus the graphical presentation of data allows the designer to appreciate a design quickly. The process of computer aided design (CAD) is to input data, carry out an application (APP), eg: a simulation, receive output data to consider and, if necessary, repeat the process with new input data.

4 TESTING SIMULATIONS

During the course of work on the revision of ISO 4190-6: 1984, *Passenger lifts to be installed in residential buildings* to create ISO/FDIS 8100-32, *Planning and selection of passenger lifts to be installed in office, hotel and residential buildings* it was decided to complement the calculation method with a simulation method. Doubts were expressed to the veracity of results obtained by simulation. As the group comprised traffic specialists with different experiences and skill sets, this presented the writer with a unique opportunity. The writer asked the group members to investigate the problem by running simulations to the same project brief with the same input data and report in the same output format.

The investigation was to run nine simulations at one percent point steps of passenger demand from 8% to 16% for an office building with low and high zones. The uppeak and midday traffic patterns were to be considered. There were 36 simulations to be carried out by each investigator.

Table 1 shows the lift traffic design criteria. Table 2 is the project brief and shows the building and lift data. Table 3 reports the uppeak results and Table 4 reports the midday results in the data format required from the simulations.

Table 1: Lift traffic design criteria

Type of Building:	Office building	
Uppeak traffic:	100 % incoming	
Midday traffic:	40 % incoming, 40 % outgoing, 20 % inter-floor	
Design criteria:	**Uppeak**	**Midday**
Required handling capacity:	12 %	11 %
Required average waiting time	30 s	40 s

5 THE RESULTS

Six sets of results were sent to the writer and anonymised. Only the writer and the investigators will recognise the results. The six data sets were identified as Series 1, Series 2, Series 3, Series 4, Series 5 and Series 6. The example values shown in Tables 3 and 4 are from Series 2.

The results were from three major manufacturers, three consultants and carried out on three software platforms. Two simulations were carried out by the same investigator using two different simulators. Four of the sets of results were made using the same platform.

The results were tabulated on a spreadsheet and graphed as shown in Figures 1 and 2.

6 SUMMARY OF RESULTS

Table 5: Summary of passenger average waiting times (AWT) in seconds.

Traffic type	Rise	Required Demand	Required AWT	Series 1	Series 2	Series 3	Series 4	Series 5	Series 6
Uppeak	Low	12%	30s	9.1	7.5	5.0	5.2	13.5	7.7
Uppeak	High	12%	30s	19.6	8.1	10.0	6.8	34.0	16.5
Midday	Low	11%	40s	15.8	21.8	23.2	23.3	23.8	19.1
Midday	High	11%	40s	20.3	24.2	25.0	26.0	31.0	26.1

The results obtained are assumed to have been **repeatable** by each individual investigator.

All the simulations return different values so the all the simulators fail to provide **reproducible** results, see Table 5.

The results for Series 5 are significantly different to the other series.

The four sets of results from the same platform (Series 2, 3, 4, 6) returned different results. This indicates different interpretations of set up parameters made by the investigator or a tailoring of the simulation engine.

7 WHY ARE THE RESULTS DIFFERENT?

Each investigator was provided with the design criteria (Table 1) and the building and lift data (Table 2) and asked to report to a standard template (Tables 3 and 4).

Although the data in Table 2 is all that the calculation method requires the data specified in Table 2 is not sufficient for the simulation method.

Investigator settings

There are many variations possible that the investigator can set including:

- Did the investigator run one simulation or several and take an average?
- Did each investigator run a constant simulation for each of the nine demand values from 8% to 16% or did they run a stepped simulation across the range?
- Dwell times are not defined and different values can be selected. Often a simulator enters default values.
- How many door recycles, as the result of multiple landing calls, are permitted? Often a simulator enters default values.
- Did the investigator allow stair traffic?
- Were passenger numbers determined by area or by weight to determine maximum lift car capacity?
- Was a factor added to allow for "running out of sequence" (bunching)?
- Is the main terminal given extra attractiveness to park there?

There are other input parameters in most simulators and the investigator can set them to their experience.

Controller settings

The control algorithm used is defined as full collective. The meaning of this algorithm is understood, but:

- In uppeak, does the simulator bring all cars to the main terminal floor, when empty?
- On arrival at the main terminal floor do the doors open immediately or wait?
- Is there a load detector operating to bring lift cars to the main terminal?

  Series 2, 3 and 4 have an improvement in waiting times near to 13.5% demand. Could this be the effect of a switching algorithm?

Simulator settings

The simulator "engine" has a number of factors generally unknown to the designer, including:

- Is the simulation event based or time based?
- To what accuracy is data measured?
- Is the data kept to the maximum accuracy or rounded?
- How is the Poisson arrival process carried out?
- Does the arrival process force exactly the current number of passengers to arrive in each 5-minute period?
- If the passenger arrival rate is a decimal number does the simulator round up or down?
- How are destination calls determined?
- What is the pre-simulation period until data is gathered (start effect)?
- If passengers are still not disembarked at their destination is their waiting and travel times included (finish effect)?

There are other simulation parameters that are not defined and that the investigator may not be aware of.

Output setting

The output module can also present data in different ways, including:

- Is the average passenger waiting times gathered as an average per 5-minute period or are they an average over the whole period?
- Have the values been rounded?
- For midday simulations are the averages for one floor?
- For midday simulations are the averages for all floors?
- Is there any result filtering?

The report module often has advanced processing features that at are not defined.

Thus, the internal workings of the simulator engine are **not transparent** to the designer. The simulator designer will know all the features, but usually will not be the user.

8 ARE THE SIMULATION RESULTS BAD?

The graphs show similar shapes. Table 5 shows there is no best simulator.

All except Series 5 follow a similar shape for uppeak traffic and all follow a similar shape for midday traffic.

The right-hand graphs show the results to a smaller time range. The design criteria for average waiting times (AWT) for the passenger demand values of 12% in uppeak (except Series 5) and 11% in midday traffic for both rises are easily achieved. Why?

A calculation for uppeak traffic shows that six 2000 kg lifts can provide:

Low Rise *%POP* = 14.3% /5 min	UPPINT = 27.3	AWT = 23.2	CF = 80%
High Rise *%POP* = 13.6% /5 min	UPPINT = 28.7	AWT = 24.4	CF = 80%

Both rise installations are over lifted. This is why at the uppeak design criteria value of 12% the performance is so good, as the cars are only 57% loaded (CF).

Different conclusions would be drawn if, for example, the uppeak design criteria were set at the 14.3% full handling capability.

Taking low rise passenger demand at 14.3% (marked with a "snowflake" on Figure 1 (B)). Examining Figure 1 (B) shows the AWT results are all less than 30 seconds (except Series 5), but show a range of AWT of approximately 5 s – 25 s.

The values obtained are better than required so does it matter there is a range?

It is possible in a tender situation that a client receiving simulation results from suppliers and consultants would favour the lower values, other matters being considered. So, there might be a competitive advantage.

Calculations show that the low rise could be served by either five, 2000 kg lifts or six, 1350 kg lifts.

Calculations show, for the high-rise installation, that six, 1600 kg lifts would be suitable.

9 CAN A SIMULATION BE MADE MORE VERIFIABLE?

The definition of all simulator parameters is a huge job, if at all possible. The parameters mentioned above are some. But do all simulators have these features anyway?

Could a benchmark be developed to certify a simulator?

Yes, it could, but simulator designers could still tune their simulators to pass the test.

10 CONCLUSIONS

The calculation method is verifiable, transparent, repeatable and reproducible.

The simulation method is not verifiable, transparent or reproducible, but is repeatable.

Simulators could be made more verifiable by defining more parameters. There is a risk, however, that defeat algorithms are inserted to ensure a successful compliance.

11 SIDENOTE

Both the proposed low- and high-rise lift installations are over lifted. This is clear from the simulations. But the simulations give no clear idea as to a more appropriate selection. The calculation method does this instantly.

Peters (2019) recommends: *"… it is good practice to start all design exercises with a round trip time calculation. …Simulation is complex and it is easy for less experienced practitioners to make mistakes, a round trip calculation may alert the practitioner of a possible error"*

REFERENCES

Barney, Gina and Al-Sharif Lutfi, 2016 *Lift Traffic Design Spreadsheet,* www.bit.ly/lifttrafficspreadsheet,
[select eResources, scroll, select Lift Traffic Design Spreadsheet, accessed 30 August 2019]

BS EN 81-20:2014 *Safety rules for the construction and installation of lifts — Lifts for the transport of persons and goods Part 20: Passenger and goods passenger lifts*.

BS ISO 18738: 2003: *Lifts (elevators). Measurement of lift ride quality*.

ISO 4190-6: 1984: *Lifts and service lifts). Passenger lifts to be installed in residential buildings. Planning and selection.*

ISO/DIS 8100-32: 2018. *Lifts for the transportation of persons and goods -- Part 32: Planning and selection of passenger lifts to be installed in office, hotel and residential buildings.*

Jackson, C., *Analytical techniques: simulation case study* Architects Journal Information Library, 8, 1970.

Peters, R.D., *Lift traffic design using simulation*, DIG/GDD: 2019, **4**.

ACKNOWLEDGEMENTS

Those members of ISO/TC178/WG6/SG5 who carried out the simulations.

BIOGRAPHICAL DETAILS

Dr Gina Barney Principal of Gina Barney Associates, Honorary English Editor of Elevatori, Member of the Chartered Institution of Building Services Engineers (CIBSE) Lifts Group Committee, Member of the British Standards Institution (BSI) Lift Committees, UK expert to ISO committee ISO/TC178/WG6/SG5 revising ISO 8100-32 Planning and selection of passenger lifts to be installed in office, hotel and residential buildings and ISO/TC178/WG10 Energy efficiency of lifts and escalators. Liveryman of the Worshipful Company of Engineers and a Freeman of the City of London. Dr Barney is the author of over 120 papers and is the author, co-author or editor of over 20 books. She has the degrees of BSc, MSc and PhD and the professional qualifications of CEng, FIEE, HonFCIBSE and Eur.Ing. Trustee of three charities and member of several Sedbergh organisations and a volunteer Area Lead for Broadband for the Rural North (B4RN) installing 1Gbps full fibre in the Rawthey Valley. For relaxation (sic) she dances ballroom, Latin, sequence and Scottish country, with gardening and dog walking and goes on cruises.

Table 2: Project brief (building and lift data)

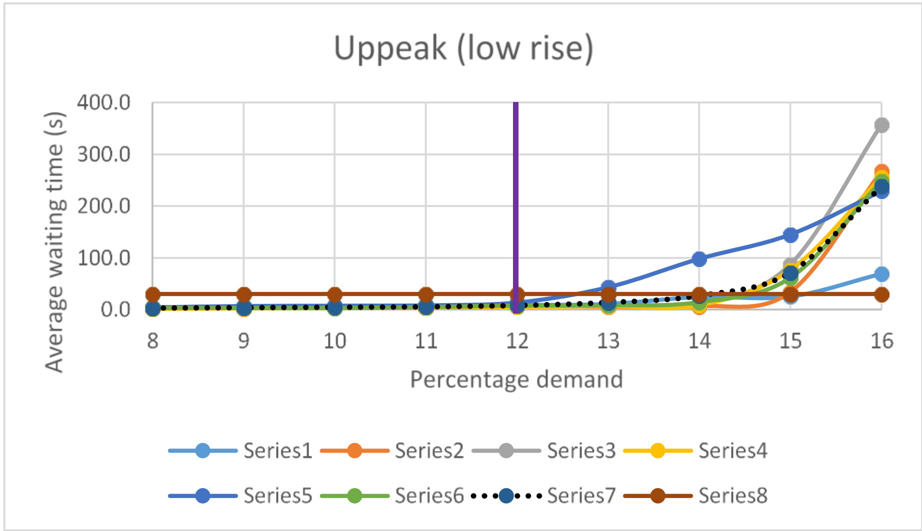
Parameter	Low Rise	High Rise
Population	1232 persons	1232 persons
Lift group control	Full collective	Full collective
Maximum passenger capacity	20	20
Rated load	2000 kg	2000 kg
Average interfloor distance	3.75 m	3.75 m
Express-Zone	—	52.5 m
Number of served floors	14	14
Number of lifts	6	6
Rated speed	2.5 m/s	5.0m/s
Acceleration / Deceleration	1.0 m/s^2	1.0 m/s^2
Jerk	1.0 m/s^3	1.0 m/s^3
Door type	1speed CO	1speed CO
Door width	1100 mm	1100 mm
Flight time	5.0 s	5.0 s
Door closing delay time	0.0 s	0.0 s
Door opening time	2.0 s	2.0 s
Door closing time	2.4 s	2.4 s
Door pre-opening time	0.0 s	0.0 s
Start delay	0.6 s	0.6s
Performance time	10.0 s	10.0 s
Single passenger transfer time	1.0 s	1.0 s

Table 3: Passenger average waiting times for uppeak traffic (series 2)

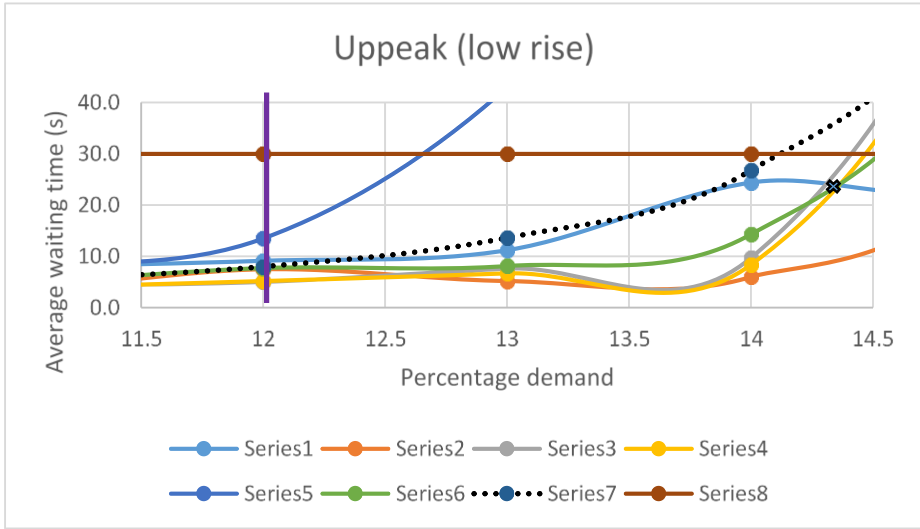
Demand (times in seconds)	**Low Rise**	**High Rise**
Avg. waiting time at 8 % passenger demand	1.7	3.5
Avg. waiting time at 9 % passenger demand	2.1	4.3
Avg. waiting time at 10 % passenger demand	3.5	6.1
Avg. waiting time at 11 % passenger demand	3.6	8.2
Avg. waiting time at 12 % passenger demand	7.5	8.1
Avg. waiting time at 13 % passenger demand	5.2	12.0
Avg. waiting time at 14 % passenger demand	6.0	24.6
Avg. waiting time at 15 % passenger demand	33.8	314.0
Avg. waiting time at 16 % passenger demand	267.0	603.0

Table 4: Passenger average waiting times for midday traffic (series 2)

Demand (times in seconds)	**Low Rise**	**High Rise**
Avg. waiting time at 8 % passenger demand	12.7	18.7
Avg. waiting time at 9 % passenger demand	14.9	19.5
Avg. waiting time at 10 % passenger demand	18.4	22.6
Avg. waiting time at 11 % passenger demand	21.8	24.2
Avg. waiting time at 12 % passenger demand	23.6	28.3
Avg. waiting time at 13 % passenger demand	24.9	29.1
Avg. waiting time at 14 % passenger demand	29.5	29.2
Avg. waiting time at 15 % passenger demand	35.7	37.0
Avg. waiting time at 16 % passenger demand	35.7	45.9



(A)



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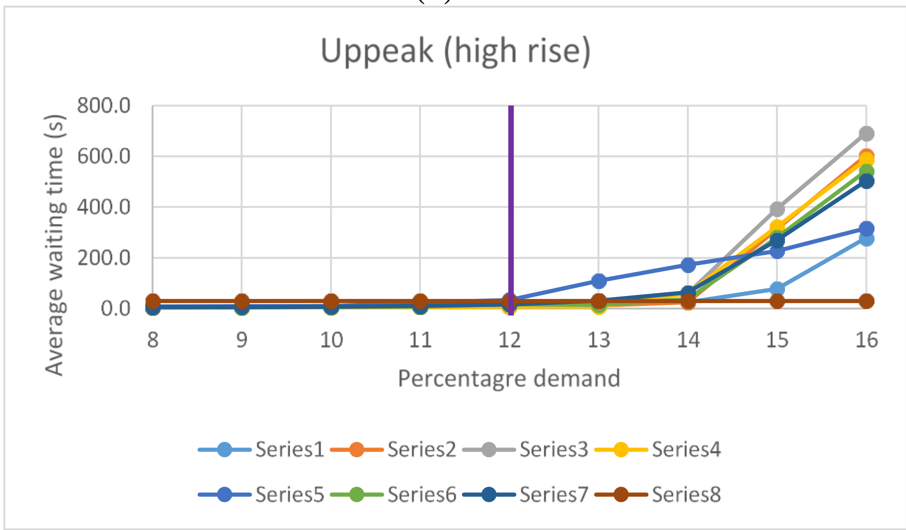
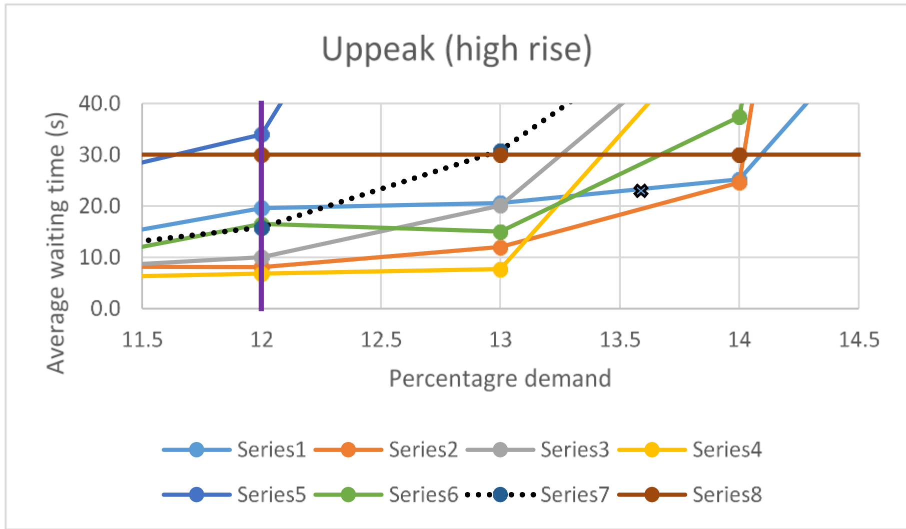
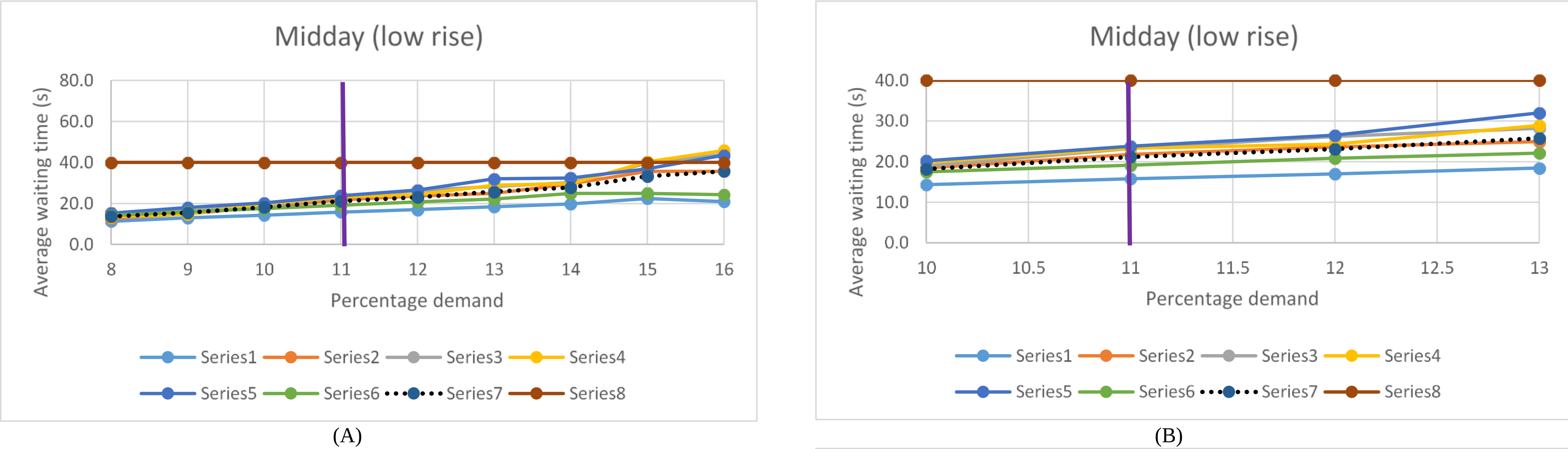


(C)



(D)

Figure 1: Uppeak results *Note: Series 7 (dotted line) is the simple average of the results. Series 8 (solid) line are datum values.*
– (A) & (C) from 8% to 16% (B) & (D) from 11.5% to 14.5% for 12% demand – shows <30 s average passenger waiting time



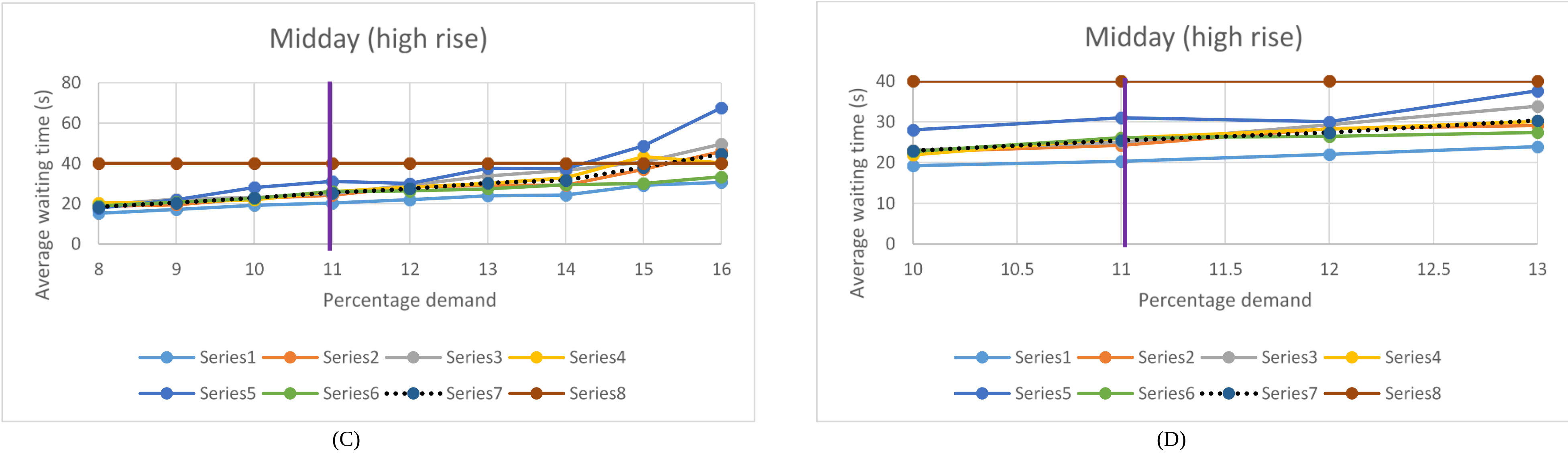


Figure 2: Midday results *Note: Series 7 (dotted line) is the simple average of the results. Series 8 (solid) line are datum values.*

– (A) & (C) from 8% to 16% (B) & (D) from 10.0%to 13% for 11% demand – shows <40 s average passenger waiting time

Cycle Lifts – Meeting The Future Demand

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Keywords: Bicycle, cycle, lift, demand.

Abstract. Recent changes to planning policy in many major cities, allied to a growing awareness of the need to address our sedentary lifestyles, is driving the need to design buildings to accommodate more and more bicycle spaces. In large commercial developments in London, this can lead to a need for more than 1000 bicycle spaces, which often are located at basement levels. From a circulation perspective this creates a need to move people and their bicycles between street level and the bicycle storage facility. Sometimes this is achieved with a ramp, or adapted stairs, but often lifts are required.

There is currently limited guidance on design benchmarks for lifts whose primary purpose is the movement of bicycles and their riders. What are acceptable waiting times? What is an acceptable queue length? How much space does a bicycle and accompanying rider occupy? How large does a lift need to be to accommodate two cycles and riders, or three cycles and riders. This paper explores the current guidance and proposes additional benchmarks for consideration when designing cycle lifts.

1 BACKGROUND & CONTEXT

Throughout a growing number of developed countries there is an increase in people's awareness of the need to protect ourselves from the insidious creep of our convenient sedentary lifestyles and unhealthy diets. Obesity and its associated poor levels of fitness and health are the number one cause of early death in many developed countries. This has led to governments focusing on affordable steps to improve the health of the nation and encouraging the use of bicycles has formed part of this strategy in the UK and particularly in London.

Cycle use fell sharply in the late 1940s as the affordability of the car came within more and more people's reach. Recently however that declining trend has started to reverse, and some traffic counts suggest that the number of miles cycled in 2017 (3.27 billion) is around 29% above the figure for 1997 [1] as shown in Fig. 1 below.

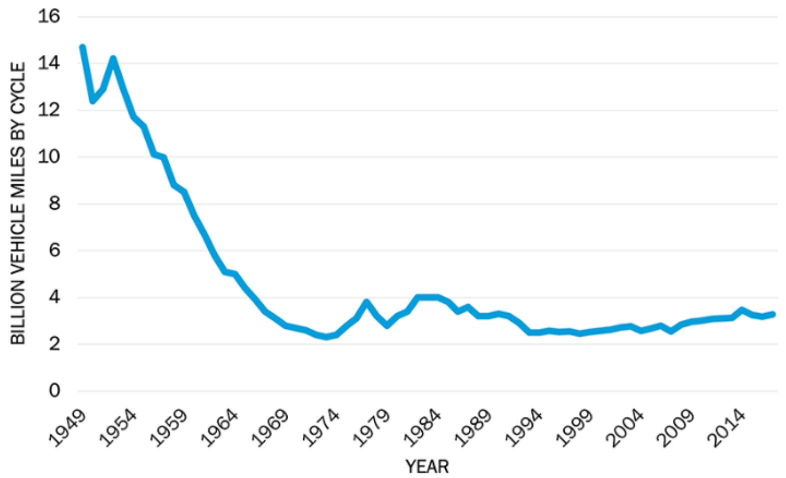


Figure 1: Cycle Use in Billions of Vehicle Miles 1949-2017 (GB)

In London however the increase is far more significant; around 27,000 people cycled across central London in 1977, compared to 184,000 in 2016, almost seven times as many [1], as illustrated in Fig. 2 below.

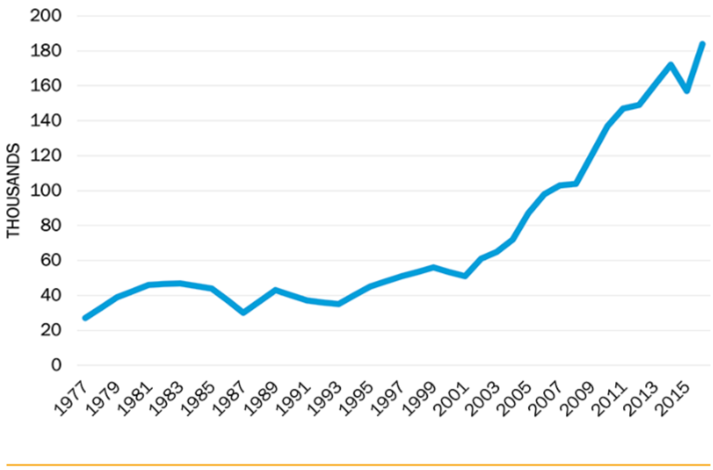


Figure 2: Long-term trends across the Central London Cordon 24-hour weekdays, both directions, 1977-2016

2 PLANNING

The design of buildings within London needs to demonstrate compliance with the London Plan [2], an established set of design principles governing the development of the City. In the foreword of the latest Draft London Plan (2019), the Mayor of London Sadiq Khan comments,

"I also see the London Plan revolutionizing the way we get around our city - enabling a boom in active travel, with walking and cycling becoming the primary, default choice for millions of Londoners because we have made it far easier and safer."

Whilst this approach is focused on the development of London, the trends it is establishing and promoting are being seen in many other cities both in the UK and overseas, and in many cases being adopted in varying forms into formal planning design requirements.

Policy T5 of the new draft London Plan provides requirements for cycle parking, a key element in removing barriers to cycling and creating a healthy environment in which people choose to cycle. One is unlikely to use a bicycle regularly unless there is a secure, safe and convenient place to store it.

The policy requires cycle parking to be fit for purpose, secure and well-located. The right amount of cycle parking for a site or area would be at a level that:

- Meets existing baseline demand
- Meets the potential demand generated by the existing and proposed land uses in the area
- Ensures there further is allowance for spare capacity (ideally, at least 20 per cent)

Development should provide cycle parking in accordance with the minimum standards based on Gross External Area (GEA) [3] set out in Table 10.2 of the plan, headline extracts from which are shown below in Table 1.

Table 1: Draft London Plan – Cycle Parking Requirements (Extract)

Class of Development	Long-stay (e.g. residents or employees)	Short-stay (e.g. visitors or customers)
B1 Offices	1 space per 75 m^2 GEA (higher standard) [*] 1 space per 150 m^2 GEA (standard)	First 5,000 m^2 GEA: 1 space per 500 m2 Thereafter: 1 space per 5,000 m^2 GEA
C1 Hotels	1 space per 20 bedrooms	1 space per 50 bedrooms
C3/C4 Dwellings	1 space per studio or 1 person / 1 bedroom dwelling 1.5 spaces per 2 person 1 bedroom dwelling 2 spaces per all other dwellings	5 to 40 dwelling: 2 spaces Thereafter: 1 space per 40 dwellings
[*] – Locations with high cycle usage currently identified as justifying a higher provision of cycle parking. Central and inner London boroughs plus others.		

Cycle parking should also permit easy access for disabled cyclists who may be using adapted cycles, as well as providing appropriate facilities for other non-standard cycles such as tricycles or bicycles with trailers.

Cycle parking also needs to be designed in accordance with the guidance contained in the London Cycle Design Standards.

3 DESIGN GUIDANCE

The London Cycle Design Standards [4] is another established guidance document setting out the requirements for effective design to meet the requirements of the London Plan, whilst also defining current best practice for all. Its guidance draws on the experience of many practitioners from around the world, and its recommendations have application outside London.

The standards contain some specific requirements relating to vertical transportation, but in doing so create further questions. Step-free access to cycle parking is a fundamental requirement of the standard and note is made that this:

"…may require provision of shallow ramps or lifts large enough to carry all types of cycle."

The standard does then provide some guidance on what type of lift should be large enough to carry all types of cycle, stating:

"To accommodate all types of cycle, lifts should have minimum dimensions of 1.2 by 2.3 metres, with a minimum door opening of 1000 mm."

This description however is somewhat unspecific. For example, it does not define:

- whether the minimum car size is 1200 mm (w) x 2300 mm (d) or vice versa?
- how many cycles with accompanying riders such a lift can realistically accommodate?
- what the minimum lift car size is for varying capacities of cycles and riders?
- what is the predicted demand pattern?

The Chartered Institution of Building Services Engineers (CIBSE) Transportation Systems in Buildings (2015) [5] is unusually silent on the issue of cycle lifts, a situation the author trusts will be addressed in the forthcoming 2020 revision.

The new 2019 British Council for Offices Guide to Specification [6] provides a little further guidance noting that cycle lifts are:

"Required where levels either above or below ground are provided with significant numbers of motorbike and bicycle spaces. The typical car configuration is at least 2300 mm deep with entrances on opposite sides…and the effect of water in the car and shaft should be considered."

But this still leaves much room for debate on capacity, demand and size.

4 THEORETICAL PERFORMANCE ASSESSMENT

In the experience of the author cycle parking is typically designed by architects in conjunction with transport consultants, and the latter is normally best placed to advise on both the loading capacity of cycle lifts and the predicted demand pattern. The latter will often vary according to the location of the building and the nature of its occupants.

The magnitude of theoretical demand can become very significant for larger developments. The requirements of the London Plan when applied to commercial buildings with hundreds, often thousands, of occupants, generates a requirement for hundreds, occasionally thousands of cycle parking spaces.

Ideally such cycle parking is located at street level but often this space is far too valuable to allocate to such a use, with retail or other such amenity being a far more attractive option for the developer. The cycle parking is therefore typically sited at a basement level, ideally at a single level with all associated facilities such as lockers showers and toilets.

Access is then preferably via ramps though the gradient of these are restricted by standard resulting in them often occupying an unjustifiable amount of valuable space and alternative access needs to be sought.

The viability of the so called "Dutch Stair" option (see Fig. 3), stairs with channels to the sides up and down which one runs bicycle wheels, has been questioned relatively recently and is not recommended, particularly where the vertical distance to be travelled exceeds one level.

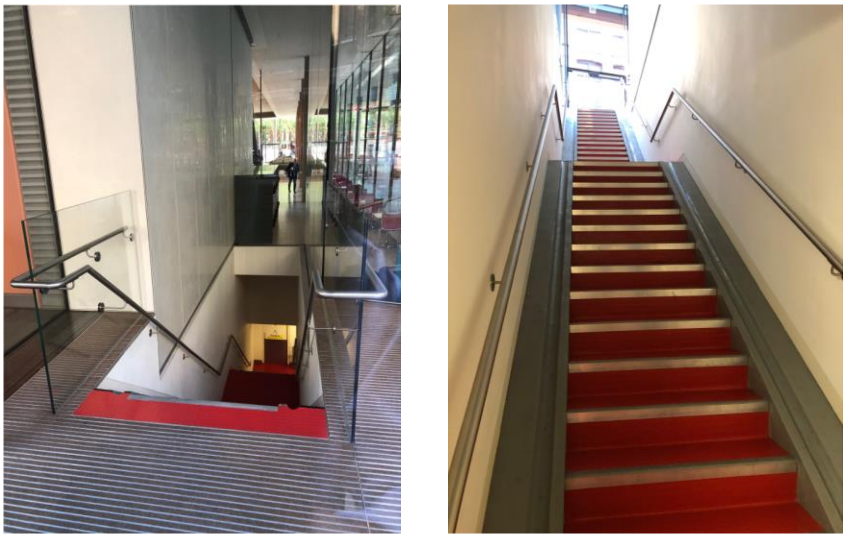


Figure 3: Cycle Access "Dutch Stair" (Central St Giles, London)

The Elizabeth House project in London illustrates the scale of the challenge for designers and the significance of some of the design criteria this paper has focused on. The development proposes more than 1,000,000 ft^2 (more than 90,000 m^2) of office accommodation with associated retail. By applying the draft London Plan guidance on total cycle parking numbers, the project's traffic consultant was able to utilize other design benchmarks and processes common to their particular discipline to define a peak demand profile for the cycle lifts, as shown in Fig. 4 below:

	Option 1 - 5 min profile		
	Entry	Exit	Total
07:00:00	30	1	31
07:05:00	34	2	36
07:10:00	33	2	34
07:15:00	38	2	40
07:20:00	44	2	46
07:25:00	44	2	46
07:30:00	49	2	51
07:35:00	51	2	54
07:40:00	62	3	65
07:45:00	54	2	56
07:50:00	54	2	56
07:55:00	63	3	66
08:00:00	51	2	54
08:05:00	58	3	60
08:10:00	56	3	59
08:15:00	55	3	57
08:20:00	43	2	45
08:25:00	50	2	52
08:30:00	47	2	50
08:35:00	45	2	47
08:40:00	32	1	34
08:45:00	36	2	38
08:50:00	27	1	28
08:55:00	24	1	25
09:00:00	21	1	22
09:05:00	21	1	22
09:10:00	18	1	19
09:15:00	11	1	12
09:20:00	11	0	11
09:25:00	11	1	11
09:30:00	8	0	9
09:35:00	8	0	8
09:40:00	8	0	8
09:45:00	11	1	11
09:50:00	8	0	9
09:55:00	7	0	7

	Option 1 - 15 min profile		
	Entry	Exit	Total
07:00	97	4	**101**
07:15	126	6	**132**
07:30	162	8	**170**
07:45	170	8	**178**
1 Hr	**556**	**26**	**581**
08:00	165	8	**173**
08:15	147	7	**154**
08:30	125	6	**131**
08:45	87	4	**91**
1 Hr	**525**	**24**	**549**
09:00	60	3	**63**
09:15	33	2	**34**
09:30	24	1	**25**
09:45	26	1	**27**
1 Hr	**143**	**7**	**149**

Figure 4: Theoretical Cycle Demand Morning Peak (Elizabeth House, London)

The theoretical demand is very significant, seeing at peak around 60 cyclists arriving in a 5-minute period, one every 5 s. The cycle storage is located at basement level 2, a nominal 10 m below street level and as such, this morning up-peak demand is a down-peak from a direction of traffic flow. Access arrangements such as ramps were considered during the design development but discounted from a space perspective in favour of dedicated cycle lifts.

A lift traffic simulation model was built to analyze lift performance when subjected to the theoretical demand pattern advised by the transport consultant. The simulation was run 100 times, for statistical accuracy, in order to assess the resulting theoretical performance, and to determine the optimum number and size of cycle lifts required.

Key to such analysis is the capacity of the lift in terms of the number of cycles and riders it can realistically accommodate. The simulation was based on capacities as shown in Table 2 below. The minimum clear internal dimensions required to accommodate two and three cycles and riders was determined by a transport consultant and adopted into the models accordingly.

Table 2: Cycle Lift Theoretical Capacity

Number of cycles and riders	Minimum clear internal car dimensions / area	Maximum Car Area / Rated Load acc. BS EN81-20 [7]
Two	1400 mm (w) x 2300 mm (d) / 3.22 m^2	3.25 m^2 / 1425 kg
Three	2100 mm (w) x 2400 mm (d) / 5.04 m^2	5.00 m^2 / 2500 kg

The lifts were configured with the parameters shown in Fig. 5 below.

Door Pre-opening Time (s)	0.50	0.50	0.50	0.50
Door Open Time (s)	2.00	2.00	2.00	2.00
Door Close Time (s)	3.00	3.00	3.00	3.00
Home Door Dwell 1 (s)	3.00	3.00	3.00	3.00
Home Door Dwell 2 (s)	1.00	1.00	1.00	1.00
Door Dwell 1 (s)	3.00	3.00	3.00	3.00
Door Dwell 2 (s)	1.00	1.00	1.00	1.00
Speed (m/s)	1.00	1.00	1.00	1.00
Acceleration (m/s^2)	0.50	0.50	0.50	0.50
Jerk (m/s^3)	0.80	0.80	0.80	0.80
Start Delay (s)	0.50	0.50	0.50	0.50
Levelling Delay (s)	0.00	0.00	0.00	0.00

Figure 5: Lift Parameters

The demand profile advised by the transport consultant was modelled as shown in Fig. 6 below. It should be noted that the traffic is predominantly down, but with some modest up component, and therefore slightly more onerous than simplistic pure down-peak traffic:

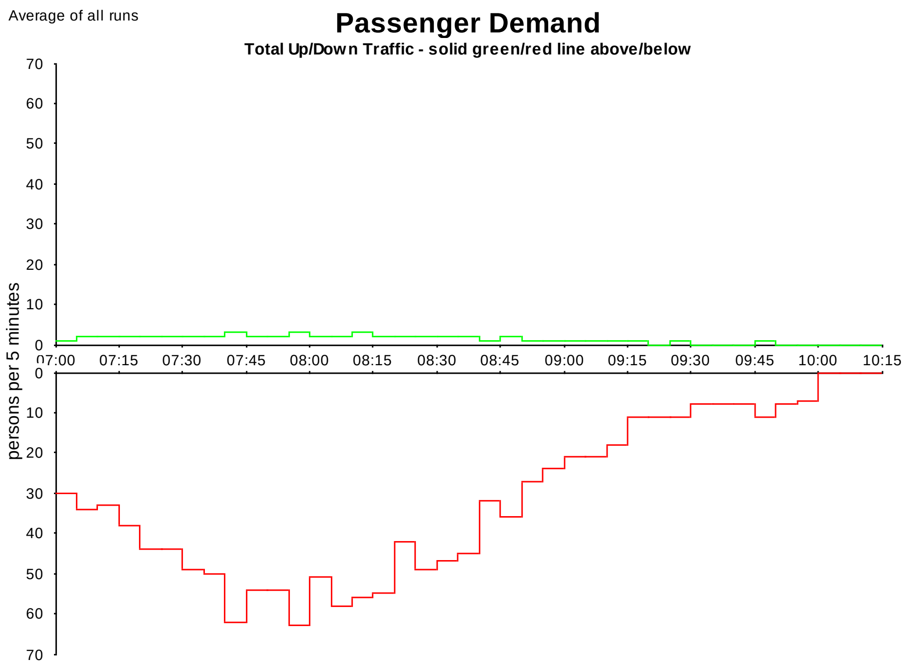


Figure 6: Theoretical Cycle Demand Profile (Elizabeth House, London)

Initially the simulation was run with the minimum car size required to accommodate two cycles and their riders, i.e. 1425 kg duty. A four-car group was assessed, and the average waiting time and queue length at the highest demand Ground floor were as shown in Fig. 7 and were clearly unacceptable. In this scenario the handling capacity of the lifts with an effective number of "passengers" (P) equal to two, is much less than the peak demand of 60 cycles and riders per 5 minutes.

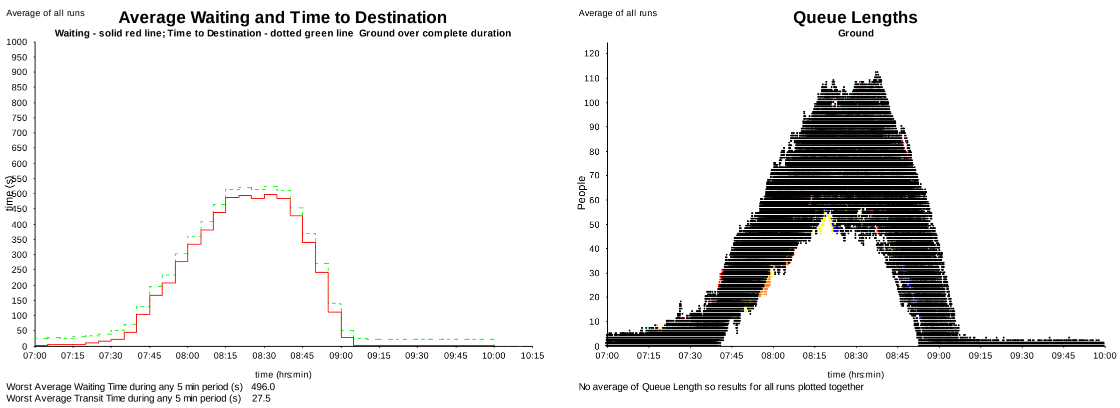
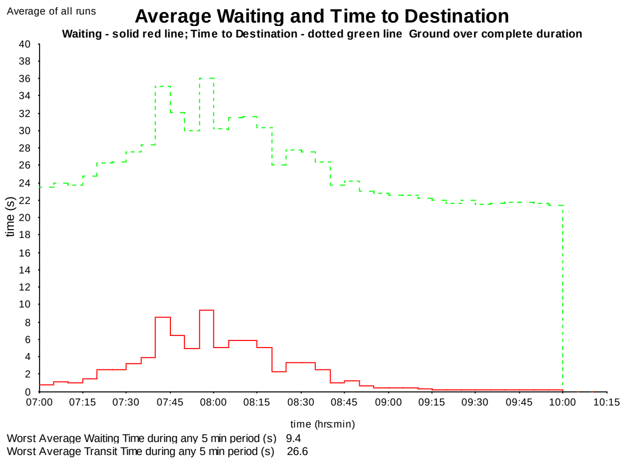


Figure 7: Predicted Average Waiting Time & Queue Length at Ground

The simulation was then run with 2500 kg duty cars capable of accommodating three cycles and their riders. The resulting average waiting time and queue length at Ground floor are shown in Fig. 8 below, and show a significant improvement when compared with the smaller lifts, and were considered acceptable:



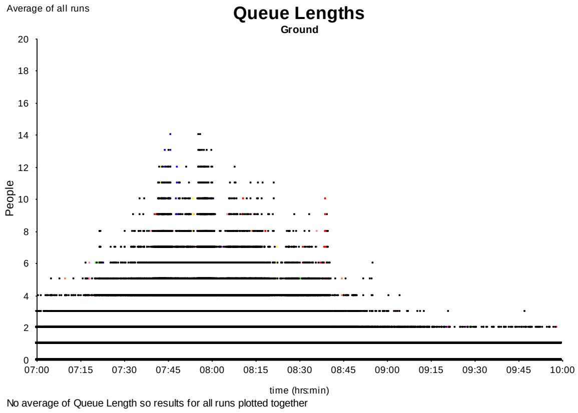


Figure 8: Predicted Average Waiting Time & Queue Length at Ground

In the author's experience, it is common for the limiting factor in cycle lift simulations not to be the average waiting time but the queue length, or more precisely the ability of the proposed lobby space to accommodate the queuing cyclists. Planning authorities are typically focused on ensuring that the predicted queues can be accommodated within the demise of the building and will not compromise circulation through adjacent public realm.

In the analyzed scenario the predicted peak queue of 12-14 cycles and riders will require a significant lobby space in which to be accommodated; if one assumes a "real-world" space requirement of 2.8 m^2 (1.2 m x 2.3 m) for a cyclist and rider, then the cycle lift lobby becomes a nominal 35 m^2. Care should also be taken to ensure the lobby does not include thoroughfares and circulation space to other demises within the building as this could cause disruptive conflict between pedestrians and waiting cyclists.

5 CONCLUSIONS & RECOMMENDATIONS

Cycle usage is increasing and is to be encouraged. The legislative environment requires a growing provision of facilities aimed at facilitating the use of bicycles.

Whilst there are some design guidelines for cycle lifts, they would benefit from further development and the inclusion of more specific and detailed guidance. CIBSE is currently well positioned to provide such guidance with the imminent publication of the 2020 update.

Demand from cycle usage, at least theoretical demand, can be very significant. Bicycles are bulky objects that quickly absorb lift capacity. The resultant cycle lift requirement can occupy a lot of valuable space and should be considered carefully at an early stage of design planning.

Formal guidance documents such as CIBSE Guide D should provide recommended criteria for designers. The following are proposed for consideration:

- Cycle lift capacities to be assessed in accordance with Table 1
- Average passenger transfer time of 2 s in each direction, i.e. 2 s to load and 2 s to unload. This figure is proposed as a reasonable average expectation but is a predicted value that would benefit from real-world surveyed data to confirm or refine.
- Utilize through car arrangements wherever possible in order to minimize transfer times and interference.

- Ensure lobby design provides sufficient space to accommodate the predicted queue length whilst delivering an average waiting time of no more than 40 s. The expectation is that the queue length and the size of lobby required becomes the defining limit and satisfying this should lead to a satisfactory theoretical performance
- Ideally locate all cycle storage and associated facilities (e.g. lockers and showers) at a single floor level to maximize the performance of the lifts.
- Consider the effect of water ingress to both the lift car and lift well.

The author would also encourage a real-world study of cycle lift usage, particularly the average capacities observed for varying car sizes. Such a study could be done in conjunction with transport planners so that the basis of their criteria for defining the peak demand pattern could also be challenged and ratified or refined accordingly.

REFERENCES

[1] Department for Transport, Road traffic statistics. Retrieved from www.gov.uk/government/organisations/department-for-transport/series/road-traffic-statistics (2019, June 13)

[2] Draft London Plan – Consolidated Suggested Changes Version July 2019. Retrieved from www.london.gov.uk/what-we-do/planning/london-plan/new-london-plan

[3] Royal Institution of Chartered Surveyors (RICS), Code of measuring practice, 6th edition. RICS, London (2015).

[4] London Cycle Design Standards. Retrieved from content.tfl.gov.uk/lcds-chapter8-cycleparking.pdf

[5] Chartered Institution of Building Services Engineers (CIBSE) Guide D Transportation Systems in Buildings (2015)

[6] British Council for Offices Guide to Specification 2019. Retrieved from: www.bco.org.uk/Research/Publications/BCOGuideToSpec2019.aspx

[7] BS EN81-20 (2014) Safety rules for the construction and installation of lifts — Lifts for the transport of persons and goods Part 20: Passenger and goods passenger lifts (BSI, 2015)

BIOGRAPHICAL DETAILS

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Adam started his career in the lift industry 28 years ago with Otis in London, UK. After twelve years working in construction, service, modernization and new equipment sales, he moved into the world of consultancy with Sweco (formerly Grontmij and Roger Preston & Partners) and has subsequently worked on the design of vertical transportation systems for many landmark buildings around the world.

Adam is the current Chairman of the CIBSE Lifts Group and of the CIBSE Guide D Executive Committee. He is the current codes and standards representative for the CIBSE Lifts Groups and sits on the British Standards Institute MHE4 technical committee. He is also a member of the BCO vertical transportation technical peer review committee. Adam is currently also the UK nominated expert for WG7 dealing with the accessibility standard EN81-70.

Designing a Vertical Transportation Strategy in the Largest and Tallest Building in the City of London

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Keywords: Planning, Development, Strategies, Vertical Transportation (VT), Helter-Skelter, City of London, High-Rise Building, Average Waiting Time (AWT).

Abstract. This paper will cover the various stages of creating the largest and tallest building in the City of London. The paper will be presented from the perspective of a specialist vertical transportation consultant.

The area around Bishopsgate and Leadenhall is the central hub for the insurance and legal professions in the City of London and over the past 10 years, it has seen substantial growth in the number of tall buildings to provide modern commercial accommodation.

The development was originally known as "The Stub" and had aspirations of being the tallest building in the City. It was properly known as the "Helter-skelter" due to its articulated top. The development failed for various reasons including being over ambitious, inefficient and poorly-funded.

A number of attempts were made to bring the project to fruition and the current professional team were able to put together a scheme which was far more appealing and responded to the reasons why the original scheme floundered.

A feasibility study for a commercial building designed to extend up to 309m in height was subsequently commissioned. As with most large projects there were extensive exchanges and discussions looking at new ideas and how they affected the core as well as the height and efficiency of the building.

It was crucial that the lifting strategy was developed at an early stage as the height and efficiency of the building would be materially affected by the design.

This paper sets out the journey through the whole design process from concept to delivery.

1 INTRODUCTION

22 Bishopsgate is on the site of the failed development which used to be known as the "The Pinnacle". The ambition, for what was to bear the nickname the "Helter-Skelter" (see Fig.1), was for it to be not only the tallest building in the City of London, but also for it to become an architectural icon. Its articulated shape at the top gave it its nickname, however, within the financial climate of London enduring at that time, it also needed to be efficient to enable the funders and developers to make enough profit. It was not only an inefficient design but also expensive to build and therefore why the original plans for the site failed. The main core had been constructed, including the basement floors, to Level 6. Yet even that progress was hesitant – being built a couple of floors at a time as the funds became available. It eventually stalled altogether and became known as "The Stump" (see Fig.2). The City of London became desperate for change.

Figure 1: The original and dramatic Helter-Skelter vision

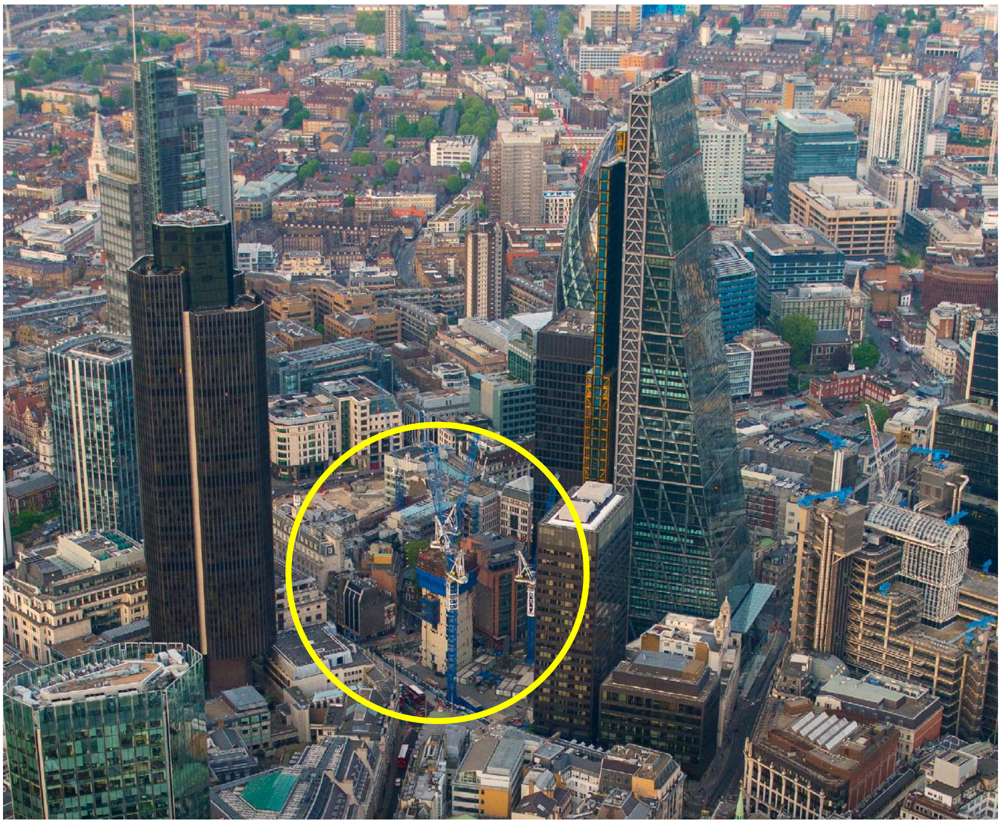

Figure 2: The Stump

A new developer became involved whose two senior partners were behind the original Broadgate scheme and who could bring an enormous amount of experience and knowledge to the project.

They courted funders and were eventually able to make a deal with the original owners, so a start was made on carrying out a feasibility study.

The original architects for the Helter-Skelter had a major split in their London practice at partner level and a new practice was formed out of the ashes. They had employed most of the original team and due to their intimate knowledge of the site and all its challenges, they were invited to look at a new scheme.

Shortly afterwards, a further company were also invited to act as multi-disciplinary engineering consultants, covering: structures, mechanical, electrical and plumbing and specialist services such as fire and life safety, façade access, environmental and of course vertical transportation (VT).

This is a journey which started in 2012 and is still is yet to be completed, however, the first occupants are beginning to move in.

2 FEASIBILITY

2.1 Setting the criteria

The project commenced by studying the existing design and aiming to make it more viable. It quickly became clear that this was not possible and as such embarked on a journey to create a new commercial office building, which might not look so distinctive, but would offer better return on investment and would be far easier to build and eventually let.

One of the most important aspects in designing tall commercial buildings, is to find a way of making the actual lettable office space as higher percentage of the overall available space as possible - having usable space on every floor and good levels of daylight.

In all tall buildings, the ratio between the total available area of a floor plate and the actual usable area which can be let to an occupier are considered. In the UK we refer normally to the Net Internal Area (NIA) and the Gross Internal Area (GIA) [1]. In very simple terms, if we can achieve a Net to Gross ratio of a minimum of 70-75%, it is seen as relatively efficient. Square and rectangular shapes are most efficient and are easier, simpler and therefore less expensive to build.

The first part in considering the form and height of a tall building, once an architectural study of the site has taken place, is to determine the parameters one can push to - looking at how much of the site can be filled. With the building itself, setting the footprint and then determining how efficient we can make the core compared to the external envelope of the building, given its target height.

Most of the core space in a tall building is taken up by lifts and their lobbies and as such there is always a challenge from developers and especially architects, to reduce the volume of the lift cores.

Finding a sweet spot in the lifting strategy will very often set the height of the building, so working closely with the developer and architect at this time is fundamental to the outcome.

In this case, the professional design team had no fees unless the building succeeded through the feasibility stage and the funders were happy with the results – then allowing the project to proceed to the design stages and Planning Application. If planning permission could be obtained, then the odds were very high it would be built. A good incentive to optimise the design you might say.

There were specific criteria the developers and funders wanted to be met:

- A population density on every office floor of one person per eight square meters (one to eight) calculated from the NIA.
- Adopting an 80% floor utilisation factor.
- Compliance with the performance recommendations of the BCO Guide 2009 (and later 2014 [2, 3]).
- The ability to board a lift in the main lobby and travel direct to your floor – considered essential in the London market.
- 309.6m is the ceiling imposed by the Civil Aviation Authority, which is set by the flight path of the aeroplanes flying in and out of City Airport

The overall site is large in comparison to others in the City. It is approximately 100m x 40m. This enables large floor plates and as such there would be a need to transport high numbers of people in the peak periods.

It immediately became evident that single deck lifts would not be able to transport sufficient numbers of people without taking up too much core space, which would deem the building unviable.

The alternatives to be considered would be:

- Sky Lobby solutions
- Double Deck [4]
- Two independent lifts in one shaft with a common motor room

Whilst sky lobby solutions are efficient in terms of core space, they do not fulfil one of the main criteria demanded in the City of London – you must be able to travel direct to your floor from the main lobby without changing lifts. This is a demand made by tenants, letting agents and seasoned developers alike.

The developer and funders were not happy with being tied into a single manufacturer to deliver what would become the largest lift and escalator contract ever placed in a commercial building in the UK. It was too much risk and as such it was decided to concentrate, for the most part, on Double Deck (DD) solutions going forward.

DD lifts are not perfect as there are several design restrictions brought about by their fixed nature, however, after presenting an analysis of the various systems looking at pros and cons, the client decided to commit to this strategy for all the main groups serving the office floors. This would be challenged from time to time and the other options reconsidered, yet it always came back to the DD strategy as being the optimum for this building.

The new building would have major entrances at the North towards Liverpool Street Station and the South towards London Bridge and East towards Fenchurch Street Stations (see Fig.3). Bank Tube station is also close to the West along with Aldgate. Additionally, there would need to be an entrance at the opposite side to Bishopsgate, where the building is facing the Aviva Building and 122 Leadenhall in a street known as Undershaft.

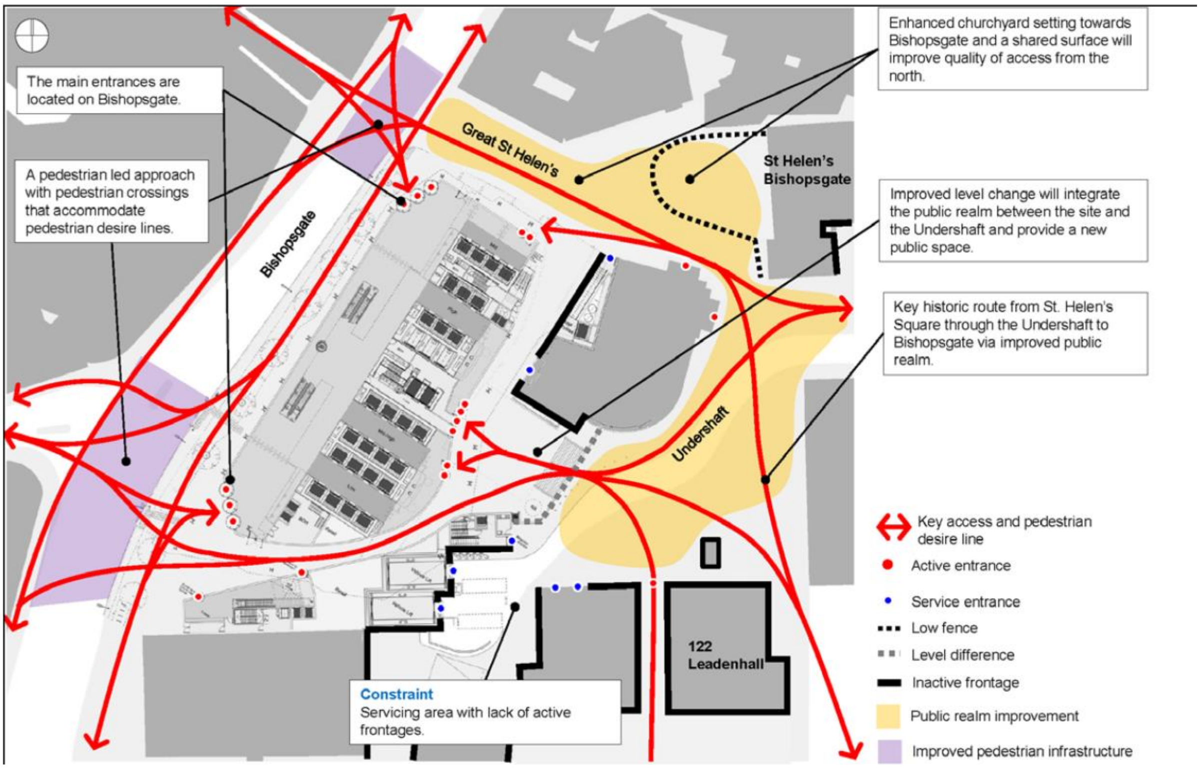

Figure 3: Pedestrian access routes – "Space Syntax Limited © 2015"

2.2 Creating Rules

From experience, it is necessary to create a set of rules which are adhered to throughout the design process so that the funder, developer and the wider team understand the engagement.

Especially in the current office environment, the way buildings are being occupied is changing. Most occupiers in major capitals, including solicitors, lawyers, insurance companies and banks, do not just sit people at desks on the office floor - they have break out areas, meeting rooms, cafes, informal relaxed areas actually on the floor. Then they might have floors dedicated to amenities or large areas devoted to such as gyms, creches, retail, food and beverage, auditoriums and many other uses.

The challenge VT consultants face is how to design for such uses prior to a tenant being signed up, which in a speculative building such as 22 Bishopsgate would not be until after construction was well under way on site.

This is where the density of occupation was used by the developer at one to eight on every floor of the building. In a building of this size they are convinced that not everyone will occupy to that density, more like an average of 1 to 10 and as such this becomes their buffer.

The occupational density has become a talking point in the City of London ever since the owners of the major dockland development to the east of London became involved with 20 Fenchurch Street. The Chairman had not used Double Deck lifts in one of his buildings before and he wanted a buffer to be sure there would be no performance issues. So, it was designed to one to eight on each floor. The building was marketed as such and ever since, there is competition amongst developers and letting agents to match or better that – so this was a tick in the box and perhaps the first rule.

There is always a fight for space in any building within the core and as such, the pressure is on to keep the number of lifts to a minimum necessary to meet the recommended performance targets. Targeting waiting and journey times here are very important and measures the quality of performance. The arrival rates and handling capacities needed to provide the correct quality of performance are also recommended by the BCO and CIBSE Guides [3, 5]. These are now clearer, as are the traffic profiles for use in commercial office buildings.

It was clear Destination Controls would have to be used, as with Double Decks [4] the only way to make them work in local groups with mixed traffic conditions is with this type of control.

This is the wording from BCO Guide to Specification 2014: [3]

- "Lifts should target an up-peak average waiting time across all floors served of no more than 25 seconds (s). Average waiting times (AWT) of up to 30 s may be acceptable in cases where the average time to destination is 80 s or less.
- Lifts should target an up-peak average time to destination across all floors served of no more than 90 s. Average time to destination (ATTD) of up to 110 s may be acceptable where the morning up-peak average waiting time is less than 25 s."

After discussions with the developer it was decided to target a 30 second AWT and 80 second ATTD - thinking that as this was a tall building, the journey time could be extended a little if necessary to make things work, as in practice people would expect to take a little longer to reach their destination than they might in say, an eight floor building, (bearing in mind a high density was being used as well). This became another rule to work to in producing results for each scheme going forward.

In taking this approach though, the limits were being pushed and it would leave no room for flexibility if it was needed to do "something different" in the building or if a tenant who was interested in taking space wanted to "over occupy" at a greater density still.

A simulation tool was used to carry out the traffic studies. Over the years, it has been learnt how to benchmark results against those of the major lift manufacturers, to grasp if there will be any surprises further down the line. This is a dynamic process and one which works well.

So, the settings used are very important and it is equally important that these are consistent through the design period.

2.3 Optioneering

In searching for the most optimum scheme which would satisfy not only the investors and developers but also the City Planners, English Heritage and all the other institutional bodies which seem to get involved and hold a lot of influence, an exhaustive number of options were run through over a period of 18 months.

The office floors started off with floor plates with an estimated 1500m^2 of NIA. This was for a scheme called "Interlocking", which referred to the architectural form of the building and was aimed at reusing as much of the existing basement and core as possible. The demolition costs of the basement and core were enormous and as such this appeared to make sense at the start.

The resultant building, however, was not so large and the team knew there would be more to come if demolishing the whole of the existing core was considered and then modifying the basement floors to a greater extent.

There was also a public right of way across the southern end of the site which needed to be maintained. In the “Helter-Skelter” scheme, escalators were used to transport people up and over this thoroughfare and it meant that the journey to the lifts was very truncated.

Similar concepts continued to be weighed up, known as “Carved Rectangle” and “Refined Carved Rectangle”, where the main groups of lifts would start from effectively Level 2 of the building for the next few months. There were many variations on the scheme as the top half of the building also went through various changes aimed at meeting the planners’ requirements. These included schemes affectionately named as “Tub Top”, “Glass Top”, “Magic Carpet” and others.

Escalators serving a lobby elevated up 15m from street level were considered and then shuttle lifts serving up to a lobby at Level 8 were reviewed, like the 200 West Street building. This latter concept does have advantages from a lifting point of view as it allows large uninterrupted floor plates beneath the lobby. There were, however, expensive structural solutions needed – remember the lift core is very often a major structural support for the building and most of it below Level 8 was being removed, on what was going to be a very tall building.

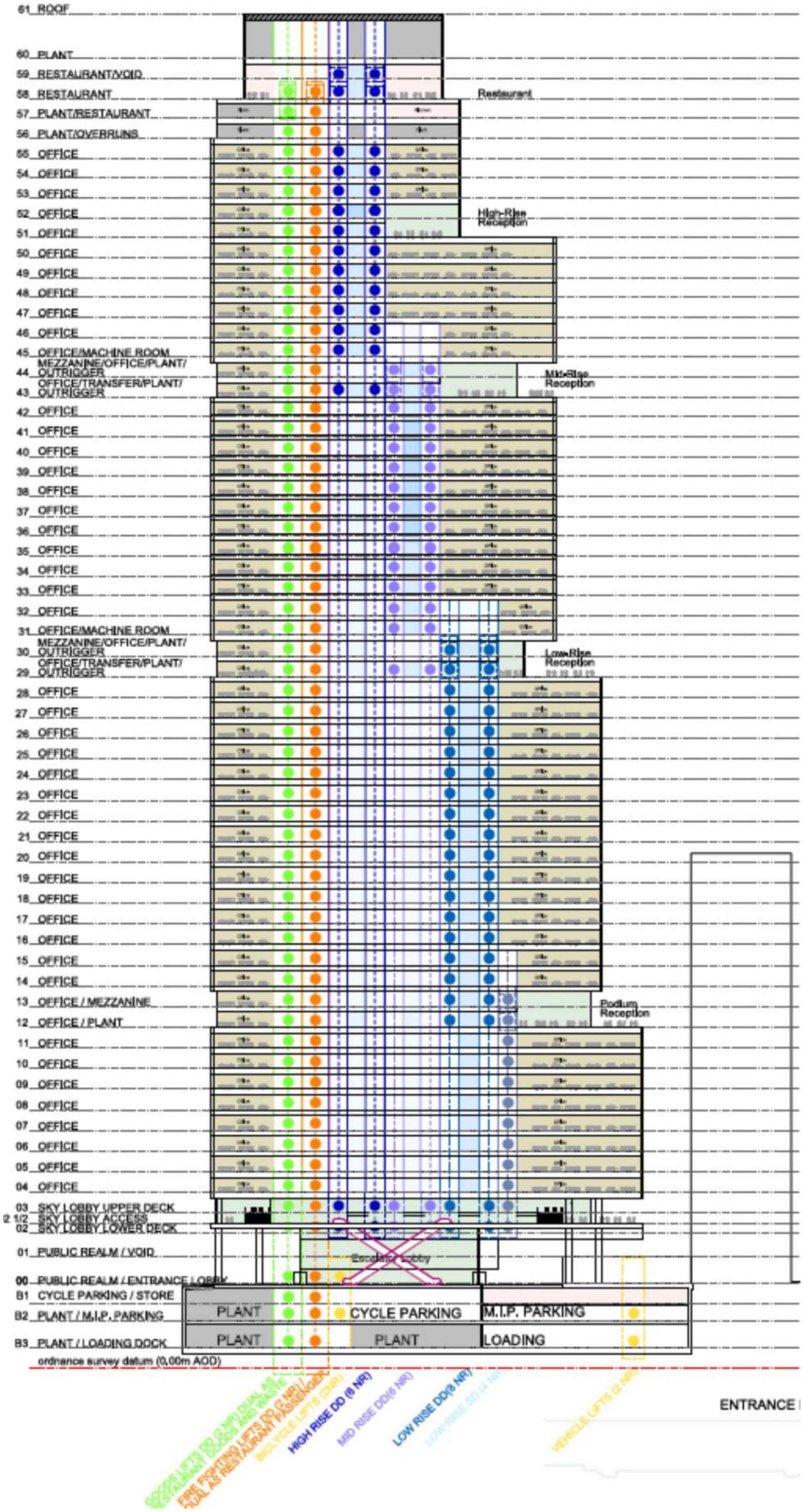

Figure 4: “Universal” Option – with the main lobby above street level

The next scheme became known as "Universal" and had larger floor plates of 2000m^2 NIA (see Fig. 4) - this was December 2013. In this scheme, escalators serving from street level to a main lobby level at Level 2, Mezzanine and Level 3, were still retained. There was a group of four low-rise DD lifts, eight car DD low mid-rise and then six car DD groups of high mid- and high-rise.

In conclusion, in this approach, the journey into the building was thought overly complicated for the occupants. It was decided that the main entrance lobby should be firmly at ground level.

In December 2013, a concept report was created based on this scheme, however, through the next 12 months many more variants were worked up, "Moonraker", "Refined", "49.15", 52, 52.1, 54, eventually coming to the basis of the scheme now being built.

The floor plates had grown to 2500m^2 up to level 30, 2100m^2 to level 42 and 1800m^2 to Level 54. The lobby was now at street level and 12 different lifting configurations were looked at in the final month in the lead up to obtaining agreement from the funders, to go ahead with designing and construction of what would be the largest speculative office building ever constructed and home to what would now potentially be 12,000 people.

Agreement was reached with the funders and at the beginning of 2014 the project became real after all the hard work the team had voluntarily contributed.

3 SCHEMATIC AND DETAILED DESIGN

Unlike just about every other project that was worked on, the traditional RIBA design stages were in fact fused together and just rolled into one.

The continual refinement was ongoing and through 2014 and 2015 more options were weighed up as the architectural, structural and services solutions were refined.

The basis of the scheme had remained the same, however it was not until June 2016 that the final configuration was settled on (see Fig. 5).

Over time with all the discussions with not only the planners but also the general contractor, who was originally appointed on the Helter-Skelter, the final height of the building had been set. It was not only a planning issue but also a buildability issue. At this time, the cranes would not be allowed to break above the 309.6m ceiling demanded by the Civil Aviation Authority for the flight paths into London City Airport – this has always been the limiting factor for London's high-rise developments.

The lifting scheme that was settled on had now been centred around three groups of eight 2000kg (26 person) Double Deck lifts.

They fitted the core well and especially the width of the building, however, they alone would not help get it as high as desired.

The lower seven floors of the building above ground were treated differently by using a group of three 2000kg (26 person) single deck lifts. This enabled office floors as high as level 57 to be reached with the high-rise 2000kg (26 person) Double Deck lifts. [6]

These three lifts were added to the north end of the core, close to the North Entrance.

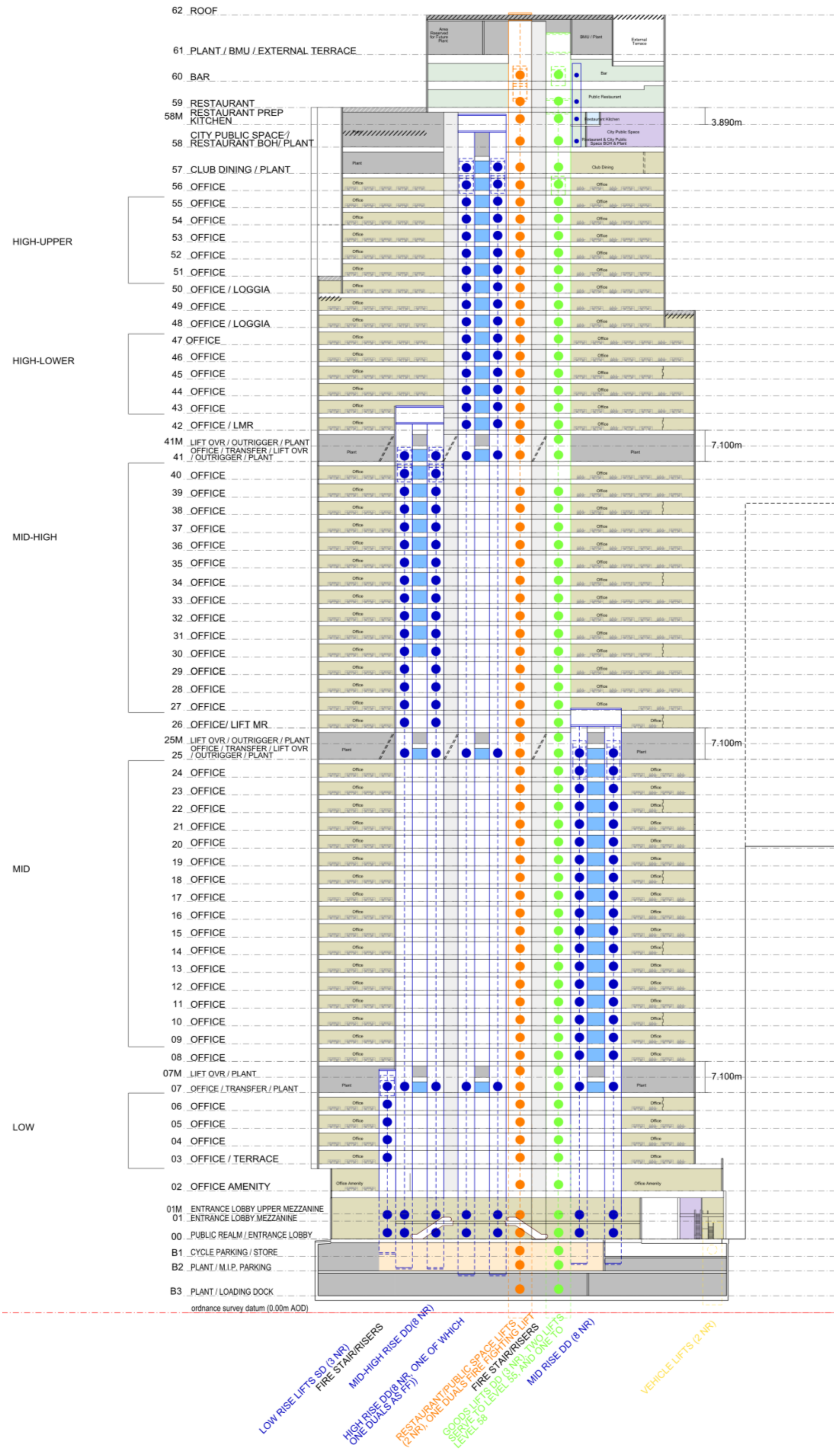

Figure 5: The basis of the final scheme

Whilst the basis was set, there were many other areas of the building that had to be designed including the goods lift service, the viewing gallery and restaurant, parking and showers for 2400 cycles in the basements and eventually the amenity spaces would start to emerge. These are all subjects in themselves and could be subject to their own papers.

3.1 Goods Lifts

There is no other commercial office building of this size in London and as such, designing the goods lift service could not be compared to anything else. Goods lift design is not well documented in the various design guides such as BCO and CIBSE. [7]

Many hours were invested in touring the other towers in London, speaking to the building managers and considering strengths and weaknesses of each design.

Generally speaking, the other tall buildings in London might have had two goods lifts as their main artery. Some buildings only had one lift serving the top floors of the building. In this case there would be no redundancy. In this type of high-quality office building, you cannot use the passenger lifts as they are too busy at peak times and you cannot risk damage.

It was settled on three 3500kg goods lifts and the aim was to have them serving every floor of the building. Initially, this was successful but as the top of the building developed the space requirements for plant, the viewing gallery and restaurant meant that at the top not all the lifts were able to serve all of those floors. This was not ideal and it also meant special buttons on the floors would be required to call particular lifts to particular floors.

Originally the electrical design demanded five large generators to be deployed at the top of the building and they were too large to fit inside a normal goods lift. After much negotiating and discussion, the electrical engineers were persuaded to switch to six smaller generators. Even now it was still needed to over rate one of the goods lifts to 7400kg, on a special operation to carry one.

These lifts are also fast at 4.0m/s in an effort to provide a good level of service within this tall building.

3.2 Viewing Gallery and Restaurant.

These floors are effectively owned and operated by a separate entity.

The original design was centred around maximising the space to accommodate as many people as possible and churn them as often as possible as the experience was going to be chargeable. The views were going to be the best in the City with uninterrupted views for 360 degrees. The most efficient way to move as many people as possible to and from those floors was assessed. There are four levels in all, served by a number of local lifts, and these were to be fed by two 2250kg (30 person) Double Deck Lifts, capable of moving in excess of 800 people per hour.

In the end, the City of London Planners changed their policy, insisting that all such viewing galleries in central must in future have free access to the general public and so the potential had diminished somewhat. The level of service had already been committed to the owner and as such that is how it remains. The two viewing gallery lifts are high speed shuttles at 8.0m/s and the top deck of one of them also functions as a firefighting lift, serving all floors from ground and above via the rear entrance. Both lifts have front and rear entrances in order to maximise and simplify traffic flow – in the same way as the lifts in some of the deeper London Underground Stations.

The Viewing Gallery has its own entrance to the south of the building which traverses Art Street. Access lifts are provided to an upper level where escalators are taken to the appropriate deck, whether you are travelling to the Viewing Gallery or Restaurants reception level. At a separate, dedicated exit, there are stairs and lifts.

All these lifts and escalators will effectively be in use 20 hours a day, to serve the many functions that will exist around the clock, which will place pressure on maintenance regimes.

3.3 Basements

There are four basements in all and an additional basement which had to be created to gain access to the lift pits of the high-speed lifts, where they are more than 2.5 m deep. This was expensive but very necessary.

Within the basement there are over 2400 cycle spaces, showers associated changing facilities, plant and the loading bay.

As this area was being developed, it was clear the main lifts could not serve down to the basements, due to the massive disruption it would cause to the lift service and it was quickly agreed for a separate group of lifts to be used to link the basements to the lobby. There would potentially be a lot of traffic going to and from the basement during peak times.

The cycles themselves use a stair with a runway for the cycles and this is supported by a disabled cycle lift.

The loading bay is served by two 26,000 kg hydraulic lorry lifts. These are enormous and are very specialist. They must be very reliable as they will be used intensively for periods during the day, especially mornings. By using a consolidation centre outside of London, the number of lorries is reduced but there will still be a substantial number of movements when you are serving 12,000 people.

There is a separate firefighting strategy for the basements and it is served by two dedicated firefighting lifts within the associated firefighting cores.

3.4 Additional Challenges

The whole site is on a slope with around 1000mm difference from one end of the core to the other. As Double Deck lifts were employed, it was imperative the floor to floor heights remain even through the whole building, so a series of gentle ramps were employed to even things out.

Due to the depth of the floor plates, the floor to floor heights needed to be taller in the lower floors so the floor to ceiling heights could be increased to allow more light in. All these variations had to be taken up and agreed with the architects and developers and solutions found for the various lifts.

Another firefighting lift was required in the main core and there was no room. Therefore the same principle as for the Viewing Gallery Lift was used and again, an upper deck of one of the high-rise lifts with a rear entrance opening into the firefighting core, was also used. Whilst this might have compromised the design of one of the main DD lifts, it saved substantial core area. These principles were all agreed with the City of London Building Control who had been very supportive throughout.

As the design continued to develop, it was essential that a theme for the building was developed and this became dedicated to art. One of the partners of the developers, being an avid art lover, was very influential in this decision. Hence the name given to the public thoroughfare of Art

Street and the amount of art which will be displayed in large areas in not only the main entrance lobby but the lifts themselves.

The reception will be a library and the use of leather and wood is much in evidence.

Lastly and late in the design process, it was decided to use Level 2 as an enormous amenity space. This would serve the whole building and would shape the design for the main entrance lobby. Only the three Single Deck lifts at the north end of the core were designed to serve this level as offices and there was no interconnectivity with the rest of the building.

Due to the fact the Double Deck lifts had been designed close to the limit, there was no way they could be allowed to stop at Level 2. It was also a single level, so a "two stop" of the lifts was necessary, which would add confusion and take far too much time. Therefore, an alternative had to be found.

A combination of escalators and lifts was decided on. The basement serving lifts were to be extended at the south end of the core up to Level 2 and increase their number to three.

The escalator banks in the main lobby area, serving the upper deck of the main groups, would be extended up to serve Level 2. This would provide a compromise in as much as the occupiers would have to change lifts, or lift to escalator, to travel to and from Level 2 but none the less this would work well.

There are also amenities and wellbeing centres at the transfer floors, not overly large, however they too need to be accessed.

4 BIOGRAPHICAL DETAILS

John Stopes has held senior positions working for major international lift and escalator manufacturers from the late 1970's until 2001, when he became a Consultant working for HH Angus on several million square foot buildings in Phase 2 of the Canary Wharf Development. He then went on to work at Watermans, Lerch Bates and WSP before founding The Vertical Transportation Studio at the end of 2013. John sits on the BCO Guide to Specification VT, Peer Review Committee, is a member of the CIBSE lift group and member of the CTBUH.

5 REFERENCES

[1] Royal Institution of Chartered Surveyors (RICS), *Code of measuring practice, 6th edition*. RICS, London (2015).

[2] BCO Guide to Specification 2009.

[3] BCO Guide to Specification 2014.

[4] J.W. Fortune, "Modern double-deck elevator applications and theory". Elevator World, Vol. 44, No. 3, 63-68 (1996).

[5] CIBSE Guide D: Transportation Systems in Buildings 2015

[6] EN81-20 Lifts for the transport of persons and goods – Part 1: Safety requirements for passenger and goods passenger lifts

[7] L. Halsey, "Goods Lifts, Who Needs Them?", Proceedings of 9th Symposium on Lift and Escalator Technologies, Northampton (2018).

Escalator Runaways

David A. Cooper

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Keywords: Escalator, runaway, rollback, accident, passenger safety, brake, drive chain, head shaft.

Abstract. There have been a number of high-profile escalator runaways in recent years resulting in passenger injury and deaths. This paper will look at the standards for escalators over the years, how they have developed with respect to the prevention of this type of accident and will also challenge the current standards as to whether they are sufficient. The paper will also look at the appropriateness of EN115 and how it allows variables dependent upon rise and angle of inclination and whether this can be improved. The paper will be supported by video evidence.

1 EXAMPLES

There have been a number of examples of escalators rolling backwards and they can be compared with lifts rolling away, due to the counterweight or car taking over and causing an overhauling situation on a lift where a gearbox or brake failure have occurred.

Recent escalator runaways include:

- 26th March 2017 Mong Kok Shopping Mall, Hong Kong (17 injuries)
- 23rd October 2018 Piazza Della Republica, Rome (20 injuries)

In reality, runaways have been occurring ever since escalators were invented, with some attracting more media attention than others.

One of the worst cases occurred in 1994, which became known as The Camden Yards incident in the USA and saw an injury toll of 43 people.

2 WHAT HAPPENS?

A runaway situation can occur in both the upward and downward modes but the ultimate event results in the escalator rolling backwards (down mode) in an uncontrolled manner.

Where the escalator was initially travelling in the up direction and a runaway occurs, it may be referred to as a runback or unintended reversal.

Where the escalator was running in the down mode, the escalator will simply be in an uncontrolled descent.

In either case the situation may or may not include acceleration of the step band.

In such situations, and especially when there has been an acceleration component involved, passengers are often deposited in a pile at the bottom end of the escalator due to the inability of passengers to egress the escalator because of its high speed.

When these events occur, passengers are often seen clambering over the handrail to avoid the collision with other passengers at the bottom of the escalator.

An accumulation of passengers can be seen building up in the below photograph, with passengers behind them unable to avoid the passengers at the bottom, as there is no way of escape due to the escalator being installed with a void to the side.

Photograph 1: Passengers at base of escalator in the Mong Kok Mall incident in Hong Kong

3 HOW CAN IT HAPPEN?

Investigation into such incidents reveals a number of ways a runaway can occur including:

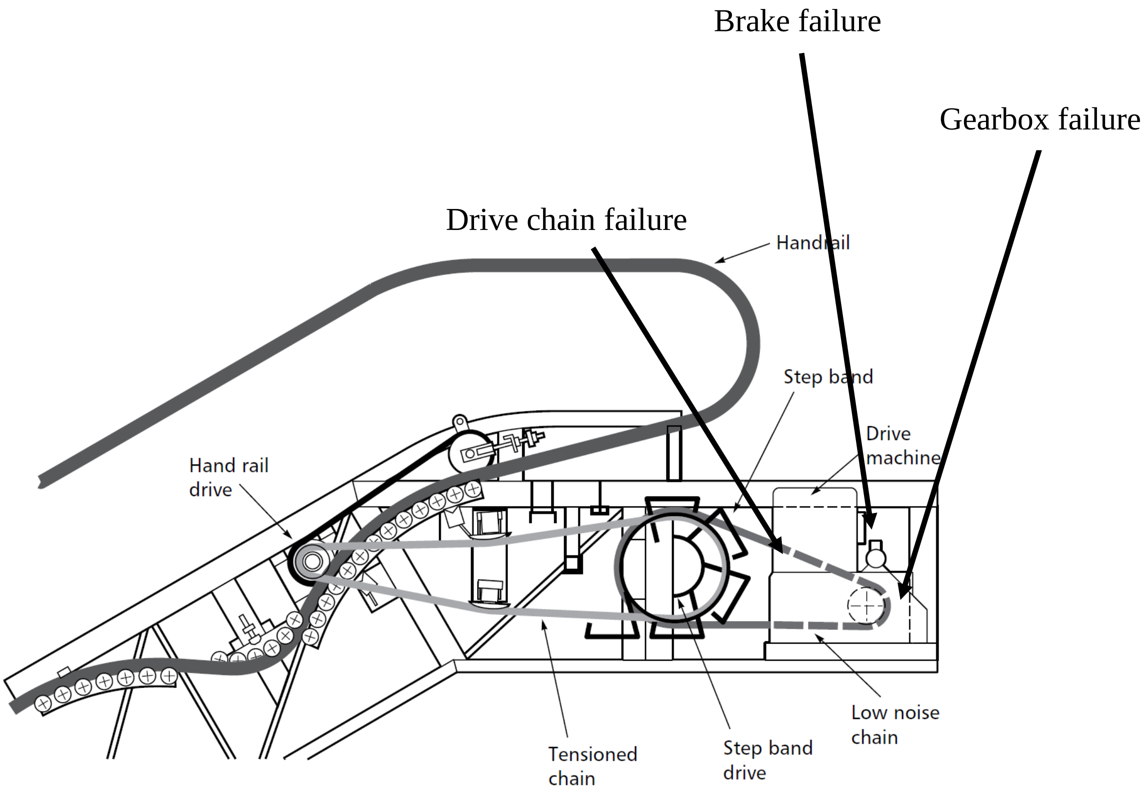

Figure 1: Principal Components of an escalator drive system (source CIBSE Guide D [1])

There have been incidents where a second component failure has also contributed to a runaway condition, primarily when an auxiliary brake is installed but has failed to bring the step band to rest.

There are other reasons why an escalator can runaway but the above are the primary reasons found in researching the subject.

One example of another reason found is a drive unit fixing failure leading to the drive chain, brake and gearbox being ineffective.

Al-Sharif has previously derived a Venn Diagram (Fig.2) showing seven possible ways accidents with escalators and escalator runaways occur, falling into the categories identified including design, maintenance and passenger behaviour.

When it comes to passenger behaviour, they have not been found to be associated with primary causation of a runaway, but minor contribution such as pressing an emergency stop button, leading to the primary reason for it becoming apparent (e.g. operational brake doesn't hold when required to do so). In addition, it has been found that in the initial stages of an accelerating runaway, passengers continue to board the escalator if it is a down running machine, unaware that it is in trouble.

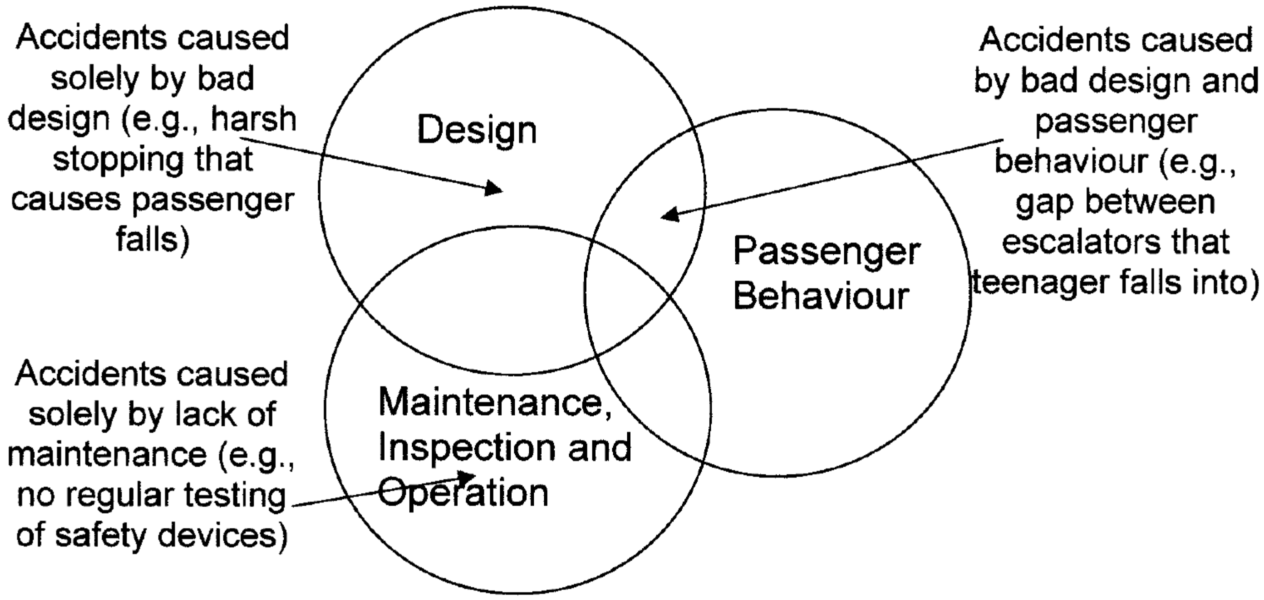

Figure 2: Al-Sharif's Venn Diagram of escalator accident causation [2]

This leads to the other two components namely design and maintenance.

When it comes to design, the inclusion of an auxiliary brake is a consideration. Not all escalators require an auxiliary brake and this is discussed in the section about whether standards are sufficient.

Consideration should also be given to the location of the operational brake, as if it is onboard the gearbox, it will provide no protection in the event of a gearbox internal failure. This is the same for lifts where the brake on geared machines is mostly found between the hoist motor and gearbox.

Maintenance is normally a key contender in escalator runaway situations, especially with respect to brake failures where issues such as lubrication getting onto braking surfaces, poor adjustment or worn pads can be a contributory factor. It should also remember that the brake is often used as a means to stop an escalator at the end of a working day and therefore, even if a VF drive, the pads are subject to wear on a regular basis.

In the incident in Rome, the CCTV footage can be seen showing the escalator slowing down and then increasing in speed.

It appears what has happened, is that someone has operated an emergency stop button and the operational brake has been asked to bring the escalator to a safe stop and hold the step band in position but failed to do so.

It appears the step band starts to accelerate in the down direction causing a passenger crowding situation.

In the environment where the escalator was installed, it would be expected that an auxiliary brake would have been installed, and on the assumption that it has, then it has clearly failed to arrest the reversal of the step band.

Photograph 2: Passengers, during the initial phase of a runaway, starting to hold the passenger in front.

4 ARE STANDARDS SUFFICIENT?

The 2017 EN115 standard (5.4.2.2) more or less mirrors the previous 2008 and 1995 standard with respect to the requirement for an auxiliary brake and states:

5.4.2.2 Auxiliary Brake

5.4.2.2.1 Escalators & inclined moving walkways shall be equipped with auxiliary brake(s) if:

a) The connection between the operational brake and the driving sprockets of the steps/pallets or the drum of the belt is not accomplished by shafts, gear wheels, multiplex chains, or more than one single chain, or
b) The operational brake has not an electrical-mechanical brake according to 5.4.2.1.2, or
c) The rise exceeds 6 m

The problem with this situation is that an escalator or inclined walk with a rise of less than 6 m, with a conformant drive chain, can still fail and runaway due to brake failure, gearbox failure or drive chain failure.

CIBSE Guide D defines an auxiliary brake as, “a fail safe brake, which is used to stop an escalator under all normal conditions or under certain fault conditions only. It is typically situated on one side of the main drive shaft.”

It should be noted that this was derived from a London Underground Glossary of terms – one of the major UK operators of escalators.

The 2017 EN115 standard (Clause 5.12.2.7.3) also calls for detection of unintentional reversal of the direction of travel and states, “a device shall be provided for escalators and inclined ($\alpha = \geq 6°$) moving walks to detect the unintentional reversal of direction of travel”. The problem with this is that it could use the operational or auxiliary brake (if fitted) to prevent the reversal and these components are known to have failed in the past.

5.12.2.7.2 also calls for the detection of excessive speed before the speed exceeds a value of 1.2 times the nominal speed.

It can be argued that the standards provide sufficient protection, however it is the authors contention that an auxiliary brake should be provided on all escalators and inclined walks in situations where the failure of the operational brake, gearbox and/or drive chain can occur. In reality, this would mean that all escalators and inclined moving walks would require an auxiliary brake.

5 CONCLUSION

Runaway escalators are still occurring despite the EN115 standard recognising that unintended reversal or an overspeed condition is a foreseeable event.

It is accepted that rather like a lift, if where the overspeed governor or safety gear fails to work, there are scenarios where an auxiliary brake does not provide full protection.

It is, however, concluded that all escalators and moving walks should be provided with an auxiliary brake to support the operational brake.

REFERENCES

[1] Chartered Institution of Building Services Engineers (2015); Transportation Systems in Buildings.

[2] Al Sharif (DnK), Escalator Human Factors: Passenger Behaviour, accidents & design

[3] British Standards Institution (2017); EN115-1 Safety rules for the construction & installation of escalators & moving walks

BIOGRAPHY

EurIng David Cooper

BSc(Hons), MSc, MPhil, CEng, FIET, FCIBSE, FRSA, FCGI, FCABE, MBES

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 Charity that runs the Lift Symposium and is an Honorary Visiting Fellow at The University of Northampton.

Extending the Horizontal Journey to the Sky

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Keywords: Polycentric, communities, vertical transportation, emerging technologies, chance encounters.

Abstract. The optimum recipe for successful master planning has long been a subject of discussion and experimentation. While experts diverge at various tangents on this complex and organic subject matter, as is evident from the collection of essays published in "Rethinking Master planning: Creating Quality Places" last year, a handful of ingredients are common to many.

In master planning, design teams create "active frontages" that focus on encouraging transportation by foot, by analysing the content of daily errands (e.g. medical appointments, grocery stores, fitness centres), and purposefully ensuring these are within comfortable walking distance of crucial amenities like parks and transportation nodes. The most successful master plans of recent times offer mixed-used, fine-grain, human-scale, high-density diversity along a planned or alluring human footfall. The focus is on the effect that vertical mixed-use, fine-grain activity nodes and paths could have on tall buildings, particularly on vertical transportation, security and fire safety. What are the challenges this new brief presents designers with and what are the new opportunities for landlords, occupants and visitors?

Does the added value outweigh the constraints? From this new brief, there is likely to be flexibility extended from the typical floor-by-floor tenant split and core arrangements to the vertical plane: soft spots, dedicated lifts, open staircases and adaptable building services for undefined spatial uses. This paper explores how these challenges can be accommodated by looking at how vertical communities can enhance our experience of buildings, our health, well-being, and make a positive contribution to the urban habitat.

1 INTRODUCTION

This paper is based on ideas first presented at a conference addressing Polycentric Cities in a workshop on Skyscrapers [1].

The presentation arose from a discussion with Hilson Moran and was developed specifically for The Council on Tall Buildings and Urban Habitat (CTBUH) conference.

An illustration proposed for Polycentric cities was that of an egg - Fig. 1.

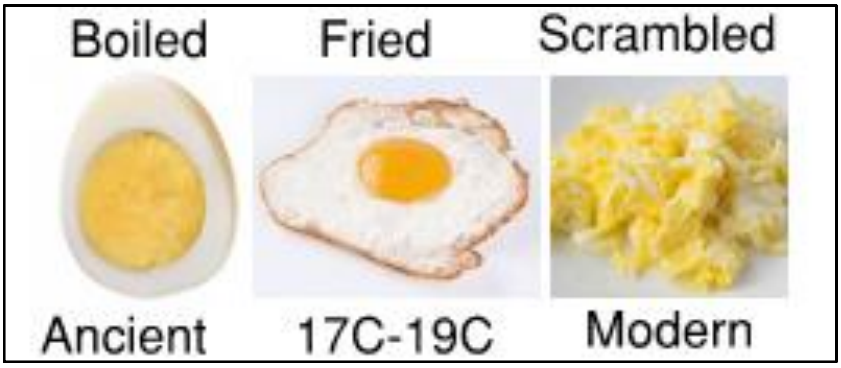

Figure 1: Egg Illustration

Ancient Cities have a clear centre and boundary; walled cities, a citadel. As time passed on, through the 17th to 19th century, while defined centres remained, the extremities became more free form. Nowadays, modern cities are more mixed with less definition, more like a scrambled egg.

Polycentric is an English adjective which means 'having more than one centre'. While the CTBUH conference itself was considering polycentric cities and examples of them, this paper considers the importance of polycentric buildings.

With increasing urbanisation, cities need to consider how they develop. Master planners seek to gauge certain criteria in the proximity of amenities with respect to transport nodes. They look to plan active frontages to encourage people to follow particular routes, and they consider how far people will walk before they look to take a bus, train or car.

Singapore is considered to be a distinguished example of a place where planning, through density of occupation and lack of land, has and continues to develop infrastructure which encourages people to use public transport. Specifically, they have been concentrating on the last mile or last 20 minutes of the commute.

The CTBUH not only looks at tall buildings but also the urban habitat. We often hear about vertical communities, however, how often do we see them? This paper's focus is to take a step back from how tall buildings have been traditionally designed, and to look into applying rules from horizontal master plans in the vertical setting. We cannot build communities, but we can provide space where they can thrive.

Take London as an example. It is an old city that has expanded beyond the square mile and, while fairly unique with its 32 boroughs - each with their own planning jurisdiction and various amenities, there are now distinct business districts across Greater London.

Years ago, London would have been a hard-boiled egg, developed through the fried egg stage. Now, however, with its distinct business centres scattered all over, London has been and is developing into the scrambled egg stage.

The City, Canary Wharf, and possibly Kings Cross, (soon to be joined by Battersea or Vauxhall), are all distinct business centres. There has also been a significant development, with the exception of the City of London, in relation to residential accommodation, offering people the opportunity to work, rest and play without extensive travel.

Typically, people who work in the City of London commute via public transport to work.

2 THE HORIZONTAL STORY

The example of a walk from a transportation hub, Cannon Street, to a fairly new, mixed use, London building, 20 Fenchurch Street, The Walkie Talkie.

Even within a short walk from a transportation hub we see various amenities. We have choices, not only in terms of the amenity but if in a major city like London, you get the choice of transport hub and then a choice of amenities en-route to your destination.

While in central London to some extent the location of these amenities is dictated by hundreds of years of history, we can still see a pattern to how frequently these appear. A series of active frontages, vibrant places between your starting point and your destination, interspersed heritage and opportunities to pass and interact with others. In fact, the location of these amenities, their frequency and the repetition of them, form part of a master planner's tool kit. They can be seen as a series of concentric circles.

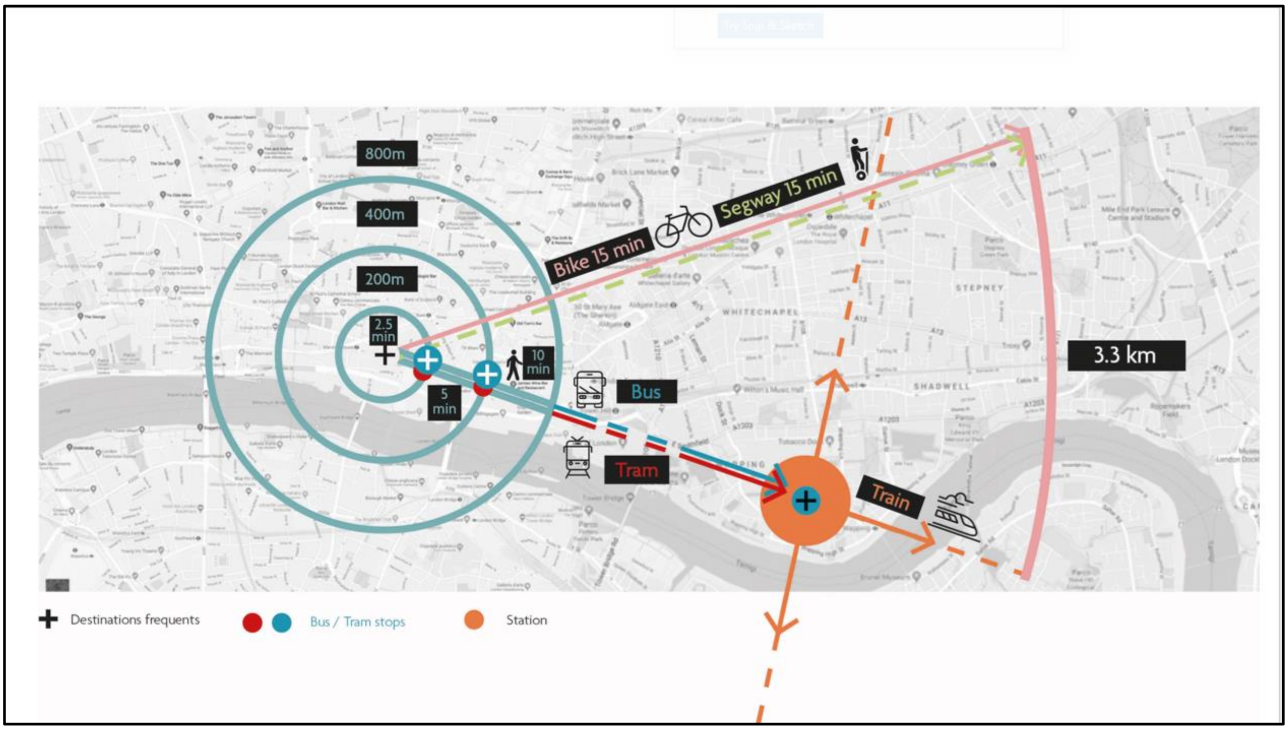

Figure 2: Map illustrating travel methods, distances and times in London, from Cannon Street to Fenchurch Street

- People are happy to walk for 10 minutes by which time they will have ideally arrived at their destination or indeed a transport hub to continue their onward journey.
- A series of amenities or active frontages that are often the key to the success of a master plan.
- Providing vibrant spaces as part of our journeys.
- The amenities are likely to be in greater density closer to the transport nodes.
- Within the first 5 minutes you are likely to experience mixtures of uses with offices beyond that.
- The other outcome of well-located amenities at the right density and mixture is the ability to encourage or give people the reason to use certain routes.

All providing ways for people to cross each other.

3 THE VERTICAL STORY

When arriving at our destination, a new set of rules is often applied. Acknowledging that this might vary with location and culture, it is important to look at the performance of the building. From a vertical transportation perspective, observations into handling capacities, average waiting times, lift speeds and the whole robustness of lift performance is necessary.

Do we need an intermediate plant level? Where will the reception desk be, what will the toilets look like and where will the sign go at the top of the building?

Our buildings typically take on a similar form.

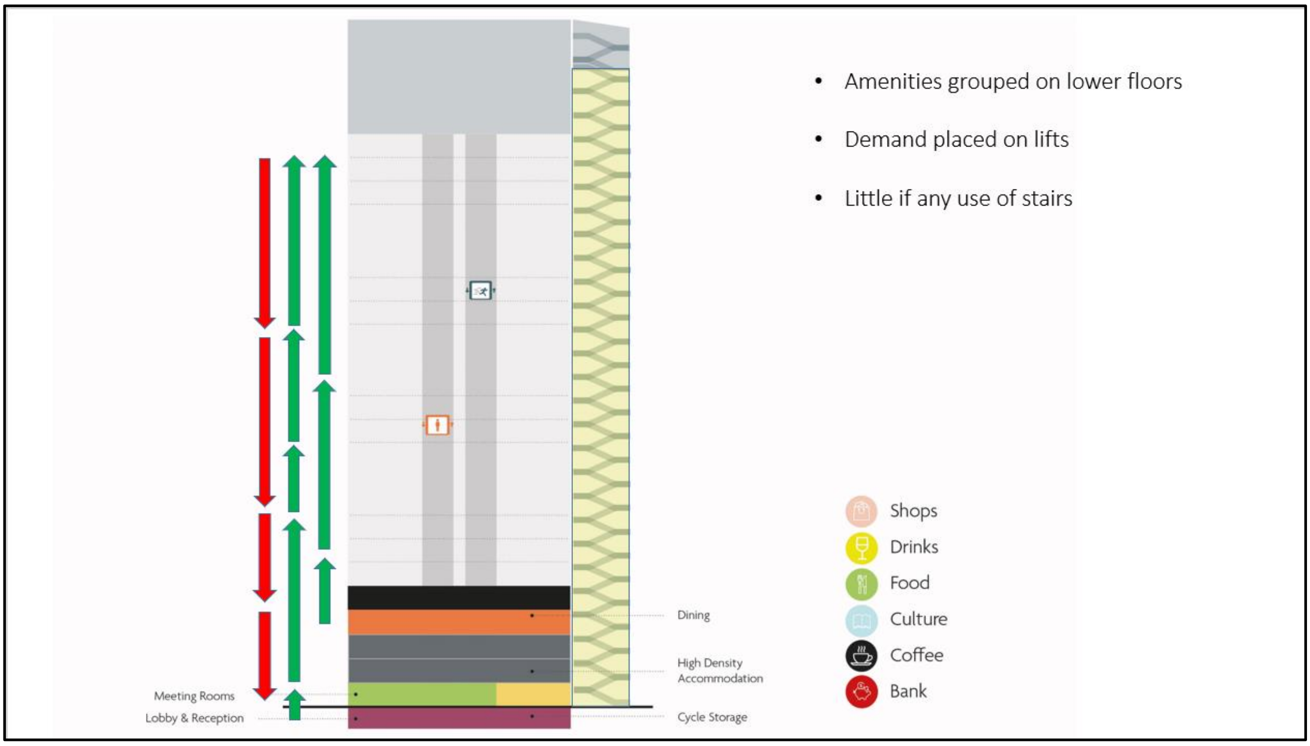

Figure 3: Typical Floor Structure and Lift Diagram

Providing amenities in or at the foot of our buildings, however tall, is not new. It is good in a commercial sense, providing a workforce with all they need so they stay on site longer.

For a typical building we might see:

- Amenities at street level and some internal dining provision with large companies
- Meeting rooms, especially those for client meetings, often centrally located
- Generally, little if any readily accessible use of the stairs

The result of this is a demand on the various systems within the building not least the lifts. People are drawn from higher up the building to access the amenities resulting in additional lift stops and the result being a reduction in service. One trend in London, and in the case of 20 Fenchurch Street, is that the planning consent was only permitted if publicly accessible space was provided within the building - in this instance the Sky Garden. The Sky Garden needs to be booked in advance but is free for visitors to access, (or you can book a table at one of the two restaurants). This approach provided more public realm than was previously available on the site in fact, as the building floor plates increase in size, the sky garden provides more public realm at the top than it could at the bottom.

The lifting provides extremely high levels of service with Double Deck (DD) lifts serving Low-Rise and High-Rise zones. There is a single transfer floor. The DD deck combined with destination control enables this inter-floor provision to be on one level.

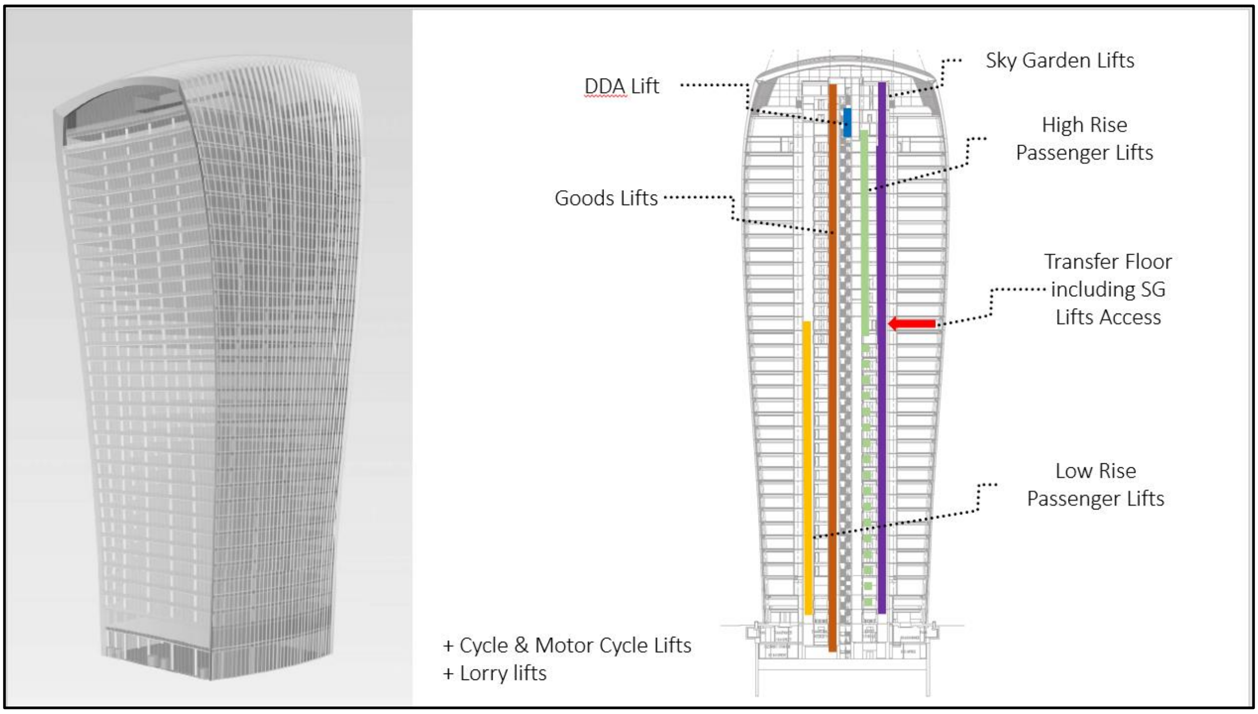

Figure 4: The Walkie Talkie and its Lift Structure

There are two entrances which are provided for the potential flexibility for one significant tenant to have a dedicated entrance. The reception desks and security line are fairly obvious and prominent. The entrances for public and office occupants are distinctly separate or indeed exclusive. The public Sky Garden is served by two dedicated lifts from the public entrance.

Access to the Sky Garden is free and time slots can be booked for the week ahead on a Monday morning. You have to be quick as they go very quickly. You can also walk up on the day to see if there is capacity or you can access the bar if your smart casual attire meets requirements. The location of the transfer floor at level 20 and an entrance in the sky garden lifts permits building residents to gain access to the Sky Garden without exiting and re-entering the building.

20 Fenchurch Street is a hugely successful building, it was fully let before construction was complete and with the sky garden and pocket park there are amenities available for both residents and public alike.

We have mentioned how master planners have a series of rules, expectations or requirements for including within their plans the required amenities at appropriate frequencies. For example, how various user groups might use and access these facilities and by what means. We then arrive at our well designed, well equipped buildings and adopt a completely different approach.

Lobbies can be quite sterile places. I mentioned one of the key factors in master planning is the provision of active frontages ensuring that routes are attractive and vibrant.

Our example of The Walkie Talkie once it had opened had the addition of a coffee shop within the lobby and the public entrance to the Sky Garden has been completely remodelled.

Buildings are more often providing landlord managed amenities; meeting rooms terraces and the like - providing facilities that some might not have provided and others to have more efficient use of. Perhaps the traditional ‘it’s part of the fit-out’ is no longer applicable. The We-Work approach has identified a demand for flexibility on numerous levels.

This approach doesn’t need to be on a grand scale. Within the AECOM office at Aldgate, an internal set of stairs provides interconnectivity between the 8th floor and the 10th floor. Providing access from each level to meeting rooms, kitchen areas and the catering outlet. This providing a vibrant route around the business providing spaces for collaboration, more formal meetings and food.

At the Bloomberg building in London all residents and guests alike arrive at the building and make their way to the 6th floor reception and double height amenity space

What if we apply some of the rules we apply to the horizontal to the vertical? What do the concentric rings of the horizontal master planning diagram look like vertically? Rather than providing amenities in single location we consider distributing them at intervals that become accessible for people across a section of floors.

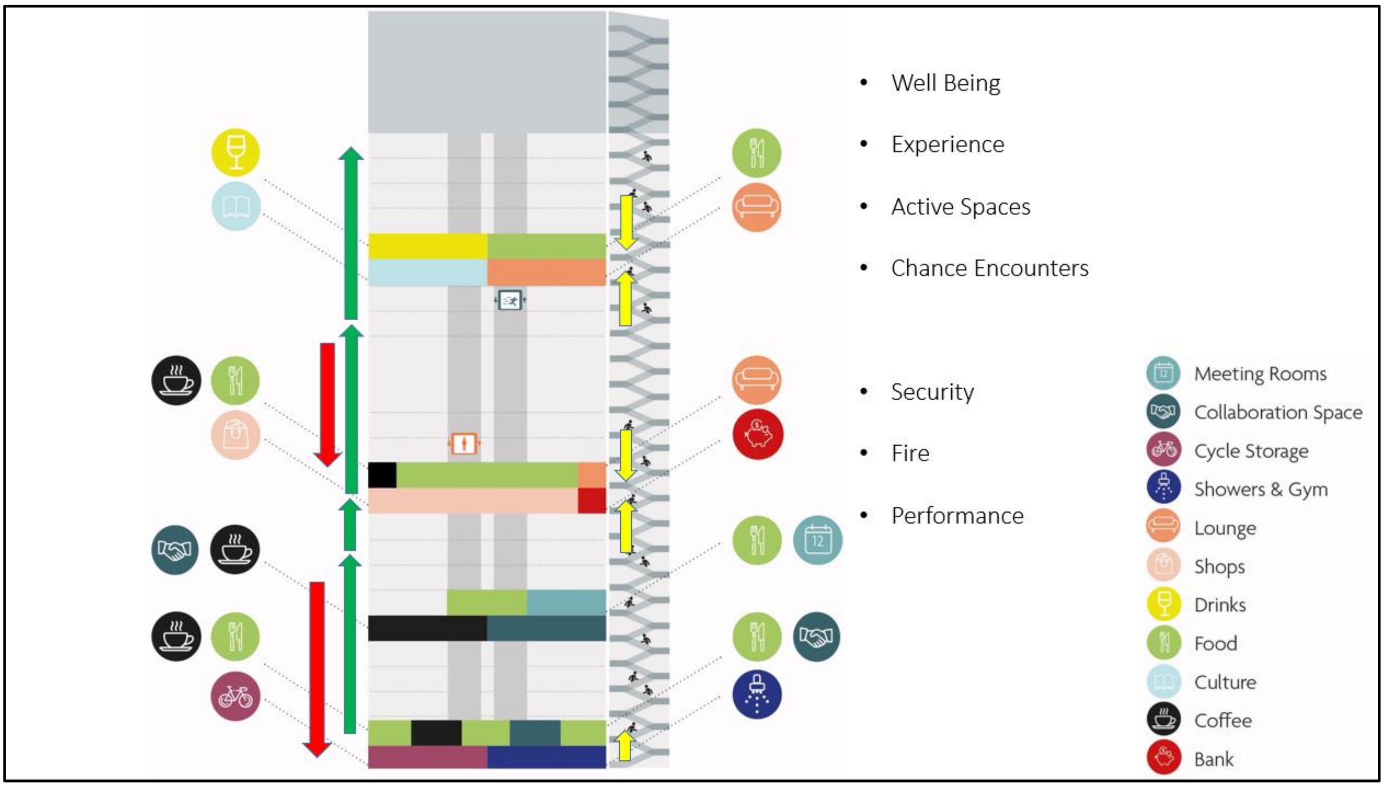

Figure 5: A Polycentric Building

As well as the circulation, within what inevitably will become communities, the routes for that circulation will become places where crossovers happen and the amenity spaces themselves become locations that give the opportunity for chance encounters. This leads to spaces and their routes becoming active, with the amenities becoming nodes.

There are obviously some areas that would need to be addressed. Security is one that is close to most people hearts especially when it comes to the work environment. Security need not be intrusive. The risks will obviously need to be assessed and appropriate provisions made. The use of existing technologies and adopting some of the more readily available technologies such a facial recognition - attend any event such as the CTBUH, you only need to visit any of the lift companies stands to see where they are integrating emerging technologies vertically.

Fire will also be an area that we will need to consider early in design of such buildings, adequate refuge, and evacuation strategies that address the building layout and compartmentation that considers some of the potential risks that are introduced by the use of some of the spaces. Nothing, however, that cannot be dealt with efficiently if considered at the early stages of design.

Rather than provide facilities for the building, why not give the community opportunities to serve the building. One example being bringing street food into the building.

Areas that have often been termed 'end of journey' facilities really need to be considered as part of the journey (e.g. access to and use of cycle storage and showers to be considered).

So where does our journey start? Let's look out for the Citymapper app that does not just look to find the best route but one that enables use of various facilities on a journey, such as picking up a coffee on the way to work.

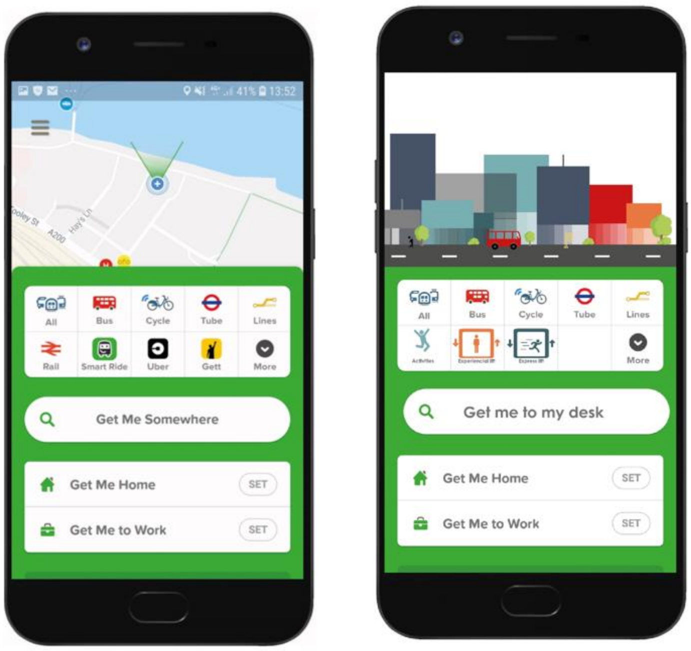

Figure 6: The Citymapper App

So, I am not saying that we should throw away all of the good things we do and have developed over the years, however, I am suggesting that we should not get stuck behind all of the figures - about arrival rates, average awaiting times and time to destination – but instead concentrate on the experience of our buildings and the surrounding habitat. Providing choices and activating our buildings to enhance wellbeing and occupant satisfaction.

Let us locate amenities that help provide a coherent and enjoyable arrival experience and beyond, for the duration of our time and across all activities throughout the day.

We will still need to understand the performance of our lifts, we need to know when they will be too busy - but demanding that a lift arrives within 25 seconds having spent the last 45 minutes commuting to work is to be questioned.

It’s not new. Shell provided a video in the 1960’s which introduces:

We just need to apply it in a way that suits the location and culture and also the technologies as they develop and present even greater opportunities to us as designers. Buildings in the not too distant future will have a number of challenges to address.

A Hackathon, sponsored by the CTBUH UK Chapter, that took place just before the conference last year, highlighted a series of common themes from competing groups around 'vertical villages', human-centred design, smart homes, community empowerment, demonstrating a mental shift in the way designers are conceptualising city habitats and opportunities to re-energise high-rise homes. While we have been looking at mixed use commercial buildings, these themes and our challenges as designers are transferable across sectors.

While we can already use our mobile phone to do most things, including managing our lift journeys, we will be looking at how our autonomous vehicles or drones can take us to work, having picked up our double skinny dry decaf on the way to a planned meeting with a colleague - on the way to the office, still with the ability for a chance encounter, that takes our day onto a new level.

Bringing local amenities into the building can enhance the urban habitat, it can make our great buildings accessible as well as great places that people want to be. Places that provide platforms for communities to develop.

Let us challenge ourselves, not only to ease the ever-increasing demand on the lift systems but seek to look at how we as designers provide the places that enable communities to develop.

REFERENCES

[1] Peter Murray – New London architecture at the CTBUH conference 2018.

BIOGRAPHICAL DETAILS

Having served a fully indentured apprenticeship Alan joined the UK engineering department of Kone Lifts.

Having worked in various positing within Kone, Alan made a move to consultancy in 1998.

Alan has experience of working on projects in the UK, Europe and the Middle East as part of international design teams and for world leading clients.

An active member of the CTBUH Alan presented as part of the Sky Spaces workshop at the 2018 CTBUH conference in Dubai.

Alan is an experienced engineering consultant with approaching 30 years of experience within the lift industry.

Fundamental Study on Rope Vibration Suppression by Middle Transfer Floor using Risk Information

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Keywords: Lift Rope, Lift Travel, Intermediate Evacuation Floor, Seismic Response Analysis, Risk Information.

Abstract. Lifts are essential for means of vertical transportation. Recently, the lifts installed in the high-rise buildings are long travel, thus the lift ropes are becoming longer. The natural period of the high-rise buildings is longer than that of the conventional buildings [1] and in addition to the lift rope becoming longer, the natural period of the lift ropes has also become longer. Accordingly, the natural period of the lift ropes gets closer to the that of the building. Consequently, the lift ropes might be hooked to the equipment of wall when the lift ropes vibrate by an external force, such as a strong wind or an earthquake. Furthermore, secondary accidents such as containment of passengers and lift service stop may occur. In the 2011 Great East Japan Earthquake, over 2000 problems such as the catch and the damage of lift ropes were reported [2]. Operation of lifts after earthquakes is required for the security of the refuge course. Accordingly, the analytical method for comparative evaluation is investigated in this study. Furthermore, a method to prevent a catch by vibration reduction of the lift ropes is investigated. In the previous research, it was confirmed that the division of the lift stroke is effective for reducing the response of the rope. When the lift stroke was equally divided, the displacement of the upper lift became larger than that of the other lift and so the effectiveness of the division ratio of lift stroke was examined in this report. The catching of the lift rope using differential analysis and risk assessment was investigated and as the result, the displacement of the upper lift was decreased by the apposite division ratio. The probability of catching rope of the upper lift is reduced. Furthermore, it was confirmed that the risk of the catching rope reduces in probabilistic risk assessment.

1 INTRODUCTION

Earthquakes occur frequently in Japan, which causes various damages to lifts. Accordingly, lifts require various seismic countermeasures including reinforcement of seismic structure as part of buildings. One of the problems is the vibration of the lift ropes. In recent years, the number of high-rise buildings is increasing in the urban areas with the development of building technology. Lifts installed in the buildings use the long components such as main rope, compensating rope and cables. Due to the increased height of the buildings, the natural period of these long objects is prolonged. Accordingly, the natural periods of the building and these long objects approach each other and resonate due to disturbances such as long-period ground motions and wind. The rope collides with the hoistway by swaying and as a result, the lift ropes catch on the protrusions in the hoistway, causing damage to the rope and the confinement of passengers. In Japan, the evacuation staircase is said to be effective as an evacuation method when lifts stop, however, it is difficult to evacuate high-rise buildings with the evacuation staircase. Moreover, there are many people in high-rise buildings. If those people evacuate all at once, they are likely to cause confusion and congestion. In recent years, evacuation refuges, that people can temporarily evacuate to on the middle floors of high-rise buildings during disasters such as earthquakes and fire, have been set up. In China, they often have an "intermediate evacuation floor" that people can stay safely for long periods during disasters. At current, the evacuation methods using lifts are attracting attention. Accordingly, lifts that can be operated at the time of disaster are required.

Therefore, lifts that can be operated even after earthquakes are investigated in this study. In the previous study, it was confirmed that the division of the lift travel is effective for reducing the response of the rope. When the lift travel was equally divided, the displacement of the upper lift became larger than that of the other lift. Accordingly, the effectiveness of the division ratio of lift travel was examined in this report.

2 ANALYTICAL MODEL

Construction of analytical method of traction type lifts is often used for high-rise buildings. Fig.1 shows the dividing model and analytical model. Model A is the case where one tall lift is installed alone. Model B is the case that the lift travel is divided into two, with two lifts installed. In this paper, three patterns for model B were examined, with the division ratios of 1:1, 1:2, and 1:3. In the analysis, the main rope is measured along the rope from the top end. On the other hand, the compensation rope is measured along the rope from the bottom end.

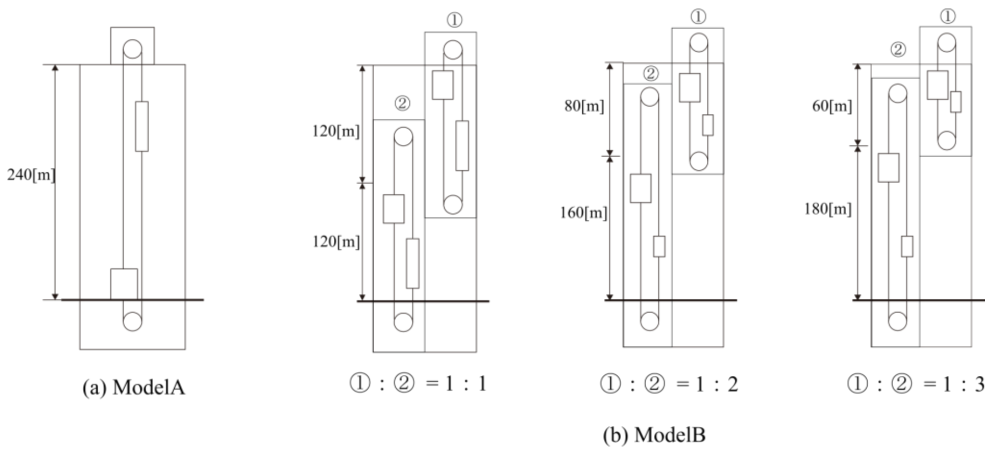

Figure 1: The dividing model and analytical model

2.1 Lift Ropes Model

The equation of motion of lift ropes as strings is shown in Eq.1.

$$\rho A\frac{\partial^2 u}{\partial t^2}+C\frac{\partial u}{\partial t}-\frac{\partial}{\partial z}\left(T(z)\frac{\partial u}{\partial z}\right)=0 \quad (1)$$

Where, ρA is a linear density of rope, C is a damping coefficient of rope, $T(z)$ is the tension considering the weight of the rope. u is the horizontal displacement of the rope, t is time, z is position of elements except traction machine side. Eq.1 is valid when the lift is stationary. Eq.1 is transformed to Eq.2 by the difference approximation method. [3,4].

$$\left(1+\frac{C\Delta t}{2\rho A}\right)u_{j+1}^{i}=2\left(1-\frac{T(z)\Delta t^{2}}{\rho A\Delta z^{2}}\right)u_{j}^{i}+\frac{\Delta t^{2}}{\Delta z^{2}}\left(\frac{T(z)}{\rho A}-g\frac{\Delta z}{2}\right)u_{j}^{i+1}$$
$$+\frac{\Delta t^{2}}{\Delta z^{2}}\left(\frac{T(z)}{\rho A}+g\frac{\Delta z}{2}\right)u_{j}^{i-1}+\left(-1+\frac{C\Delta t}{\rho A}\right)u_{j-1}^{i} \tag{2}$$

Where, Δt is time step, Δz is length step, i is time coordinates, j is space coordinates, g is gravitational acceleration. Fig.2 shows a lattice point of the difference method.

2.2 Building Model

Fig. 3 shows an analytical model of a building. The building is modeled as a single-mass system. The equation of motion of structure is as shown in Eq.3.

$$m\ddot{x}+c\dot{x}+kx=-m\ddot{z}_{H} \tag{3}$$

Where, m is the mass of the building, c is the damping coefficient of the building, k is the stiffness of the building, $\ddot{z}_H$ is the acceleration of input wave.
The natural period of building is calculated using Eq.4 [4].

$$T_{H}=0.025\times H \tag{4}$$

Where, T_H is the natural period of building and H is the height of building. The vibration mode shape of the building is not straight but curved. Accordingly, the vibration behavior of the position of the building is calculated using a correction coefficient, which is corrected by the vibration mode. The correction equations used for the correction coefficients are shown in Eq.5 and 6.

$$w=\alpha_{1}\times h+\alpha_{2}\times h^{2}+\alpha_{3}\times h^{3} \tag{5}$$

$$h=\frac{H_{position}}{H_{top}} \tag{6}$$

Where, w is the vibration mode of building, $H_{position}$ is the position of the building, H_{top} is the height of the top of the building, α_1 = 1.138, α_2 = 0.5743 and α_3 = -0.7083. $\alpha_{1,2,3}$ were calculated by the Stodola method. The response at the top of the building is calculated from Eq.3. The response of each building height is calculated by multiplying the response obtained from Eq.3 by the correction coefficient of each building height obtained from Eq.5 and 6. The top and bottom of the rope vibrate synchronously with the building. Accordingly, the response obtained by the above method is the input to the top and bottom of the rope.

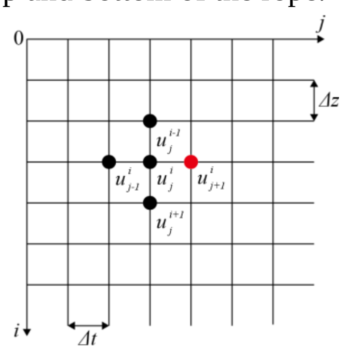

Figure 2: Lattice point

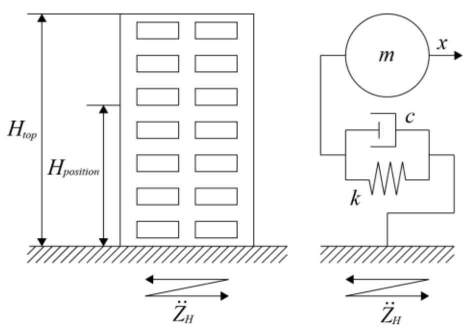

Figure 3: Structure model

3 ANALYTICAL CONDITION

3.1 Specifications of Building and Lifts

The seismic response analysis was conducted by the derived equations in Section 2. Table 1 shows the parameters of the building. Tables 2 to 3 show the parameters of each lift. Building height where the lift is installed is 240 m. The rope length was determined taking into consideration the height of car and sheave, hoisting machine and so on. The gap was determined in consideration of the actual lift dimensions.

Table 1: Specifications of building

Building height [m]	240
Natural period of buildings [s]	6
Damping ratio of buildings	0.02

Table 2: Specifications of model A

Roping		2:1
Cage mass [kg]		2350
Counterweight mass [kg]		3450
Compensating sheave mass [kg]		554
Gap (cage side) [m]		0.8
Gap (counterweight side) [m]		0.2
Main rope	Linear density [kg/m]	0.494
	Length(Cage side) [m]	3~238
	Length(Counterweight side) [m]	3~238
	Damping ratio	0.002
Compensating rope	Linear density [kg/m]	0.704
	Length(Cage side) [m]	3~236
	Length(Counterweight side) [m]	3~235
	Damping ratio	0.02

Table 3: Specifications of model B

Division ratio		1:1		1:2		1:3	
Lift number		First	Second	First	Second	First	Second
Roping		2:1	2:1	2:1	2:1	2:1	2:1
Cage mass [kg]		2220	2220	2220	2220	2220	2220
Counterweight mass [kg]		3170	3180	3090	3220	3090	3220
Compensating sheave mass [kg]		167	167	167	167	167	167
Gap (cage side) [m]		0.8	0.8	0.8	0.8	0.8	0.8
Gap (counterweight side) [m]		0.2	0.2	0.2	0.2	0.2	0.2
Main rope	Linear density [kg/m]	0.494	0.494	0.494	0.494	0.494	0.494
	Length(Cage side) [m]	3~118	3~124	3~78	3~164	3~58	3~184
	Length(Counterweight side) [m]	3~118	3~124	3~78	3~164	3~58	3~184
	Damping ratio	0.002	0.002	0.002	0.002	0.002	0.002
Compensating rope	Linear density [kg/m]	0.704	0.704	0.704	0.704	0.704	0.704
	Length(Cage side) [m]	3~116	3~121	3~76	3~161	3~56	3~181
	Length(Counterweight side) [m]	3~115	3~121	3~75	3~162	3~55	3~182
	Damping ratio	0.02	0.02	0.02	0.02	0.02	0.02

3.2 Input Earthquake Wave and Specifications of Analysis

Fig.4 shows an input earthquake wave, which was observed in 2011 off the Pacific coast in the Tohoku Earthquake at Shinjuku North-South Direction [5]. Due to this earthquake a large number of lifts were confirmed damaged. Table 4 shows analysis time, time step and length step.

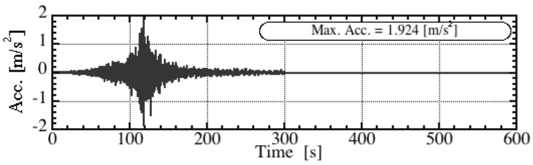

Figure 4: Input wave

Table 4: Specifications of Analysis

Analysis time [s]	600
Time step [s]	0.005
Length step [m]	1

4 PROBABILISTIC RISK ASSESSMENT

Probabilistic risk assessment is a method to quantitatively evaluate the frequency of occurrence and the effect of the occurrence of an accident that may occur. In this report, the risk of the rope catch is evaluated. The evaluation formula for the fragility curve is as shown in Eq. 7 [6]. In this report, it is assumed that probability distribution of various elements of the fragility curve is a log-normal distribution, as a method to make the failure probability curve simply. Assuming that the probability distribution of various elements of the fragility curve is log-normal, Eq. 7 can be applied to various phenomena.

$$P_f\left(Z_m\left(s\right)\right) = \phi\left[\frac{\left(Z_m(s)/A_m\right) + \beta_u \phi^{-1}(Q)}{\beta_r}\right] \tag{7}$$

Where, P_f is the failure probability, $Z_m(s)$ is the velocity of the earthquake, Am is the median of the index due to catch of the rope, β_u is a logarithmic standard deviation representing epistemic uncertainty, β_r is the logarithmic standard deviation representing accidental uncertainty, $\phi(\cdot)$ is standard normal distribution, $\phi^{-1}(\cdot)$ is the inverse function of $\phi(\cdot)$ and Q is the non-exceeding probability of failure probability considering epistemic uncertainty. When making a fragility curve based on Eq.7, it is necessary to experimentally determine the median and the uncertainty of the index caused by the catching rope. In this report, as a basic examination of probabilistic risk assessment, if displacement occurs up to 0.8 m in car side and up to 0.2 m in counterweight side, the rope will not be caught at 99% probability. Uncertainty such as error in rope analysis, error due to principle of occurrence of the catch and effects of dividing lift stroke are assumed to be constants. In this report, βr and βu are evaluated as 0.1. Moreover, in this report, evaluations are made by a 95% reliability curve which is high reliability.

5 RESULTS AND CONSIDERATION

5.1 Rope Analysis

Fig. 5-8 show seismic response analysis results of the lift ropes. Fig.5 shows the maximum displacement of each rope length of the main rope and the compensation rope in the model A. Fig. 6-8 show the maximum displacement of each rope length of the main rope and the compensation rope of the model B.

From Fig.5, the maximum displacement of main rope increases in proportion to the length of the rope. The natural period becomes longer as the rope becomes longer. As the result, the natural period of the main rope is close to the natural period of the building. Also, the maximum displacement of compensation rope is obtained when the rope length is around 100 m. After that, the displacement is decreasing, and the displacement increases in the vicinity of 240 m. Because the compensation rope has lower tension than the main rope, the natural period of the compensation rope is longer than of the main rope. In the vicinity of 100 m, it is considered that the first natural period of the compensation rope is close to the natural period of the building.

From Fig.6, the displacement of the upper lift in both the main rope and the compensation rope is larger than the displacement of the lower lift. The displacement of the rope is considered to depend on the amount of vibration at the top and the bottom of the rope. Since the vibration input of the upper lift is larger than that of the lower lift, the displacement of the upper lift is considered to be large.

From Fig.7, when the division ratio changes from 1:1 to 1:2, the displacement of the upper lift decreased. The vibration input of the upper lift is larger than that of the lower lift. The displacement is decreased by changing the division ratio and shortening the lift stroke. Also, when the division ratio changes from 1:1 to 1:2, the displacement of the lower lift increased. The vibration input of the lower lift is smaller than that of the upper lift. The displacement was increased by changing the division ratio and lengthening the lift stroke.

From Fig.8, the displacement decreases in the upper lift and increases in the lower lift compared to the cases where the division ratios are 1:1 and 1:2. As in the case of a 1:2 ratio, this is considered to be caused by a change in the division ratio.

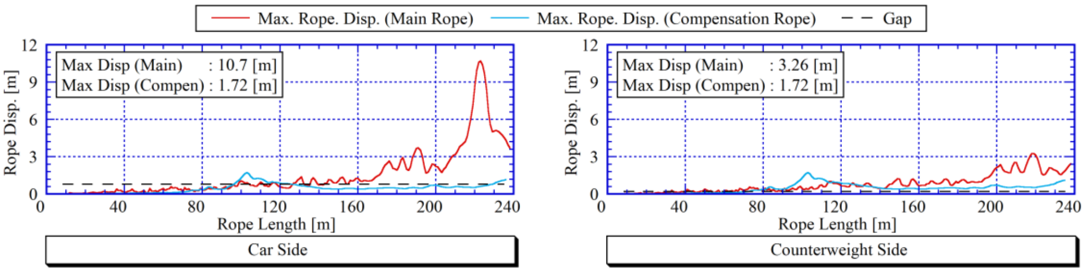

Figure 5: Numerical result of model A

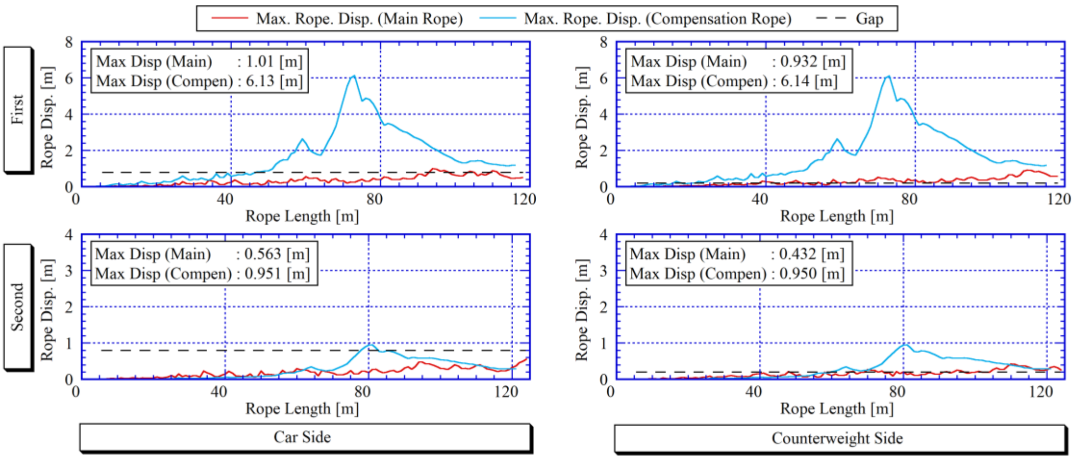

Figure 6: Numerical result of model B (1:1)

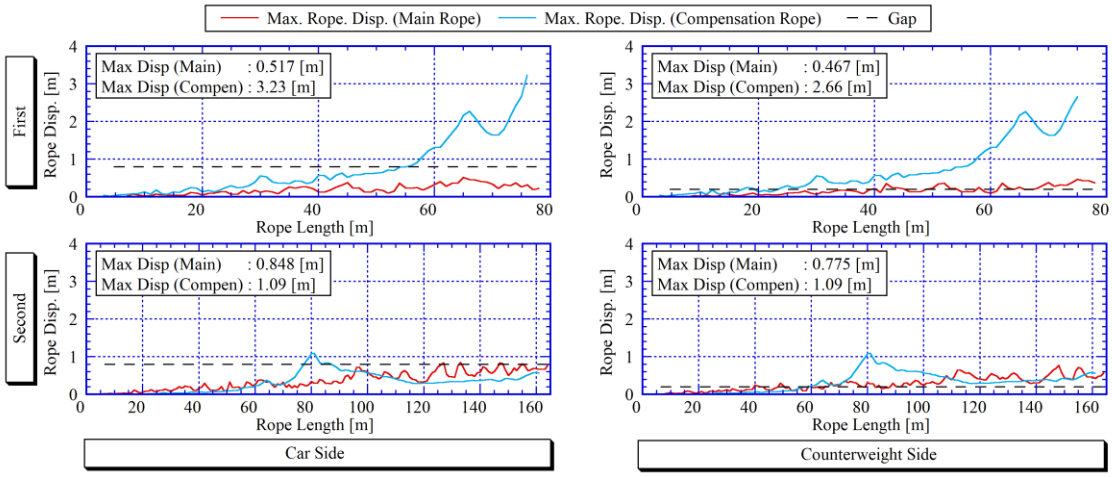

Figure 7: Numerical result of model B (1:2)

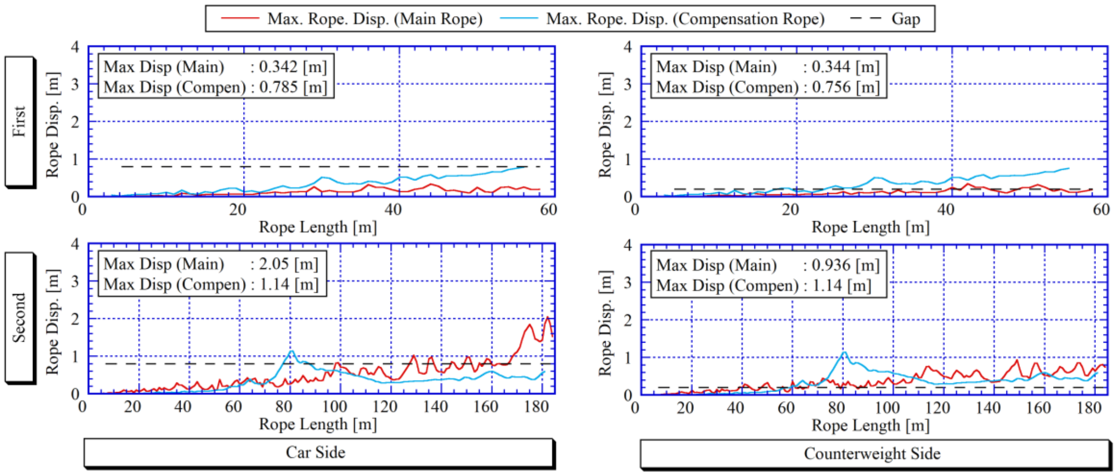

Figure 8: Numerical result of model B (1:3)

5.2 Probabilistic Risk Assessment

Fig. 9-12 show the fragility curves for each lift. Fig. 9-10 show the fragility curves for main rope and compensation rope of model A. Fig. 11-12 show the fragility curves for main rope and compensation rope of model B. The HCLPF values for each lift are shown in Table 5. The HCLPF value, which guarantees the performance of the equipment mainly used in the nuclear field, is the value of 5% failure probability in the 95% reliability curve.

From Fig. 9-10 and Table 5, the main rope and the compensation rope in Model A have a high probability of catching rope, even by small input seismic waves.

From Fig. 11-12 and Table 5, the probability of the catching rope was lower in model B than in model A because by dividing lift stroke, the displacement of the lift rope decreased. When the division ratio is 1:1, the probability of the catching rope is larger in the upper lift than in the lower lift because the upper lift vibrates more than the lower lift, the displacement of the upper lift becomes large. Division ratio changes from 1:1 to 1:2 or 1:3, and the lift stroke of the upper lift shortens. Therefore, the probability of catching rope also decreases. On the contrary, lower lift increases the probability of the catching rope because the lift stroke becomes longer.

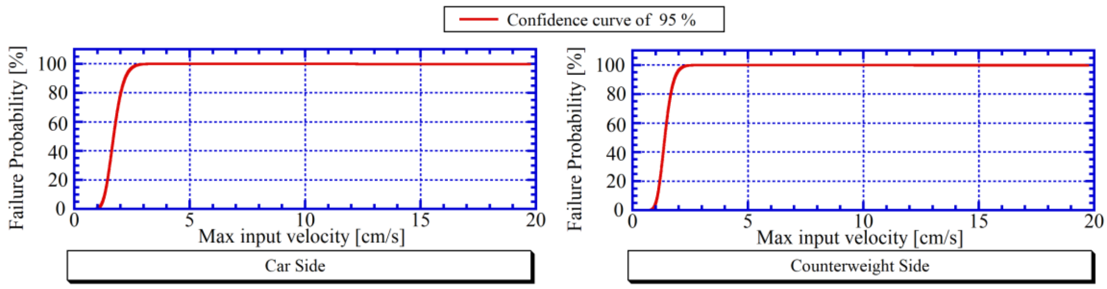

Figure 9: Fragility curve of model A of main rope

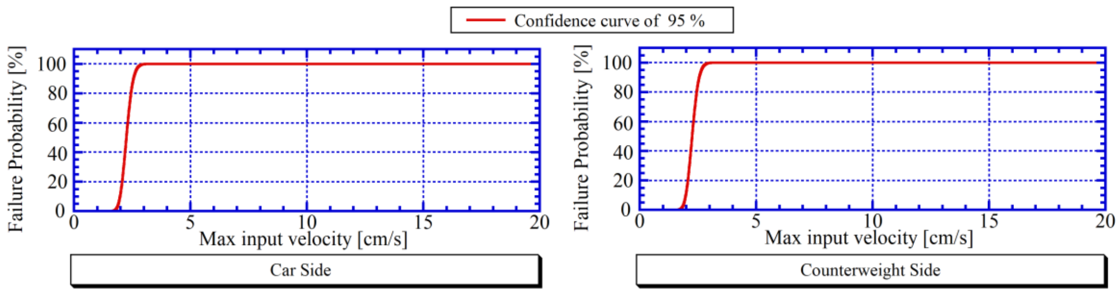

Figure 10: Fragility curve of model A of compensation rope

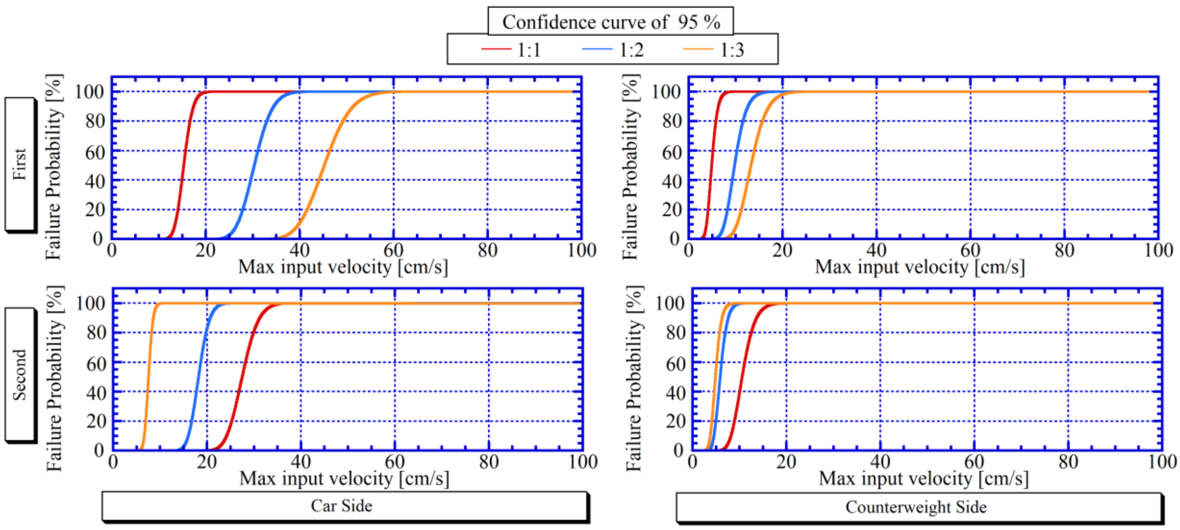

Figure 11: Fragility curve of model B of main rope

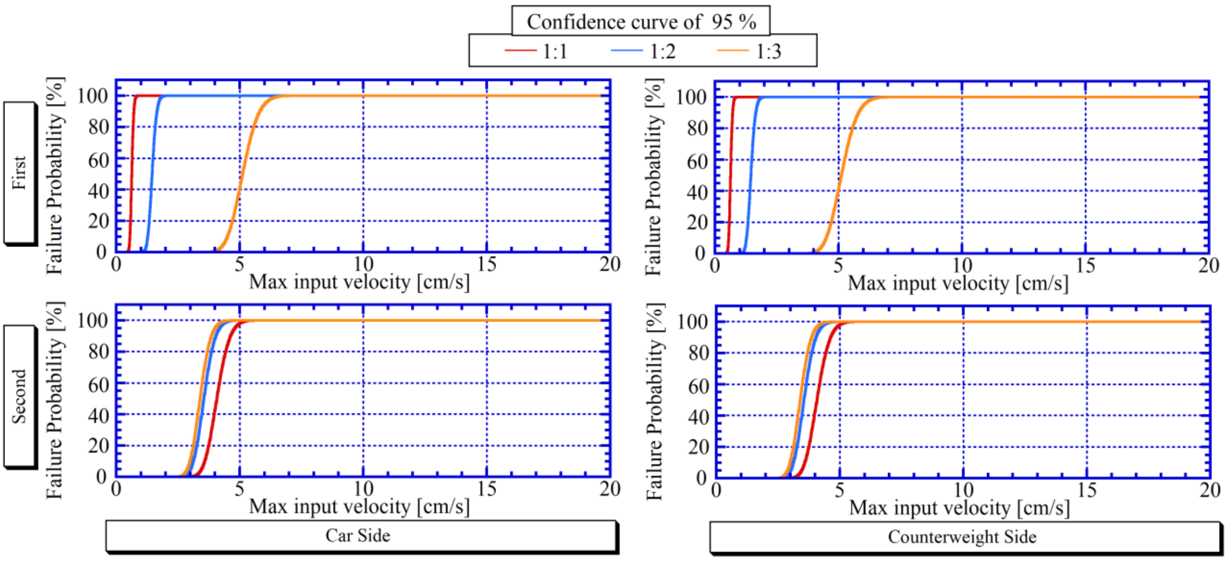

Figure 12: Fragility curve of model B of compensation rope

Table 5: HCLPF Value of each lift

	Division ratio	Lift Number	HCLPF [cm/s]			
			Main Rope		Compensation Rope	
			Car side	Counterweight side	Car side	Counterweight side
Model A			1.23	1.01	7.63	1.91
Model B	1:1	First	13.0	3.52	2.14	0.536
		Second	23.3	7.59	13.8	3.45
	1:2	First	25.7	7.02	4.06	1.23
		Second	15.4	4.23	12.0	3.01
	1:3	First	38.4	9.53	16.7	4.34
		Second	6.40	3.50	11.5	2.88

6 CONCLUSIONS

In this paper, as a vibration reduction method of lift rope in a high-rise building, the effectiveness of installing multiple lifts by dividing the lift travel and the effectiveness of changing the division ratio of the lifting travel were evaluated using the maximum displacement of rope and the fragility curve. As the result, the occurrence probability of displacement and the probability of catching rope of the upper lift decreased, by changing the division ratio of the going lift travel, and displacement and the probability of catching rope of the lower lift increased. By appropriately setting the division ratio in consideration of the vibration behavior and the length of the rope, the probability of the rope catch can be suppressed. Therefore, the safety of the lift can be improved during and after seismic events including long period earthquakes.

REFERENCES

[1] Ishiyama Y., *Seismic regulations and structural dynamics Basic knowledge for understanding the building structure*, Sanwa Publishing Co., Ltd, 2008, (in Japanese)

[2] Miyata T., Fujita S., Shimoaki M., *Damage to Elevators in the Great East Japan Earthquake*, A collection of lectures at the 21 Traffic and Logistics Conference, 2012, pp.1-6. (in Japanese)

[3] Kimura H., Ito H., Nakagawa T., *Vibration Analysis of Elevator Rope: Forced Vibration of Rope with Time – Varying Length*, Transactions of The Japan Society of Mechanical Engineers, C71 (706), 2005, pp.1871-1876. (in Japanese)

[4] Shibata A., *Current Seismic Structural Analysis*, Morikita Publishing Co., Ltd., 1981. (in Japanese)

[5] National Research Institute for Earth Science and Disaster Prevention, K-NET.KiK-NET, http://www.kyoshin.bosai.go.jp/kyoshin/, September 2016. (in Japanese)

[6] Nuclear Society Standard, *Atomic Energy Society of Japan, Standards for Probabilistic Safety Evaluation due to Nuclear Power Plant Earthquakes*, Atomic Energy Society of Japan, 2007, pp.313-315. (in Japanese)

BIOGRAPHICAL DETAILS

Suzuko Tamashiro is master's course student in mechanical engineering of Tokyo Denki University. She researches vibration suppression of lift rope.

Prof. Satoshi Fujita, a JSME (Japan Society of Mechanical Engineers) Fellow, has ten years of management experience as a director, a dean of school of engineering and currently a vice-president of Tokyo Denki University. He has been engaged in engineering research and development of seismic isolation systems and vibration control systems for buildings or key industrial facilities for over 35 years at both University of Tokyo and Tokyo Denki University.

Kazuhiro Tanaka, has been in Toshiba Elevator since 1995, is in charge of development for elevator system and representative of quality expert in Development Dept. He has developed many special elevators especially high-rise ones applied in tall towers. He is also chairperson of expert committee of machine technology in Japan Elevator Association since 2016.

Tomohiro Shiki entered Toshiba elevator in 2011. He belongs to the Development Dept. and is engaged in the development of cage mainly.

Associate Professor Shigeki Okamura has been in Toyama Prefectural University since 2018. Previously, he had been in the research institute and manufacturing. He has been engaged in engineering research and development of seismic isolation systems and the seismic evaluation method for the important facilities, such as, nuclear power plant/components. In addition, he had been engaged in seismic design of nuclear power plant/components.

Impact of Learning Style Preferences and Social Media Use on the environment of Distance Learning for Engineers in the Vertical Transportation Industry

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Keywords: Learning, Training, Adult Education, Training Concepts, Social Media, Engineering, Learning Style Preferences, Vertical Transportation

Abstract. The world became a digital world, where the internet and modern communication channels have changed the way people interact and communicate with each other.

On the other hand, digital technology drives the concepts of advanced learning and allows access to learning environment anytime, anywhere.

Based on the results of a quantitative survey conducted with participation of engineers and students across the entire world, a new pedagogic concept for Distance Learning (for the subject of Advanced Machine Dynamics) has been developed in this study.

The paper examines the concept and structure of the survey and looks into the analysis of the results. Furthermore, it emphasizes the impact of Social Media on the success and effectiveness of learning considering different Learning Style preferences.

The paper concludes with recommendations to improve the Distance Learning mode of delivery to ensure a learner-centric approach and optimized learning results.

The results of this study, combined with the results of research projects that focus on the performance of rope-less Passenger Transportation Systems, will help to improve the Learning Environment and concept of Distance Learning for engineers in the Vertical Transportation industry.

1 INTRODUCTION

Learning is the driver for the development of the human species and an ongoing process to pursuit knowledge. This knowledge transfer changed over the last decades through permanent scientific innovation and evolving technology (typography, personal computers, internet).

Also, the way the learning process is understood altered, as - in many cases – today, learning (to acquire knowledge), goes together with the application of that specific knowledge (e.g. at a workplace) [1]. The effectiveness of that knowledge transfer process is a condition of the way a human being receives that learning content; it depends on the individual Learning Style, which is the method a person uses to learn or study [2].

This paper evaluates the interaction of learning preferences and modern communication channels and proposes a state-of-the-art concept for efficient and effective Distance Learning courses in Engineering Education.

2 LEARNING STYLES

In general, learning can be categorized into the following types:

- *Auditory Learning,*
- *Visual Learning,*
- *Haptic Learning and*
- *Intellectual Learning*

While auditory, visual, and haptic learning are somewhat related and all focus on perceptions and inputs that come through the same type of nerve cord, intellectual learning is different in its receptive channel.

Bloom's Taxonomy splits types of learning into the following levels [3]:

- *Remembering (Recall or recognition of an expression.)*
- *Comprehension (Understanding of facts. Ability to organize them and bring into relation.)*
- *Application (Deeper understanding. Use/apply information for related problem solving.)*
- *Analyzing (Break-up information into smaller chunks, organize them and relate them together.)*
- *Synthesizing (Ability to structure patterns from given/known information. Develop ideas and critical doubts about the subject.)*
- *Evaluating (Ability to take in external information and relate your knowledge to them to make decisions.)*

Those six levels work in hierarchical order with *Evaluation* as the highest level of understanding and *Remembering* on the other end. This categorization is important for the development of learning concepts and training outlines.

Every individual, however, has their own way to receive and process information. When it comes to the process of studying or learning, we can observe a number of different kinds of learning style preferences.

We can categorize the following types of learners [4,5]:

- Visual, aural and verbal learners;
- Social (active) and solitary (reflective) learners and
- Physical (sensing) and logical (intuitive) learners.

Other sources also blend learning style preferences with the way people pick up information (sequential/systematic and global/random learners) [6]:

- Sequential learners have a tendency to gain understanding in linear steps (one step is logically following from the previous step),
- While Global learners tend to learn in bigger steps, randomly absorbing content with probably no obvious connections, however, finally they "get it".

2.1 Visual, aural and verbal learners

Visual learners (a.k.a. learners with a visual learning preference) remember content best, when they see for instance pictures, diagrams, flow charts or video sequences, while Verbal learners gain more out of words and text in written. Aural learners get most out of sound and spoken explanations.

2.2 Social and solitary learners

Social learners tend to keep and understand information best by doing something active with it (for example: applying/discussing/explaining. Social (reflective) learners tend to enjoy group work and workshops more than solitary learners, who prefer working alone (reflection).

Reflective learners prefer to think about it for themselves in the first place.

Sitting quiet throughout lectures only taking notes is hard for these two learning types, but even harder for social learners.

2.3 Physical and logical learners

Physical learners tend to like content such as facts and figures, while logical learners often prefer to discover possibilities and inter-relationships.

Everybody has a preference for a specific learning style and sometimes tends to the opposite the other day. Our preferences for one or the other maybe strong, moderate, or weak.

To be an effective learner or problem solver, people should be able to function in both directions of a category.

3 MODERN SOCIAL INTERACTION

3.1 Importance of Social Interaction

"Social interaction is the reciprocal influence human beings exert on each other through inter-stimulation and response."[7]

This definition obviously emphasizes two main conditions of social interaction: social contact and communication. For social contact in our context, mental, not physical, proximity is essential and it may be direct (involves the presence of persons) or indirect (through any means of communication, such as telephone or TV), and positive (directs to tolerance, compromise or cooperation) or negative (leaves a feeling of i.e. hate, rival or jealousy). That social interaction works via communication and has a central place in society and is a necessity for social contacts. Today, it varies from writing a letter, to the communication means of the 21st century.

3.1 Social Media

Social Media refer to forms of digital platforms, whether mobile or stationary, involving interactive (human) participation. Social Media is the entirety of interactive online collaborative channels dedicated to input and shared content coming from the participating community. [8]

Amongst other types of Social Media, Facebook, WhatsApp or Bebo replaced the very well established one-to-one communication such as face-to-face conversation or telephone calls. In any way, a social interaction or social relation is the way people talk and act with each other and includes interactions in a team, or family and incorporates any relationship between two or more individuals. It is an important source of socialization and characterizes all different types of social relationships. As a university environment represents a subgroup or society with a specific intention, Social Media seems to be an obvious tool to communicate up-to-date in this context. [9]

There are few rationales of Social Media existing:

- Create a community → Social Media helps to centralize the knowledge of a specific class, which studies the same topic at the same time, and helps increasing the communicating efficiency (even with the involvement of a professor or teacher).
- Continue the conversation → Social Media helps individuals to tap into a study group when classes have been missed or ask questions to experts.
- Organize learning resources → Tools provided within Social Media networks help keeping course content organized and offer ease access to it.
- Supplement course materials → Social Media helps identifying additional topic content to amend the initial instruction.

Social Media can help students to create and manage a study community to gain the most efficiency and effectiveness out of available study time and to find additional resources to supplement studying.

4 THE SURVEY

To identify a correlation between Learning Style preferences and the usage of Social Media, a questionnaire has been designed to verify (or disprove) these theses [10].
Within a timeframe of October 25, 2018 and December 31st, 2018, 353 replies were counted after accessing the following student and engineering populations through an official invitation:

- Global R&D workforce of a German Lift manufacturer
- Student force of the University of Northampton, UK
- Student force of Georgia Institute of Technology, U.S.
- Student force of Shanghai-based Tongji University, P.R.C.
- Student force of the University of Stuttgart, GER
- Student force of the University of Applied Science Furtwangen, GER

4.1 Survey design

The idea of that completely anonymous survey is to find out (through self-assessment) individual Learning Styles and the individual need to interact with other learners. These very specific characteristics differ from person to person and correlate to different experiences of one´s socialization in the past [11].

The considered survey result will be incorporated into a new Learning Model and consequently into the design of a short analytical task on the subject of Machine Dynamics, which will be carried out via Distance Learning. Thereafter, an engineering student cohort will conduct a second Distance Learning item that follows this new Learning Model.

A second cohort will be the reference group by following the old distance learning approach.
Both cohorts finish their assessments with a small exam to prove and compare the learning success.
That result is used to finally evaluate the new learning concept.

The principle workflow of the study is shown in Fig. 1.

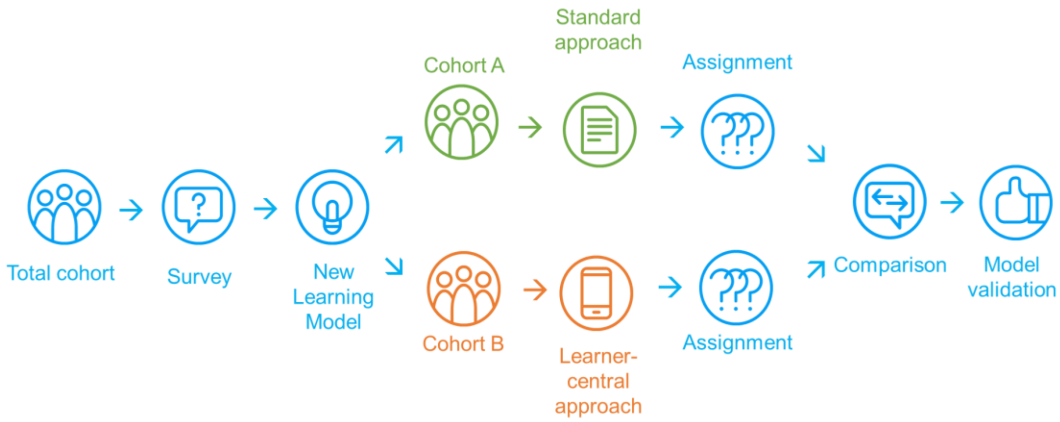

Figure 1: Study design

4.2 Survey results and implications

The total number of replies to the survey is 353 with the following distribution to age, gender, profession, and geographical region as shown in Fig. 2:

- 44% are younger than 30 years
- 74% are Male
- 54% are Mechanical Engineers
- 53% are based in Asia; 38% are based in Europe

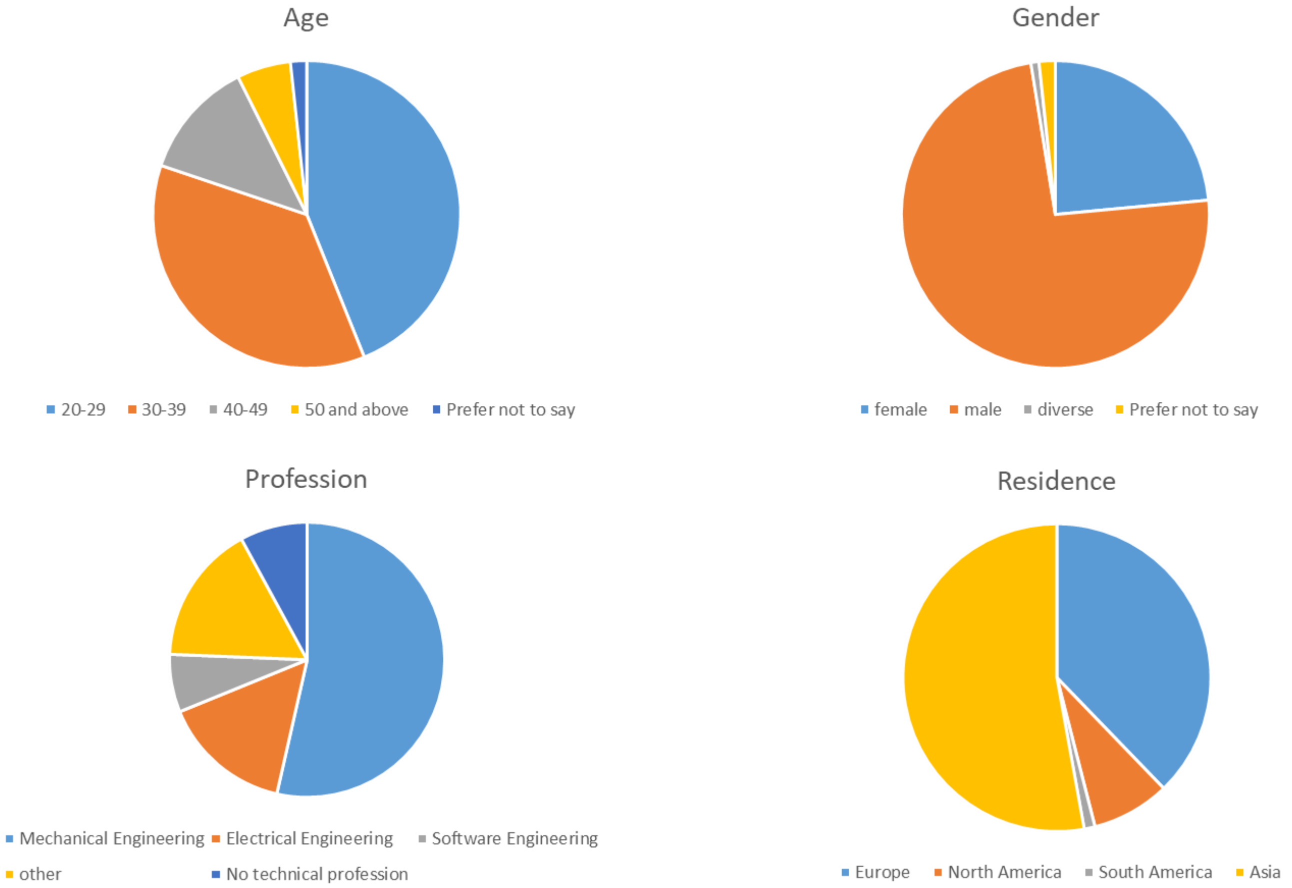

Figure 2: Survey main data

This outcome of randomly contacted and globally distributed survey replies corresponds to the multi-national global R&D population of thyssenkrupp Elevator, one of the lift manufacturers with global operations.[1] This means: The data shown refers to an unrelated global engineering population but is pursuant to the R&D population of this specific lift manufacturer.

The lift business itself is a global business with country or region specific safety regulations, such as EN 81, and therefore it is essential for global enterprises to have a diverse staff population that is familiar with these regulations and local markets.

Engineering topics specific for lift engineers include, but are not limited to [12]:

- Lift Applications Engineering (important mathematical, mechanical and electrical processes and mechanisms involved) with an exploration of the parameters effects influencing the overall performance of the lift system
- Codes and Standards
- Lift Control Systems
- System Dynamics and Vibration
- Hydraulic Systems
- Lift Component Applications
- Microprocessor Applications
- Utilization of Materials

[1] According to the General Data Protection Regulation, individual information (e.g. gender or age) has to be handled very sensitively and therefore cannot be published. The author of this paper has the data analysis at his disposal accordingly.

- Vertical Transportation Systems

The detailed analysis of the survey results shows the following findings:.

4.2.1 Real friends or just a collection of contacts?

Interviewed persons, who stated that they know all or most of their social network, show a tendency not to prefer using body, hand and/or sense of touch when learning something new.
However, the majority of this group (52%) says, that they prefer logic and reasoning to learn best. Logically, this part group uses social networking sites more likely that the total population of interviewees.

It is to prove why this part group is younger than the total population.

On the other hand, there is a significant shift to a higher degree of "unknown" friends in the social network of people from Asia (mean rank moves from 2.8 to 3.6, with 5 possible answers from 1 = "I know all of them" over 3 = "I know about half of them" to 5 = "I know none of them").
Another significant difference is obvious, when it comes to the degree of "friends" met in person in social networks of participants from Europe, North America and Australia. Here 84% of the population state that they know most or all of the "friends" of their social network.

4.2.2 Solitary learners

45% of the total survey participants called themselves a Solitary Learner ("I prefer to work alone and use self-study.") and logically claims that it helps them to understand something, when they think about it by themselves.
However, 55% prefer to learn in groups or with other people.

4.2.3 Devices

Throughout the entire survey population, the preferred device to connect with the internet are laptop and smart phone.

4.2.4 Places to study

86% of the participants of the survey claim that they are at home when studying or attending online courses

4.2.5 Preferred media

Almost 60% of the total survey participant group prefers to read digital academia articles or eBooks and to watch videos.

4.2.6 Recap difficult topics

For 60% of the interviewed persons it is helpful, when they talk to someone to understand something.

4.2.7 Just listen or be active

For a classic classroom situation, 59% of the survey participants claim to learn better, when they can actively bring in their ideas.

4.2.8 Daily time spent online

46% of the participants coming from Europe, North America or Australia are spending at least 3 hours online

4.2.1 Learning style preferences

When it comes to learning style preferences (see chapter 2 LEARNING STYLES), there are significant different shapes of the distribution of the specific degree of preference.

- Visual (question 1): 64% moderate or high degree
- Aural and (question 2): 26% moderate or high degree
- Verbal learners (question 3): 50% moderate or high degree
- Physical/sensing learners (question 4): 37% moderate or high degree
- Logical/intuitive learners (question 5): 69% moderate or high degree
- Active learners (question 6): 64% moderate or high degree

4.3 Implications and new pedagogic model for Distance Learning

Learning by itself can be described as a transformation process, and the model illustrated in Fig. 3 shows the important interactions within the learning process [13] enabled by technology.

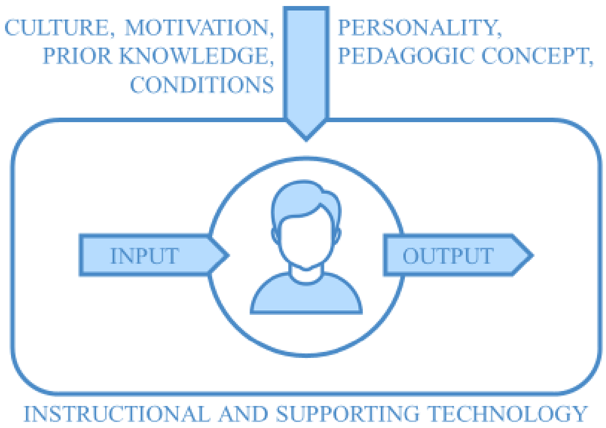

Figure 3: Transition Model of Distance Learning

Based on the survey results and the following statements (derived from the survey)

- Social networks are working in the same way with real friends (known in person) or unknown people.
- People are used to studying for themselves.

- People like to study at home.
- People like using laptops/tablets or mobile phones to study.
- People are used to reading online sources and prefer video clips.
- People like to recap difficult topics with others.
- Online sources are used for a significant time of the day.
- The most prominent shapes of learning style preferences are visual, logical and active.

A new model to capture the student needs and to respect the differences in Learning Style is suggested. This new model (shown in Fig. 4) considers the following aspects and therewith it represents a new pedagogic model for Distance Learning to improve its effectiveness:

- A social network needs to be established (within the student population) to enable students to recap difficult topics with other students.
- Learning formats have to be responsive to ensure the application via mobile devices and include visual content.
- The learning content should challenge the learners with logical context and should animate them to actively use other senses.

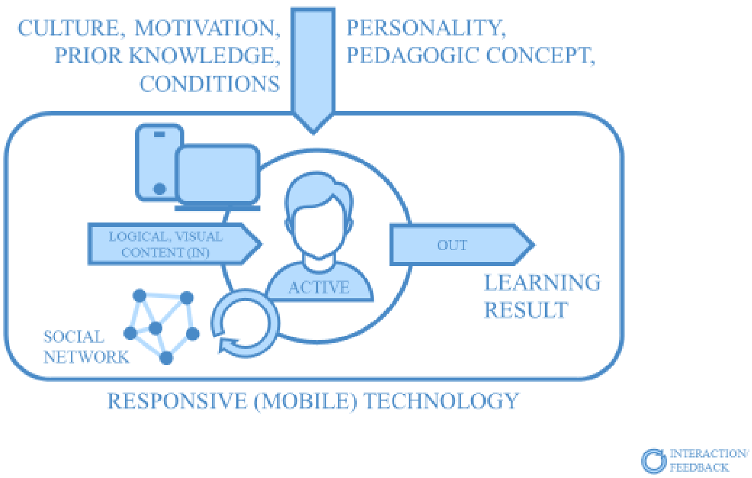

Figure 4: New Model for Distance Learning

5 CONCLUSION

The results of the survey show that there are no significant differences between geographical regions, although assumed initially. However, the number of real “social media” friends is different, when comparing Asia with Western cultures. For both geographical regions, Social Media is the perfect complement to Distance Learning to enhance the student interaction.

Out of six different learning style preferences the most common seem to be visual, logical and active, of which all can be integrated into new learning formats.

As people usually study at home, Social Media seems to be a kind of window to the outside world and therefore should be incorporated into the pedagogic concepts of the future Distance Learning courses. On the other side, it is highly recommended to motivate Distance Learning students to initiate and maintain their own and topic specific communication channels via Social Media.

For distance learning programs, such as the MSc Lift Engineering course at The University of Northampton (UoN), this new pedagogic concept offers a huge potential to increase the efficiency and effectiveness of such a program.

The MSc Lift Engineering program delivered, offered through distance learning by experienced academics and practitioners from the national and international lift industry, benefits lift engineers and consultants as well as members of senior management in the lift industry. A virtual learning environment delivers online sessions that can be accessed from anywhere in the world.

That UoN learning environment will undergo an improvement process to apply the findings of this paper and to strengthen its best practices.

REFERENCES

[1] Fischer, Gerhard, Lifelong Learning - More than Training. Journal of Interactive Learning Research, Volume 11, issue 3/4, pp 265 - 294. (2000)

[2] M. l-Bishouty, A. Aldraiweesh, U. Alturki, R. Tortorella, Richard, J. Yang, S. Graf. *Use of Felder and Silverman learning style model for online course design*. Educational Technology Research and Development. (Volume 67, Issue 1, 2018)

[3] Lorin W. Anderson, David R. Krathwohl, A Taxonomy for Learning, Teaching, and Assessing. (2000)

[4] R.M. Felder and L.K. Silverman. *Learning and Teaching Styles in Engineering Education*, Engr. Education 78(7), pp 674 - 671. (1988)

[5] VARK Learn Limited. *The VARK Modalities*. www.vark-learn.com, accessed on June 10th, 2019

[6] R.M. Felder and R. Brent. *Teaching and Learning STEM: A Practical Guide*, Jossey-Bass, San Francisco. (2016)

[7] Rajendra Kumar Sharma. *Fundamentals of Sociology*, Atlantic Publishers & Dist., New Dehli. (1996)

[8] Jimmie Manning. *Definition and Classes of Social Media*. Encyclopedia of Social Media and Politics, Sage Publications, pp 1158 - 1162 (2014)

[9] Neil Selwyn. *Social Media in Higher Education*. The Europa World of Learning (2012)

[10] Study results of online survey (onlinesurveys.ac.uk). Designed by Thomas Ehrl and conducted between October 25th, 2018 and December 31st, 2018

[11] Malcolm S. Knowles, Elwood F. Holton, Richard A. Swanson, *The Adult Learner*, Oxon, New York (2012)

[12] Content of the Distance Study *Lift Engineering MSc* of The University of Northampton, https://www.northampton.ac.uk/courses/lift-engineering-msc/ last assed on June 20th, 2019

[13] Thomas Ehrl, Jonathan Adams, Stefan Kaczmarczyk, Benedikt Meier, *Improvement of the learning environment at an international multicultural company through the assessment of relevant methodology and technology goals*. Proceedings of the 7th Symposium on Lift and Escalator Technologies, Northampton (2017)

BIOGRAPHICAL DETAILS

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Mechanical Design Engineer (degree in 1994), Part-time PhD student with the Faculty of Arts, Science and Technology of The University of Northampton. Professional career started in 1994.

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- Head of seed campus Global of thyssenkrupp Elevator AG, Essen/GER
- Head of Research & Innovation Center of thyssenkrupp Elevator Innovation GmbH, Rottweil/GER
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Interests: Family life, cooking, dog (charcoal labrador), travelling, running, soccer, music, and vintage English motorcycles. Networking.

ISO DIS 8100-32 on Planning and Selection of Passenger Lifts

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Keywords: Traffic planning, lifts, hotels, offices, residential buildings

Abstract. Work to revise the ISO 4190-6:1984 standard on lift planning and selection of passenger lifts, to be installed in residential buildings [1], started in 2014. This spring (2019), the new ISO DIS 8100-32 [2] was approved for the final ballot. The Draft International Standard (DIS) extends the lift traffic planning, from residential buildings of the current standard ISO 4190-6, to planning and selection of passenger lifts to be installed in office, hotel and residential buildings. In addition, the draft document takes into account the accessibility for persons with impaired disabilities. The draft considers not only the morning up-peak traffic but also traffic mixes for lunch hour and two-way traffic. It can be applied to conventional control with up and down call buttons and destination control systems. The use of the planning methods is demonstrated by examples in the Annexes of the draft document.

1 INTRODUCTION

The current ISO 4190-6 [1] gives a simple guidance for passenger lift selection in residential buildings. Lift selection graphs have been produced using the up-peak traffic formulas. Lift group configuration is selected using the charts for a given number of floors and population. The ISO lift selection standard 4190-6 is from 1984 and needs revision.

In this millennium, discussion started about how to perform lift traffic simulation with stable results [3,4] and how to compare and avoid the misinterpretation of results [5, 6]. ISO TC178 Working Group 6 (WG6) made an initiative to update ISO 4190-6 in the ISO TC178 25th plenary meeting in New York in 2013. A decision was made to revise the current standard, with an extension of the scope to include buildings other than residential buildings.

WG6 established Subgroup 5 (SG5) to conduct the work and named 17 experts in the group. The number of SG5 experts has varied during the years, being currently 14, of which nine were in the original group. The current SG5 members are in alphabetical order of ISO member bodies: Theresa Christy/ASME, Albert Hsu/ASME, Chen Fengwang/ CN, Ming Kai Wang/ CN, Gina Barney/ BSI, Richard Peters/ BSI, Hans Jappsen/ DIN, Jörg Müller/ DIN, Olaf Rieke/ DIN, John Tibbits/ SA, Ami Lustig/ SII, Marja-Liisa Siikonen/ SFS, Janne Sorsa/ SFS and Lukas Finschi/ SNV.

So far, the project has taken about five calendar years. SG5 had its first meeting in Helsinki in spring 2014. Until now, (Summer 2019), there have been totally 51 SG5 meetings, and 11 WG6 meetings where this item has been followed. The first six SG5 meetings were face-to-face, but soon the group discovered that live video-meetings were the best way to conduct the work.

ISO TC178 accepted the revision work as a new working item in 2017. The working draft (WD) was registered as a Committee Draft, ISO CD 8100-32, in September 2018. At the end of 2018 the CD was approved for registration as Draft International Standard (DIS). After the DIS ballot this spring, the ISO DIS 8100-32 was approved for final ballot. The text will be revised and submitted to the ISO Central Secretariat and after that it will go to final ballot for International Standard.

This paper briefly describes the goal of the revision work, the basic principles of the calculation and simulation method, and the effects of the mass and area-based method in choosing the rated load. Finally, a comparison of the selected lift configurations with the current standard ISO 4190-6 and the ISO DIS 8100-32 is demonstrated.

2 GOALS OF THE REVISION WORK

The target of the revision work was to update the current ISO 4190-6 standard to cover offices and hotels, in addition to current residential buildings. SG5 set a goal to develop a simple and quick standard for selecting passenger lifts in different types of buildings that would be in line with the current ISO 4190-6. The revised standard should present state-of-the-art technology and be transparent for users.

For advanced control systems, simulation of more realistic traffic patterns, such as lunch-time traffic, is needed to determine whether the lift(s) are able to handle the traffic in all traffic situations. The state-of-the-art of lift traffic analysis is to simulate passenger traffic in buildings with conventional control, destination control or some other lift system and determine how well the selected lift system serves the defined passenger traffic pattern. Therefore, an additional goal was set to include the traffic simulation as part of the document. The simulator models and validation of the simulator software were considered to be beyond the scope of the document. The simulation method describes only the inputs and the outputs of the simulation, i.e. the traffic patterns that are used as an input for the simulations, and lift performance and passenger service level parameters that are received as an output from the simulation. The calculation and the simulation methods support each other - which can be demonstrated with examples. Simulation gives results in terms of passenger waiting time, as opposed to interval which is provided by the calculation method.

For the lift selection, simple design criteria and their values are defined. To be in line with the current standard, lift selection graphs - to make the initial selection for lift configuration and lift speed - are provided for each building type. The selection graphs can be used as the first approach in defining the lift in the building.

At the beginning of the project, it was thought the task to include consideration of the non-linearity of the car platform area and the rated load was too demanding. In the course of time, however, one more goal for choosing the rated load by mass or area was added in the document.

3 CALCULATION METHOD

The calculation method is based on the up-peak round trip time formula. Up-peak traffic is a situation where people arrive from the main entrance and travel to upper floors. They arrive with a constant arrival rate or following a Poisson arrival process. People enter the nearest car in the lobby until it is filled up to a certain ratio. There is no passenger traffic downwards or between the floors. Lifts are automatically returned to the main entrance when they become vacant, after serving all car calls and all people have exited the cars.

The up-peak round trip time equation was developed in the last century. The development of traffic planning theory was started in the 1920s by the elevator consultant engineer Basset Jones, who derived an equation for the probable number of lift stops in up-peak. In 1923, Mr. Basset Jones [7] derived an equation for the probable number of stops, S, during an elevator up-trip in a building with N floors above the entrance floor and average number of P persons inside the car:

$$S = N\left[1 - \left(1 - \frac{1}{N}\right)^{P}\right] \tag{1}$$

In 1955, Schröder [8] derived the equation for the highest reversal floor, *H:*

$$H = N - \sum_{i=1}^{N-1} \left(\frac{i}{N}\right)^P \quad (2)$$

These equations were used by Strakosch [9] and developed further [10]. The most popular form of the up-peak formula, using Eqs. (1) - (2), was introduced in the middle of the 1970s [9]. In the formula t_v is the time to travel between two adjacent floors at rated speed:

$$RTT = 2Ht_v + (S+1)t_s + 2Pt_p \quad (3)$$

In the 8100-32 DIS, the simplest form of the up-peak round trip time equation was selected. Eqs. (1) and (2) assume constant passenger arrival rate and even population distribution on upper floors and Eq. (3) assumes an average floor distance for all floors. More advanced up-peak formulas considering a Poisson arrival process [10] and uneven population distribution [11], uneven floor heights [12], multiple entrances [13] as well as generalisation of the up-peak formulas to involve all traffic situations [14, 15, 16] have been developed and the up-peak formulas have been verified with real traffic [17].

In planning, elevators are expected to transport the whole building population from the lobby to upper floors within about 20-60 minutes, depending on the building or tenant type [18]. Filling times correlate to lift group handling capacity, that show the percentage of the population that the lifts can transport in five minutes. Each building type has its own requirement for lift handling capacity and lift handling capacity should meet the traffic demand of a building. People flow measurements in buildings have revealed that pure up-peak traffic, is often not the worst traffic situation for the lifts during the day, as passenger waiting times during mixed up-peak or lunch time traffic can be much longer. It is difficult to estimate lunch time waiting times accurately with up-peak RTT, since control systems affect the passenger service quality in mixed traffic situations. With traffic simulations, passenger waiting and journey times can be determined in various traffic situations.

4 SIMULATION METHOD

In the simulation method, a simple procedure for how to give inputs and how to print and interpret output results is described. The simulator software and control software are the propriety of the developer companies and are not within the scope of this document. A validation method for the simulation software, however, would be useful in the future [17].

In lift traffic simulation, various traffic patterns can be used for different types of buildings. Some of them are based on measurements, and others describe the traffic situations on a more theoretical basis [19, 20, 21, 22]. According to the measurement results in office building lift lobbies, passengers arrive randomly in office buildings [10]. That is why, in simulation, the passenger arrivals should follow a Poisson distribution. In the ISO simulation method, the simplest possible passenger traffic patterns were defined, i.e. patterns where the passenger arrival rate is constant. For different traffic patterns, the mixes of passengers entering the building, exiting the building or travelling between floors are described. Each building type has its own traffic mixes. The traffic mixes of the constant traffic patterns follow the typical daily traffic profiles, such as morning up-peak and lunch-time traffic in offices. Each defined traffic mix is simulated for several passenger arrival rates.

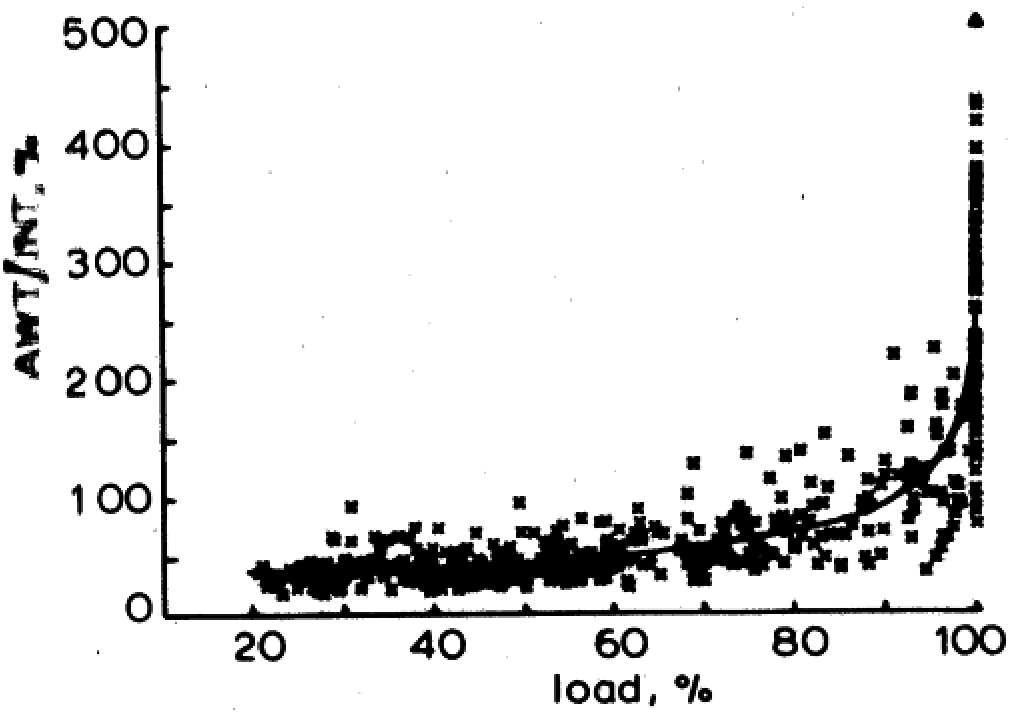

Figure 1: Up-peak waiting time scaled to interval as a function of car loading with collective control system [11]

In the studies of the 1970s and even earlier, it was shown that in up-peak, passenger waiting times start to increase when the traffic demand increases and cars are filled, e.g. close to 80%, of the rated load (see Fig. 1). The rated load of a lift is the load for which the lift has been built and designed to operate. Rated capacity is the maximum number of passengers a lift can transport without being in conflict due to safety norms. It is calculated from the rated load by dividing it by the average mass of a person. The observed measurements show that cars are filled normally to 75-80% of the rated capacity [9]. To consider the comfort of the passengers inside cars, in simulations the maximum number of passengers allowed to enter the car can be set smaller, e.g. 80 % of the rated load.

Waiting times increase rapidly, especially in up-peak, while in other traffic mixes the increase can be slower. In the ISO simulation method, the first simulation is made for arrival rate at the required handling capacity, e.g. 12 % of the building population in five minutes [20, 21]. A series of three simulations is performed with increasing arrival rates, e.g. 12%, 13% and 14% of the population in five minutes. The simulation time for each arrival rate should be long enough, preferably two hours, which ensures stable output results in most cases. For statistical reasons, the first 15 minutes transient from the beginning of the simulation and the last 5 minutes from the end of the simulation are removed [2, 3, 4]. Thus, from a two-hour simulation, the results are analysed for 100 minutes. If, for instance, simulation time was half an hour, the simulation results are analysed for only 10 minutes which is rather a short time for statistical analysis. In this case, to achieve stable results, the simulation should be repeated, e.g. 10 times with slightly different random passenger arrivals.

Average passenger waiting times are calculated for each arrival rate and they are compared to given criteria, e.g. 30 s in office buildings. If the waiting times meet the criteria at all points, the lift configuration can be selected, but it may have excess handling capacity. On the other hand, if none of the simulated average waiting times meet the criteria, the lift configuration can be rejected. If the average waiting time meets the criteria at the arrival rate of required handling capacity and slightly exceeds the given criteria with higher arrival rates, then the lift system meets the requirements of this standard.

5 SELECTION OF RATED LOAD

The lift traffic calculations determine how many passengers a lift or lift group should transport within a certain time, i.e. lift handling capacity. The most important lift characteristics that affect the lift handling capacity are the selected number of lifts, the rated passenger capacity and the speed of the lifts. According to Fig. 1, waiting times start to saturate at an average of 80 % of the rated load. With traffic calculations, the average number of passengers inside a lift is determined, and the rated load is calculated by dividing it by 0.8.

For safety reasons, the car platform area does not increase linearly with the rated load and the rated passenger capacity. The area per person gets smaller with higher loads, which causes a problem in passenger capacity per area. The lift traffic analysis can consider the accommodation of passengers in cars when choosing the rated load. A touch zone of passengers according to Fruin [23] is 0,28 m^2. In crowded cars even densities such as 0,14 m^2 have been observed [9]. The required passenger space depends on the culture and even the gender [24] of the people.

In the selection charts and examples of ISO DIS 8100-32, the average mass of 75 kg [25] and area of 0.21 m^2 per person [23] were chosen. For the passenger mass and area, local measures of each country and area are encouraged to be used. Table 1 shows how the rated load is chosen from the calculated average car load when using the mass-based or area and mass-based selection method.

Table 1: Selection of rated load based on the average number of persons inside a car

Average number of passengers in the car at departure from the main entrance floor	6 persons	8 persons	10 persons	13 persons	16 persons
Area and mass-based selection	630 kg	1000 kg	1275 kg	1600 kg	2000 kg
Mass-based selection	630 kg	800 kg	1000 kg	1275 kg	1600 kg

Example selection of the rated load:

Let’s assume that the calculation model has given the result that lifts should be able to transport an average number of eight persons inside a car.

a) Mass-based selection

Assuming a weight of 75 *kg* per person, the lifts should be able transport 8*75 *kg*= 600 *kg* with 80*%* filling ratio. The rated load should be greater than 600/0.8= 750 *kg*. According to ISO DIS 8100-30: 2017 [26], the nearest rated load exceeding 750 *kg* is 800 *kg*, which would be the selected rated load.

b) Area and mass-based selection

Assuming 0.21 m^2 per person, the required area with 80*%* filling ratio 8*0.21 m^2 = 1.68 m^2. For 100*%*, platform area should be 1.68/0.8 = 2.1 m^2. According to ISO 8100-1:2018 [27] the nearest rated load with maximum platform area greater than 2.1 m^2 is 1000 *kg*.

6 FIRST APPROACH FROM SELECTION GRAPHS

In ISO 4190-6 the building may have two entrance floors, the main entrance floor and a parking floor. The floor height is 2.8±0.2 m and the building can have up to 20 floors and the population up to 800 persons. The lift group can include one, two or three lifts with speed up to 2.5 m/s and load up to 1000 kg. The selection charts are formed using the up-peak formula. The criterion for the lift handling capacity is 7.5 % of the population in five minutes, and separate selection graphs are provided for 60s, 80 s or 100 s intervals.

In ISO DIS 8100-32, similar selection graphs as in ISO 4190-6 standard were depicted for the three building types. The graphs are based on the up-peak formula, Eq. (3). The method for how the graphs are produced has been introduced and discussed in previous symposiums on lift and escalator technologies [28, 29]. The selection graphs cover up to 40 floors and a 1200-person population. Lift speeds vary form 1.0 m/s to 3.5 m/s and loads from 630 kg to 1800 kg. For accessibility reasons smaller cars are not included. The floor-to-floor distance varies from 3.0 to 4.0 m depending on the building type. Simple design criteria for the required handling capacity and the interval are given in the document for different types of buildings.

The requirements of ISO 4190-6 and ISO DIS 8100-32 differ slightly. In residential buildings the handling capacity requirement is 7.5 % in ISO 4190-6 and 6 % in the ISO DIS 8100-32. The current standard provides selection graphs for 60 s, 80 s and 100 s intervals, called selection Programmes 60, 80 and 100. In the new DIS, the interval criteria is 60 s. The passenger transfer time in the existing residential graphs was assumed to be 1.75 s, while in the new draft it is 1.0 – 1.2 s depending on the door width. For narrow doors the transfer time is longer than for wider doors.

Table 2: Comparison of lift arrangements in a residential building without parking level [1, 2, 29]

Population / number of floors	**Number of lifts and rated load**			
	ISO 4190-6: 1984			**ISO DIS 8100-32: 2019**
	Programme 100	**Programme 80**	**Programme 60**	
100 / 5	1 x 630 kg	1 x 630 kg	1 x 630 kg	1 x 630 kg *
300 /10	1 x 400 kg + 1 x 1000 kg	1 x 400 kg + 1 x 1000 kg	1 x 400 kg + 1 x 1000 kg	2 x 630 kg*
500 / 15	2 x 1000 kg	2 x 400 kg + 1 x 1000 kg	2 x 630 kg + 1 x 1000 kg	3 x 630 kg*
700/ 20	1 x 630 kg + 2 x 1000 kg	1 x 630 kg + 2 x 1000 kg	-	3 x 800 – 1000 kg*

The lift arrangements according to the selection graphs of the current 4190-6 standard and the new DIS are compared for residential buildings with one entrance floor. Table 2 shows the lift configurations suggested by Programme 100, 80 and 60 of the current ISO 4190-6, and by Figure C.1 of the new ISO DIS 8100-32 [28]. Some low-rise buildings were selected as test examples. According to the table, the number of cars in Programme 60 and Figure C.1 are the same. For a 500-person population and 15 floors, however, Programme 100 suggests one car less than in the other alternatives of the table, since the interval requirement is longer. For accessibility reasons, ISO DIS 8100-32 does not have a car smaller than 630 kg, otherwise the suggested loads are about the same. The graphs in the new DIS show only symmetrical lift groups, but one car in a group is recommended to be at least 1000 kg, to accommodate accessibility requirements and to be able to transport furniture, prams etc.

Table 3: Comparison of lift speeds in a residential building without parking level [1, 2, 29]

Population / number of floors	Rated speed (m/s)			
	ISO 4190-6: 1984			ISO DIS 8100-32: 2019
	Programme 100	Programme 80	Programme 60	
100 / 5	0.63	0.63	0.63	1.0
300 /10	1.0	1.0	1.6	1.0
500 / 15	1.6	1.6	2.5	1.6
700/ 20	2.5	2.5		2.0

According to Table 3, the lift speeds of 4190-6 are partly lower and higher than they are in the new DIS. In the new DIS, the speed range starts from 1.0 m/s, and has an additional speed class for 2.0 m/s which makes a difference in the recommended speeds. As a summary, considering the recommended lift groups of ISO 4190-6 Programmes and ISO DIS 8100-32, one can say that they are not exactly the same, but they are in line with each other, considering that they have slightly different handling capacity criteria and constraints in car loads.

7 CONCLUSIONS

In this paper, the main contents of the new ISO DIS 8100-32 are described. SG5 provided demanding goals to the document and after five years of intensive work, found a consensus. The new draft international standard covers passenger lift planning for three types of buildings: offices, hotels and residential buildings. It presents the state-of-the-art technology by covering all types of group control systems and traffic patterns, including a theoretical up-peak traffic calculation and traffic simulation method for other types of traffic patterns. The tables and graphs of the new draft document reflect current lift safety standards and accessibility for persons with disabilities. The final goal of choosing the rated load was solved after thorough discussions. The SG5 arrived at a solution where the rated load can be selected either according to passenger mass, or area and mass. The new DIS is in line with the current standard by providing similar graphs for quick lift selection as in ISO 4190-6, but extending the graphs to cover the three building types.

The subject has inspired the experts of SG5 for long-lasting debates on various issues. Many articles have been published on these subjects during the work, some of which are mentioned in the references of this article: a few of the issues were briefly touched upon in the paper concerning the ISO 4190-6 revision from 2016 [30].

REFERENCES

[1] ISO 4190-6:1984, *Lifts and service lifts (USA: Elevators and dumbwaiters) – Part 6: Passenger lifts to be installed in residential buildings – Planning and selecti*on.

[2] ISO DIS 8100-32:2019, *Lifts for the transportation of persons and goods – Part 32: Planning and selection of passenger lifts to be installed in office, hotel and residential buildings*.

[3] H. Hakonen and M-L. Siikonen, "Elevator traffic simulation procedure". *Elevator Technology 19*, Thessaloniki, 2008; 131-140; IAEE.; *Elevator World* 2009; 57(9): 180-190.

[4] Finschi, L., "State-of-the-Art Traffic Analysis". *Elevcon Lucerne 2010*, Elevator Technology 20: 106-115, IAEE

[5] Christy, T., "Common Misconceptions Regarding Elevator Traffic Simulations". *3th Symposium on Lift & Escalator Technologies*, Northampton 2013; (3): 30-35. ISSN 2052-7225 (Print), ISSN 2052-7233 (Online).

[6] Jappsen, H. and Rieke, O. "Difficulties in Comparing the Results of Lift-Traffic-Simulations". *Elevcon Miami 2012*, Elevator Technology 21, IAEE and *Elevator World 2014;* (1): 96-105.

[7] Jones, B., "The probable number of stops made by an elevator". *General Electric Review* 1923; 26(8): 583-587.

[8] Schröder, J., "Personenaufzuge". *Födern und Heben 1955*.

[9] Strakosch, G.R., *Vertical Transportation: Elevators and Escalators*, Wiley, New York 1967.

[10] Alexandris, N.A., *Statistical Models in Lift Systems*. PhD Thesis, Victoria University of Manchester 1977.

[11] Barney, G.C. & Dos Santos, S.M., *Elevator traffic analysis design and control*. Peter Peregrinus Ltd., London 1977: 386. ISBN 0-86341-042-1

[12] Roschier, N-R. and Kaakinen, M. , "New Formula for Elevator Round Trip Time Calculation". *Supplement to Elevator World 1978*; (3).

[13] Lutfi Al-Sharif, Ahmad Hammoudeh, "Evaluating the Elevator Round Trip Time for Multiple Entrances and Incoming Traffic Conditions using Markov Chain Monte Carlo". *International Journal of Industrial and Systems Engineering (IJISE)*, Inderscience Publishers 2014; 18(1): 51 - 64.

[14] Hakonen, H. and Siikonen, M-L, "Generalized calculation of Round Trip Time". *Elevcon Helsinki 2006*, Elevator Technology 16*:* 90-99.

[15] Peters, R., "Lift traffic analysis: Formulae for the general case". *Building Services Engineering Research & Technology 1990*; 11(2): 65-67.

[16] Al-Sharif L and Abu Alqumsan A M. "An Integrated Framework for Elevator Traffic Design under General Traffic Conditions Using Origin Destination Matrices. Virtual Interval and the Monte Carlo Simulation Method." *Building Services Engineering Research and Technology 2015*; 36(6): 728-750.

[17] Sorsa, J. and Siikonen, M-L. "Up-peak Roundtrip Time in Theoretical Calculation, Traffic Simulation, and Reality". *Elevcon Paris 2014*, Elevator Technology 22: 347-258, IAEE.

[18] Powell, B.A., "Elevator banking for high-rise buildings". *Transportation Science 1975*; (5): 200-210.

[19] Siikonen, M-L., "Traffic Patterns in Hotels and Residential Buildings", *3th Symposium on Lift & Escalator Technologies*, Northampton 2013; 3. ISSN 2052-7225 (Print), ISSN 2052-7233 (Online).

[20] Chartered Institute of Building Services Engineers (CIBSE) Guide D 2015. *Transportation systems in buildings*, CIBSE

[21] British Council for Offices, *Guide to specification*. British Council for Offices, London 2014.

[22] Barney, G.C., *Elevator Traffic Handbook.* Spon Press, London 2015: 438.

[23] Fruin, J.J., *Pedestrian planning and design.* Metropolitan Association of Urban Designers and Environmental Planners; 206.

[24] Sorsa, J., Ruokokoski, M. and Siikonen, M-L., "Human Body Size in Lift Traffic Design". *4th Symposium on Lift & Escalator Technologies*, Northampton 2014; 4: 213-223. ISSN 2052-7225 (Print), ISSN 2052-7233 (Online).

[25] ISO/TR 11071-2:2006, *Comparison of worldwide lift safety standards – Part 2: Hydraulic lifts (elevators)*

[26] ISO DIS 8100-30:2017, *Lifts for the transport of persons and goods – Part 30: Class I, II, III and IV lifts installation*

[27] ISO 8100-1:2018, *Lift (Elevator) installation — Part 1: Class I, II, III and VI lifts*

[28] Ruokokoski, M. and Siikonen, M-L., "Lift Planning and Selection Graphs". *7th Symposium on Lift & Escalator Technologies*, Northampton 2017; 7(22). ISSN 2052-7225 (Print), ISSN 2052-7233 (Online).

[29] Barney, G. and Peters, R, "The Evolution of Lift Traffic Design from Human to Expert System". *9th Symposium on Lift & Escalator Technologis*, Northampton 2018; 9(20): 1-14. ISSN 2052-7225 (Print), ISSN 2052-7233 (Online).

[30] Siikonen, M-L, "*ISO 4190-6* Revision – Planning and Selection of Lifts in Office Buildings, Hotels and Residential Buildings". *Elevcon Madrid 2016*; Elevator Technology 23: 230-329. IAEE.

BIOGRAPHICAL DETAILS

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Lift and Escalator Management Systems: Requirements and Implementation

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Keywords: IoT, monitoring, management, protocols, interface

Abstract. This paper addresses the challenges of developing a Lift and Escalator Management (LEM) System for owners and property management companies that operate multiple sites with lift and escalator equipment from multiple vendors. The requirements of people managing lifts and escalators are different to those supplying and maintaining the equipment. Sometimes this can create conflicts of interest. With the absence of a popular open standard, extracting information from modern lift and escalator controllers can be complex. A solution proposed accepts data over RS232, RS485, CAN, Ethernet and volt-free. Once an interface is in place, data needs to be transferred securely over the internet. For reliability, a wired internet connection is preferred, although mobile broadband is possible where there is coverage. Wired connections over secure company networks require special solutions to minimise blocking of data by firewalls. Users now expect a modern interface working on any web browser on computers, tablets and phones. The volume of data collected is enormous, requiring management and analysis to provide useful user feedback. Any equipment installed on site needs to be maintenance free to avoid excessive ongoing costs.

1 INTRODUCTION

The authors' research in lift and escalator monitoring (LEM) originally arose from the need to verify the operation of lift dispatcher design, and for traffic research to support traffic analysis and simulation.

Lift dispatchers, even if designed with simulation, need to be verified in the real-world using monitoring data. Simulation passengers behave as they are told, and simulated lifts do not break down; the real world is different so new dispatchers need scrutiny when they are first put into service. Smith & Peters [1] discuss logging every destination call and lift movement, re-playing every lift and passenger movement in simulation software so that performance parameters such as time to destination can be compared with simulated results for the same traffic profile. Some of the things learnt from this work, completed as part of a dispatcher verification process, were that:

i. company IT networks are increasingly secure and opening ports to communicating with a server over the internet for off-site processing of the data is seen as a risk
ii. lift maintenance companies and their personnel, quite reasonably, are nervous about the client having such detailed information about their performance in keeping the lifts operating and responding quickly to problems
iii. lifts can incorrectly report that they are in service when they are not.

Another LEM application is for traffic research. Researchers have proposed a range of methods for extrapolating passenger demand, even with collective control, which could be applied if LEM was ubiquitous and data was shared [2] [3] [4]. It is not, and consequently traffic design guidance including CIBSE Guide D [5] still bases many design recommendations on traffic data which has had to be collected manually. To improve traffic design further, more traffic data, collected automatically, needs to be available.

Most major lift suppliers now offer remote monitoring systems. They are ideal if you have lifts from just company X and are happy with the service from company X. Data available is typically presented in plots which is of minimal value to researchers who need a log of every event (lift movement, door operation, etc.). They are less ideal when lift maintenance companies are not performing as they are effectively writing their own reports. Finally, where companies manage lifts in different buildings with a range of equipment from multiple suppliers, they need a LEM system which can monitor their whole estate.

This is the context in which the authors began to develop a LEM solution. The initial market sector chosen was building owners and property management companies that operate multiple sites with lift and escalator equipment from multiple vendors. This paper provides an overview of the authors' experience of working on current projects in this sector, interfacing with most of the major lift manufacturers and a wide range of independents.

2 CLIENT REQUIREMENTS

A manufacturer's monitoring system could potentially report the part number of a failed component, and perhaps even order a replacement. Someone managing an estate has different requirements, e.g.

i. to be messaged if a lift goes out of service, or goes into a special mode, e.g. car top control
ii. to be able to see if the lifts are in use (floor position and door operation)
iii. to be able to respond to a report from the public or staff that a lift is out of service remotely by inserting a call to see if the lift moves
iv. to have historical data, e.g. what % of the year has the lift been in service, the number of lifts movements, etc.

Of course, much more data could be collected. But this basic information, in most instances, is enough to manage an estate.

Other requirements have included the monitoring of escalators, and outputs to third party systems to trigger a security control room response.

3 TALKING TO LIFTS AND ESCALATORS

The ISO Open System Interconnection (OSI) model is a useful paradigm for assessing different protocols which are divided into layers. It has an abstract model of networking (seven-layered model) and set of specific protocols. More practically, Transmission Control Protocol/Internet Protocol (TCP/IP) is a suite of communication protocols to interconnect network devices on private networks and the internet. Some vendors now offer a TCP/IP connection which addresses the making a connection, but the applications on either side of the ethernet cable still need to know how to talk to each other.

CIBSE Guide D [6] discusses initiatives from supporters of the philosophy of open architecture and interoperability. There are many competing "standards" including BACnet, LonWorks, Modbus, KNX and CANopen. In reality every supplier has a different approach and even if they use the same communications standard, the implementation is different.

To address the range of interface possibilities a custom LEM interface board was developed which would accept all the widely used communication formats. The board has Ethernet, USB, two CAN channels, five RS 485, plus one RS 232 or RS 485 channel, see Figure 1. An SD card is used to store information. Because this is a low powered board without moving parts, it can be expected to run for

20+ years without maintenance; at the time of writing there have been no in-service board failures since the original installation in 2014.

With the hardware in place, the biggest challenge is protocols. Quite reasonably, lift companies prefer to sell their own monitoring solutions, so are reluctant to share their protocols unless agreed as part of the contract specification and protected by non-disclosure agreements. A number of confidentiality agreements have been signed in order to gain access to proprietary protocols. These have generally been obtained when specific clauses for the monitoring system have been included in a new lift or modernisation specification. With the right interface, all the lifts and escalators in a major development can be connected with a single interface board.

Upgrading an existing lift controller to add a LEM interface is possible, but typically more expensive to achieve; a recent quotation to add the inputs and outputs necessary to a controller was almost two thousand pounds per lift. This assumes discrete (volt-free) inputs, which then have to be converted into a digital format before being received by the LEM interface board, see Figure 2. Further custom interface boards are being developed to reduce the cost of accepting discrete inputs.

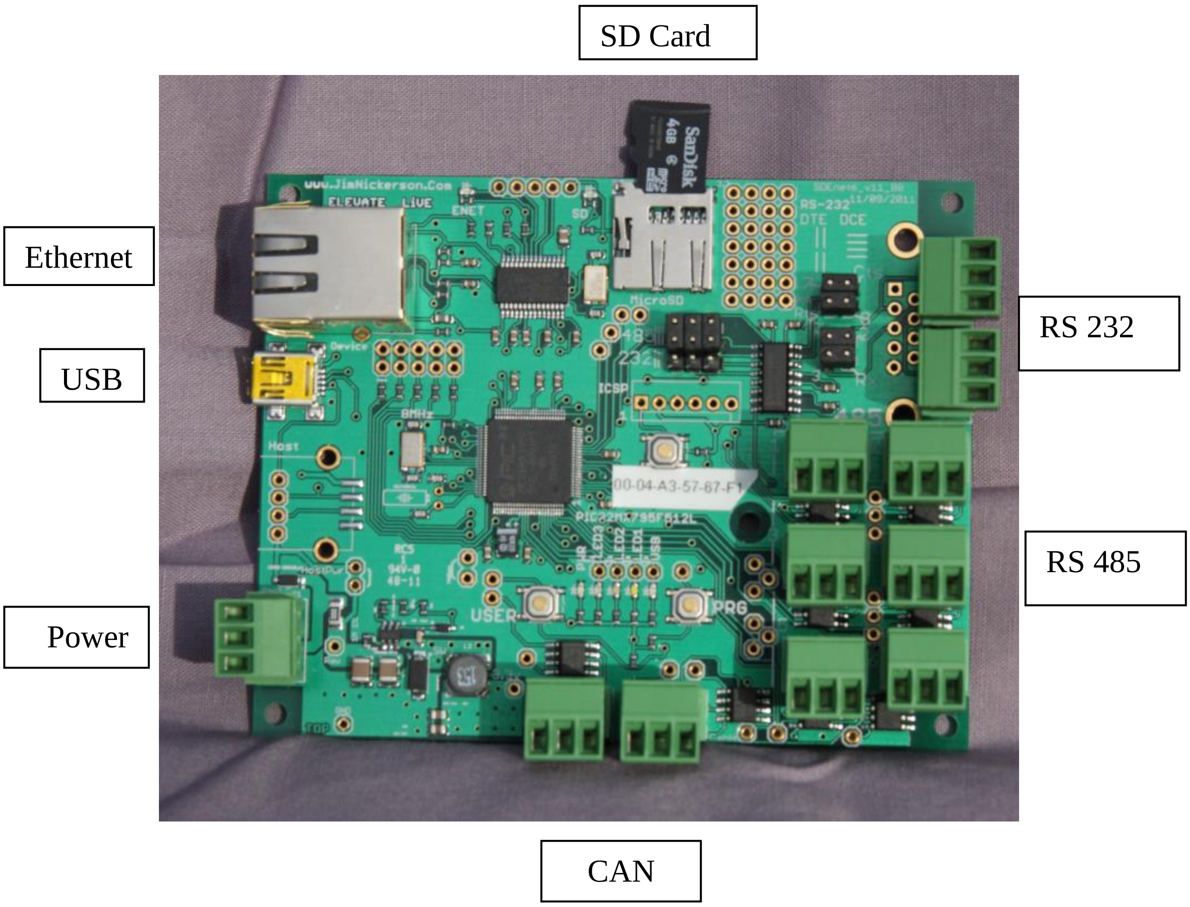

Figure 1 LEM interface board

Figure 2 LEM board with discrete inputs

A more cost-effective approach for existing (and sometimes new) installations is to interface with an existing indicator network already connected to the controller. To this end, LEM interfaces with two populator indicator suppliers [7] [8] have been developed, see Figure 3. This opens the possibility of a low-cost interface to a vast array of lift controllers where non-proprietary indicators have already been installed. Not every preferred input and output is available via an indicator network, e.g. the lift position and availability status would normally be reported to the indicator, but it would not be known if the lift was on car top control or had broken down. The LEM board communicates directly with the indicator network board [7] [8] using RS485.

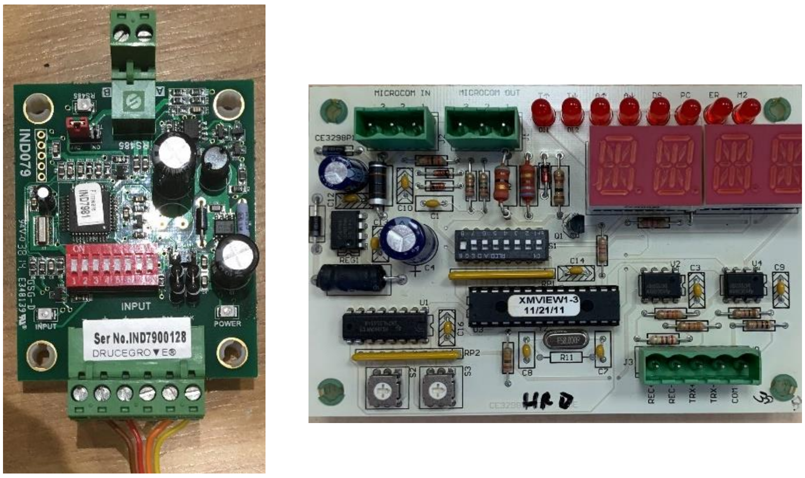

Figure 3 Indicator network interfaces

It is also practical to implement connection free interfaces using an accelerometer to determine floor position [9]. Lack of movement could be used to infer a lift is out of service for maintenance or breakdown.

4 CENTRAL MONITORING AND CONTROL

Historically, lift and escalator monitoring systems provided by manufacturers have had dedicated local networks. Some systems have provided remote access, see Figure 4.

The trend from local monitoring servers to cloud based services in Building Automation Systems is also reflected in lift and escalator monitoring systems systems. With a cloud based system, no equipment other than the interface board is needed on site, In the system discussed in this paper the LEM board communicates directly to the server which reports via web pages, see Figure 5.

To address security issues discussed in section 1(i), the LEM board talks to a server only using Hyper Text Transfer Protocol Secure (HTTPS), which is the protocol used by a web browser. This avoids the need to configure firewalls and open specific ports; if the internet connection provided can view a web page, it can talk to the LEM board.

When connected via Ethernet locally, the LEM board displays an internal web page for an engineer who can make changes in configuration and review current status, see Figure 6. The board software may be updated from a local PC via Ethernet or from a web server via remote control, allowing for offsite software development and debugging. Remote download of software updates has been a major benefit; the alternative is debugging software interfaces in lift motor rooms and escalator pits, often out of hours in order to minimise the disruption to building operations.

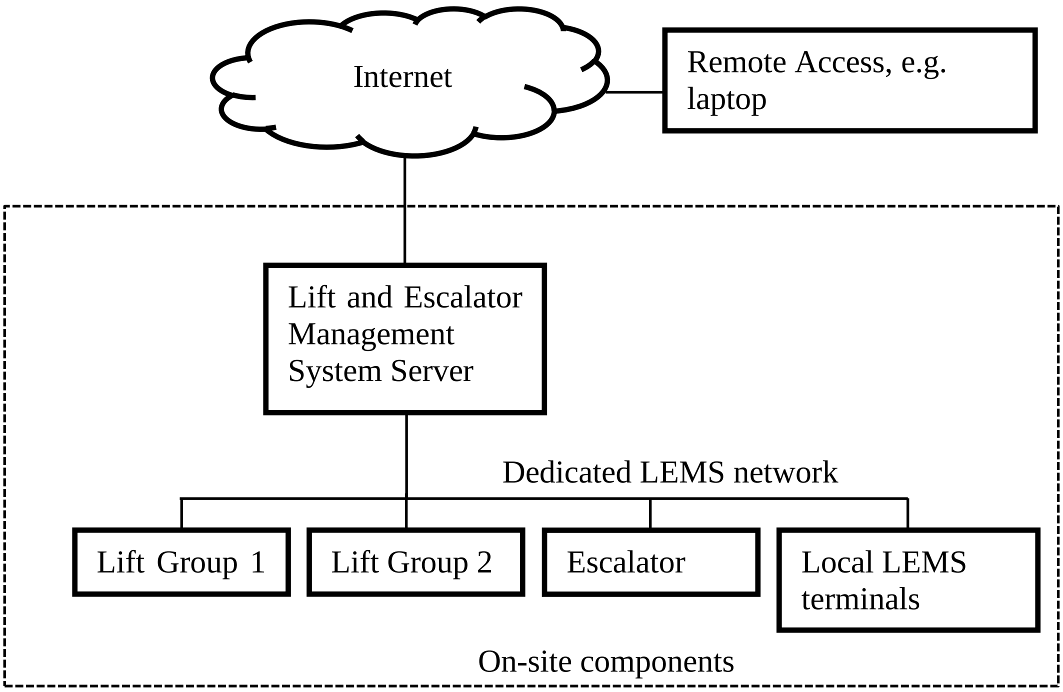

Figure 4 Traditional LEM schematic using a dedicated network

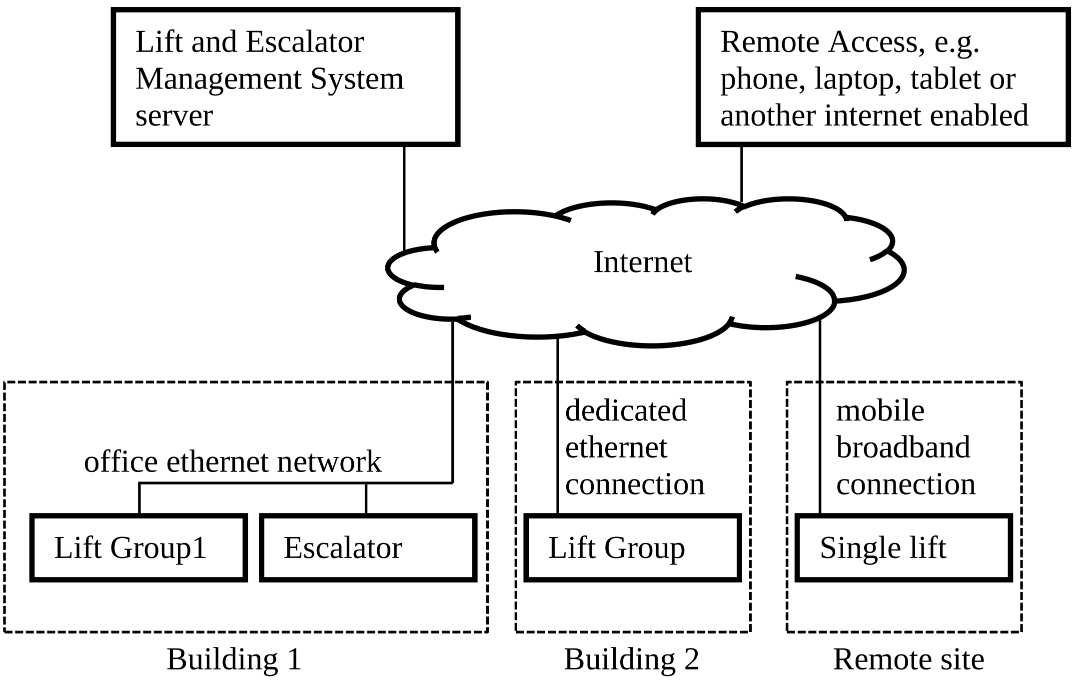

Figure 5 Cloud based LEM schematic

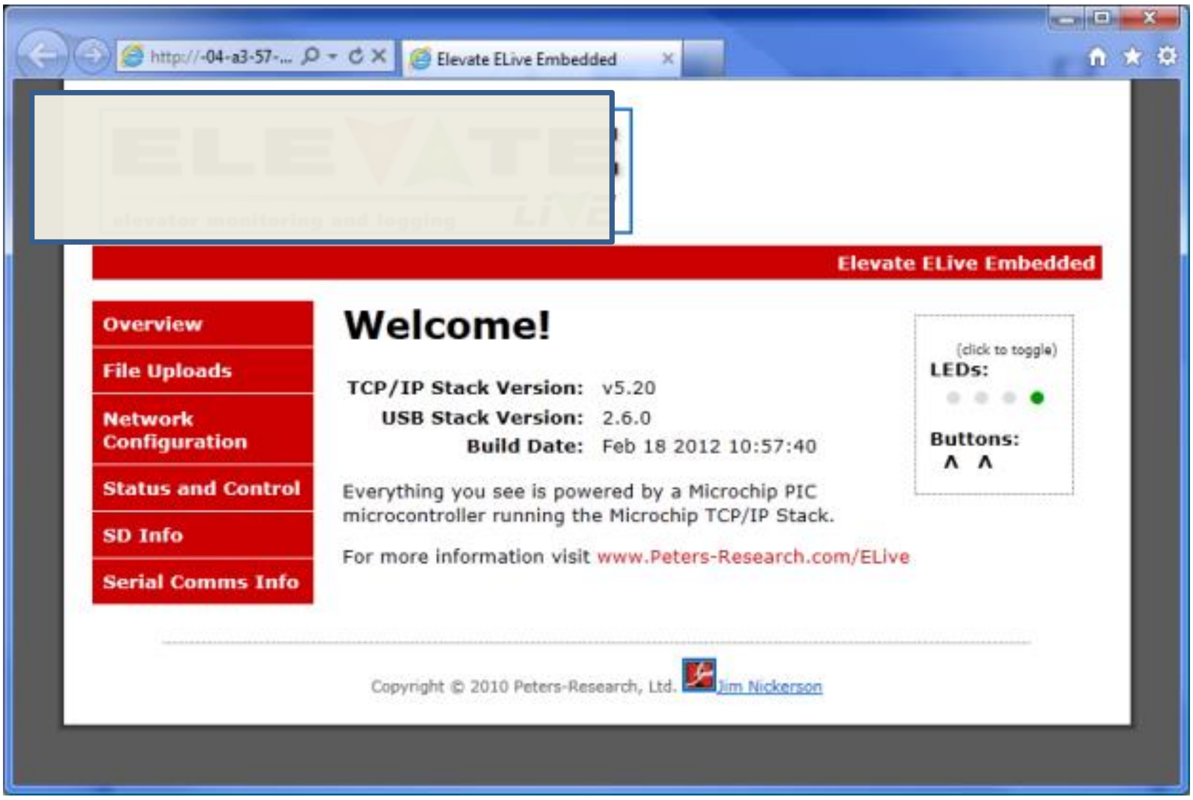

Figure 6 Internal display for LEM board

The raw communication messages with each board can be viewed on the server application, see Figure 7.

mac	mb raw	version	Age	ReportDelta	ip	ty	devtype
D8-80-39-B6-28-0E	82_01_00_00_00_00_00_00	2018-10-27 0941 BL 20160411 00160438	36 Sec	11 Sec	185.69.145.107	DRGL	lift
	83_01_00_00_00_00_00_00		42 Sec	6 Sec	185.69.145.107		
	02_51_00_00_00_00_00_00	2018-10-27 0941 BL 20160411 00160438	21 Sec	4 Sec	185.69.145.107		
	42_01_00_00_00_00_00_00	2018-10-27 0941 BL 20160411 00160438	25 Sec	4 Sec	185.69.145.107		

Figure 7 Messages from a LEM board displayed on server

User displays on phones, tablets, laptops and other internet enabled devices are presented in animated graphical form, see Figure 8. The green N indicates normal operation. The lift position and door states are shown with the current floor mnemonic overwritten on the lift graphic. The green and red arrows allow terminal floor buttons to be selected on a touch screen device, or with a mouse. A door re-open button allows the doors to be cycled.

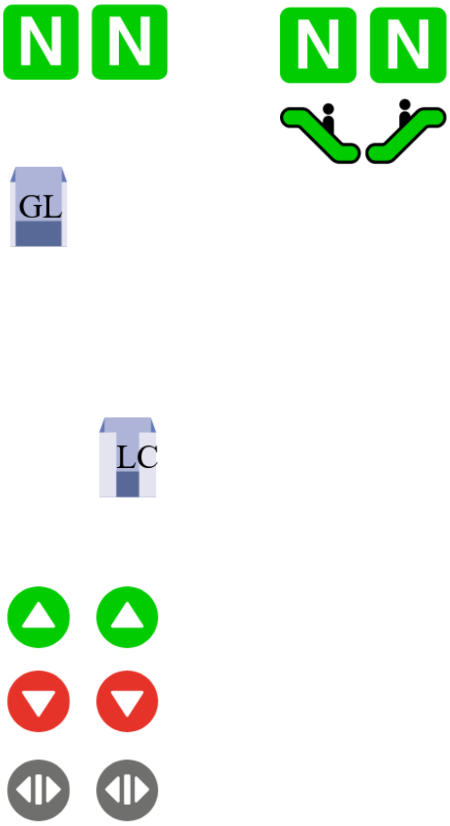

Figure 8 Animated presentation of lift and escalator status

Multiple groups of lifts and escalators are brought together on a static display with colour changes to indicate if a lift or escalator is not in normal service, see Figure 9.

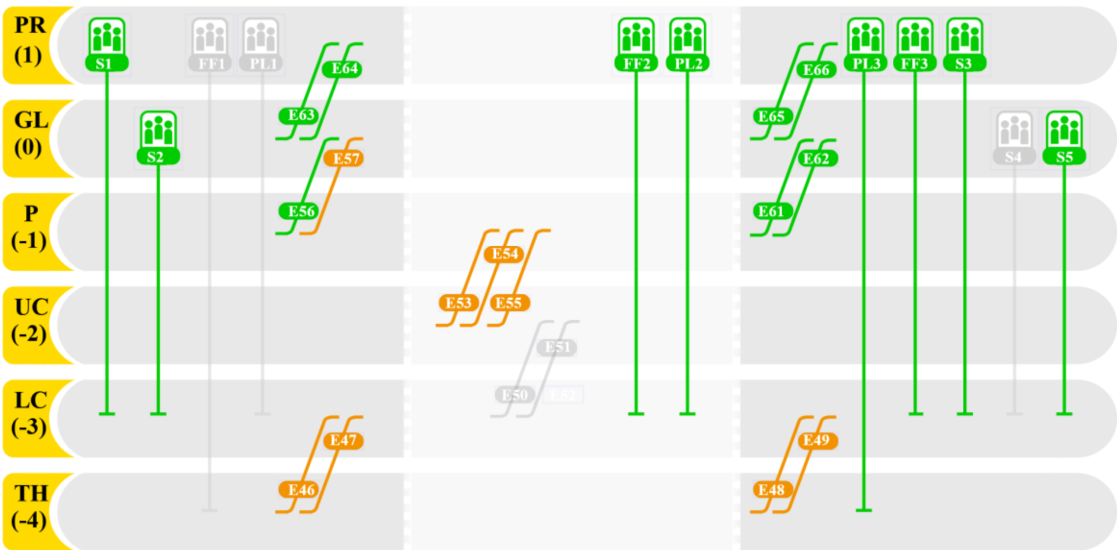

Figure 9 Cloud based LEM schematic

Alerts are programmable so that any change of state, e.g. normal to out of service or inspection service can trigger an alert email.

5 CONCLUSION

A frustrated engineer in 1995 [10] presented a paper at a CIBSE *Open Forum Meeting on Remote Monitoring*. Why was it necessary to have three pieces of proprietary software to dial up three different manufacturers' lift systems? Why would the lift industry not adopt a common protocol so that there could be integrated LEM systems for the benefit of their clients?

Almost a quarter of a century later, it is still challenging to collect data from multiple sites with lift and escalator equipment from multiple vendors and amalgamate the results to present everything on a signal platform. But it is possible. Adoption of standard or open communications protocols is not a popular cause within the lift and escalator industry. Understandably, many lift manufacturers are wary of standard protocols as apart from commercial considerations, the integrity of systems may fall outside their control. But it does seem an awful waste of the industry's time and clients' money to have so many different communication methods and proprietary protocols. The authors have invested heavily in TCP/IP communication in the vertical transportation domain and are open to cooperation with others who share the goal of open communications protocols.

Although discrete (volt-free relay) interfaces are ubiquitous and relatively simple to implement, they rely on moving parts and connections that can come loose. With a large building, there could be 1000s of relays which could be replaced by a single digital connection linked to a single LEM board.

The indicator interface route does provide a low-cost route to implementation. Not all the inputs/outputs required by clients managing an estate are available, but with some basic artificial intelligence, some issues can be inferred, e.g. breakdown or a maintenance mode when a lift is not moving regularly at times when it is normally, even though the rest of the lift group is.

Likewise, accelerometers have been demonstrated to be an effective connection diagnostic tool and can be installed without direct connection to the controller. Again, not all the inputs/outputs required by clients managing an estate are available, but the cost benefit is such that it is a solution worth considering. Connecting the accelerometer to the internet is possible, but a retrofit is likely to require use of a wireless connection.

In all cases, to fit and forget, a wire is always more reliable than wireless. Although mobile broadband and wireless connections are available, it is wise to extend the building ethernet network to every lift motor room, escalator pit and lift cab when specifying a new job or refurbishment.

Although the LEM graphical displays are attractive to watch and detailed event logs are of interest to researchers, the main value to clients managing an estate is knowing immediately that a lift or escalator has broken down. In a shopping centre or transport terminal, escalators breaking down are a hazard and can take a considerable time to be reported to maintenance staff. In an office building, during traffic surveys it has become apparent that lifts are regularly out of service and no-one knows there is a problem.

Lift maintenance companies and personnel are understandably wary of third-party cloud-based monitoring systems. However, in a world where devices from different vendors are increasing being connected to the internet and each other, the application of this technology is inevitable for the lift and escalator industry. LEM will highlight companies and personnel that deliver a good service. Recognising this can only help support a rise in standards.

REFERENCES

[1] R. Smith and R. Peters, "Analysis of Elevator Performance and Passenger Demand with Destination Control," in *Elevator Technology 17, Proceedings of ELEVCON*, Thessaloniki, 2008.

[2] R. Peters, P. Mehta and J. Haddon, "Lift Passenger Traffic Patterns: Applications, Current Knowledge and Measurement," in *Elevator Technology 7, Proceedings of ELEVCON*, Barcelona, 1996.

[3] A.-S. L, "New Concepts in Lift Traffic Analysis: The Inverse S-P (I-S-P) Method," in *Elevator Technology 4, Proceedings ELEVCON*, Amsterdam, 1992.

[4] R. Basagoiti, M. Beamurgia, . R. Peters and S. Kaczmarczyk, "Passenger Flow Pattern Learning Based on Trip Counting in Elevator Systems Combined with Real-Time Information," in *Proceedings of The 3rd Symposium on Lift & Escalator Technology*, Northampton, 2013.

[5] CIBSE, "CIBSE Guide D: 2015, Chapter 3 and 4," London, Chartered Institution of Building Service Engineers, 2015.

[6] CIBSE, CIBSE Guide D: 2015, Chapter 14, London: Chartered Institution of Building Service Engineers, 2015.

[7] Electronics, CE, [Online]. Available: http://www.ceelectronics.co.uk.

[8] Drucegrove Ltd, [Online]. Available: http://www.drucegrove.com/.

[9] A. Peters and R. Peters, "Logging and Analysis of Lift Journeys Using an Accelerometer," in *Proceedings of 10th Symposium on Lift & Escalator Technologies*, Northampton, 2019.

[10] R. Peters, "Remote Monitoring: What we want - a consultant/researcher viewpoint," in *CIBSE Remote Monitoring of Lifts Open Forum*, London, 1995.

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Lift Traffic Design: Calculation or Simulation?

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Abstract. Lift traffic design has become an integral part of tall building design. Typically, design calculations and/or simulations are iterated many times from early sketches until lifts are in use. Each iteration requires a significant effort from the parties involved in the design, namely, architects, consultants, developers and often also lift suppliers. Therefore, lift traffic design should be carried out with the most appropriate method to minimize the effort. Traffic calculation based on uppeak roundtrip is a well-known method and fast to execute but its validity is limited to collective control systems and simple building configurations. Lift traffic simulation, on the other hand, allows complex building models, traffic patterns and lift products such as destination control systems, double-deck lifts and multi-car lift systems. Simulations usually have long runtime and are susceptible to statistical inaccuracies possibly unknown to the designer. Hence, some combination of calculation and simulation is desirable to benefit from both methods, but they should provide consistent results. This paper re-establishes the link between traffic calculation and simulation with a collective control system, which sets the standard for using both methods consistently in lift traffic design with both collective and destination control systems.

1 INTRODUCTION

Lift traffic design has become an integral part of tall building design to guarantee efficient vertical transportation. It has been based on morning uppeak traffic in office buildings, which is the most difficult traffic pattern for a lift group with a collective control system. Thus, if the lift group can handle uppeak traffic adequately, then other traffic peaks follow. Two design parameters have been used: handling capacity (*HC5*), *the maximum sustainable number of passengers per specified time period that a lift group can transport for a specific traffic mix under specified loading constraints*, and, uppeak interval (*INT*), *the average time between successive car departures from the main entrance floor* [1]. Handling capacity can be interpreted as a passenger demand that a lift group can handle without uncontrollably increasing lobby queues and passenger waiting times. Throughout the years, similar but slightly different design criteria for handling capacity and interval have been applied to building projects [e.g. 1,2,3].

Handling capacity and interval are derived from lift roundtrip time (*RTT*), which depends on lift technical parameters and random variables. The randomness arises from uncertain passengers' destinations and random passenger arrival times. The random variables determining roundtrip time, i.e., *average highest reversal floor* (*H*) and *probable number of stops* (*S*), have exact formulae and depend only on *the average number of passengers* (*P*) *in the car at departure from the main entrance floor* and *the number of served floors* (*N*) [1]. The random variables can be derived by assuming either uniform or random passenger inter-arrival times [3,4].

The advent of new lift products to boost uppeak traffic such as the Destination Control System (DCS) has raised the need for lift traffic simulation, which models a lift group and its control system as well as any combination of incoming, outgoing and interfloor traffic [5,6,7]. For example, pure uppeak traffic assumed in calculation consists of 100% incoming traffic. In practice, uppeak traffic typically contains also outgoing and interfloor traffic. Traffic surveys have shown specific traffic mixes that often occur in office buildings: uppeak traffic with 85% incoming, 10% outgoing and 5% interfloor traffic, lunch traffic with 40% incoming, 40% outgoing and 20% interfloor traffic or lunch traffic with 45% incoming, 45% outgoing and 10% interfloor traffic [8,9].

To use both calculation and simulation in lift traffic design, as well as to keep new designs consistent with the old ones, the methods should produce consistent results. Due to intrinsic differences between the methods, the results cannot be exactly equal. Consistency, however, should be reached statistically if the underlying, often unspoken, assumptions were understood properly and replicated between the methods to the greatest extent possible. Calculation can be linked to simulation by observing that *P* passengers transported during a roundtrip represent an average value. The connection is expressed more formally in hypothesis *H1*:

H1 *Uppeak traffic simulation, with passenger demand equalling handling capacity, results in such average number of passengers in the car at departure from the main entrance floor and average roundtrip time that are close to parameter P and calculated roundtrip time.*

Once consistency has been established, lift traffic simulation can reliably be used to derive results important to the design process and in relation to calculation. For example, simulation can be used to verify handling capacity for a general traffic mix or a control system, for which roundtrip time formulae have not been developed. For such purposes, uppeak roundtrip can be generalized for any traffic mix as follows [10]:

- *Roundtrip begins when a lift starts up and ends when the lift starts up again after reversing its travelling direction twice;*
- *Lift utilization during a roundtrip is described by the maximum number of passengers in the car at departure from any floor in any direction;*
- *Handling capacity corresponds to the passenger demand, where average lift utilization reaches P passengers.*

Throughout this paper, series of simulations with KONE Building Traffic Simulator (KONE BTS™) are conducted to test different hypotheses [11]. Lift and building parameters listed in Appendix A are used in all simulations. In each simulation, passenger demand is kept constant for 240 minutes. Simulation quantities occurring in the first 15 minutes and the last five minutes are removed from the results to avoid the statistical effects of initial and end transients [10]. To minimize the possibility of incorrect statistical inferences, each simulation is replicated 20 times.

The rest of this paper is organized as follows. Section 2 discusses in detail lift traffic design with a collective control system. In Section 3, attention is directed to the DCS, which has become the *de facto* standard for tall office buildings. Section 4 concludes the paper.

2 LIFT TRAFFIC DESIGN WITH A COLLECTIVE CONTROL SYSTEM

2.1 Assumptions

Lift traffic calculation considers the operation of a lift with the following assumptions:

A1 Passengers are independent with respect to their destinations and arrival times;
A2 The lift loads *P* passengers on the main entrance floor and closes its doors;
A3 The lift transports the passengers to their destinations by stopping on *S* upper floors;
A4 The lift becomes vacant on floor *H* and reverses its travelling direction;
A5 The lift expresses back to the main entrance floor and opens its doors.

In lift traffic simulation, passenger arrivals are usually modelled with a Poisson process, which satisfies assumption *A1*, but passenger inter-arrival times are exponentially distributed [e.g. 11].

Traffic calculation assumes *P* passengers to be transported during every roundtrip as stated in assumption *A2*. Lift traffic simulation, on the other hand, needs an exact definition for passenger capacity (*PC*): *the maximum number of passengers allowed in the car during simulation*. The two methods can be linked by these two parameters,

$$P = CF \times PC, \tag{1}$$

where capacity factor *CF* defines the target filling rate of a lift. It is worth noticing that culture strongly affects how many passengers actually accept boarding a lift. Thus, the designer needs to carefully select passenger capacity for a particular car size.

Queuing theory and simulations have been used to show that the service of a lift group with a collective control system in pure uppeak traffic saturates if utilization factor, i.e., average number of passengers transported during a roundtrip, exceeds 80% of passenger capacity [3,4]. Therefore, capacity factor should not assume a value higher than 80% although lower values may be used to reserve more space to the passengers. Eq. 1 leads to a hypothesis stronger than *H1*:

H2 *Calculation and simulation are consistent if Eq. 1 holds with capacity factor of at most 80%.*

Assumption *A2* states that P passengers board the lift sequentially within time Pt_p. Then, door closing delay time elapses and doors start to close. In simulation, at most PC passengers board the lift depending on queue length. If no new passenger arrivals occur after a passenger transfer and before lift doors are closed, the lift starts its travel. Contrary to calculation, a new passenger arrival may occur in simulation during this time. For example, a passenger, who arrives during door closing delay time, boards the lift normally but resets the closing delay. Simulation may also allow door re-opening. Thus, passenger loading may contain delays that are not modelled in calculation.

The modelling of lift operation is mostly related to assumptions *A3* and *A4* with the usual technical parameters: *the time to travel between two floors* (t_v) *with standard floor-to-floor distance at rated speed v*, *the time consumed in stopping* (t_s) and *average one way passenger transfer time* (t_p) [1]. The calculated *S* and *H* are usually real numbers and do not represent physical quantities, but each roundtrip in simulation has a discrete number of stops and reversal floor.

According to assumption *A5*, a vacant lift expresses to the entrance floor without any delay. As a result, new roundtrips start exactly at average intervals. For a collective control system, passenger demand realizes only in an up-call on the main entrance floor. Without proper uppeak detection, the control system cannot dispatch more than one lift to serve the demand. Therefore, control systems are usually capable of dispatching additional lifts automatically to the main entrance floor to enable simultaneous passenger loading with more than one car [8].

2.2 Testing consistency between calculation and simulation

Hypotheses *H1* and *H2* are tested by simulating pure uppeak traffic with groups of one to eight lifts and passenger demands equal to the calculated handling capacity of the lift group. Simulated uppeak performance is described in Table 1 by the average number of passengers per roundtrip (*P*), the average number of stops per uptrip (*S*), the average reversal floor (*H*) and the average roundtrip time (*RTT*). In addition, average passenger waiting time (*WT*) and its proportion to the calculated interval (*INT*) are shown. The values indicate means and 95% confidence limits in parenthesis for the observed averages in simulations replicated 20 times. Due to the long simulation with constant passenger demand, the confidence intervals are narrow, less than ±1% from the means, except in the case of average waiting time.

Testing the hypotheses turns out to be more complicated than it sounds. Generally, calculation and simulation results are close to each other. However, the calculated values shown in Appendix A deviate statistically significantly from simulations since they do not belong to the confidence intervals. On the other hand, the simulated values are usually within 5% of the calculated ones, which could be considered an acceptable accuracy from a practical point of view.

Table 1: Simulated means and 95% confidence limits of uppeak roundtrip variables

L[N]	P[N]	S[N]	H[N]	RTT[s]	WT[s]	WT/INT[%]
1	15.7 (±0.14)	9.1 (±0.11)	12.5 (±0.05)	181.3 (±1.4)	87.0 (±4.7)	47.2 (±2.5)
2	15.1 (±0.13)	8.7 (±0.09)	12.3 (±0.04)	174.7 (±1.2)	54.3 (±2.4)	58.9 (±2.6)
3	15.1 (±0.12)	8.6 (±0.07)	12.3 (±0.04)	173.9 (±1.1)	38.0 (±1.5)	61.8 (±2.4)
4	15.8 (±0.11)	8.9 (±0.07)	12.4 (±0.04)	178.3 (±1.0)	31.1 (±1.3)	67.4 (±2.7)
5	16.2 (±0.15)	9.1 (±0.09)	12.4 (±0.04)	180.7 (±1.3)	22.9 (±1.2)	61.9 (±3.3)
6	16.5 (±0.11)	9.2 (±0.06)	12.4 (±0.03)	183.2 (±0.9)	15.1 (±0.8)	49.0 (±2.4)
7	17.1 (±0.08)	9.5 (±0.04)	12.5 (±0.03)	187.0 (±0.7)	9.7 (±0.4)	36.7 (±1.4)
8	17.9 (±0.08)	9.8 (±0.05)	12.5 (±0.03)	192.0 (±0.7)	7.8 (±0.4)	33.6 (±4.0)

Passenger arrival process seems one source for the observed deviations. Its effect can best be seen in the results for (a group of) one lift since the interaction of multiple lifts do not affect the process. Both the average number of transported passengers (15.7) and roundtrip time (181.3 seconds) are below the expected values of 16 passengers and 184.6 seconds, respectively. However, traffic calculation based on the Poisson process gives roundtrip time of 182.7 seconds, which belongs to the 95% confidence interval for the simulated mean roundtrip time [4]. Thus, in the case of one lift, simulation is consistent with calculation according to a strict statistical criterion.

Lift groups with two to eight lifts show an increasing trend in the number of passengers and roundtrip time with respect to the number of lifts, which can be attributed to the automatic returning of idle lifts. In the simulations with two- and three-car groups, automatic returning empties the lobby in a more efficient manner than calculation assumes. The results with four or five lifts match closely with calculation, which indicates that the automatic returning corresponds to, on average, the efficiency required by calculation. On the other hand, the returning of only one lift at a time in large groups may leave some lifts to stand idle on upper floors. Consequently, the number of passengers per roundtrip becomes clearly greater than the expected 16 passengers. If the control system is configured to return automatically two idle lifts, simulation with the eight-car group results in 15.6 passengers per roundtrip and roundtrip time of 176.6 seconds, which are close to calculation. As a conclusion, simulation seems consistent with calculation but, to prove it with a statistical argument, requires additional measures to fine-tune lift group operation.

2.3 An example of an inconsistent uppeak simulation

Regardless the difficulties in showing consistency between calculation and simulation, inconsistency between them becomes evident if capacity factor CF is set at 100%, i.e., $PC = P = 16$. Roundtrips in simulations with a six-car group are very close to calculation since the lifts always transport 16 passengers. The average number of stops per uptrip equals 9.5, average reversal floor is 12.7 and average roundtrip time is 185.8 seconds. However, the lift group undergoes saturation, which is indicated by an average waiting time much longer than interval, 180.3 seconds, as well as by an infinitely growing lobby queue. These simulation results imply that the lift group cannot handle the specified passenger demand while calculation results suggest the contrary.

2.4 Lunch traffic simulation

Lunch traffic performance of a six-car group is studied to find out the relation of uppeak and lunch traffic handling capacity as well as between uppeak interval and lunch traffic average waiting time.

Uppeak handling capacity of this group equals 12% of population in five minutes with 100 persons on each floor and interval 30.6 seconds, which represents a standard office building design [e.g. 1]. Lunch traffic consisting of 40% incoming, 40% outgoing and 20% interfloor traffic is simulated with increasing passenger demands from 10% to 16% in five minutes. Simulations are conducted with both a full collective control based on lift estimated time of arrival on a call floor (ETA) and a highly efficient full collective control, optimizing lift routes in real time with a genetic algorithm (OPT) [3,12]. The ETA can be shown to provide passenger service quality similar to Elevate ETA-control [13]. Table 2 shows average lift utilization for generalized roundtrips, the corresponding average roundtrip times, average passenger waiting time and average passenger time to destination.

Table 2: Lunch traffic results for a six-car group

Demand [%/ 5-mins]	P [N]		RTT [s]		WT [s]		TTD [s]	
	ETA	**OPT**	**ETA**	**OPT**	**ETA**	**OPT**	**ETA**	**OPT**
10	6.9	7.1	160.1	159.9	23.2	18.3	80.2	77.8
11	8.5	8.6	179.3	180.3	26.2	19.9	88.3	84.8
12	10.1	10.3	198.2	199.3	29.4	21.8	96.1	91.2
13	11.8	12.0	218.0	221.0	32.9	23.8	104.1	98.4
14	13.7	13.7	236.5	240.8	36.8	25.9	111.7	103.3
15	15.4	15.2	254.0	258.4	41.6	28.8	120.0	109.2
16	16.7	16.6	268.8	274.6	49.6	32.7	130.4	115.7

Average lift utilization exceeds 16 passengers, i.e., parameter P in calculation, between passenger demands of 15% and 16%, which indicates 25-30% higher handling capacity than in uppeak. Accordingly, lunch traffic handling capacity would be more than sufficient if 11% passenger demand was the target for a standard office. With 11% demand, average passenger waiting times are also shorter than uppeak interval, even with the ETA. However, the modern OPT provides average waiting times shorter than interval up to 15% demand. In addition, average waiting times with the OPT are 20-30% shorter than with the ETA across all simulated demands.

3 LIFT TRAFFIC DESIGN WITH A DESTINATION CONTROL SYSTEM

3.1 Uppeak calculation

The DCS affects lift group performance in uppeak by grouping passengers that are travelling to the same destination into one lift. As a result, the number of stops during roundtrip decreases and handling capacity increases. The original derivation of DCS traffic calculation considered a group of L lifts as a large car carrying $L \times P$ passengers and serving $2N$ floors in two up-trips [14]. A slightly modified version replaced L by a look-ahead factor k in the range of two to four lifts [3]. Maximum handling capacity with the DCS, however, can be achieved by dynamic zoning, which dedicates each lift to serve a particular range of N/L floors [15].

The effect of the DCS can also be understood through the effective number of lifts $\hat{L}$ serving a destination floor. In a collective control system, all lifts serve all upper floors, i.e., $\hat{L} = L$. When the DCS boosts uppeak to the maximum, only one lift serves an upper floor, i.e., $\hat{L} = 1$. The DCS can dedicate any number of lifts per upper floor, which implies that the number of effective lifts can vary from one to L, i.e., $\hat{L} \in [1, \dots, L]$, and can even be a real number for calculation purposes. Interestingly, it is also inversely proportional to the number of zones Z into which the served floors are divided by the dynamic zoning,

$$\hat{L}Z = L. \tag{2}$$

The following uppeak formulae for the DCS are based on a variable number of zones and consider a large car of size $Z \times P$. Probable number of stops for the DCS ($\hat{S}$) becomes

$$\hat{S} = \frac{N}{Z}\left[1 - \left(\frac{N-1}{N}\right)^{ZP}\right]. \tag{3}$$

Average highest reversal floor ($\widehat{H}$) models the number of passengers ($\widehat{P}$) that is equivalent to a lift with a collective control system stopping $\hat{S}$ times [15]. This parameter can be solved from probable number of stops by using the inverse S-P method [3],

$$\widehat{P} = \ln\frac{N-\hat{S}}{N} \Big/ \ln\frac{N-1}{N}, \tag{4}$$

$$\widehat{H} = N - \sum_{i=1}^{N-1}\left(\frac{i}{N}\right)^{\widehat{P}}. \tag{5}$$

Roundtrip time for the DCS, $\widehat{RTT}$, is calculated according to the usual formula (see Appendix A), but probable number of stops and average highest reversal floor are replaced by eqs. 3 and 5.

Eqs. 3-5 reduce to traditional calculation if the number of effective lifts per floor equals L or, equivalently, the number of zones equals one. Thus, DCS calculation describes lift group performance with increasing levels of uppeak boosting up to the maximum. On average, each lift serves a zone of N/Z floors, stops $\hat{S} \leq S$ times during uptrip and reverses its travelling direction on floor $\widehat{H} \leq H$. As a drawback of uppeak boosting, the DCS increases the time between successive lift departures to a destination floor and, consequently, also passenger waiting times. Service interval $\widehat{INT}$, the average time between successive lift departures to a destination floor, describes this effect:

$$\widehat{INT} = \frac{\widehat{RTT}}{\hat{L}} = \frac{\widehat{RTT}}{L/Z}. \tag{6}$$

The use of DCS calculation as well as the effect of increasing the number of zones are demonstrated by a five-car group. The results are shown in Table 3. In this case, the DCS increases handling capacity up to 79% by reducing probable number of stops to less than one third.

Table 3: Uppeak calculation results for a five-car group

Z [N]	$\hat{S}$ [N]	$\widehat{H}$ [N]	$\widehat{P}$ [N]	$\widehat{RTT}$ [s]	$\widehat{HC5}$ [p/5-mins]	$\widehat{HC5}/HC5$ [%]	INT [s]	$\widehat{INT}$ [s]
1	9.4	12.6	16.0	184.6	130.0	100.0	36.9	36.9
2	6.0	12.0	7.7	145.9	164.5	126.5	29.2	58.3
3	4.2	11.3	4.9	124.7	192.5	148.1	24.9	74.8
4	3.2	10.6	3.6	111.7	214.8	165.2	22.3	89.4
5	2.6	10.0	2.8	103.0	233.0	179.2	20.6	103.0

3.2 Uppeak traffic simulation

To show the validity of DCS calculation, pure uppeak traffic is simulated with a five-car group. Population on each floor is assumed 100 persons. Then, uppeak handling capacity ($\%HC5$) of this lift group equals 10% with a collective control system ($Z = 1$) and at most 17.9% with the DCS ($Z = 5$). Simulation results are shown in Table 4 below with a standard DCS, which minimizes the total passenger time to destination, and with a DCS applying dynamic zoning (DZ), which increases the number of zones according to the measured passenger demand.

Table 4: Uppeak simulation results for a five-car group

Demand [%/ 5-mins]	P[N]		RTT[s]		WT[s]		TTD[s]	
	DCS	DZ	DCS	DZ	DCS	DZ	DCS	DZ
10	9.6	9.5	110.2	109.9	20.5	20.7	70.3	70.4
12	12.5	10.7	119.7	102.9	22.4	24.0	76.7	74.2
14	15.6	12.4	128.8	102.1	25.3	30.6	83.9	82.0
16	19.8	15.2	156.5	109.8	181.4	35.5	254.3	90.8
18	20.0	16.7	160.5	106.7	230.3	39.4	305.4	95.2

The results confirm that the DCS can improve uppeak handling capacity greatly, as indicated by calculation results. The standard DCS reaches 14% handling capacity, which falls between handling capacities calculated with $Z = 2$ and $Z = 3$ (see Table 3). This result is also in line with the recommendation of choosing look ahead factor k between two and three [3]. The DZ, on the other hand, reaches at least close to the calculated maximum of 17.9%.

With the DZ, roundtrip time does not increase monotonically as with the standard DCS but decreases in jumps. A jump point corresponds to an increase in zones. For example, 10% passenger demand is easily handled by the standard DCS and, hence, the DZ does not take any action. For 12% passenger demand, the DZ defines two zones with 6.5 served floors and 2.5 lifts serving each upper floor on average, which decreases average roundtrip time from 109.9 seconds to 102.9 seconds. Thus, by increasing the number of zones gradually, the DZ maintains roundtrip time near the value provided by the standard DCS for 10% passenger demand. Passenger waiting times increase steadily but with a rate far from the rate of calculated service interval.

3.3 Lunch traffic simulation

Lunch traffic consisting of 40% incoming, 40% outgoing and 20% interfloor traffic is simulated with a five-car group as above. In addition to the standard DCS, simulations are conducted with Advanced DCS (ADCS), which applies a new passenger interface concept to upper-floor passenger terminals: an allocated lift is not shown on a terminal display but indicated to the waiting passengers later upon its arrival [16]. This allows the control system to optimize call allocations and adapt to changing conditions until the last moment. Table 5 shows the simulation results.

Table 5: Lunch traffic simulation results for a five-car group

Demand [%/ 5-mins]	P[N]		RTT[s]		WT[s]		TTD[s]	
	DCS	ADCS	DCS	ADCS	DCS	ADCS	DCS	ADCS
10	8.2	8.6	173.7	180.5	35.7	31.0	89.6	87.9
11	9.6	10.1	188.4	197.6	38.2	33.7	95.4	94.0
12	11.0	11.5	200.0	211.1	40.3	35.8	100.5	99.1
13	12.6	13.1	213.4	226.5	42.8	38.2	106.5	104.9
14	14.0	14.7	222.9	239.5	45.6	40.4	111.9	110.1
15	15.5	16.1	235.0	249.7	48.4	42.8	117.5	114.6
16	16.8	17.4	244.8	262.8	52.8	46.3	124.1	120.7

According to the average lift utilization P, lunch traffic handling capacity with the DCS is about 15%. However, average passenger waiting times with such high demands exceed 40 seconds and are not acceptable. This shows clearly that the main challenge of the DCS lies in passenger waiting times during lunch traffic. The ADCS, on the other hand, decreases passenger waiting times consistently across all passenger demands by more than 10%. As a result, the ADCS raises the limiting passenger demand, where waiting times are still acceptable, from 11% to 13%.

4 IMPLICATIONS TO LIFT TRAFFIC DESIGN

Showing consistency between lift traffic calculation and simulation turned out to be more complex than hypothesized and only partially successful. However, uppeak traffic offers a way to anchor traffic simulation to quantities that can be verified by calculation. Instead of looking at immediate simulation results, statistically sound validation of traffic simulation could be based on individual roundtrips. Nevertheless, to have any hope of the methods being consistent, their parameters must be linked: average number of passengers in the car at departure from the main entrance floor in calculation should not be more than 80% of passenger capacity in simulation.

Traffic calculation is widely adopted, but, as such, valid only for a collective control system. Due to its simplicity, calculation is also an ideal tool for quickly evaluating numerous vertical transportation alternatives for a speculative building. Traffic simulation, on the other hand, was originally developed to test control systems and to analyse lift group performance under varying traffic conditions. Simulation is the only tool to accurately estimate lift performance and reliably design lift products such as the DCS, which do not have widely accepted uppeak formulae and for which uppeak is not the limiting traffic mix.

The proposed DCS traffic calculation could be applied to lift traffic design with some care. Observations arising from the studied office building could serve as guidelines to follow. In this case, lift traffic design targeted at 12% handling capacity and interval of 30 seconds for a collective control system. These requirements were satisfied by a group of six lifts. Lunch traffic performance was verified to be good with average waiting time less than 30 seconds with 11% passenger demand. Speculatively, performance with the DCS was simulated for a group of five lifts, which showed 14% uppeak handling capacity and acceptable waiting times with 11% lunch traffic demand. Thus, in this case, the DCS enables a design with a reduced number of lifts.

Based on these observations, acceptable lift traffic design with the DCS could be achieved (at least) in two ways by using traffic calculation:

1) Target a lower uppeak handling capacity and higher interval with a collective control system, e.g., 10% instead of 12% and 40 seconds instead of 30 seconds;
2) Target a higher uppeak handling capacity with DCS traffic calculation using 2.5-3 zones, e.g., 14% instead of 12%, but target the same interval as with a collective control system.

Both of these conditions were satisfied by the studied five-car group. Before applying the method more widely, however, the generality of the above rules should be carefully assessed.

Commonly accepted design criteria for DCS traffic calculation would allow the development of selection graphs and expert systems that would genuinely take into account the strengths of the DCS. While not replacing simulation in detailed lift traffic studies, these approaches would allow fast evaluation and feedback of proposed vertical transportation alternatives during concept design. Lift traffic simulation would then, for example, validate the design, provide more detailed analysis based on tenant requirements and evaluate special control options.

REFERENCES

[1] ISO, *ISO/DIS 8100-32 – Lifts for the transportation of persons and goods – Part 32: Planning and selection of passenger lifts to be installed in office, hotel and residential buildings*. ISO, Switzerland (2019).

[2] G.R. Strakosch, *Vertical Transportation: Elevators and Escalators, 2nd Edition*. John Wiley, New York (1983).

[3] G.C. Barney, *Elevator Traffic Handbook: Theory and Practice*. Spon Press, London (2003).

[4] M-L. Siikonen, "Customer service in an elevator system during uppeak". *Transportation Research Part B: Methodological*, Vol. 31, No. 2, 127-139 (1997).

[5] M-L. Siikonen, "Elevator traffic simulation". *Simulation*, Vol. 61, No. 4, 257-267 (1993).

[6] R. Peters, "Simulation for control system design and traffic analysis". In G.C. Barney (ed), *Elevator Technology 9*, IAEE, 226-235 (1997).

[7] B. Powell, "Elevator Planning and Analysis on the Web". *Elevator World*, Vol. 50, No. 6, 73-77 (2002).

[8] M-L. Siikonen, *Planning and control models for elevators in high-rise buildings*. Ph.D. thesis, Helsinki University of Technology, Systems Analysis Laboratory (1997).

[9] R. Peters, R. Smith, and E. Evans, "The appraisal of lift passenger demand in modern office buildings". *Building Services Engineering Research and Technology*, Vol. 32, No. 2, 159-170 (2011).

[10] H. Hakonen, and M-L. Siikonen, "Elevator traffic simulation procedure". *Elevator World*, Vol. 57, No. 9, 180-190 (2009).

[11] M-L. Siikonen, T. Susi, and H. Hakonen, "Passenger traffic flow simulation in tall buildings". *Elevator World*, Vol. 49, No. 8, 117-123 (2001).

[12] T. Tyni, and J. Ylinen, "Genetic algorithms in elevator car routing problem". In L. Spector et al (eds), *Proceedings of the Genetic and Evolutionary Computation Conference (GECCO-2001)*, Morgan Kaufman Publishers, 1413-1422 (2001).

[13] Peters Research Ltd, *Elevate Version 8.26*. (2019).

[14] J. Schröder, “Elevatoring Calculation – Probable Stops and Reversal Floor “M10” Destination Hall Calls + Instant Car Assignment”. *Elevator World*, Vol. 38, No. 4, 40-46 (1990).

[15] J. Sorsa, H. Hakonen, and M-L. Siikonen, “Elevator selection with destination control system”. *Elevator World*, Vol. 54, No. 1, 148-155 (2006).

[16] R. Barker, “Harmonized Elevator Dispatching and Passenger Interfaces”. *Elevator World*, Vol. 66, No. 11, 82-90 (2018).

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Appendix A

Table A1: Building and lift parameters

Parameter	Symbol	Value
Number of populated floors	N	13
Average interfloor distance	d_f	4.0 m
Number of lifts in group	L	1…8
Floor population (*L*=6)	U_i	100
Passenger capacity	PC	20
Average number of passengers in the car at departure from the main entrance floor	P	16
Rated speed	v	2.5 m/s
Acceleration and deceleration	a	1.0 m/s^2
Jerk	j	1.0 m/s^3
Average one way passenger transfer time	t_p	1.0 s
Door opening time	t_o	2.0 s
Door closing time	t_c	2.7 s
Door pre-opening time	t_{pre}	0.0 s
Door closing delay time	t_{cd}	2.0 s
Start delay	t_{sd}	0.6 s
Time consumed in stopping	t_s	10.8 s
Door reopen by landing call		None
Number of lifts returned to the lobby		1

Table A2: Uppeak formulae [3] and results for $P = 16$ and $N = 13$

Parameter	Equation	Value
Probable number of stops	$S = N[1 - ((N-1)/N)^P]$	9.4
Average highest reversal floor	$H = N - \sum_{i=1}^{N-1} (i/N)^P$	12.6
Roundtrip time	$RTT = 2Ht_v + (S+1)t_s + 2Pt_p$	184.6 s
Handling capacity (*L*=6)	$HC5 = 300 \times P \times L/RTT$	156.0 p/5-mins
Interval (*L*=6)	$INT = RTT/L$	30.8 s
Average waiting time	$AWT = [0.4 + (1.8\,P/PC - 0.77)^2] \times INT$	26.1 s

Logging and Analysis of Lift Journeys Using an Accelerometer

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Keywords: Kinematics, accelerometer, performance, logging, passenger demand

Abstract. Data measured with an accelerometer in or on a lift car can be very useful. Using an accelerometer to measure individual trips allows engineers to confirm that a lift is working as specified. Further analysis of extended measurements can also provide an understanding of lift passenger demand, useful in planning new buildings and addressing traffic problems in existing buildings. Accelerometers can also be used as part of lift monitoring systems, collecting data about the lifts without the need for interfacing with lift controllers, which can be expensive due to the use of proprietary protocols. In this paper the authors address the analysis of accelerometer data for a multi trip scenario. With real as opposed to ideal data, the analysis procedure must account for accelerometer drift, noise and other data anomalies. The final analysis software provides an idealised version of the measured data including the distance, velocity, acceleration and jerk for each trip. The distance measurements combined provide a spatial plot of lift position.

1 INTRODUCTION

The logging of lift motion is valuable when measuring lift performance, analysing lift traffic and lift monitoring. Accelerometers can be used as part of lift monitoring systems, collecting data without the need for interfacing with lift controllers, which can be expensive due to the use of proprietary protocols [1].

Software has been developed to process data collected by a low-cost computer and accelerometer placed on top of a lift car. By analysing a sequence of individual lift journeys, the software is able to provide a summary of lift stops analysed by floor and time of day.

1.1 Motivation

Estimates of lift passenger demand are required in the planning of new lift installations and when addressing lift traffic problems in existing buildings. By recording and processing the output of an accelerometer, a spatial plot of lift motion can be produced. An indication of lift passenger demand can then be determined without the need for human observers.

This is possible as the spatial plot data recorded by the accelerometer software can be applied in the development of mathematical models to extrapolate passenger demand from stops. This work is outside the scope of this paper, but a range of methods have been proposed by several researchers over many years [2], [3] with recent work showing how good passenger demand predictions can be estimated with limited data sets [4].

The software developed can also support the monitoring of lift installations by providing a connection-free solution. Because the application of interfacing standards is rare, third party monitoring of lift installations can be expensive.

1.2 Ideal Lift Kinematics

It is possible to derive equations to represent the ideal motion of a lift, which can be plotted as continuous functions that represent the optimum displacement (D), velocity (V), acceleration (A) and jerk (J) profiles, see Figure 1.

Modern variable speed drives can be programmed to match these ideal lift kinematics curves closely. Since it is necessary to model each lift trip as accurately as possible, a good approach is to fit the measured accelerometer data to the idealised kinematics plots.

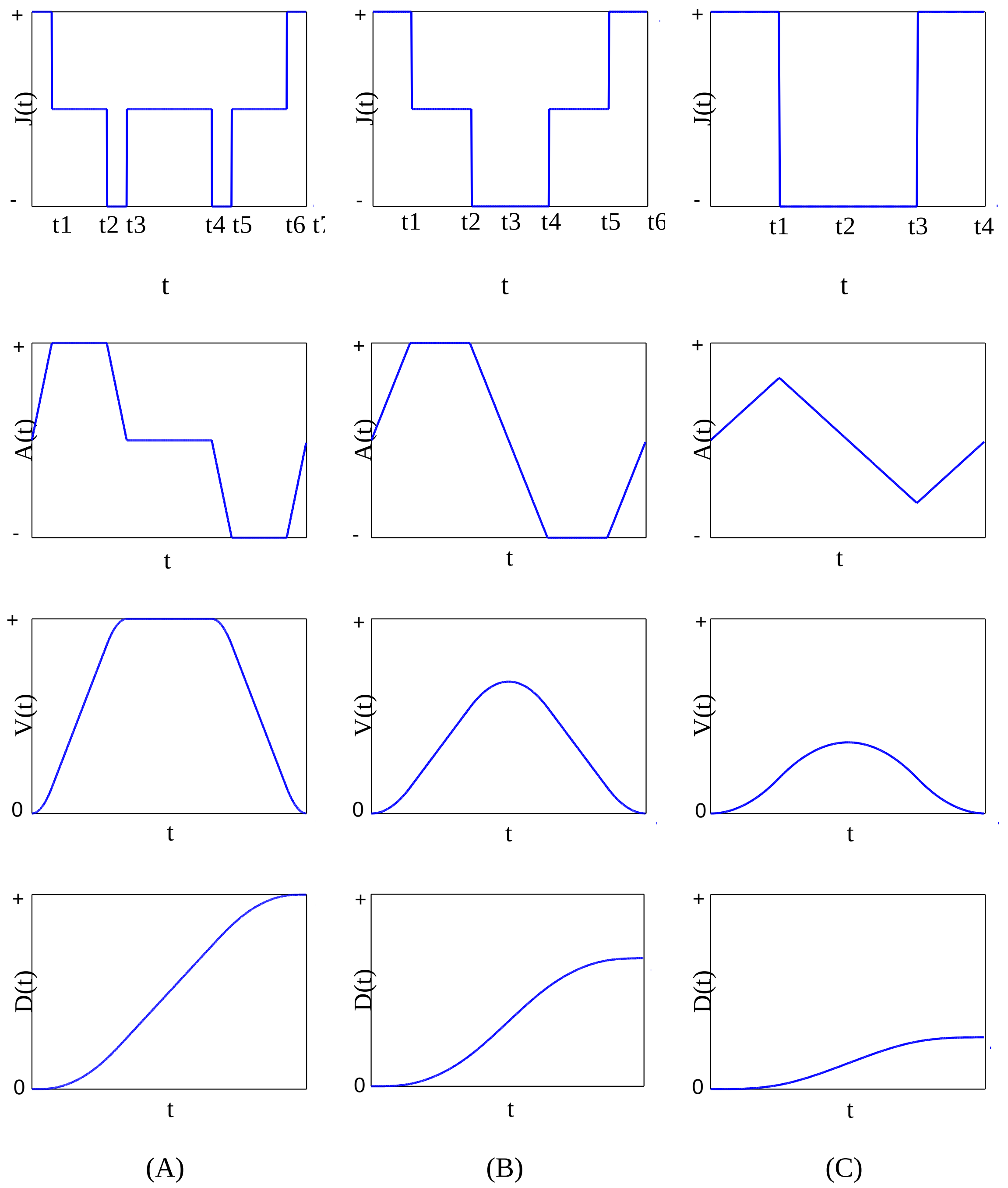

Figure 1 [5]: Ideal lift kinematics for: (A) lift reaches full speed; (B) lift reaches full acceleration, but not full speed; (C) lift does not reach full speed or acceleration

Ideal lift kinematics represents a lift acceleration profile by a series of straight lines. The software therefore applies a linear regression method to fit raw measured data to an ideal plot.

2 CODING METHODOLOGY

2.1 Raw Accelerometer Data

The software is required to process a full set of raw accelerometer data as shown in Figure 2.

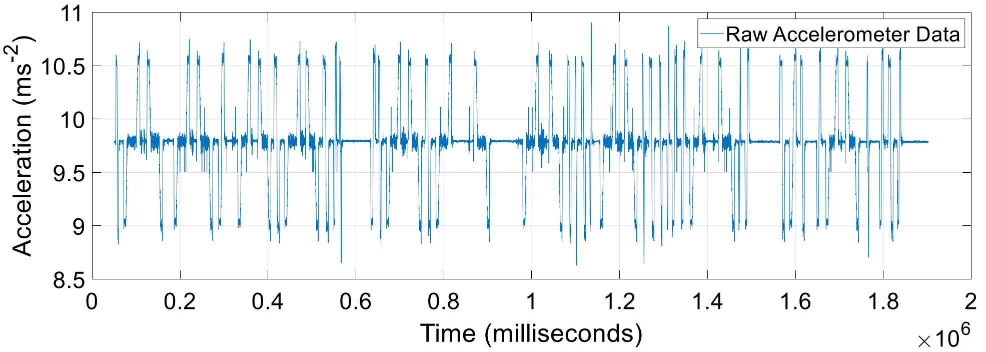

Figure 2: Multiple Lift Trip Raw Accelerometer Plot

To simplify the problem, the data set is isolated into a series of single up and down lift journeys (trips) that can each be analysed individually. An example of an isolated single trip is illustrated in Figure 3.

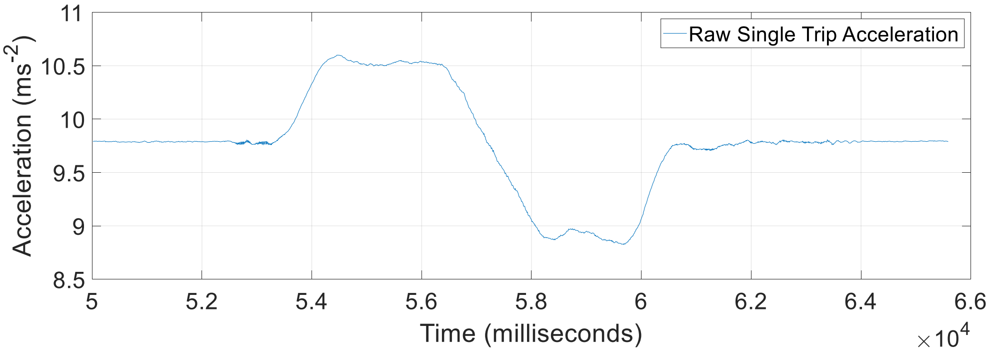

Figure 3: Single Lift Trip Raw Accelerometer Plot

2.2 Language Selection

The software was written in the C++ programming language and is object orientated. Object orientated programming combines groups of related variables and functions into a class. Properties and methods can be hidden inside the class making the software easier to use, understand and maintain [6].

2.3 Processing Ideal Data

The basic methodology of the software was created, and initially tested on self-generated *ideal* lift journeys. This ensured that the code could correctly follow an expected journey before tackling real world data. These *ideal* journeys followed a profile identical to ideal lift kinematics curves, therefore the software outputted an identical profile.

Each isolated single trip can be separated into two phases, one of acceleration and the other deceleration. Since it is assumed that the accelerometer data will start and finish with a stationary lift, there will be an even number of acceleration and deceleration phases. Therefore, for each single trip, the following analysis is carried out twice, once for each phase.

It must be decided whether another phase exists. A new phase occurs when the modulus of the acceleration reaches a threshold value, 50% of the maximum acceleration identified. The next phase is the first case in the remaining data set that this threshold is reached, as shown in Figure 4.

If a phase is identified, it must be determined whether this is an acceleration or deceleration phase. A positive acceleration determines an acceleration phase and a negative value determines a deceleration phase.

For each phase, linear regression analysis is carried out on the two sections where acceleration is non-constant:

(a) Modulus of the acceleration rising

(b) Modulus of the acceleration falling

In anticipation of noise that will be present in real data, linear regression analysis is not carried out over the full length of the phase sections. A reasonable assumption is to carry out analysis on the segments of the sections that fall within 20% and 60% of the maximum acceleration.

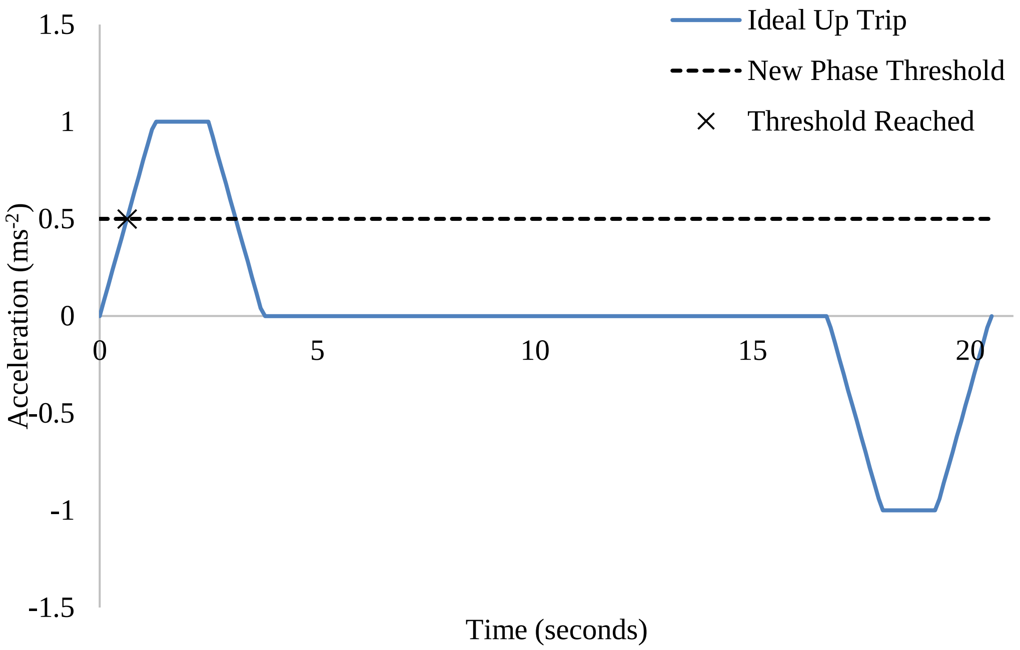

Figure 4: Identification of an Acceleration Phase Within an Up Trip

Linear regression analysis is carried out on all the data that falls between the four calculated limits. Two linear regression lines are identified that minimise the sum of the squares of the errors between the lines and the raw data, with results shown in Figure 5.

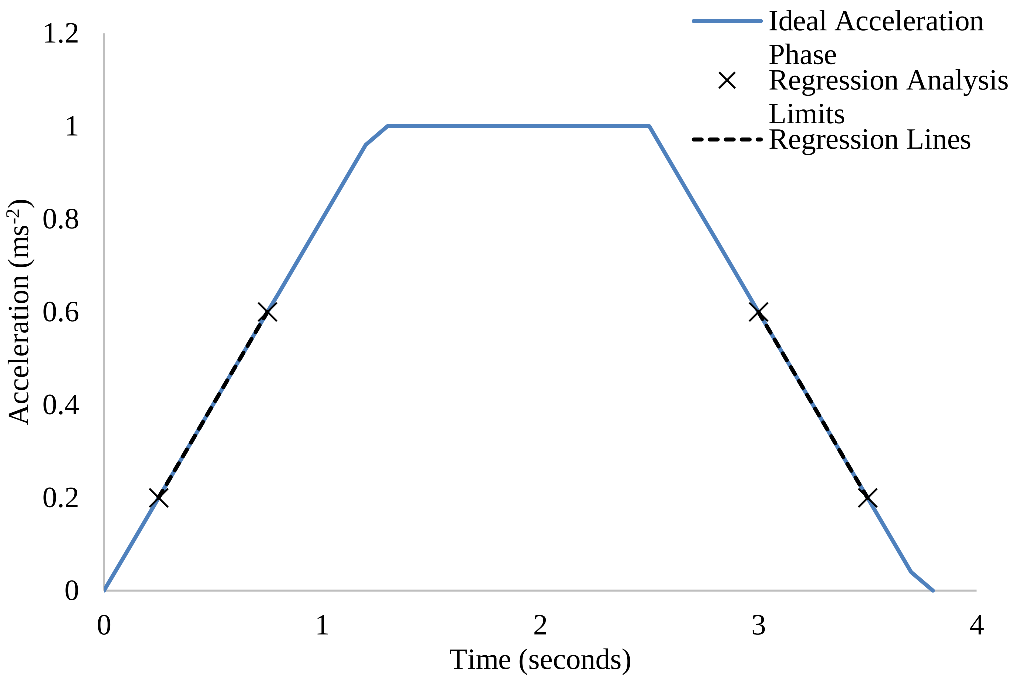

Figure 5: Linear Regression Fit of Acceleration Profile Between Calculated Limits

The software identifies the length of the regression lines (that are to be joined with a horizontal line in specific cases) that minimise the sum of the squares of the errors between the approximated and the raw accelerometer data. Figure 6 demonstrates the process of extending the regression line to the length of minimum error.

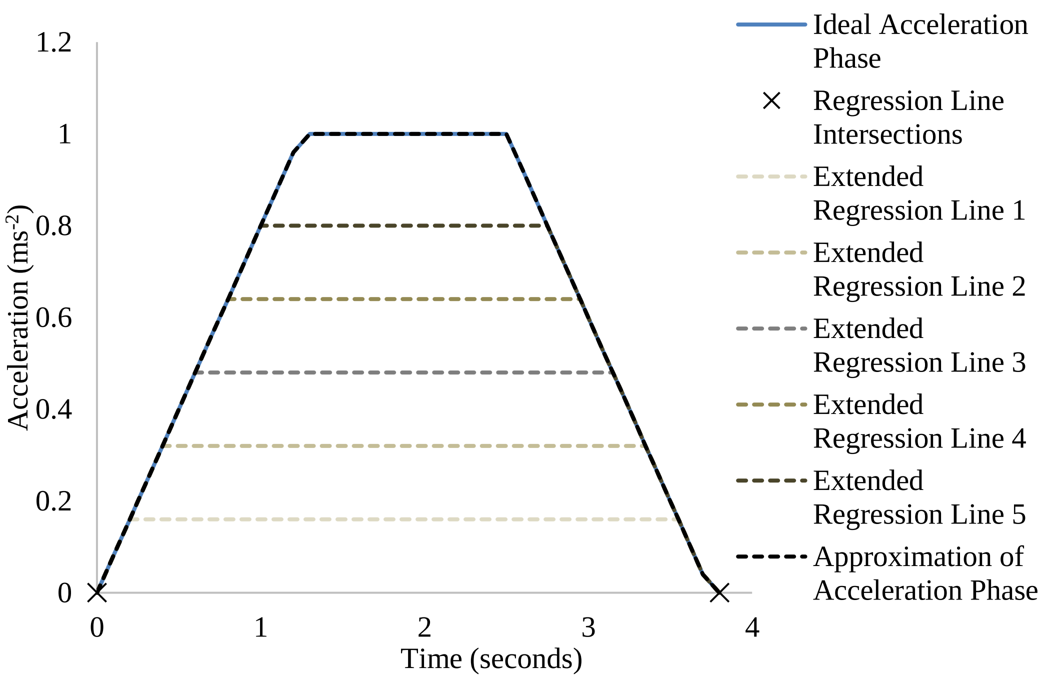

Figure 6: Identification of the Correct Regression Line Length

The series of time and acceleration coordinates to represent each phase are stored in a vector. Zero acceleration coordinates are added from the start of the test data to the beginning of the acceleration/deceleration phase. The regression analysis is then repeated for the second phase of the trip. Figure 7 plots the approximated single up trip profile against the ideal up trip, confirming that the software could accurately represent the data prior to testing on real data.

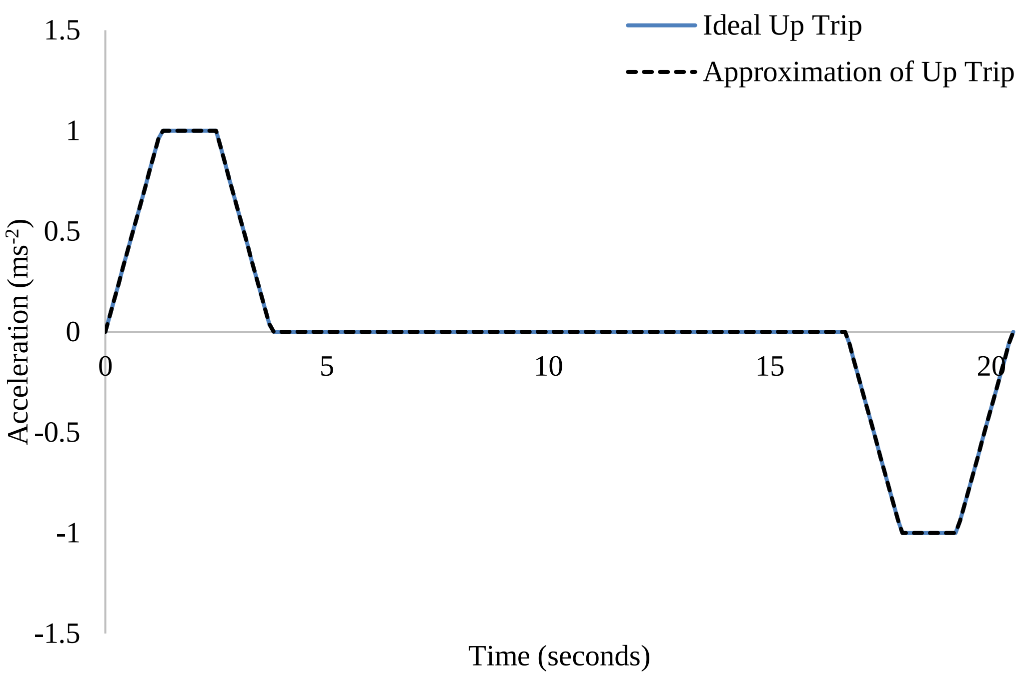

Figure 7: Ideal vs. Approximated Acceleration Profiles of a Single Up Trip

An approximation of the ideal jerk profile is generated via a central difference differentiation of the approximated acceleration profile.

A trapezium rule integration is carried out on the approximated acceleration profile, generating an approximated velocity profile. From ideal lift kinematics, it is known that the integral of a single trip should equal zero, since the lift starts and ends stationary. A scaling factor is determined from the difference between the integrals of the acceleration and deceleration phases. This scaling factor is applied to the acceleration profile such that the integral will equal zero.

To determine the approximated displacement profile, a trapezium rule integration is carried out on the approximated velocity profile as shown in Figure 8. The end value of the displacement represents the total vertical distance moved between the floor on the single trip and is stored separately for later use in multiple trip analysis.

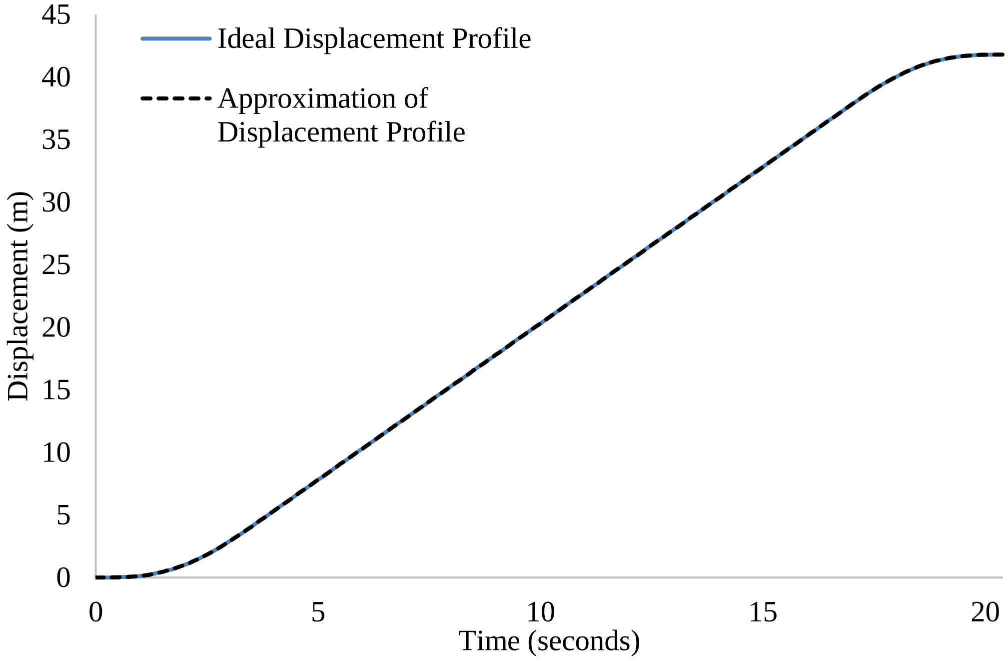

Figure 8: Ideal vs. Approximated Displacement Profiles of a Single Up Trip

A data set containing multiple trips is simply a series of linked single trips. To carry out multiple trip analysis, single trip analysis is looped until the end of the data set is reached. Since the software is capable of outputting the final displacement of each single trip, these can be stored allowing a spatial plot of the lift's motion to be plotted over time. At this point, it is possible to begin to see the effects of accelerometer drift as the approximated positions can be compared to building data.

2.4 Processing Real Data

The introduction of real data introduced a series of issues to be tackled. The solution to each identified issue was integrated into the existing software such that it was capable of correctly representing the raw data.

2.5 Time Section Representation

Existing ideal lift kinematics curves are defined by a set of equations which are divided into time sections, identified by a change in jerk. To tackle an issue introduced with real data, a similar approach was taken. Rather than plotting continuous lines, five significant points are identified for each phase with respect to changes in acceleration, shown in Figure 9. A benefit of recording significant points rather than continuous data is the reduction in file size.

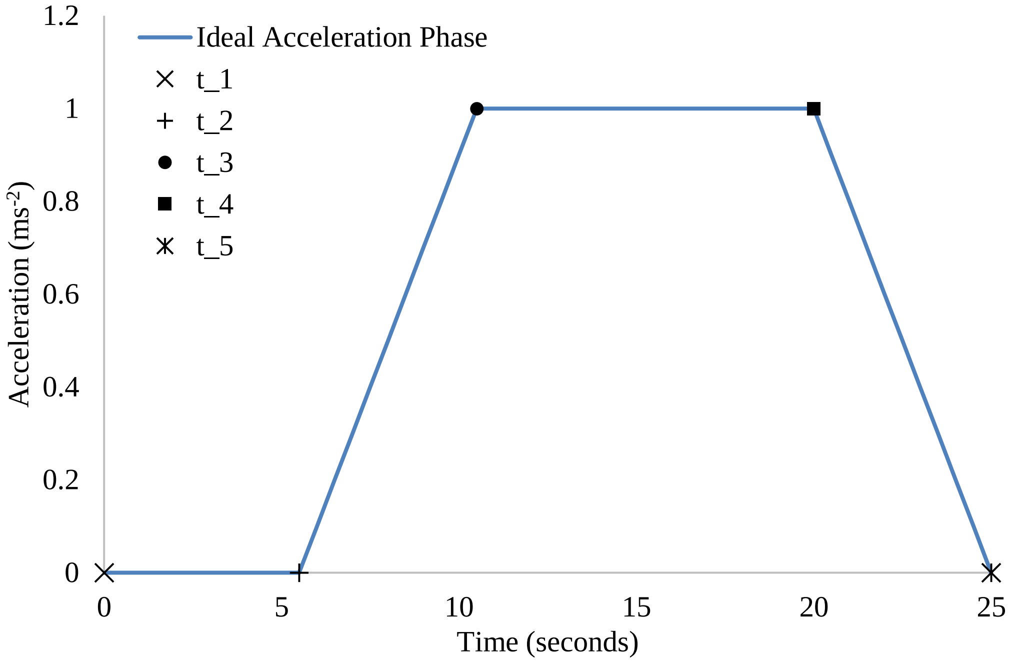

Figure 9: Representation of Time Sections For an Acceleration Phase

2.6 Spatial Plot Generation

The software creates two spatial plots; approximated and calibrated. The approximated spatial plot combines the displacement values stored for each single trip and adjusts the values at points where it is assumed that identical floors have been met. Access to real floor positions from building data allows the calibrated spatial plot to be generated. The approximated spatial plot is adjusted to the correct floor positions such that it can correctly plot the lift motion by floor and time of day.

3 RESULTS

The first set of results processed were from data collected in a high-rise building in Central London, with an express zone using an accelerometer included in a low-cost consumer tablet. The existence of an express zone in the high-rise building resulted in the inability to generate a calibrated spatial plot due to the lack of accelerometer precision. The analysis was repeated using data collected in a low-rise office building. This three-story building does not have an express zone and therefore it is possible to calibrate and test the results to determine the accuracy of the software approximation.

3.1 High Rise Building

Figure 10 plots the raw displacement data against the approximated spatial plot generated by the software for the 39 floor building. The effects of drift are clear, and it is visible how the software has managed to tackle this problem.

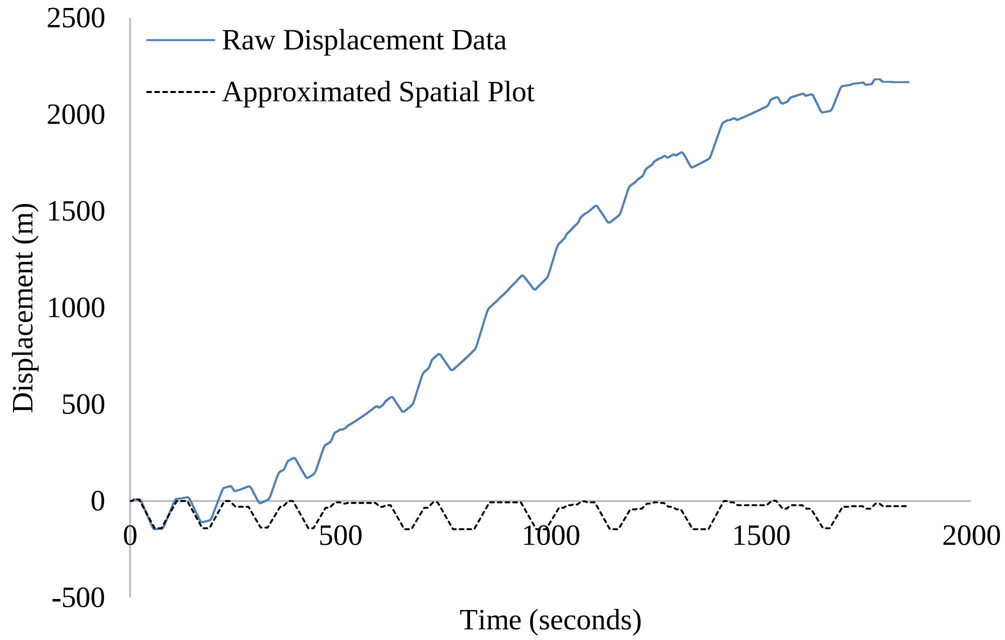

Figure 10: Calibrated vs. Approximated Displacement Profiles (High Rise Building)

3.2 Low Rise Building

Figure 11 plots the raw displacement profile without correction against the approximated spatial plot created by the software. It is clear from the scale of the raw data the significance of drift when modelling continuous lift motion.

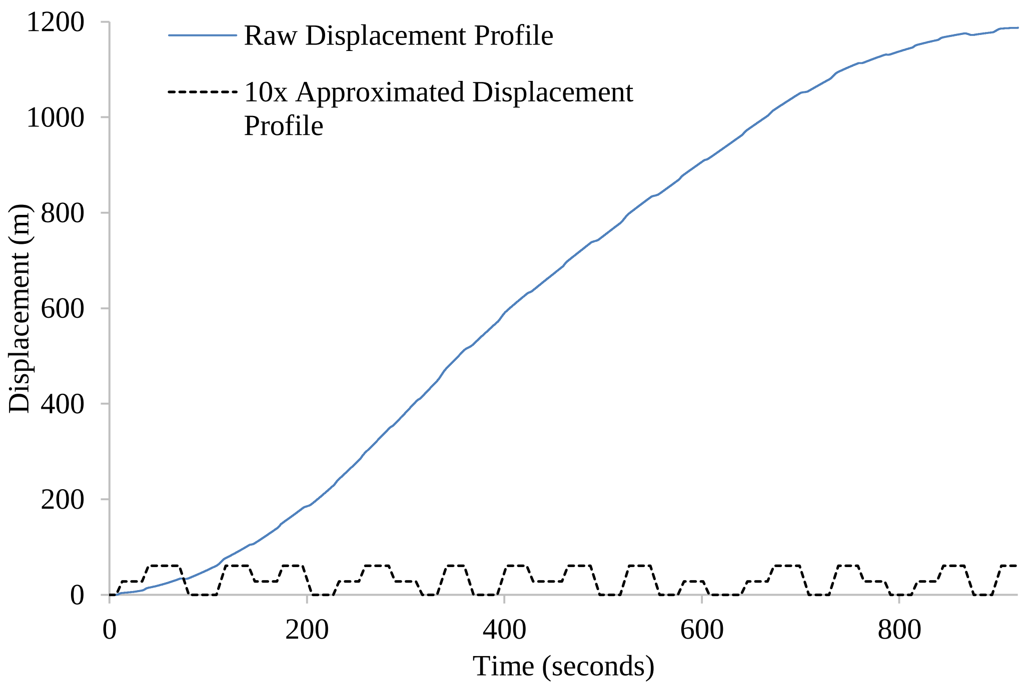

Figure 11: Calibrated vs. Approximated Displacement Profiles (Low Rise Building)

The lack of express zone in the low rise building allowed calibration to be carried out against real building data. Figure 12 plots the approximated spatial plot generated by the software against the adjusted spatial plot once calibration has been carried out.

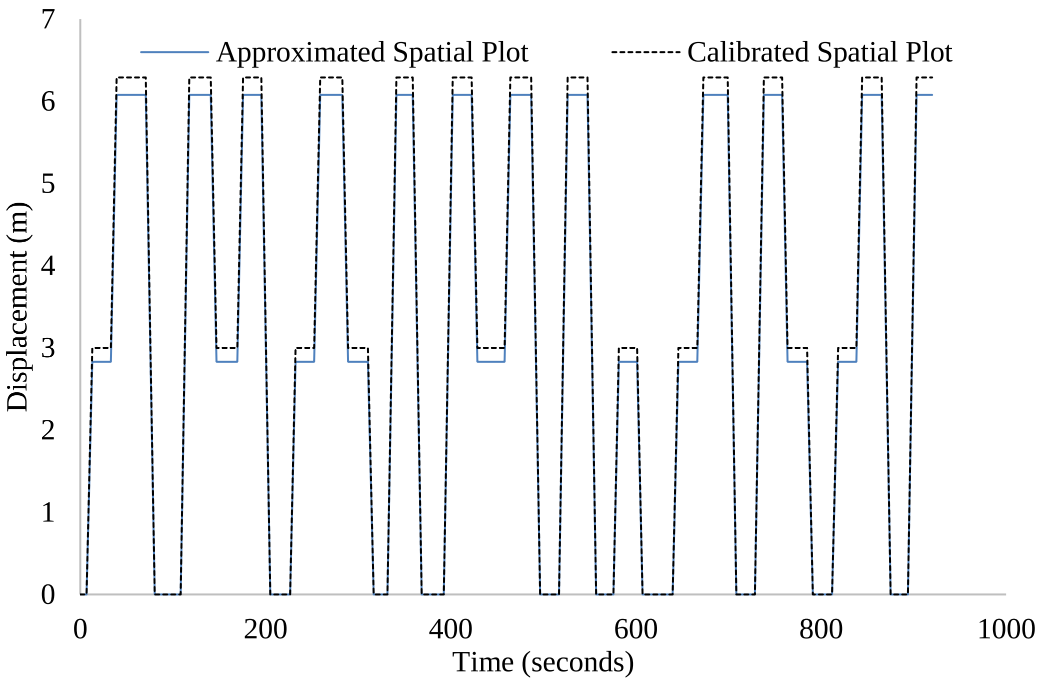

Figure 12: Approximated vs. Calibrated Displacement Profiles (Low Rise Building)

Table 1 shows a comparison between the approximated floor positions found by the software and the real floor positions provided from building data.

Table 1: Comparison of Approximated and Real Floor Positions

	Level 1	**Level 2**	**Level 3**
Approximated Floor Position	0.00	2.83	6.08
Real Floor Position	0.00	3.00	6.29
% Error	0.00%	5.61%	3.38%

4 DISCUSSION AND CONLUSIONS

Sensors are not ideal and solving a task with idealised data does not necessarily provide a real-world solution.

The high-rise data was collected by an accelerometer integrated in a budget tablet. The sampling frequency was inconsistent over the data set and the data contained significant noise. This made it particularly challenging to process, but ultimately led to a more robust software processing technique.

Using the accelerometer provided with an existing lift performance measurement tool [7] on a low-rise building, the floor positions were identified reliably with a floor position error of up to 5.6%. Given that in a commercial building, the floor to floor height is at least three meters, these errors do not inhibit the floor positions being identified. However, in the instance of a 100-meter express zone, a 5.6% error corresponds to 5.6 meters which is greater than a typical floor height. A more accurate sensor would be required to address this issue.

The software can be applied in lift monitoring applications, and the development of mathematical models to extrapolate passenger demand from stops [3]. It could be extended to work in three dimensions to be applied to other positioning monitoring applications.

There is a relationship between noise and sampling frequency, i.e. it is possible to reduce noise level by lowering the sampling frequency [8]. An investigation into the optimal sampling frequency and minimum resolution in relation to this application would be worthwhile. That is to minimise noise without compromising the identification of the key phases of the acceleration profile.

REFERNCES

[1] CIBSE, *CIBSE Guide D: Transportation systems in buildings*. Chartered Institution of Building Services Engineers London, 2015.

[2] L. Al-Sharif, 'New Concepts in Lift Traffic Analysis: The Inverse S-P (I-S-P) Method', in *Proceedings of the International Conference of Elevator Technology*, Amsterdam, 1992.

[3] R. D. Peters, 'Lift Passenger Traffic Patterns: Applications, Current Knowledge and Measurement'. [Online]. Available: https://www.peters-research.com/index.php/support/articles-and-papers/50-lift-passenger-traffic-patterns-applications-current-knowledge-and-measurement. [Accessed: 22-Mar-2019].

[4] R. Basagoiti, M. Beamurgia, R. D. Peters, and S. Kaczmarczyk, 'Origin Destination Matrix Estimation and Prediction in Vertical Transportation', in *Proceedings of The 2nd Symposium on Lift & Escalator Technology (CIBSE Lifts Group and The University of Northampton)*, 2012.

[5] R. D. Peters, 'Ideal Lift Kinematics'. [Online]. Available: https://www.peters-research.com/index.php/support/articles-and-papers/53-ideal-lift-kinematics. [Accessed: 22-Mar-2019].

[6] R. M. Asha, M. D. Kavana, S. J. Parvathy, and C. M. Shreelakshmi, 'Object-Oriented Programming and its Concepts', *IJSRD - Int. J. Sci. Res. Dev.*, vol. 5, no. 09, 2017.

[7] Peters Research, 'Elevate Perform', 2018. [Online]. Available: https://www.peters-research.com/. [Accessed: 26-Mar-2019].

[8] 'RMS noise of accelerometers and gyroscopes', *Knowledge Base*. [Online]. Available: http://base.xsens.com/hc/en-us/articles/115000224125-RMS-noise-of-accelerometers-and-gyroscopes. [Accessed: 28-Apr-2019].

BIOGRAPHICAL DETAILS

Anna Peters is a Research Assistant at Peters Research Ltd and a fourth-year engineering student studying for a MEng in Aeronautics and Astronautics at the University of Southampton. This paper is a shortened form of her third-year dissertation, supported by Professor Alexander I J Forrester (academic supervisor).

Richard Peters has a degree in Electrical Engineering and a Doctorate for research in Vertical Transportation. He is a director of Peters Research Ltd and a Visiting Professor at the University of Northampton. He has been awarded Fellowship of the Institution of Engineering and Technology, and of the Chartered Institution of Building Services Engineers. Dr Peters is the author of Elevate, elevator traffic analysis and simulation software.

Machine Frames Made of Wood

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Keywords: Wood, plywood, glued laminated timber (glulam), laminated veneer lumber (LVL), cross laminated timber (CLT), BauBuche, machine frame, Environmental Product Declaration (EPD).

Abstract. At present, wood is barely used in lifts at all. However, as the number of high-rise buildings made of wood continues to increase, it seems only logical to consider using wood for lift construction as well. This article provides information on the special characteristics of wood as a building material and describes some extraordinary opportunities for reducing energy consumption and environmental impact – and thus producing better lifts.

In particular, this article describes how wood can be used efficiently as the machine frame, which supports the motor and pulley in the machine room and maintains the distances specified for the rope from the car and counterweight, while achieving the best possible angle of wrap for the rope around the traction sheave. Apart from this example, the author describes generally how wood should be used to a greater extent in lift construction, not only to improve aspects such as noise insulation within the building, but also as a means of reducing costs and increasing sustainability.

1 INTRODUCTION

The idea originated from Mr Fredrick von Maltzahn, the owner of CTV S.L. Málaga, who came from a timber-producing family in Mecklenburg (northern Germany). He also financed the two initial sample machine frames and provided the attached photographs.

At present, an increasing number of high-rise buildings around the world are being constructed of wood. Among them, there are two types of such buildings. The first of them is a wooden construction built around a concrete core. A typical example of this is the eight-storey-high LifeCycle Tower, which was constructed in Dornbirn (Austria) in the year 2012 – see Fig. 1.

Figure 1: LifeCycle Tower in Dornbirn (Austria)

Purists prefer buildings constructed completely of wood, such as Mjøstårnet, which is 85.4 m high, has 18 storeys and was completed in Brumunddal (Norway in March 2019). It is officially the world's tallest timber building (see Fig. 2).

Figure 2: Mjøstårnet in Brumunddal (Norway)

Ambitions extend even further. Researchers at the University of Cambridge together with PLP Architects are planning the Oakwood Timber Tower with a height of almost 300 m in the centre of London (see the computer rendering in Fig. 3).

Figure 3: The Oakwood Timber Tower planned for the centre of London

It is therefore only logical that the components for the lifts in this building should also be made of wood to the greatest possible extent. The machine frame made of wood in the following is an example of this.

2 WOOD – MATERIAL CHARACTERISTICS AND DESIGN EXAMPLES

2.1 Materials for wooden buildings

EN 1995-1-1 [1] is decisive for the dimensioning and design of timber structures. This standard distinguishes between the various timber materials by strength classes, with the rated value of the class corresponding to the permitted bending strength, which like the other calculated values increases with bulk density of the material (see the attached table from EN 1995-1-1 – Fig. 4)

Strength Classes – solid timber (EN 338)

Table 1 — Strength classes - Characteristic values

		Poplar and softwood species												Hardwood species					
		C14	C16	C18	C20	C22	C24	C27	C30	C35	C40	C45	C50	D30	D35	D40	D50	D60	D70
Strength properties (in N/mm²)																			
Bending	$f_{m,k}$	14	16	18	20	22	24	27	30	35	40	45	50	30	35	40	50	60	70
Tension parallel	$f_{t,0,k}$	8	10	11	12	13	14	16	18	21	24	27	30	18	21	24	30	36	42
Tension perpendicular	$f_{t,90,k}$	0,4	0,5	0,5	0,5	0,5	0,5	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6	0,6
Compression parallel	$f_{c,0,k}$	16	17	18	19	20	21	22	23	25	26	27	29	23	25	26	29	32	34
Compression perpendicular	$f_{c,90,k}$	2,0	2,2	2,2	2,3	2,4	2,5	2,6	2,7	2,8	2,9	3,1	3,2	8,0	8,4	8,8	9,7	10,5	13,5
Shear	$f_{v,k}$	1,7	1,8	2,0	2,2	2,4	2,5	2,8	3,0	3,4	3,8	3,8	3,8	3,0	3,4	3,8	4,6	5,3	6,0
Stiffness properties (in kN/mm²)																			
Mean modulus of elasticity parallel	$E_{0,mean}$	7	8	9	9,5	10	11	11,5	12	13	14	15	16	10	10	11	14	17	20
5% modulus of elasticity parallel	$E_{0,05}$	4,7	5,4	6,0	6,4	6,7	7,4	7,7	8,0	8,7	9,4	10,0	10,7	8,0	8,7	9,4	11,8	14,3	16,8
Mean modulus of elasticity'perpendicular	$E_{90,mean}$	0,23	0,27	0,30	0,32	0,33	0,37	0,38	0,40	0,43	0,47	0,50	0,53	0,64	0,69	0,75	0,93	1,13	1,33
Mean shear modulus	G_{mean}	0,44	0,5	0,56	0,59	0,63	0,69	0,72	0,75	0,81	0,88	0,94	1,00	0,60	0,65	0,70	0,88	1,06	1,25

EN 1995-1-1 Design of Timber Structures

Figure 4: Strength classes of solid wood

Strength classes are higher for wood species with a greater bulk density. The native softwood species (fir, spruce, pine) with bulk densities of approx. 410 – 520 kg/m³ lie in the range between C35 and C50, while the hardwood species (beech and oak) with bulk densities between approx. 740 and 870 kg/m³ lie in the upper range of the table. This means that only hardwood species come into consideration for the buildings with more stringent requirements on strength.

When solid timber is employed, the dependence of load on the grain of the wood has to be taken into consideration. Furthermore, the strength of the material decreases as moisture content rises (see Fig. 5), with an increase in moisture content of the material from 12 to 20% reducing strength by 26%.

Furthermore, the dimensions change as well. This is why, more than 150 years ago, plywood was invented, which involves several layers of wood each with the grain rotated by 90° being glued together. This leads to higher strength values and the swelling and shrinkage of the individual wood layers is homogenized.

Over the course of the years, further timber materials have been introduced, which in principle are based on the technology of and experienced gained with plywood. Examples include:

- Laminated timber made of softwood or poplar (glulam) in accordance with EN 14080, with the boards having the grain in the same direction when glued together – glulam from hardwood is currently used together with cross-laminated timber, CLT, (which is made of boards glued together with the grain arranged perpendicularly) for high-rise timber buildings

- Laminated veneer lumber from softwood species (LVL) in accordance with EN 14279 and 14374, in which veneer layers with parallel grains are largely glued together with phenol formaldehyde resins to produce beams or boards

- In the early 1990s, Germany and Austria then saw the development of laminated veneer lumber types, in which the individual veneer layers were glued together with the grain pattern normally rotated through 90° (in a similar way to CLT, which uses boards instead of veneer). By using hardwoods, these components then achieve strength values that enable steel structures to be replaced.

  The design of the machine frame used such a laminated veneer lumber made of beech for load-bearing purposes – boards of BauBuche Q (henceforth called “special beech LVL”) produced by Pollmeier, a company from Creuzberg in the German state of Thuringia. Design and calculation were then conducted in accordance with the BauBuche manual for structural calculation [3].

2.2 Special aspects to consider when designing with timber

The influence of grain is reduced by crosswise gluing of the veneer layers but does have to be considered in the calculation. The maximum load-bearing capacity is achieved when the grain is in the longitudinal direction of a support.

The large influence of *moisture content* in wooden structures has already been mentioned above and this is depicted once again in the following graph (Fig. 5).

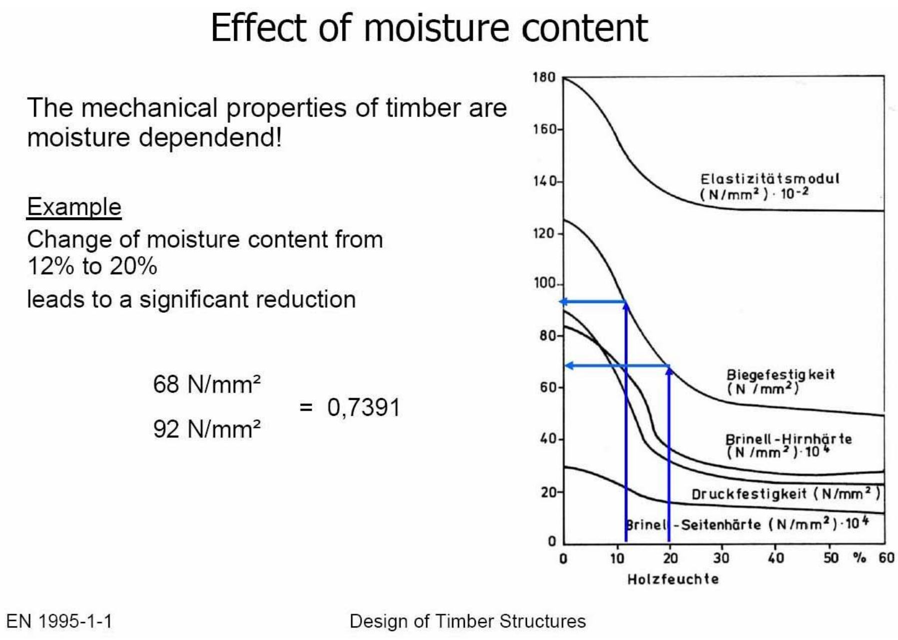

Figure 5: Influence of moisture content on the strength of wood

Biegefestigkeit = Bending Strength [N/mm²]

In order to take account of moisture content, service classes have been defined which then have to be considered in the calculations.

Wood deforms more markedly than steel, and, under constant load, the deformation is no longer reversible. The calculation therefore needs to take account of the *load-duration classes*, from permanent load to instantaneous loads.

Wooden materials naturally contain *formaldehyde*. In laminated timber this content is further increased by the use of adhesives to join the individual layers. As formaldehyde is a substance harmful to health, it is important that the maximum values of Class E1 (=0.1 ppm) quoted in the Declaration of Performance for the special beech LVL is observed.

The *fire behaviour* of wood is also considerably more favourable than would appear at first glance. Admittedly, wood as a material is flammable and is indeed classified by the German standard as normally flammable. Nevertheless, wood withstands a fire for a surprisingly long time. In the process, a carbonized layer forms on the surface of wood which has a heat-insulating effect and thus maintains the temperature on the inside at a low level [4]. The design of the structural framework for exposure to fire has to be compliant with EN 1995-1-2 [2]. Table 1 in this reference specifies a charring rate of 0.65 or 0.7 mm/min for laminated veneer lumber with a bulk density of ≥ 480 kg/m³. These values are also guaranteed for the special beech LVL. As there are also fire doors made of wood [5], it also has to be possible to produce lift doors from wood.

Wood has to be protected against *pests* (fungi, insects, bacteria). The most important protection involves keeping the wood dry as then no chemical wood protection is necessary in such cases. In hoistways, special attention is required to ensure that no condensation can arise due to temperature differences.

2.3 Examples of components made of wood in lift construction

Beams on 2 supports

The benefits of a timber construction made of laminated veneer lumber can best be shown with the aid of a simple example. Fig. 6, for instance, shows a bending beam on 2 supports, with a load and dimensions typical for the beam in the headroom of a lift with a capacity of 630 kg and a machine in the well.

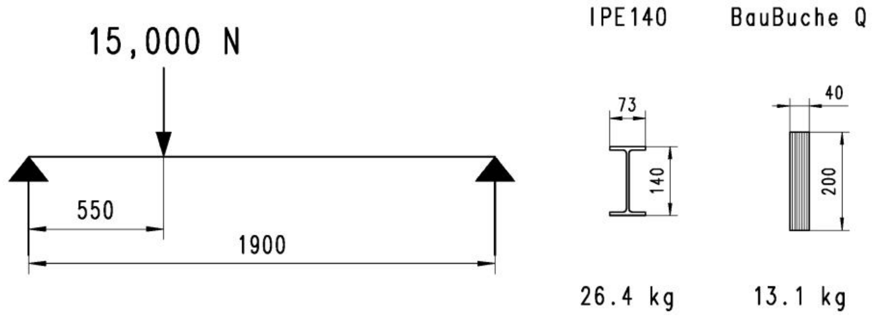

Fig. 6: Example of a simple bending made of wood compared with steel

Owing to this load, a steel beam IPE 140 is required and the maximum bending of this beam that results is approx. 1.5 mm (less than 1/1000 of the span). To achieve the same deflection, a wooden beam of 40 mm of special beech LVL would have to have a height of 300 mm and would be approx. 26% lighter. As EN 1995-1-1 permits deflections of up to 1/300 of the span, it would even be sufficient to have an overall height of only 200 mm for the wooden beam. Verification of the bending stress shows that we are then also far below the permissible limit of bending stress for the special beech LVL with this value. In this case the wooden beam would then weigh only 13.1 kg and would thus be only half as heavy as the steel beam.

Machine frame made completely of wood using the special beech LVL

The first machine frame that was designed, consisted entirely of wood. In this design, all steel components were systematically avoided (see Fig. 7).

Figure 7: Machine frame made entirely of wood

Machine frame made of the special beech LVL using steel parts

As a second version, a design was then produced that primarily consists of wood but uses a number of steel parts (see Fig. 8).

Figure 8: Machine frame made primarily of wood

Owing to the existing production options, this second version was preferred. It does also, however, have substantial advantages for the absorption of internal horizontal forces. It is better suited to the creation of a complete production series in left-hand or right-hand design with a simple adaptation to the required rope centre distances, ASL, between car and counterweight. Fig. 9 illustrates how it is possible with a few simple saw cuts to maintain rope centre distances of 650 mm to 1000 mm with an accuracy to the nearest millimetre.

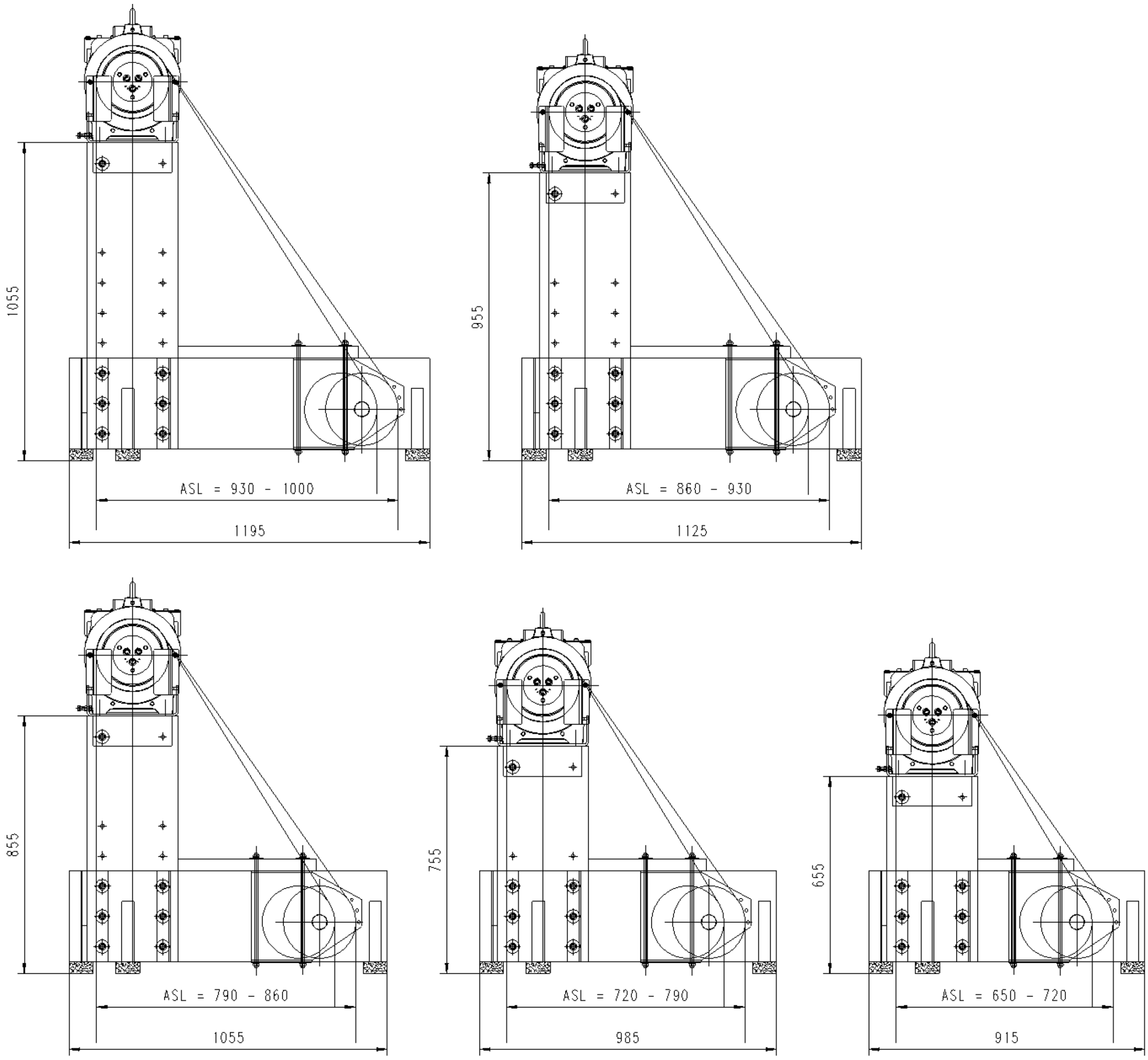

Figure 9: Simple adaptation of the required rope centre distances, ASL

The design displayed has been drafted for a lift with a capacity of 450 kg and a speed of 1.0 m/s, with a direct reeving (1:1) of car and counterweight. The weight of the motor required for this design is approx. 200 kg and the machine frame weighs approx. 100 kg, of which the steel parts including the polyamide pulley accounts for approx. 40 kg - the proportion of wood therefore amounts to approx. 60 kg.

The low weight facilitates transport on the building site and installation. A further advantage is that wood, unlike steel, has a lower tendency to vibrate.

3 USE OF WOOD AS A CONTRIBUTION TOWARDS REDUCING THE ENVIRONMENTAL BURDEN

The greatest advantage of using wood, however, is the contribution that it makes to reducing the burden on the environment. It is sufficient to consider one small aspect at this point: namely the amount of energy required to produce a steel part (e.g. a beam or plate) from iron ore. – The manufacture of wooden materials involves much shorter production routes and much less energy to manufacture the end product. And prior to this, the tree has already been contributing to an improvement of the environment by producing oxygen.

Today, large lift companies advertise with the aid of an Environmental Product Declaration in accordance with ISO 14025 in order to indicate that their product is especially environmentally friendly. It is referred here, for instance, to a declaration such as that for the OTIS Gen2 Stream [6], where it can be clearly seen that the greatest environmental burden occurs in the procurement of the material (U1) and during the operation of the lifts (D4) over a number of years (see the following diagram – Fig. 10 – which has been taken from this EPD).

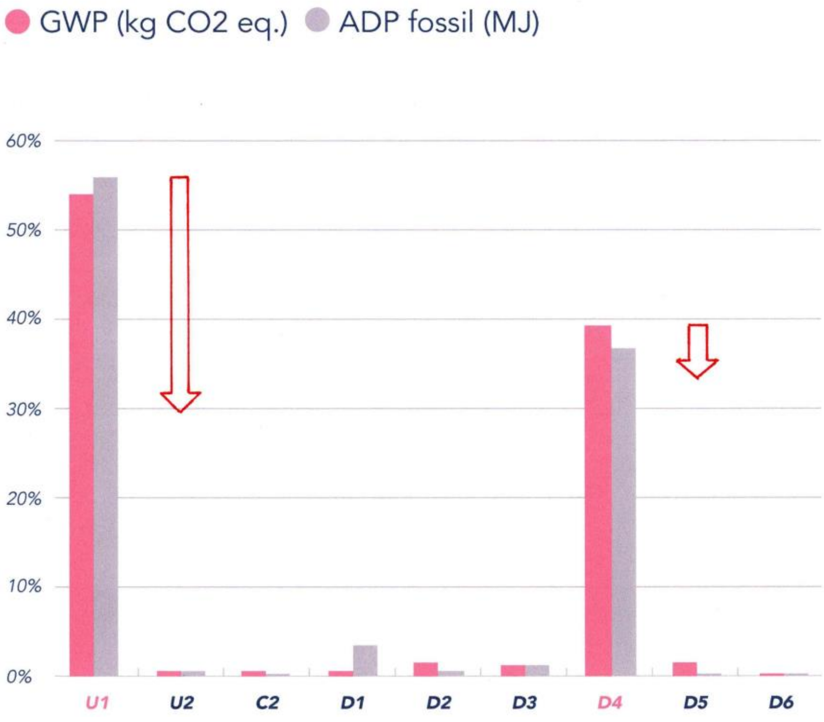

Figure 10: Life Cycle Assessment OTIS Gen2 Stream

GWP – Global Warming Potential [kg CO2 eq.]

ADP – Abiotic Depletion Potential [MJ]

This also clearly sets out how the environmental burden can be effectively reduced. One particularly effective measure lies in the field of material procurement by reducing the steel content:

- By reducing the masses (lightweight construction)
- By eliminating entire components (e.g. the counterweight with its guides in drum lifts)
- By replacing steel with wood – the more components that are replaced (e.g. machine frame, car, landing doors, …), the more effectively the environmental burden can be reduced and very large savings can be achieved in this way.

The savings potential to be achieved in the operating costs is lower:

- Due to the lower mass (e.g. wood instead of steel) that subsequently has to be moved during operation, the frictional losses decrease during the journeys, which means the efficiency within the system improves and, accordingly, the required motor output and power consumption decrease.

- Added to this is the fact that the lower masses lead to a reduction in the start-up and braking currents.

However, this also requires a change in thinking for driving the lifts. In the traction drive, which is the most commonly used system at present, the friction is produced on the traction sheave by the large masses of car and counterweight. If the masses are reduced through the use of wood, the advantage lies with other drives:

- For smaller travel distances (up to 25 m), the winding drum lift (or other drives that function in a similar manner) offers a solution.

- In the case of greater travel distances, traction lifts are conceivable in which suspension ropes and driving ropes are separated and the friction for the drive is produced via weights (or, for example, similarly functioning drives). Such drives have been familiar since the beginning of the last century and have been produced by a number of lift manufacturers up to the present day (see US Patent No. 810 941 dating from 7 May 1903 [7]).

Wood can be used for the following lift parts: beams, machine frame, cabins, car doors and landing doors and hoistway cladding panels. In many cases, timber is already the predominant material for scaffolding and barriers needed during installation as well as for packaging.

REFERENCES

[1] EN 1995-1-1 : 2010-12: *Eurocode 5: Bemessung und Konstruktion von Holzbauten Teil 1-1: Allgemeines – Allgemeine Regeln und Regeln für den Hochbau*

EN 1995-1-1 : 2010-12: *Design of timber structures - Part 1-1: General - Common rules and rules for buildings*

[2] EN 1995-1-2 : 2010-12: *Eurocode 5: Bemessung und Konstruktion von Holzbauten Teil 1-2: Allgemeine Regeln – Tragwerksbemessungen für den Brandfall*

EN 1995-1-2 : 2010-12: *Eurocode 5: Design of timber structures - Part 1-2: General - Structural fire design*

[3] BauBuche *Buchen-Furnierschichtholz* Bemessungshilfe *für Entwurf und Berechnung nach Eurocode 5 – 2. überarbeitete Auflage*

BauBuche *Beech laminated veneer lumber* - Design assistance *for drafting and calculation in accordance with Eurocode 5*

[4] Schopbach, *Ungeschützte Holzbauteile im Brandfall. HOLZBAU 5/2016 [Unprotected timber components in the event of fire]*

[5] Schörghuber, *Spezialtüren aus Holz [Special doors made of wood]*

[6] Environmental Product Declaration *OTIS Gen2 Stream. EPD registration number S-P-01068 – Issue date: 2018-04-05*

[7] US-Patent No. 810,941, *Nelson Hiss & Henri de Buren – Traction Apparatus – May 7, 1903*

BIOGRAPHICAL DETAILS

Dipl.-Ing. Roland Stawinoga has been involved in the mechanical design of elevators (and escalators) for more than 60 years. He is a member of the IAEE and well-known for his technically authoritative lectures (ELEVCON from 1993 in Vienna till 2001 in Berlin), which have also been published in the most important elevator trade journals (Elevator World, Lift-Report, China Elevator and others).

In 1990, he founded his own engineering office in Hamburg and – since planning and supervising the construction of the lifts for two of the five buildings in the German Bundestag – he has been living in Berlin. He passes on his experience to lift firms by providing them with technical advice and delivering special designs and calculations. In 1997, he was invited by OTIS to conduct further training seminars for their employees and since then has conducted far in excess of 100 seminars with a total of approx. 1,100 participants (among them 470 OTIS employees). A large number of these seminars took place in Rosswein in Saxony, where four seminars are again scheduled at MFM this year. Furthermore, he has also conducted seminars for firms directly on company premises, most of which have been held in English, Spanish and Polish.

Polish Lift Industry Education & Training

Tadeusz Popielas
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Keywords: PALM, staff education, lift maintenance

Abstract. The Polish Association of Lift Manufacturers (PALM) has been running a staff education program for the lift industry since 2004. This was due to a shortage of employees for the installation and maintenance of lifts. This deficit widened after Poland's accession to the European Union and the rapid outflow of specialists from the Polish market to EU countries. PALM decided to conduct staff education in the public education system in Poland at the level of secondary technical school (technical school). PALM runs this program in a situation of continuous educational reform, especially vocational education. The reform began in 2000 and continues to the present, which makes the program very difficult. In addition, in the initial period PALM taught a profession that did not exist in the list of professions of the Ministry of National Education, so PALM had to create this profession and then enter it into this list.

1 INTRODUCTION

The education system in each country is shaped by many years of tradition, cultural conditions and state policy. In the case of vocational education, the conditions resulting from industrial culture and its condition must also be taken into account. In Poland, as a result of the system transformation after 1989, there was a huge restructuring and privatization of state-owned enterprises. Many of these enterprises went bankrupt or split into smaller units. At the same time, vocational schools were liquidated in these enterprises. In addition, the number of secondary technical schools and the opportunities for students of these schools to practice in enterprises have decreased. This political and economic situation in the years 1990 - 2004 caused a growing problem with the recruitment of employees by companies, especially in the area of advanced technology. Additionally, a lack of employees results from Poland's accession to the European Union. Over 2 million young Poles left Poland, which deepened the bad demographic situation. Also, the reform of the vocational education system introduced in 1999 caused the outflow of young people from vocational schools.

2 PALM PROGRAMME – SECONDARY TECHNICAL SCHOOLS

2.1 Public vocational education in Poland structure 1999-2020

The reform of the public vocational education system has been in Poland for 20 years. After 20 years, we returned to the system that was in Poland before the reform of 1999. The reform of 1999 ruined the system of vocational education. Almost all basic vocational schools and a large number of secondary technical schools have been liquidated.

The time schedule of the implemented vocational education reform in Poland:

- **1999 - The reform of the education system – beginning**
- 1999- 2017 Basic vocational school - 3 years
- 1999 -2019 Secondary technical schools – 4 years
- **2012 - Amending the act on the education system - liquidation of specialization from 2014**, Apprenticeship only in occupations approved by the Minister of Education

- **2017 - entered into force: Education Law and Regulations introducing the Act - Educational Law**
- 2017/2018 – Basic vocational school -> Stage I sectoral vocational schools – 3 years
- **2020/2021 – Stage II sectoral vocational schools – 2 years**
- **2019/2020 - Secondary technical schools – 4 years -> 5 years**

2.2. Curriculum delivered by the Polish Association of Lift Manufacturers

The PALM personnel education and training program for the lift industry began in 2004. PALM curriculum was designed for the **public technical secondary schools.** Our goal was the best possible preparation of young staff for the lift & escalator industry based on core curriculum for technical secondary schools. The programme is realised in co-operation with the Polish Office of Technical Inspection.

The time schedule of implementation of PALMs' programme:

- **2004-2010 -** from the 3rd Grade**, specialization in existing official professions - electrician technician, mechatronics technician, electronics technician.**
- **2010-2012** – Realisation of Human Capital Operational Programme, Priority 9 Development of education and competencies in the regions, Measure 9.2. Improvement of attractiveness and quality of vocational education – **New opportunities, new qualifications - specialization of mechanic of lifting equipment (€** 250,000 EU subsidy).

The Program resulted in the development of a professional specialization program respecting the Employee Skills Methodology (MES) module.

Curriculum Structure:

- The curriculum was divided into 10 M (Modules),
- Each of the 10 M is divided into 40 TUs (Training Units),
- The 40 TUs containing 210 hours of teaching,
- Placements: 4 weeks in grade 3
- Practical training at employers' sites: 50% of all the classes in grade 3 and 4,
- SEP (Association of Polish Electricians) Certificate -- maintenance up to 1kV awarded in grade 3,
- Category III qualifications – maintenance awarded in grade 4.

The list of Modules:

- M-01: Defining the types of lifts and escalators, their structure and work cycles
- M-02: Maintenance of mechanical elements assembled in a lift shaft
- M-03: Machine room and sheave room maintenance
- M-04: Electrical drive assembly maintenance
- M-05: Brake systems maintenance
- M-06: Hydraulic systems maintenance
- M-07: Control and electrical systems maintenance
- M-08: Determining the principles of conducting overhauls, commissioning and maintenance work in lifts
- M-09: Maintenance of lift devices for the disabled
- M-10: Revision/preparation for examination

- **2012-2014** PALM creates a new professional qualification for the lift industry - **lift equipment technician** which has been approved by the Minister of Economy and the consent of the Minister of Education.

PALMs' participation in the development of curriculum documents for a new profession:

- Basics of program education in the profession
- The curriculum for the profession
- Qualifications exams

Goals of education in the profession - performing the following professional tasks:

- Mounting lifting devices,
- Assessment of the technical condition of lifting equipment
- Performing activities related to the operation and maintenance of lifting equipment,
- Modernization of lifting equipment,
- Organizing works related to the assembly, operation, maintenance and modernization of lifting equipment.

- **2015 – 2019** PALM realised programme in secondary technical school – 4 year
  - Grade 2 - 17 days professional practice in companies (one day a week)
  - Grade 3 - 30 days professional practice in companies (one month).

- **From 2019/2020** – secondary technical school – 5 years - recruitment of students to these schools began in May 2019.

- **From 2020/2021** – Stage II sectoral vocational school – 2 years - there are no necessary ordinances of the Minister of National Education (**as a result of our experience, also to meet the needs of lift companies, we are thinking about launching a stage II sectoral vocational school program).**

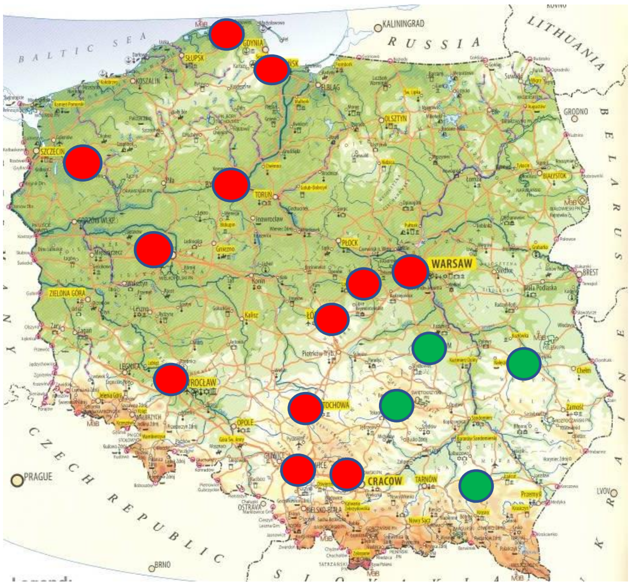
PALM, together with representatives of Schools, conducts the promotion of the profession (educational fairs, open days, technology days, seminars, website, social media – Facebook).

For the needs of the new profession, lifting equipment workshops are created in schools.
There is a possibility of taking patronage over the workshop of lifting devices by lift companies.

Purchases of the necessary equipment for vocational education and for exams in professional qualifications are being carried out. The purchases are financed from the EU structural funds and from the budgetary resources of local municipalities

The PALM program can also be used in vocational adult education. This program can be implemented in the same schools in the form of courses lasting 750 or 1000 hours depending on whether a person works in the lift industry or not.

The dynamic development of technologies, including technologies in the lift industry, makes us think about tools supporting the curriculum, such as virtual reality. These tools are already being used by lift companies to train their employees and are beginning to be used to conduct, among others, diagnostics and maintenance of lifts. The development of technology raises questions about the meaning of many years of education. Maybe soon the only justification for it is that young people have to acquire experience in the area of safe, responsible and independent work on a lift within a few years of school.



Key:

12 schools with the PALM patronage

4 new schools in 2019/2020

Figure 1: PALM programme – secondary technical schools in Poland – where we are

3 CONCLUSIONS

The vocational training program in post-elementary schools is implemented within 4 to 5 years. It requires political stability because, first and foremost, students should be recruited and their parents should be persuaded to support their decisions. In addition, schools need to adapt to new conditions together with changes in the education system, both due to their educational base and teachers. Employers also have to adapt to these changing conditions, for example by changing the safety procedures for young people. This paper shows how difficult it is to implement the education program of future employees, including, for example, the lift companies, in a situation of nearly 20 years of reforming education in Poland.

BIOGRAPHICAL DETAILS

Tadeusz Popielas - MSc. Environmental engineering. A graduate of the Faculty of Environmental Engineering at the Warsaw University of Technology. Postgraduate studies at the Warsaw University of Technology. A member of the Mazovian Chamber of Civil Engineers. Secretary General of the Polish Association of Lift Manufacturers, member of the Technical Committee No. 131 of the Polish Committee for Standardization of elevators, escalators and moving walkways. Member of the Statistics Committee and member of the Working Group on education and training of the European Lift Association (ELA). He is an organizer of a number of seminars and conferences related to the safety and accessibility of passenger lifts, escalators and moving walkways. Author of numerous articles and publications devoted to the safety of lifts. He is an initiator of the personnel training program for the lifting industry in Poland at the level of secondary technical school.

Technical challenges involved with designing the vertical transportation in a large football stand

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Keywords: Stadium, football stand, wheelchair, evacuation lifts, firefighting lifts, accessible stadia, ambulant disabled evacuation.

Abstract.

This paper discusses the vertical transportation aspect of a project of replacing the main stand of a stadium for a Premier League Football Club, from design concept to completion. It looks at how the design incorporated the multi-use of lifts and the Vertical Transportation (VT) requirements for both general admission and corporate hospitality guests. Compliance with The Accessible Stadia; Sports Ground & Stadia Guide [1], firefighting and wheelchair evacuation provision was required.

The paper examines the implication of time constraints when moving passengers with vertical transportation. Where appropriate these were evaluated against overcrowding, potential pinch points within the access and egress times.

In addition to this Local Authority requirements were addressed in regard to non-ambulatory attendees and evacuation procedures in case of emergency. The design development included working with football club officials to ensure that the lifts were only used as directed.

A fundamental aspect of the project design brief was to minimise the number of lifts in the stand. The project included working with the club and the main contractor to ensure all vertical transportation equipment was installed and commissioned in time for test events and first match.

The project was completed successfully within the set timeframe and budget with no significant issues at completion. The vertical transportation system has operated successfully since it's installation.

1 INTRODUCTION

A Premier League Football Club planned to replace their existing main stand with a much larger 'New Main Stand'. The New Main Stand was to comprise of general admission spectators and corporate guests. The accessible stadia requirements were to be met by providing facilities for a large number of supporters using wheelchairs.

The project involved developing the concept design through to the completed operational stand.

The design included the multiuse of lifts to minimise the number of lifts on the stand and evaluation of the use of escalators in place of lifts to move able bodied General Admission (GA) spectators up to the upper concourse.

The design development included working with the football club to obtain City Council Building Control approval of the firefighting lift provision and supporters using wheelchairs evacuation and grant a licence.

The on-site duties included working with the club and main contractor to ensure all vertical transportation equipment was installed and commissioned in time for test events and first match.

2 PROPOSAL SUBMISSION

A request for a fee proposal (RfP) submission for a replacement of the main stand at a Premier League Football Club with a much larger one was received. It is an iconic football ground and the vertical transportation design needed to meet their stringent requirements and the level of service required to be commensurate with the football club image.

As part of the fee proposal submission it was required that a lift strategy document was prepared. This strategy document included commentary and observations on the on the RfP proposal drawings. Part of the strategy document that was submitted was the initial considerations on positions and arrangements of the lifts - this took the form of sketches marked on the RfP drawing.

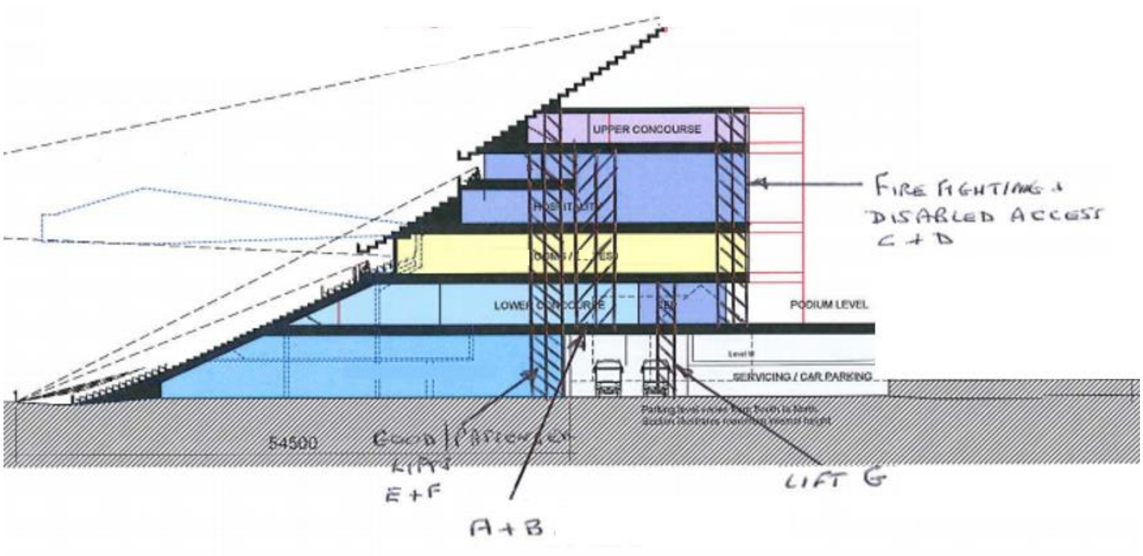

Figure 1: Initial considerations on vertical locations.

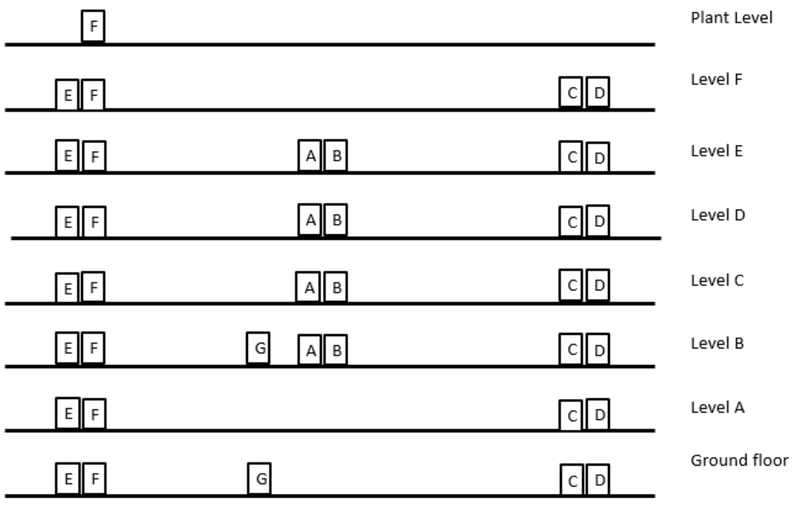

Figure 2: Initial considerations on floors served.

The submission was successful, and appointment made.

3 INITIAL DESIGN

Development of the overall vertical transportation strategy involved working with the football club and architect to design a scheme that would enable:

- Goods to be moved up to the concourses to supply the various units prior to an event and rubbish removal following an event,
- A large number of wheelchairs and ambulant disabled spectators to move up to their viewing positions on different locations and levels on the stand.
- A large number of General Admission (GA) spectators to move up the stand to the upper concourse and onto the upper terrace,
- Various grades of corporate guests to move up to their respective levels (various levels),
- Firefighting operations on the upper levels,
- Emergency evacuation of wheelchair users and ambulant disabled spectators.

4 MULTI-USE OF LIFTS TO MINIMISE THE NUMBER OF LIFTS

A fundamental aspect of the strategy was to minimise the number of lifts in the stand to control capital costs, this was achieved by multiuse of lifts e.g. the same lifts used for moving goods up the stand pre-match, wheelchair/disabled access to the upper levels viewing positions, emergency wheelchair/disabled evacuation, firefighters access, wheelchair egress and rubbish removal.

The Club has a very strong Health and Safety organisation and this provides the strict management control that this multi-use strategy of the lifts demands, thus ensuring that the lifts are in a satisfactory condition for the required application at the required time.

4.1 Lift usage

To facilitate the multi-use of the lifts they were sized to accommodate the following:

Goods delivery and rubbish removal:

Goods to be moved:

- 2 No. Euro pallets, *or*
- Approx. 6 No. roll cages, *or*
- 2 No. Beer palletisers, typically 1100mm x 1000mm (size depending on providing brewery), *or*
- 2 No. 1100 litre wheeled Eurobin.

Wheelchair and ambulant disabled movement:

2 No. wheelchairs and their companions and approx. 8 No. ambulant disabled persons at the same time - the number of ambulant disabled was based on practical experience. The wheelchair sizes were based on British Standards for manually operated Wheelchairs. [2]

Wheelchair and ambulant disabled emergency evacuation:

The lifts were designed to transport 2 No. wheelchairs and up to 8 ambulant disabled persons per trip. They complied with British Standard BS 9999 [3], as well as the applicable lift standards and codes [4].

Firefighting operations:

The lifts were designed to act as firefighting lifts complying with BS EN 81-72 [5] and BS 9999. [3].

Lift car capacity and size

These lifts are 21 person, 1600kg capacity, 1400mm wide x 2400mm deep.

Hoist machinery arrangement

Due to the location of the lifts being under the rake of the upper seating terrace it was necessary to 'hand' the lifts at each end so that the hoist machinery was under the highest part of the area beneath the rake of the stand.

Lift car finishes

The lift car finishes will be suitable for passenger and goods movement with durable hard-wearing finishes, heavy duty door panels and operators. Handrails and bumper rails at below dado height and low level on all walls.

Location and number of lifts

An analysis was carried out of the required applications for the multi-purpose use of the lifts, including the following factors:

- Amount of goods and rubbish to be moved,
- Number of wheelchairs and ambulant disabled persons to be moved in normal and emergency evacuation modes (see wheelchair evacuation section below),
- Maximum wheelchair travel distances from viewing positions to the evacuation lifts,
- Constraints of firefighting operations e.g. hose run distances, access on Fire Service Access Level (FSAL) from fire protected access point to firefighting lifts,
- Availability of fire protected refuges for wheelchair and ambulant disabled persons.

The conclusion was that a single lift at each end of the stand satisfied the above requirements.

5 WHEELCHAIR AND AMBULANT DISABLED PERSONS

The Accessible Stadia [1] requirements and BS 8300 [6] were to be met by providing facilities for a large number of supporters using wheelchairs. To provide equal opportunities for wheelchair spectators to view the match/event from positions other than the traditional touch line, viewing positions are located at various levels and positions in the new stand.

There are separate viewing positions for GA wheelchair users and corporate wheelchair users. The access up the stand is separated but the emergency evacuation is combined.

In order to ensure the safe evacuation of all the wheelchair users the stand layout incorporated a number of fire protected refuges. The purpose of the refuges is to protect the wheelchair users from smoke and fire during the emergency evacuation of the stand. The principle is that wheelchair users move from one place of safety to another in a controlled manner during an emergency evacuation. The following are the fire protected refuges with a minimum one hour fire protection:

Table 1: Fire protected refuges

Level	Location of refuge	Refuge purpose	Size of refuge
Upper concourse	Adjacent to each exit from the viewing position on the terrace	To hold wheelchairs whilst GA spectators evacuate	Capable of holding at least all the wheelchairs using that exit
All levels	Adjacent to each lift	To hold wheelchairs waiting for the lift to evacuate them down to ground floor	Capable of holding at least all the wheelchairs users on that level

In order for the club to obtain an operator's licence from the City Council Building Control, stringent spectator and wheelchair emergency evacuation times were required to be complied with. Due to the locations of wheelchair viewing positions being on various levels and positions in the new stand and other factors including the evacuation of the able-bodied GA spectators, a report was prepared demonstrating the evacuation times for each of the levels wheelchair viewing positions were on, overall evacuation times and different scenarios such as:

- The loss of a lift due to being commandeered by the fire service,
- The loss of a lift due to breakdown/failure,
- Changes in the number of wheelchairs on different levels due to design changes.

The report was prepared and satisfied the City Council Building Control and the licence granted.

6 GA SPECTATOR MOVEMENT:

6.1 General admission spectators

The upper concourse is where the General Admission (GA) spectators access the upper concourse seating, the upper concourse is over the equivalent to 6 office floors above ground floor and the upper terrace seating rises above the upper concourse vomitory by a considerable amount, so it was considered by the design team that a means of vertical transportation would be required to assist moving the GA spectators up to the upper concourse. Due to the height rise of the upper concourse and the additional height of stairs on the upper terrace to the seating, the stair factor would be negligible.

Lifts

The original design concept was to use lifts only to move the GA spectators up to the upper concourse.

An aspect of the football club supporters is that they tend to live close the stadium and generally arrive at the last minute, which can result in the majority of the GA spectators arriving in the last hour before a match.

A lift traffic analysis was carried out using lift traffic analysis simulation software [7] which demonstrated that moving the require large number of GA spectators by lifts was not practical with the resulting time to move all the GA spectators being in excess of the required time even with a large number of lifts and the risk of lift failure could cause major issues.

Escalators

A report was prepared using calculations and reference to CIBSE Guide D Transportation in Buildings [8] which showed that escalators could handle this volume of spectators. Therefore the most practical way of moving this volume of GA spectators in the required time constraints was by installing escalators.

Table 2: Escalator carrying capacity

Escalator width	Carrying capacity per hour
600mm	2,250 per hour
800mm	3,375 per hour
1000mm	4,500 per hour

The escalators were positioned at each end of the stand to handle half the GA spectators that would access the stand at the entrances at each end.

Table 3: Time taken to move required total population of GA spectators

Escalator width (one escalator each end of the stand)	Time to move total population
600mm	1 hour 40 minutes
800mm	1 hour 7 minutes
1000mm	50 minutes

As previously stated the GA spectators tend to live close the stadium and generally arrive at the last minute, which can result in the majority of the GA spectators arriving in the last hour before a match. By designing the escalators in 2 banks, one of 4 and one of 5 escalators, all with the same height rise, laid one on top of each other. To avoid bunching between escalators they were designed in a “walk around” arrangement.

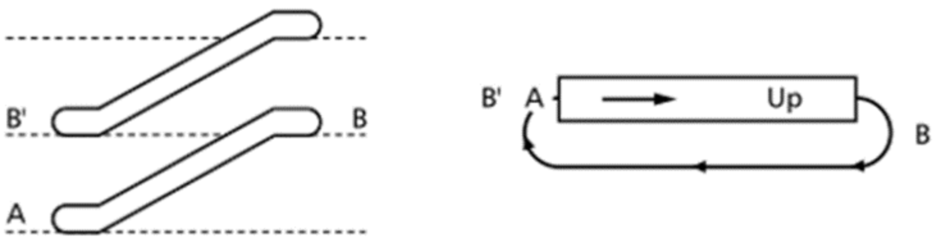

Figure 3: Walk around arrangement - schematic.

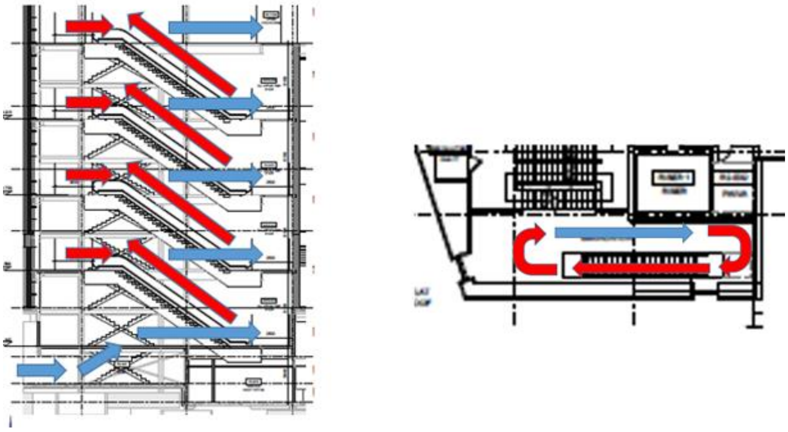

Figure 4: Walk around arrangement – applied to the scheme.

6.2 GA spectator normal egress and emergency evacuation

Normal egress

Following an event, the escalators will be reversed to assist with GA spectators' egress from the stand.

Emergency evacuation

The football stand emergency evacuation policy states that, in an emergency evacuation of GA spectators down from the upper concourse, the escalators shall be turned off and not used.

7 CORPORATE HOSPITALITY

7.1 Corporate hospitality guests

There are various grades of corporate guests in the stand with different hospitality offerings on various levels. There are a large number of corporate hospitality guests to be moved, the hospitality offering for each grade results in differing arrival times prior to an event. The number of wheelchair users for each level is identified.

To establish the likely demands on the vertical transportation system a review of the quantity of guests for each grade of hospitality and the time of arrival before an event was carried out and the results analysed. The results showed that arrival of corporate guest was spread over a period of time with the slightly larger peak nearer to the kick-off time for a match.

To evaluate whether to use lifts or escalators to move the guests a report was prepared using the information gathered above and calculation and references from CIBSE Guide D Transportation in Buildings [8], the performance of lifts and escalators was compared and concluded that escalators could move the largest group of corporate guests within the required time and lifts only did not.

Additional benefits of using escalators as the main means of moving able-bodied guests up to their respective levels (various levels) is that it enhances the appearance of the corporate hospitality entrance and circulation areas.

The lifts will be used to move corporate guest wheelchair users and ambulant disabled guests to and from their respective levels and for emergency evacuation of both GA and corporate guest wheelchair users and ambulant disabled persons. The lifts are the same size and configuration as the GA multi-purpose lifts i.e. 21 person, 1600kg.

7.2 Hospitality catering

The main catering kitchen for the corporate hospitality is on the ground floor with satellite kitchens on the corporate hospitality levels. To provide resilience and efficient service 2 No. 21 person, 1600kg lifts are provided, they are the same configuration as the GA multi-purpose lifts.

8 PLANT REPLACEMENT STRATEGY

The majority of the mechanical ventilation plant is located on the top floor of the stand above the upper concourse. To develop an effective plant replacement strategy involved devising a safe method of moving heavy plant from the plant level down to the ground floor to repair or replace it. Due to the close proximity of the rake of the upper seating terrace over the multi-purpose lifts at each end of the stand it was only possible to use these lifts for transporting the heavy plant down to the ground floor. To move the heavy plant from the top floor plant area to the upper concourse, it was necessary to install lifting beams and power hoists.

9 INSTALLATION AND COMMISSIONING

The installation was carried out during the construction of the stand with the escalators protected (entombed in wood) following installation and prior to commissioning.

Some of the lifts were used for beneficial use and refurbished and recommissioned following beneficial use.

The lift testing was carried out in an agreed sequence with witness testing taking place on completion of each lift.

10 OPERATION OF THE VERTICAL TRANSPORTATION SYSTEM

There were no escalators on the stadium prior to the New Main Stand construction and staff/steward operation and safety training was carried out.

Extensive staff/steward training took place prior to the first match at the stadium including two test events where stand evacuations took place. The equipment performed to the required standards without any issues.

11 CONCLUSIONS

The lifts and escalators were installed to the agreed design, the projects timescales were met and the project completed within agreed budgets.

The vertical transportation system in the New Main Stand worked well and met the requirements the club and local authority requirements.

12 LESSONS LEARNT

Some of the lessons learnt are:

- During the evacuation of the wheelchair users, the family members who had accompanied them to the stadium but were seated in GA seats came to the evacuation lift upper floor lobbies to ensure their wheelchair user relatives safely exited the stand, this increased to number of ambulant users of the lifts but the evacuation times were still satisfied.
- Extensive escalator operation training was essential for stewards and due to the nature of the stewards not being permanent members of staff and different stewards on the escalators each match.
- The multi-use of the lifts worked very successfully without any issues.

REFERENCES

Note: The project was designed and carried out between 2012 and 2015 and the codes and standards in the references below were current during this period with the *current codes and standards in italics.*

[1] Accessible Stadia: Sports Ground & Stadia Guide No.1. (2003). 1st ed. London: The Football Stadia Improvement Fund. *Guide edition is still current*.

[2] BS EN 12183:2009 - Manual wheelchairs. Requirements and test methods. (2010*). Current standard BS EN 12183:2014 - Manual wheelchairs. Requirements and test methods, (2014)*

[3] BS 9999:2008 Fire safety in the design, management and use of buildings. Code of practice. (2008). *Current standard 2. BS 9999:2017 Fire safety in the design, management and use of buildings. Code of practice. (2017).*

[4] BS EN 81 suite of lift safety and engineering standards.

[5] BS EN 81-72:2003 - Safety rules for the construction and installation of lifts. Particular applications for passenger and goods passenger lifts. Firefighters lifts. (2003). *Current standard BS EN 81-72:2015 - Safety rules for the construction and installation of lifts. Particular applications for passenger and goods passenger lifts. Firefighters lifts. (2017).*

[6] BS 8300-1:2009+A1:2010 Design of buildings and their approaches to meet the needs of disabled people. Code of practice. BSI, (2010). *Current standard BS 8300-1:2018 Design of an accessible and inclusive built environment. External environment. Code of practice. BSI, (2018).*

[7] Elevate lift traffic simulation software. Peters Research Ltd.

[8] CIBSE Guide D 2010 Transport Systems in Buildings, London CIBSE. *Current guide CIBSE Guide D 2015 Transport Systems in Buildings, London, CIBSE*

BIOGRAPHICAL DETAILS

Philip Pearson started his engineering career as a technician apprentice at GEC Power Engineering in the early 1970's and following a successful career in building services, got involved with the lift industry over 30 years ago. Since then he has run his own lift and escalator company, designed lifts and escalators and since 2001 has been in lift and escalator consultancy. In 2015 he founded his own consultancy practice Pearson Consult Ltd.

The IoT mirror for lift cars

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Keywords: IoT, lift car, interactive mirror, digital signage & communication, touch-screen, maintenance & safety/emergency.

Abstract. We present here "Gateway", IoT (Internet of Things) technology applied to glass mirrors in lift cars (Italian Patent No. 102017000031537 – 22 March 2017; European patent pending). It transforms common lift car mirrors into interactive touch-screen displays (managed remotely via internet).

Unlike traditional lift car video screens, the system has many different purposes:

- touch-screen interactive display;
- digital signage and communication;
- emergency connection to 24-hour servicing (through an additional micro camera);
- maintenance support (direct video/audio connection between HQ and maintenance personnel on site).

The system is extremely light and thin, with no impact on lift car weight and space. The whole system is a tailor-made product that can be easily adapted to all situations (new cars and modernisation).

1 INTRODUCTION

1.1 Traditional lift cars

Lift cars are traditionally equipped with pushbuttons to control the lift operation and to handle emergencies. However, these facilities in cars have the drawback of limiting communications between the user and the operational centre merely to an audio system.

Furthermore, warnings, messages, information and similar, are traditionally displayed in the lift car by means of posting paper notices or using small closed-circuit TV screens, exclusively devoted to this function.

The main object of the "magic mirror" is to provide a lift car where, unlike traditional equipment of this type, communication is not limited to audio signals but also includes video signals and internet connection, to provide features allowing the user to interact with the outside world and vice versa.

Another object of the invention is to provide a car having, within a single system of communication, the function of displaying notices and general information messages, both useful for the user and commercially relevant, whose dimensions do not affect the interior design or are undesirable in the smallest cars.

This new feature is particularly relevant, as it enables the lift owner to sell commercial communication/advertising with quick pay-back on his investment.

1.2 The IoT revolution

The Internet of Things (IoT) is the network of physical devices, vehicles, home appliances and other items embedded with electronics, software, sensors, actuators, and connectivity which enable these objects to connect and exchange data. Each thing is uniquely identifiable through its embedded computing system but is able to inter-operate within the existing internet infrastructure [1],[2],[3].

Experts estimate that the IoT will consist of about 30 billion objects by 2020 [4]. It is also estimated that the global market value of IoT will reach $7.1 trillion by 2020 [5].

A growing portion of such IoT devices are created for consumer use: i.e. connected cars, entertainment, home automation, wearable technology, connected health, and appliances (such as washer/dryers, robotic vacuums, air purifiers, ovens, or refrigerators/freezers that use Wi-Fi for remote monitoring) [6].

All these technologies are now applied to lift car mirrors.

2 CONNECT THE LIFT CAR TO THE OUTSIDE WORLD

In traditional lift systems, cars are passive, i.e. they lack the means suitable for communication, able to provide the user with audio and video signals or similar. If present, the auxiliary communication means (traditional TV screen, touchpad, etc) affect the appearance and design of the space inside the lift car. Such devices have limited quality in terms of design opportunities, video dimensions and brightness, tailor-made solutions. Moreover, TV screens and touchpads are exposed to various risks (e.g. vandalism and theft).

The system presented here provides new solutions. It hides the entire hardware behind a mirror (see below for glass protection technical details), avoiding the above-mentioned risks. It provides architects and designers with a new opportunity to create elegant, luxury lift cars, and includes the “wow effect”, deriving from the new communication and digital signage system.

Furthermore, the system opens the door to multiple and real-time management of communication on every single lift car, from a single remote point.

The “magic mirror” invention is for the field of cars for lifts and goods lifts (Lift Directive 2014/33/EU) and the field of carriers for lifting platforms (Machinery Directive 2006/42/EC).

The system applies the IoT technology to lift car mirrors, transforming them into new, powerful, revolutionary devices. It turns a normal mirror into a completely new multimedia tool, connected to the internet.

The external aspect (if switched off) is a traditional lift car mirror, but unlike conventional systems, this new solution offers new functions never before seen in a car, coupled with an elegant layout.

Figure 1: Rendering

2.1 Video with touch-screen technology

As an option, the mirror becomes a full screen touch video which can create interaction between the passenger/user and the outside virtual world (via the web). This feature allows maintenance operators to read operational parameters directly on site and opens the door to many other options and services that need interaction between the system and the service personnel.

2.2 System features

The system integrates a professional display, specially designed to operate 24 hours a day and 7 days a week with high brightness efficiency. The video system can be permanently active, or (depending on owner needs/requirements) it can be activated by sensors (proximity, light, weight, etc.). The touch mode can be activated/deactivated remotely or locally (depending on owner needs/requirements).

The displays features are as follows:

- Full HD (1920x1080 resolution);
- Connectivity options (either offline or online connection): LAN, Wi-Fi, HDMI, DVI-D, OPS, USB, SD CARD, IR, Audio, RJ45;
- Display dimensions (touch-screen video area - standard options): 42”, 49” and 55” (other options available);
- Display orientation: horizontal or vertical.

Table 1: Technical specifications

	Feature	42"	49"	55"
POWER	Power supply	100-240V~, 50/60Hz	100-240V~, 50/60Hz	100-240V~, 50/60Hz
	Power type	Built In	Built In	Built In
	Power consump.	110 W	125 W	140 W
DISPLAY	Dimensions	949x555x32 mm	1095x637x32 mm	1230x714x32 mm
	Resolution	1,920x1,080 (FHD)	1,920x1,080 (FHD)	1,920x1,080 (FHD)
	Contrast ratio	1,300:1	1,300:1	1,300:1
DIMENSIONS & WEIGHT	850 x 2130 mm	35 Kg	39 Kg	45 Kg
	950 x 2130 mm	37 Kg	41 Kg	47 Kg
	1100 x 2130 mm	41 Kg	45 Kg	51 Kg

2.3 Frame & mirror structure

2.3.1 Frame

The magic mirror is a tailor-made product that can be easily adapted to all situations (new cars and modernisation).

It has a frame made of special aluminium profiles that support the whole structure, its weight and gives the fixing point to the wall of the car. The frame holds the tempered mirror and the digital display.

It can be installed on new cars as well on existing ones (modernisation), simply adapting the fixing system. The fixing system might be personalized depending on the individual design situation. Owing to the rigidity of the whole system, fixing points are at the top and bottom transoms and their screws can be easily hidden.

The whole structure is lightweight, slim and elegant:

- negligible impact on rated load;
- negligible impact on lift car area (mirror thickness 35/40 mm).

The car frame structure is provided on the top transom with an air space to evacuate the heat generated by the electronic hardware.

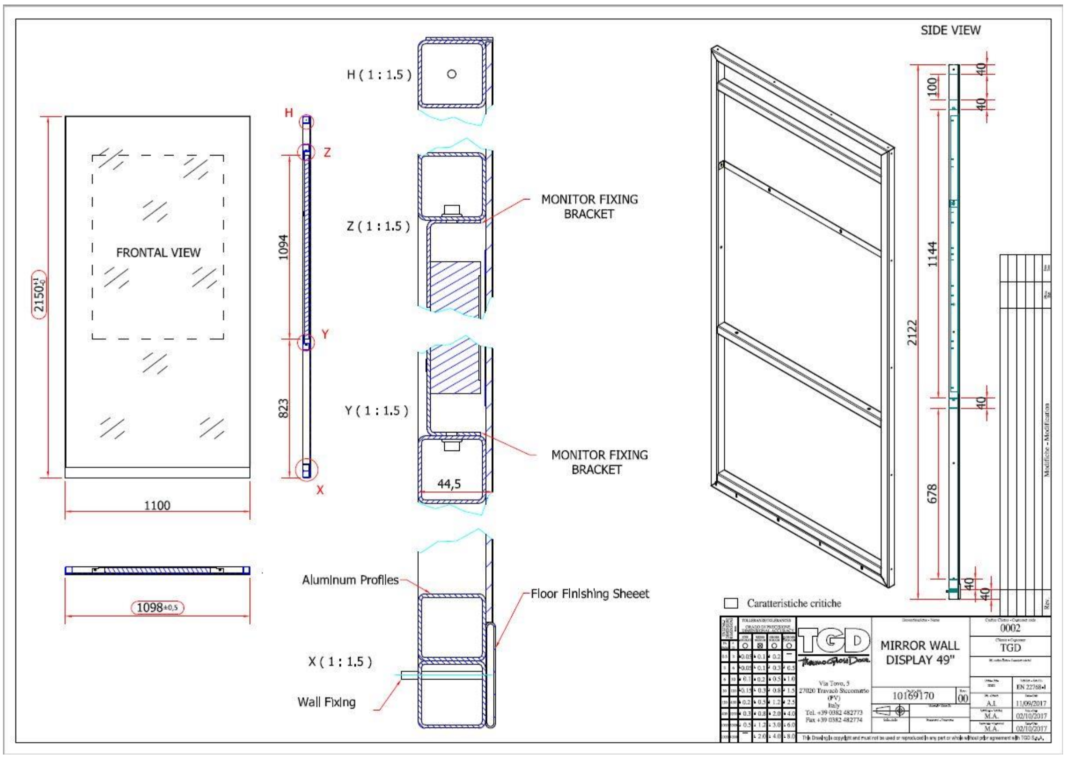

Figure 1: Frame & mirror structure (dimensions: 1100 x 2150 - 49")

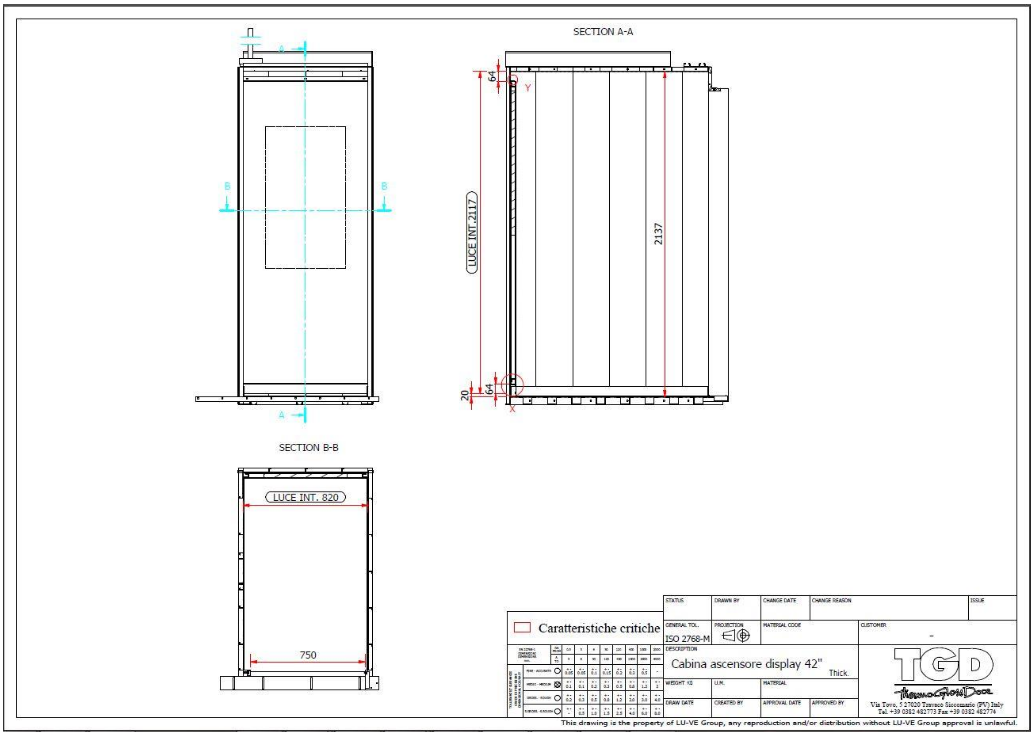

Figure 2: Mirror car integration (dimensions: 820 x 2137 - 42")

2.3.2 Glass

The mirror glass is tough and reliable. It is based on a technology already applied to glass doors for refrigerated cabinets, in shops and supermarkets (intensive use, impact resistant, high reliability over time). The glass is tempered according to EN12150 (Glass in buildings – Thermally toughened soda lime silicate safety glass) which is specific for the tempering of flat glass (it also complies with ANSI Z97.1 Safety glazing materials used in buildings). The tensile strength of the tempered glass is $150N/mm^2$, which is about five times that of normal glass. Moreover, in case of breakage, the glass shatters into small blunt-edged fragments that do not cause damage and injuries to people.

The glass panel has a reflective treatment providing a mirror-like effect when the screen is dark (or turned off), while it is transparent when the screen is lit, i.e. turned on.

2.3.3 Adaptable design

The system design is customizable both for the mirror and for finishing. Elegance and adaptability are a very important aspect of the structure design, as the magic mirror is supposed to be installed in high-end lift systems. It is also possible to customize the mirror serigraphy (screen printing), according to the customer's needs and requirements (e.g. logo).

3 CONNECTIVITY

The "magic mirror" has multiple possibilities of connection with the digital world. Once it is plugged in to the power source with a simple PC cable, it can be connected to local network (by LAN or Wi-Fi) and then have access to the internet.

Once it is connected, the system becomes a real interface that displays an infinite variety of contents that can be managed on three different levels.

3.1 Entry level

On connection to the local LAN (by cable or Wi-Fi), the system runs basic software with a certain number of templates which can be customized through a remote PC connected to the same network. Once the contents are completed, the system asks for the scheduling times and duration and transfers the contents to the display. It is possible to schedule many different contents at different times. At this level it is possible to personalize only the existing templates, with pictures and videos (no connection to RSS feed).

3.2 Pro level

This level has all the features of the Entry Level, but has a wider range of templates. It also provides the opportunity to create new content lay-out and connection to RSS feed. It still operates on a local network but the system can manage a group of displays logged on to the same network. The owner can manage the contents distribution, from a single PC for all the connected devices, giving different scheduling and layout to every single device.

3.3 Advanced level

This level has all the features of the Pro Level and in addition provides the opportunity to manage a network of devices that are connected to different local networks and are physically located far away from each other (e.g. international hotel chains). Using dedicated hardware and software, it connects all devices through the internet, so it allows the owner to create, schedule and distribute contents from a central office. This level is mandatory when the system integrates a micro TV camera or any other interface system controlled from a remote place.

Figure 3: First magic mirror delivered
(courtesy: Wittur Group)

4 APPLICATIONS & FUNCTIONS

The magic mirror is a new clever solution for lifts installed in hotels, shopping malls, office buildings, high-rise buildings, public buildings, cruise ships, airports, railway stations, hospitals, exhibition centres, high-end private lifts and home lifts, etc.

4.1 Communication and digital signage

Digital signage is defined as a "*remotely managed digital display typically tied in with sales, advertising and marketing*" [7] or as "*a network of electronic displays that are centrally managed and individually addressable for the display of text, animated or video messages for advertising, information, entertainment and merchandising to targeted audiences*." [8]

Digital signage is a sub-segment of electronic signage. Digital displays use technologies such as LCD, LED and projection to display content such as digital images, video, streaming media, web pages, weather data, restaurant menus, texts, etc. They can be found in public spaces, transportation systems, museums, stadiums, retail stores, hotels, restaurants, and corporate buildings etc., to provide wayfinding, exhibitions, marketing and outdoor advertising [9].

In this case, the magic mirror becomes a communication and digital signage device opening the lift car to the outside world. The mirror becomes a new channel of communication towards users. The system is able to transmit information, photographs, videos, web pages, advertising and much, much more, with the possibility of remotely changing the contents in real time.

The passenger/user can also ask and receive customised information, focused on his/her needs, within the services provided by the manager.

Figure 4: Communication example

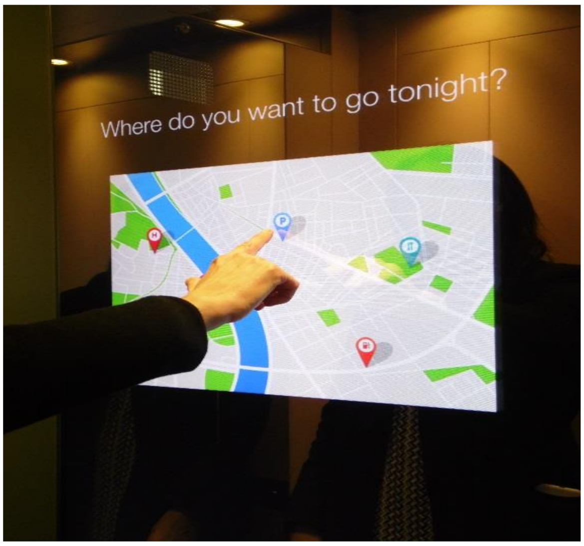

Figure 5: Touch-screen feature

4.2 Emergency mode

Calm passengers are safe passengers. In the event of an alarm, the new system can improve the safety of users, becoming a new bi-directional communication channel between the passenger and the outside world (emergency connection to 24-hour rescue service).

Through the application of a micro web-cam (invisible – hidden behind the mirror), the car has an audio/visual communication between the safety/assistance service and the passenger. The safety operator might see what is going on inside the car: health emergency, special needs (i.e. writing messages on the video screen for hearing-impaired passengers), presence of children, false alarm detection, etc.

On the passenger side, the ability to see a human face (rather than just hear an audio conversation) might reduce panic and fear.

Moreover, the audio/video system significantly improves the communication quality between the passenger/user and the safety/assistance service.

4.3 Maintenance support

Given the possibility of transforming the mirror into the touch-screen of a remote computer (i.e. servicing HQ, control room etc.), the system is a new powerful tool to support maintenance personnel on-site.

Audio-video communication coupled with touch-screen technology allows maintenance staff to connect to the service centre, access files (manuals, instructions, documents, navigate technical information to facilitate and speed up operations on the lift system, etc.). It can also provide better and faster technical information regarding the lift system on a large, user-friendly touch screen.

Due to its interactivity, the system can also turn into a powerful device to support programmed and predictive maintenance service, displaying useful information/tools (graphics, video recording, working parameters, etc.) to the operator on site.

5 CONCLUSIONS

The magic mirror applies IoT technology to lift car mirrors, transforming them into new, powerful, revolutionary devices. The system can be installed not only inside the lift car but also in the lift lobby and on floor doors to inform, entertain and guide users.

The system derives from a technology already applied to glass doors for refrigerated cabinets in shops and supermarkets. In this application field, it plays a further important role for other possible applications:

- digital signage (product information, advertising and promotion, brand building, etc.);
- audience measurement systems (how many people there are in front of a fridge, gender, age group, opening/closing cycles, etc.);
- user activity (gaming, fidelity card activities, unlocking special offers, interaction activated by proximity sensors, mobile social engagement, etc.).

Some, if not all, of these new features might be applied to lift cars, to improve information, safety/emergency and maintenance.

Lifts can provide real-time user-friendly:

- public & internal information (news, weather forecasts, local information, building directory with a map, corporate messages, etc.);
- commercial advertising on promotions, sales and other services close to lift location (in building or in the area);
- information to enhance the customer service experience in special buildings (tourist and cultural attractions, museums, exhibitions, etc.);
- enhancing customer experience (an interactive video might reduce perceived waiting time, inside lift cars and in lift lobby);
- safety information (emergency exit, building map, passenger behaviour guidelines, etc);
- maintenance (user-friendly and easy to reach technical information during service operation, remote file access, diagrams and functions display, etc);
- passenger tracking (gender, age group, boarding modes, etc.);
- two-way communication of customised information/service focused on the user’s needs (e.g. turning the touch screen into a very large push button for people with impaired view).

In the end, when dealing with IoT possibilities, the only limit is… imagination.

BIOGRAPHICAL DETAILS

Fabio Liberali is co-owner, member of the Board of Directors and head of the Communications and Public Relations Department at LU-VE Group (an international HVACR company, listed on the Milan Stock Exchange). He was the editorial manager of "Elevatori – The European Elevator Magazine" for some 23 years and a contributor to several international lift industry magazines. He is a member of Elevatori Technical Committee, on an honorary basis. He has been the Team Leader of the Italia Magnifica/Interlift 2013. He has been a consultant for several communication departments, trade associations, trade fair organisers, companies and others. He is the founder partner and co-owner at Ekuota (online, corporate finance risk management). He is co-owner of the Gateway patent. (www.luvegroup.com).

Alessandro Cremaschi is co-founder at TGD-Thermo Glass Doors (a member company of LU-VE Group). He is a member of the TGD Board of Directors and head of New Business Development. He holds a university degree in Civil Engineering (1992) and he has registered, as inventor, seven European Patents, regarding improvement of glass doors for refrigeration including LED technologies for product illumination and product branding and advertising. He has a 25 year-long experience in the use of glass and aluminium both for architectural applications (curtain walls – windows - interior partitions) and commercial refrigeration doors for negative and positive temperature cabinets. He is co-owner of the Gateway patent. (www.tgd.it).

REFERENCES

[1] Brown, Eric (13 September 2016). "Who Needs the Internet of Things?" Linux.com. Retrieved 23 October 2016.

[2] Brown, Eric (20 September 2016). "21 Open Source Projects for IoT". Linux.com. Retrieved 23 October 2016.

[3] "Internet of Things Global Standards Initiative". ITU. Retrieved 26 June 2015.

[4] Nordrum, Amy (18 August 2016). "Popular Internet of Things Forecast of 50 Billion Devices by 2020 Is Outdated".

[5] Hsu, Chin-Lung; Lin, Judy Chuan-Chuan. "An empirical examination of consumer adoption of Internet of Things services: Network externalities and concern for information privacy perspectives".

[6] "How IoT's are Changing the Fundamentals of Retailing". Trak.in – Indian Business of Tech, Mobile & Startups. 30 August 2016. Retrieved 2 June 2017.

[7] Schaeffler, J., Digital Signage: Software, Networks, Advertising and Displays: A Primer for Understanding the Business, [NAB Executive Technology Briefings], 1st edition, Focal Press, 2013, p. 1

[8] Schaeffler, J., Digital Signage: Software, Networks, Advertising and Displays: A Primer for Understanding the Business, Focal Press, 2013, pp 3-4

[9] https://en.wikipedia.org/wiki/Digital_signage

The resonance conditions and application of passive and active control strategies in high-rise lifts to mitigate the effects of building sway

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Keywords: Resonance sway, suspension, compensation, hydraulic tie-down, simulation, passive and active control

Abstract. Tall buildings and high-rise structures are subjected to sway motions of large amplitude and low frequency due to the structural resonance conditions induced by wind loads and long-period seismic excitations. To mitigate the effects of resonance interactions on suspension and compensating ropes in a high-rise lift system the masses and geometry of the system can be adjusted to change the resonance frequencies to shift the resonance regions. However, in most cases the structural constraints and system design limitations do not leave much space for the possible changes to be effective. This paper revisits the system design parameters and how the simulation models and control strategies can be deployed to mitigate the effects of resonance conditions.

1 INTRODUCTION

In the modern high-rise lift installations traction drive systems are used. Strong wind conditions and earthquakes cause tall buildings to vibrate (sway) at low frequencies and large amplitudes which results in vibrations of car/ counterweight suspension ropes and compensating ropes. Under resonance conditions this results in complex dynamic interactions in the system [1,2].

Model-based control strategies can be developed to mitigate the effects of resonance interactions. In this paper, a simulation model to predict the dynamic responses taking place in a high-rise system is discussed and used in a case study to demonstrate and explain the interaction phenomena involved. It is then demonstrated how the design parameters can be optimised to minimize the effects of adverse dynamic responses, and possible control strategies are discussed.

2 SIMULATION MODEL

A schematic diagram of the dynamic model of the lift system is shown in Fig. 1. The modulus of elasticity, cross-sectional effective area and mass per unit length of the ropes are denoted as E_1, A_1, m_1 and E_2, A_2, m_2 for the compensating ropes and the suspension ropes, respectively. The compensating ropes are of length L_1 at the car side and the suspension ropes are of length L_2 at the counterweight side, respectively. The length of the suspension rope at the car side and the compensating rope at the counterweight side are denoted as L_3 and L_4, respectively. The lengths of suspension ropes and compensating cables are varying with the position of the car in the shaft (denoted by l_{car}). The masses and dynamic displacements of the car, counterweight and the compensating sheave assembly are represented by M_{car}, M_{cwt} and M_{comp}, q_1, q_2 and q_3, respectively. The compensating sheave rotational motion is represented by the angular coordinate θ and the second moment of inertia is I_{comp}. The compensating sheave assembly (CSA) is equipped with a hydraulic tie-down device. The building structure sway deformations, represented by the shape function $\Psi(\eta) = 3(\eta)^2 - 2(\eta)^3$, $\eta = z/Z_0$, results in harmonic motions $v_0(t)$ and $w_0(t)$ of frequency Ω_v and Ω_w, in the in-plane direction and out-of-plane direction, respectively.

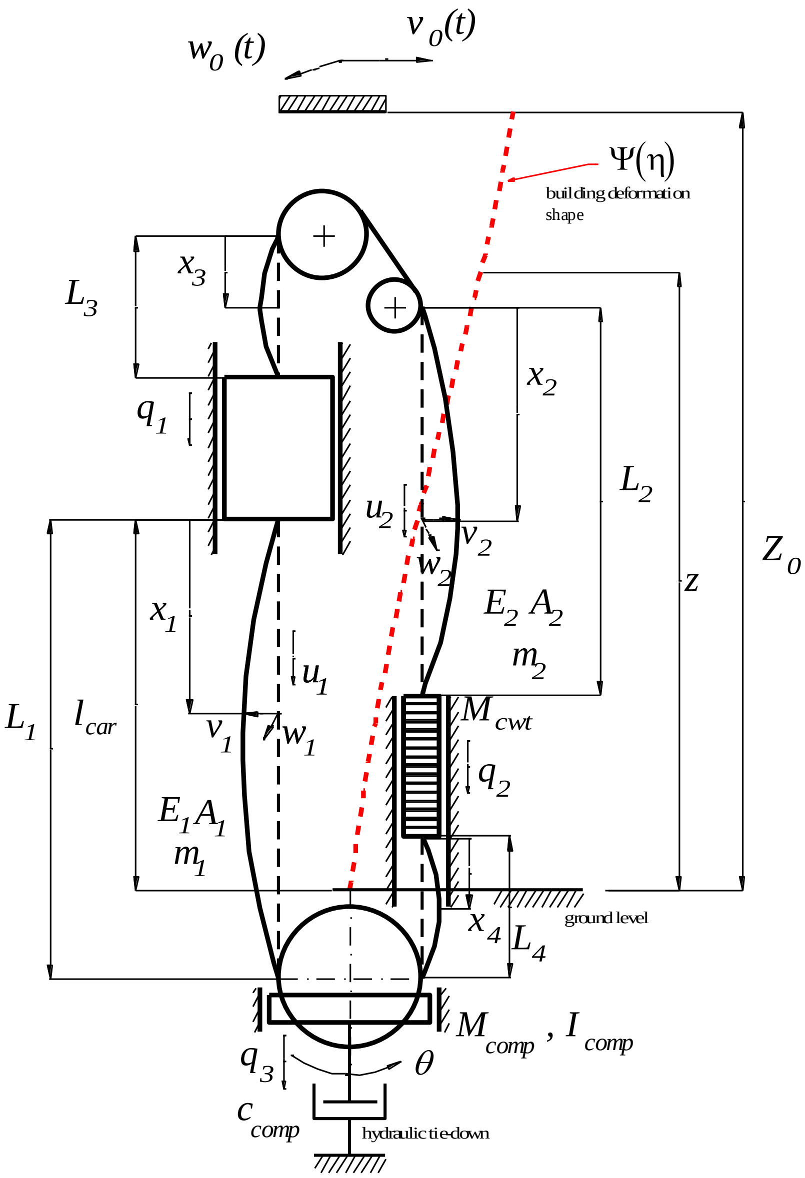

Figure 1: Model of a high-rise lift system with a hydraulic tie-down

The natural frequencies of the system change with the position of the car. An adverse situation arises when the building sways at its fundamental natural frequency which in turn is tuned to the natural frequency of the lift system, thus leading to resonance conditions. The resonance phenomena can be captured by the development of a suitable dynamic model. The model is represented by Eq. 1, where V, a represent the speed and acceleration/deceleration of the car, e_i denote the quasi-static axial strains in the ropes, $\bar{v}_i(x_i,t), \bar{w}_i(x_i,t)$, i = 1,2,…, 4, represent the dynamic displacements of the ropes, T_i, denote the rope quasi-static tension terms.

F_d is the damping force provided by the hydraulic tie-down of the constant damping coefficient c_{comp}, and α is a positive number ($0<\alpha\leq 1$). The longitudinal displacements of the compensating ropes and $x_1 = L_1$ and $x_4 = L_4$ at the car side and the counterweight side of the CSA are expressed in terms of the sheave vertical displacement and rotation as $u_1 = q_3 + R\theta$ and $u_4 = q_3 - R\theta$, respectively. Thus, the constrain relationship $2q_3 - u_1 - u_4 = 0$ is used in Eq. 1.

$$
\begin{aligned}
&m_i \bar{v}_{itt} - \left\{ T_i - m_i \left[V^2 + (g - a_i) x_i \right] + E_i A_i e_i \right\} \bar{v}_{ixx} + m_i g \bar{v}_{ix} + 2 m_i V \bar{v}_{ixt} = F_i^v \left[t, L_i(t) \right],\ i = 1, \dots 4, \\
&m_i \bar{w}_{itt} - \left\{ T_i - m_i \left[V^2 + (g - a_i) x_i \right] + E_i A_i e_i \right\} \bar{w}_{ixx} + m_i g \bar{w}_{ix} + 2 m_i V \bar{w}_{ixt} = F_i^w \left[t, L_i(t) \right],\ i = 1, \dots 4, \\
&M_{car} \ddot{q}_1 - E_1 A_1 e_1 + E_2 A_2 e_3 = 0; \\
&M_{cwt} \ddot{q}_2 - E_1 A_1 e_4 + E_2 A_2 e_2 = 0; \\
&M_{comp} \ddot{q}_3 + E_1 A_1 e_1 + E_1 A_1 e_4 + F_d = 0,\ F_d = c_{comp} \dot{q}_3 \left| \dot{q}_3 \right|^{\alpha - 1} \\
&I_{c\,comp} \ddot{\theta} - R E_1 A_1 e_1 + R E_1 A_1 e_4 = 0, \\
&e_1 = \frac{1}{L_1(t)} \left[u_1(L_1, t) - q_1(t) + \frac{1}{2} \int_0^{L_1} \left(\bar{v}_{1x}^2 + \bar{w}_{1x}^2 \right) dx_1 + \frac{\Psi_1^2}{2 L_1(t)} \left(v_0^2 + w_0^2 \right) \right], \\
&e_2 = \frac{1}{L_2(t)} \left[q_2(t) + \frac{1}{2} \int_0^{L_2} \left(\bar{v}_{2x}^2 + \bar{w}_{2x}^2 \right) dx_2 + \frac{(\Psi_h - \Psi_2)^2}{2 L_2(t)} \left(v_0^2 + w_0^2 \right) \right], \\
&e_3 = \frac{1}{L_3(t)} \left[q_1(t) + \frac{1}{2} \int_0^{L_3} \left(\bar{v}_{3x}^2 + \bar{w}_{3x}^2 \right) dx_3 + \frac{(\Psi_{car} - \Psi_{mach})^2}{2 L_3(t)} \left(v_0^2 + w_0^2 \right) \right], \\
&e_4 = \frac{1}{L_4(t)} \left[u_4(L_4, t) - q_{M2}(t) + \frac{1}{2} \int_0^{L4} \left(\bar{v}_{4x}^2 + \bar{w}_{4x}^2 \right) dx_4 + \frac{\Psi_{cwt}^2}{2 L_4(t)} \left(v_0^2 + w_0^2 \right) \right],
\end{aligned} \tag{1}
$$

The system of Eq. 1 is discretized by using the Galerkin method [3] so that the resulting set of nonlinear ordinary differential equations (ODEs) can be simulated numerically.

3 NUMERICAL SIMULATION AND ANALYSIS

To demonstrate the dynamic behavior, the simulation is implemented for a high-rise installation roped *1:1* with the car of mass 5500 kg carrying rated load of 2620 kg. The travel height is H = 300 m and the installation is equipped with compensating ropes with a synthetic fiber core (SFC) of diameter 36 mm and mass per unit length m_{cr} = 4.76 kg/m each. The car and counterweight (balanced at 50%) are suspended on 9-stranded steel core ropes of diameter 19 mm and mass per unit length m_{sr} = 1.54 kg/m each [4]. The horizontal (bending mode) natural frequencies (eigenfrequencies) of the building structure are given as $\Omega_v = 0.1$ Hz in the in-plane direction and $\Omega_w = 0.15$ Hz in the out-of-plane direction, respectively

Fig. 2 shows the variation of the first two lateral natural frequencies (ω_1, ω_2) of the compensating ropes. The frequency curves are plotted against the position of the car in the shaft, with the in-plane and out-of-plane excitation frequencies represented by red horizontal lines, respectively. At the car side it is evident that when the car is approaching the top landing the in-plane excitation frequency is tuned to the first natural frequency of the ropes and the fundamental resonance takes place. Simultaneously the out-of-plane excitation frequency becomes close to the second natural frequency of the ropes which will activate the second resonance. Similar resonance effects are taking place with the car at the bottom landing, when the resonances occur at the counterweight side.

Fig. 3 shows the variation of the first two lateral natural frequencies of the suspension ropes at the car side. The plots demonstrate that when the car is at the bottom landing, the out-of-plane excitation frequency is tuned to the second natural frequency of the ropes, which results in the second mode resonance.

Another possibility of resonance interactions arises when the out-of-plane excitation frequency is tuned to the fundamental natural frequency of the counterweight suspension ropes, with the car positioned at the top landing (see Fig. 4).

The variations of the first four vertical mode natural frequencies ($\hat{\omega}_i$, $i = 1,\ldots,4$) are illustrated in Fig. 5. It is evident that those frequencies are much higher than the resonance frequencies of the building structure.

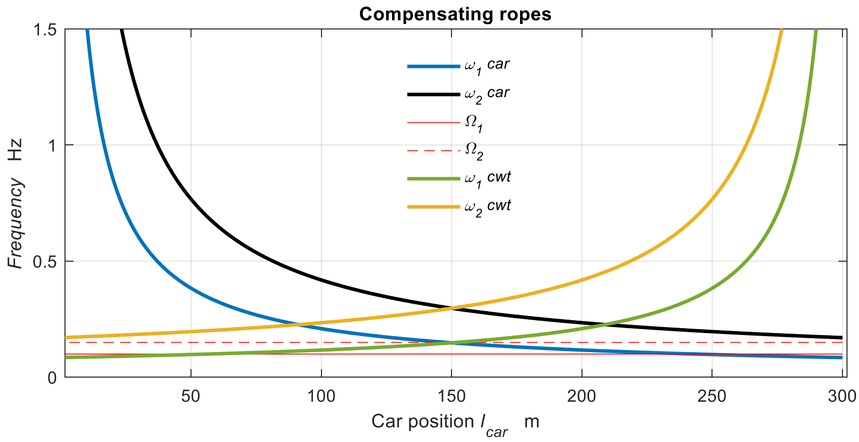

Figure 2: The natural frequencies of the compensating ropes

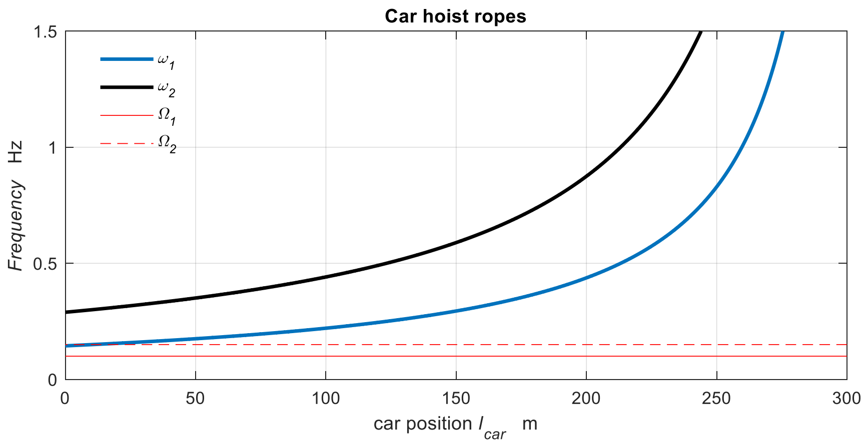

Figure 3: The natural frequencies of the suspension ropes at the car side

The effects of resonances that take place when the car is at the bottom landing are demonstrated by simulated records of the dynamic responses presented in Fig. 6 – 8. The building structure sways at the amplitudes of 0.9 m (in-plane) and 0.2 m (out-of-plane), respectively. The hydraulic tie-down damping force characteristic curve is shown in Fig. 9. The out-of-plane displacements of the car suspension ropes presented in Fig. 6 show the effects of the resonance when the out-of-plane building frequency (0.15 Hz) becomes near the fundamental frequency of the ropes. The in-plane displacements of the compensating ropes at the counterweight side presented in Fig. 7 illustrate the effects of the resonance condition when the in-of-plane building frequency (0.1 Hz) becomes near the fundamental frequency of the ropes. The FFT spectra shown in red in Fig. 6/7 demonstrate the resonance frequency tunings (0.15 Hz and 0.1 Hz, respectively). The lateral responses of the ropes are coupled with the vertical motions of the car, counterweigh and the CSA (see Fig. 8). The damping action of the hydraulic tie-down is evident from the subplot (c), where the displacements of the CSA are almost zero.

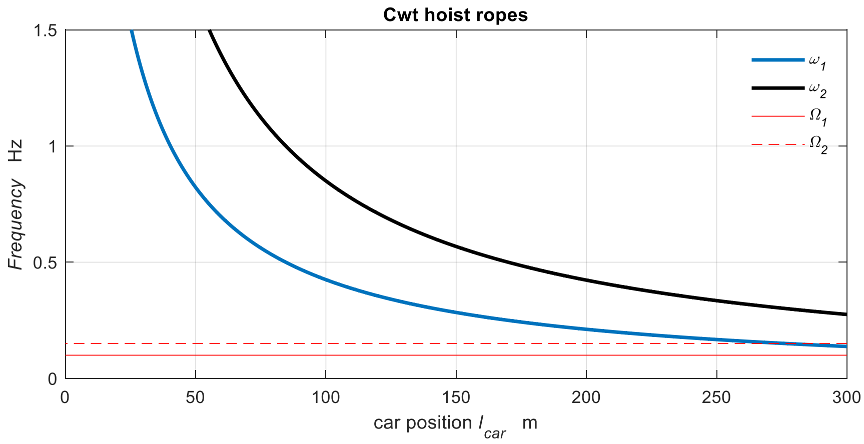

Figure 4: The natural frequencies of the suspension ropes at the cwt side

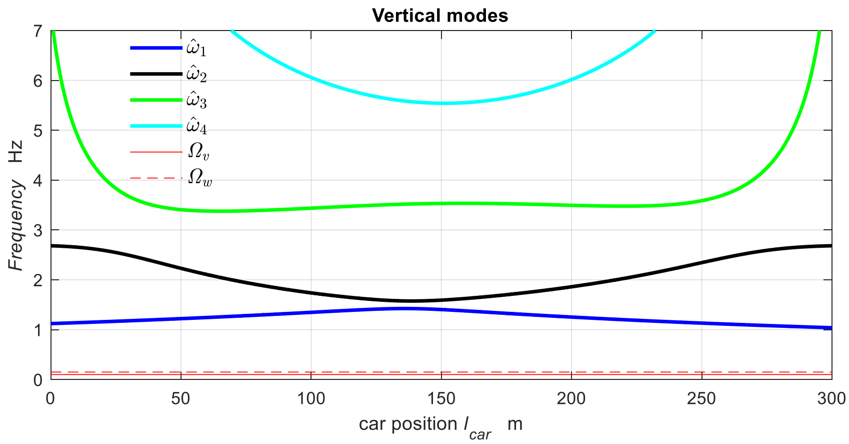

Figure 5: The natural frequencies: vertical modes

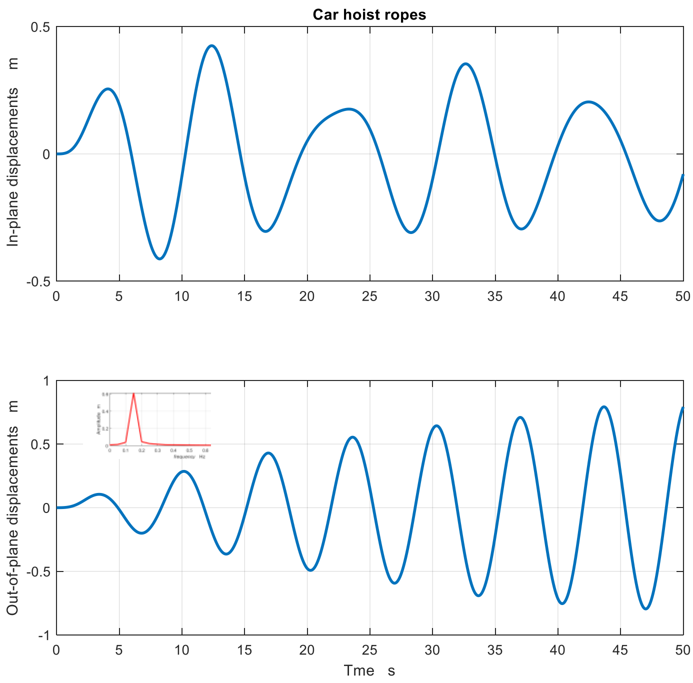

Figure 6: Displacements of the car suspension ropes at x_3 = 155 m (in-plane), 164 m (out-of-plane)

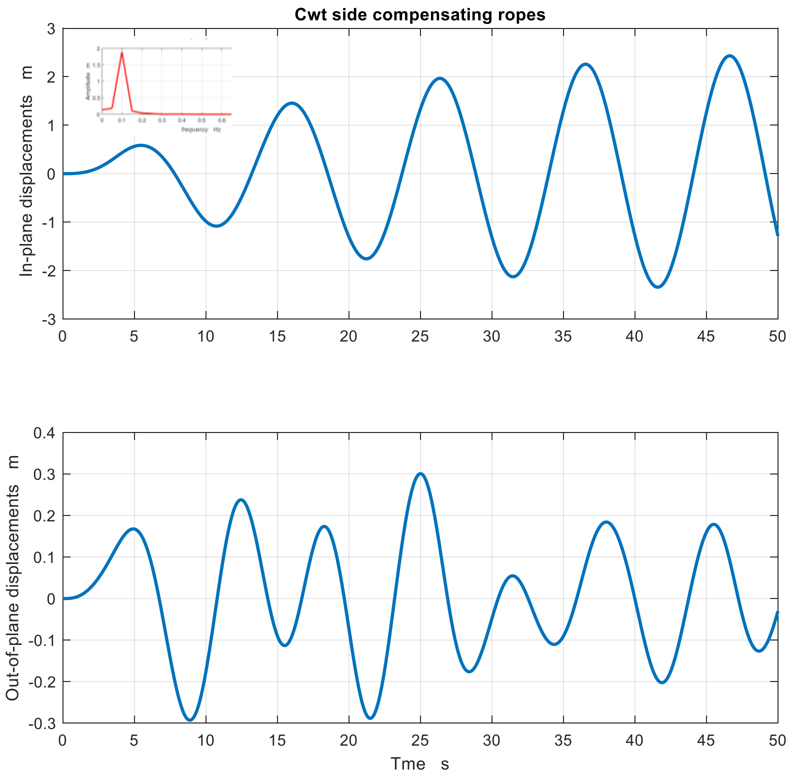

Figure 7: Displacements of the cwt compensating ropes at x_4 = 183 m (in-plane), 223 m (out-of-plane)

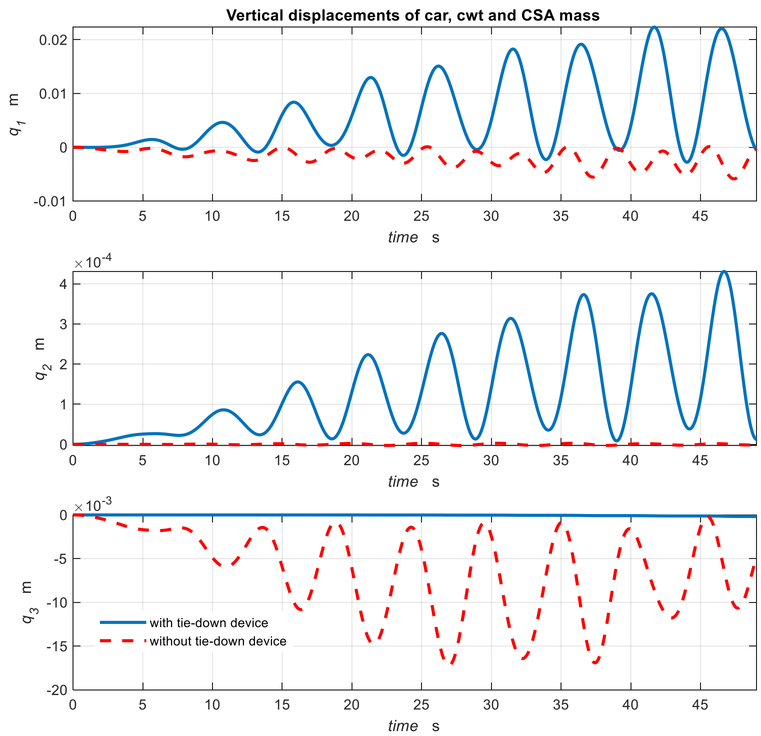

Figure 8: Vertical displacements of the car (q_1), counterweight (q_2) and compensating sheave (q_3) with and without hydraulic tie down

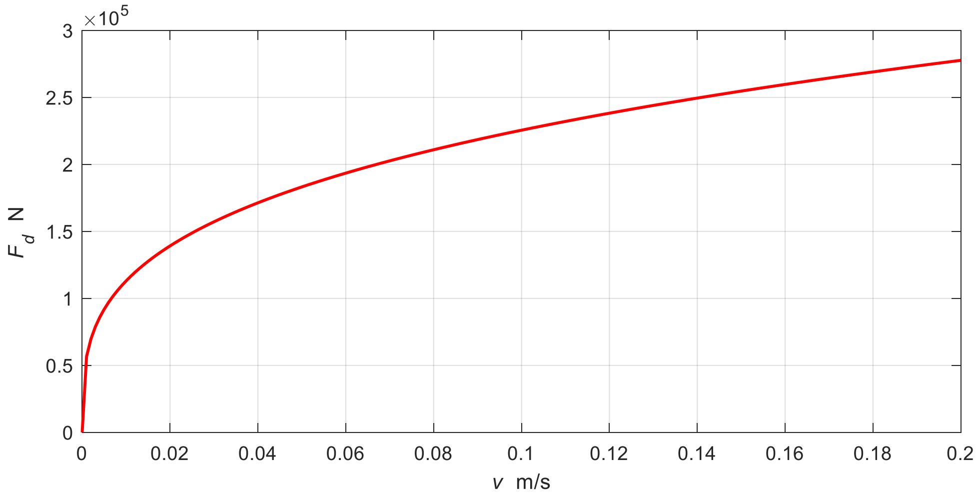

Figure 9: Hydraulic tie-down speed-force characteristic curve

4 DESIGN AND CONTROL STRATEGIES TO MITIGATE THE EFFECTS OF RESONANCE CONDITIONS

The modelling and simulation techniques are used to predict a range of dynamic interaction and resonance phenomena. This in turn informs the system design strategies. The application of a passive hydraulic tie-down device of suitable dynamic characteristics is effective in reducing the vertical motions of the CSA. However, this will not mitigate the effects of resonance conditions affecting the rope dynamics.

Various ways to limit large motions of lift ropes in high-rise applications due to low frequency building sways can be considered. Gibson [5] and Caporale [6] as well as Sun [7] discussed the use of a car follower to restrain the movements of ropes. This approach was used to control excessive rope and travelling cable sway in the World Trade Centre Towers in New York as well as in the Sears Tower in Olympia and Center Building in Chicago.

The resonance frequencies of the ropes can be shifted / changed by the use of different masses of the compensating sheave assembly. The masses of the compensating sheave assemblies can be increased or decreased in order to shift the resonance conditions. The number of ropes and their characteristics would then need to be considered. This would in turn trigger checking the system design parameters. Relevant calculations need then to be carried out to ensure that the minimum values of factors of safety and the traction conditions/ requirements would satisfy the safety regulations [8].

It should also be considered that the nature of the dynamic conditions present in the building structure is such that a small change in the natural frequencies of the structure might result in large changes of the resonance conditions. The overall stiffness of the structure depends on a number of factors and there might be some uncertainties about the final values of the structure eigenfrequencies. Thus, it is important to be aware that the natural frequencies of the structure might change with time.

Passive methods might involve the application of viscous dampers placed near the rope terminations at the car/ counterweight and acting in a lateral direction [9]. Semi-active control strategies include the application of magnetorheological dampers that achieve significant vibration reduction compared to viscous dampers [10]. The application of transverse tuned mass damper (TMD) technologies can reduce the dynamic responses in the system [11]. More recently passive negative stiffness control technique has been considered [12].

Active vibration control methods using boundary lateral motion [13,14] or longitudinal motion [15-16] have also been considered. The latter strategy utilizes the fact that the longitudinal elastic stretching of the slender element is coupled with its lateral motion. An actuator is used to produce a longitudinal oscillatory motion of the support in order to cause the time variation of transverse (lateral) stiffness which in turn results in extracting energy from the system. Such an active control method is termed *active stiffness control* [17].

The active stiffness method can be applied to minimize the effects of adverse dynamic responses of suspension and compensating in lift systems [18-20]. The means to induce a variation of the rope tension of the compensation rope comprises at least one servo actuator. For example, the system shown in Fig. 10 is equipped with a servo actuator to produce the control vertical motion $\underline{u_{comp}}$ to adjust the position of the CSA. The motion of the CSA is dictated by a suitable feedback control law. Fig. 11 show the maximum displacements of the compensating ropes and demonstrate the effectiveness of this approach when a multimode feedback law is applied. This law is implemented to reduce the resonance response of the compensating ropes when the car position corresponds to the distance l_{car} = 57 m. At this position the compensating ropes are subjected to the fundamental resonance condition (see Fig. 2). A multimode feedback law applied is given as

$$u_{comp}(t) = a_u \frac{\sum_{n=1}^{N} q_n \dot{q}_n}{\sum_{n=1}^{N} \alpha_n^2 q_n^2} \tag{2}$$

where a_u is the control factor q_n represent the modes of the compensation rope system and α_n are the mode weighting coefficients. The results presented in Fig. 11 show that the application of the tie down passive system results in smaller displacements (the line in blue). The active control results in a more substantial reduction of the rope displacements (shown in red). The control motion of the CSA (shown in green) is generated by using a_u = 0.5 in (2). The control law accommodates all in-plane and out-of-plane modes of the ropes so that the modal spillover phenomenon [17] is avoided.

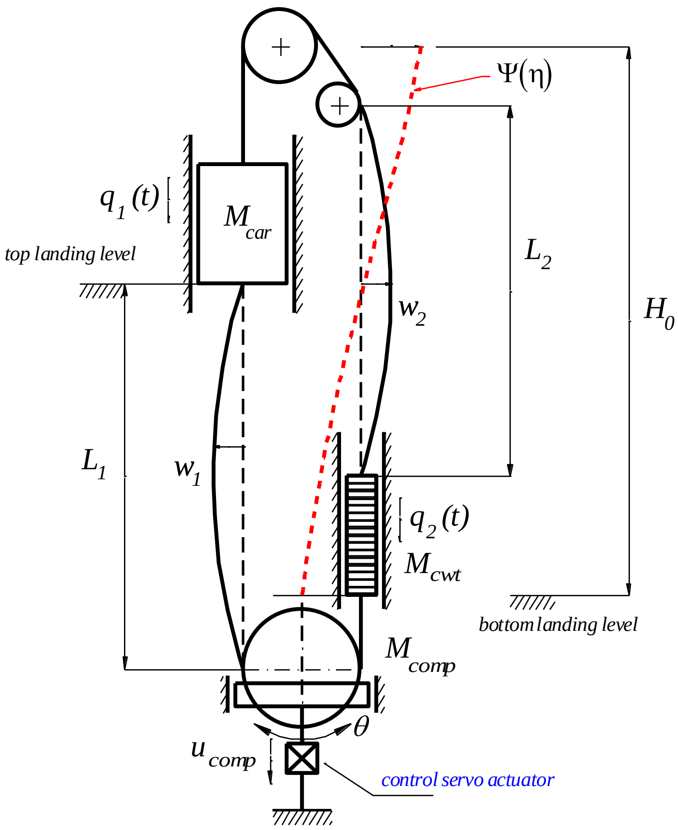

Figure 10: Active control strategy

5 CONCLUDING REMARKS

Numerical simulation results presented in this paper show the effect of resonance conditions on the dynamic responses of high-rise lift systems arising due to the sway of the host building structure. The system suffers from large lateral displacements of the suspension and compensating ropes that often exceed allowable limits. These responses are coupled with the vertical motions of the car. Counterweight and CSA. The simulation results inform the development of measures to be taken to mitigate the effects of adverse dynamic interactions that arise. Various passive methods can be deployed to mitigate the effects of resonance conditions that arise in the system. However, it should be noted that the nature of the dynamic conditions present in high-rise building systems is such that small changes of the natural frequencies of the structure might result in large changes of the resonance conditions that arise in the lift installation. Thus, more advanced strategies, such as the active stiffness method can be developed to minimize the effects of adverse dynamic responses of the system.

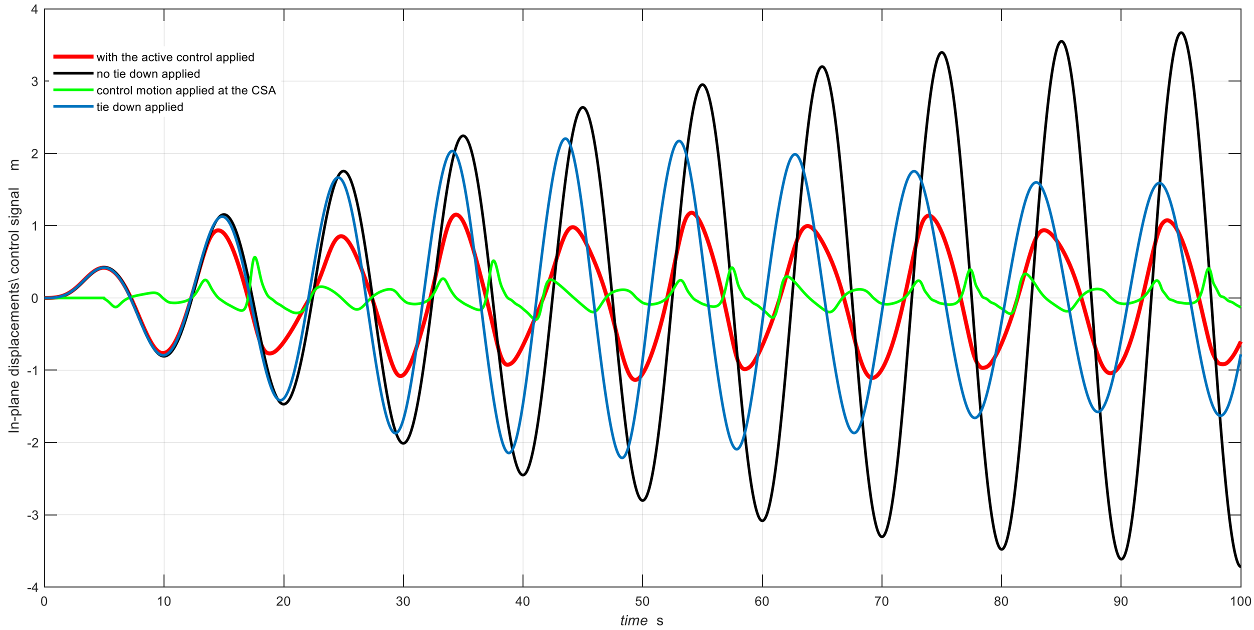

Figure 11: Effectiveness of active control strategy applied to reduce the response of compensating ropes

REFERENCES

[1] S. Kaczmarczyk, "The Dynamic Interactions in High-Rise Vertical Transportation Systems ". *Proceedings of the 8th Symposium on Lift and Escalator Technologies*, Hong Kong, 15-16 May 2018.

[2] R.S. Crespo, S. Kaczmarczyk *et al.*, "Modelling and simulation of a stationary high-rise elevator system to predict the dynamic interactions between its components". *International Journal of Mechanical Sciences*, Vol. 137(1), 2018, 24-45.

[3] L. Meirovitch, *Analytical Methods in Vibrations.* Collier Macmillan Canada, Ltd. Toronto (1967).

[4] Pfeifer DRAKO *Elevator Products* *https://www.pfeifer.info/out/assets/PFEIFER-DRAKO_ELEVATOR-PRODUCTS_BROCHURE_EN.PDF* (Accessed 01 Jul 2019).

[5] G.R. Strakosch (Editor), *The Vertical Transportation Handbook.* 1998 John Wiley, New York.

[6] R.S. Caporale, *The Effect of Building Sway on Lifts.* 2001 MSc Dissertation, University of Northampton.

[7] L. Sun, Building Sway and Elevator Rope Vibration Part III: Practical Solutions to the problems. *Elevator World*, May 1995 pp. 84-87.

[8] British Standards Institution, *Safety rules for the construction and installation of lifts — Lifts for the transport of persons and goods Part 20: Passenger and goods passenger lifts.* BS EN 81-20:2014.

[9] S. Chen, N. Darivandi, F. Ghrib, "The design of an optimal viscous damper for a bridge stay cable using energy-based approach". *Journal of Sound and Vibration*, **296**, 4689-4704, (2010).

[10] Q. Zhou, S.R.K. Nielsen, W.L. Qu, "Semi-active control of three-dimensional vibrations of an inclined sag cable with magnetorheological dampers". *Journal of Sound and Vibration*, **329**, 1-22, (2006).

[11] S. Kaczmarczyk, "The prediction and control of dynamic interactions between tall buildings and high-rise vertical transportation systems subject to seismic excitations". *Proceedings of the 25th International Congress on Sound and Vibration (ICSV 25), Hiroshima, Japan, 08-12 July 2018*.

[12] E. Saito, D. Nakazawa, T. Hirai, S. Watanabe, "Passive Vibration Control of Elevator Rope Using Negative Stiffness and Damper" *The Proceedings of the 27th Transportation and Logistics Division Conference (TRANSLOG 2018)*, 5th – 7th December 2018, The University of Tokyo, Japan.

[13] C.F. Baicu, C.D. Rahn, B.D. Nibali, "Active boundary control of elastic cables: theory and experiment". *Journal of Sound and Vibration*, **198**, 17-26, (1996).

[14] R.F. Fung, J.W. Wu, "Exponential stabilization of an axially moving string by linear boundary feedback", *Automatica*, **35**, 177-181, (1999).

[15] J.C. Chen, "Response of Large Space Structures with Stiffness Control", *Journal of Spacecraft and Rockets*, **21**, 463-467, (1984).

[16] Y. Fujino, P. Warnitchai, B.M. Pacheco, "Active Stiffness Control of Cable Vibration", *Trans. ASME Journal of Applied Mechanics*, **60**, 948-953, (1993).

[17] S. Kaczmarczyk, and P.D. Picton, "The Prediction of Nonlinear Responses and Active Stiffness Control of Moving Slender Continua Subjected to Dynamic Loadings in Vertical Host Structures". *The International Journal of Acoustics and Vibration* Vol.18(1), 2013, 39 – 44.

[18] S. Kaczmarczyk, "Nonlinear Sway and Active Stiffness Control of Long Moving Ropes in High-Rise Vertical Transportation Systems". *Proceedings of the 10th International Conference on Vibration Problems* ICoVP-2011, September 5-8, 2011, Prague, Czech Republic.

[19] R. Smith, S. Kaczmarczyk, J. Nickerson and P. M. Bass, *Elevator Rope Positioning Apparatus.* United States Patent. Patent No. US 8,123,002 B2; 28 February 2012.

[20] S. Kaczmarczyk, and R. Smith, *Elevator System.* European Patent. 21 September 2016. Patent number EP2913289 B1

BIOGRAPHICAL DETAILS

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The systems analysis and design of lifts (elevators): the models and assumptions appraised

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Keywords: systems engineering, traction drive, design criteria, structural integrity, safety code requirements.

Abstract. With modern computer systems equipped with relevant software tools / programs to automate the calculations, the systems analysis and design of lifts appears to be relatively straightforward. However, thorough understanding of engineering principles and models applied is of paramount importance in conducting the system calculations. This is critical in correct understanding of the assumptions applied in the safety standard formulae and requirements. In this context the importance of application of design / structural integrity criteria associated with the worst-case scenario dynamic conditions, to achieve a system which complies with accepted safety code requirements, is discussed and appraised. The paper demonstrates this through practical examples involving traction-drive systems designed to operate across a range of system design parameters.

1 INTRODUCTION

The design of a lift system involves bringing individual components together to arrive in a complete vertical transportation system (VTS) which will comply with the requirements of safety standards and codes and will carry the required load at the required speed over the necessary travel [1].

In any manufacturing environment, the process of system design must start with a preliminary selection of equipment. In particular, in order to commence design calculations, there must be an initial selection of hoist machine and diverter/secondary pulley. Selection of the machine must, in the first place, treat the machine as a structural member and will be based on the specified rated load and rated speed, together with an estimate of car mass based on the manufacturer's product range. Having selected a machine with its traction sheave and diverter pulley, compliance with the minimum 40:1 sheave/rope diameter ratio specified by EN81 will now determine a maximum permissible rope size.

The design process is based on system calculations which involve the application of suitable models with the calculations based on engineering principles. The complete VTS is a dynamic system with time-varying loading conditions and parameters.

The detail of the system calculation may well require a review of the initial equipment selection, since issues such as compensation and alterations to the balance factor may result in a total loading which exceeds the rating of the initially selected machine. This simply demonstrates that in common with the majority of engineering systems, design is an iterative process, both in detail and overall.

This paper demonstrates how simplified models are developed and applied in the system calculation.

2 SYSTEM DESIGN CALCULATION

The principles of engineering mechanics form the foundation for system analysis and design of a VTS. The first stage involves the system identification by developing a *physical model*. Engineering systems, such as VTS, are often very complex and certain simplifying assumptions must be made beforehand. It is expected that the simplified model will then represent the behaviour of the actual system reasonably well.

A simple model of a traction-drive lift system (without compensation) is presented in Fig. 1(a). The fundamental design calculation for the lift system involves the following parameters:

- an estimate of the frictional characteristics of the traction system,
- the rated load and speed,
- an estimate of the masses/inertias of the various components in the hoistway and,
- the maximum accelerations to be expected under normal and emergency conditions.

This model may involve a number of simplifying assumptions. For example, in the first instance it can be assumed that:

- the rail guides are perfectly rigid so that the car and the counterweight are constrained in the horizontal direction and can move freely in the vertical direction only;
- vibration effects of the ropes/ car. counterweight can be neglected.

In the fundamental analysis and system design calculations these assumptions and parameters are used to calculate the nature and mass of compensation means (if any) required to avoid slippage between the ropes and the driving sheave under defined conditions. For safety reasons, the systems calculation also seeks to guarantee that under some circumstances slippage between ropes and traction sheave must occur.

Consider a schematic diagram of a simplified model of the lift system without compensation means shown in Fig. 1(a). The diagram in Fig. 1(b) shows the suspension rope tensions T_{car} and T_{cwt} at the traction sheave at the car side and counterweight side, respectively. The angle of wrap of the ropes on the sheave is denoted as α. In considering the system calculation, the procedure prescribed in EN81-50 clause 5.11.2 is to be followed so that the following inequality formulae, that originate from the Eytelwein-Euler equation [1], are applied:

$$\frac{T_1}{T_2} < e^{f\alpha} \tag{1}$$

for traction to be maintained during normal operation/ car loading and emergency braking conditions, or

$$\frac{T_1}{T_2} > e^{f\alpha} \tag{2}$$

for traction to be lost during car/ counterweight resting on the buffers (stalled conditions), where T_1 and T_2 represent the greater and the lesser ($T_1 > T_2$) dynamic tensions in the suspension ropes at either side of the traction sheave (representing either T_{car} or T_{cwt} respectively, depending on the loading /position in the hoistway conditions). In inequalities in equations (1-2) $e = 2.718...$ is the natural logarithm base, and f is the friction factor which depends on the coefficient of friction (μ) as well as on the geometry of the rope – sheave contact configuration.

The determination of traction requirements is the fundamental consideration in lift system calculation. As noted earlier, the maximum possible rope size is constrained by the sheave/pulley diameter(s) on the selected traction machine.

The first step is the selection of suspension rope size. In order to make an initial selection of the rope size and number of ropes, the minimum safety factor needs to be established by considering the procedure in EN81-50 clause 5.12. Consider a low speed lift installation with the fundamental system parameters shown in Table 1, where the constant $g = 9.81$ m/s^2 represents the acceleration of gravity.

Table 1: Fundamental system parameters

Load $\boldsymbol{Q}$ [kg]	**Car mass** $\boldsymbol{P}$ [kg]	**Travel** $\boldsymbol{H}$ [m]	**Traction sheave diameter** $\boldsymbol{D_t}$ [m]	**Diverter pulley diameter** $\boldsymbol{D_p}$ [m]	**Rated speed** $\boldsymbol{V}$ [m/s]	**Normal acc./ decc.** $\boldsymbol{a}$ [m/s^2]	**V-groove Angle** γ **[º(**deg)]
800	1000	25	560	560	1	0.1g	40

The minimum required safety factor is determined by the formula given in EN81-50 clause 5.12.3 which can be re-written as

$$S_f = 10^F$$
$$F = 2.6834 - \frac{8.8425 + \log_{10}\left(N_{equiv}\right) - 8.567\log_{10}\left(\dfrac{D_t}{d_r}\right)}{1.8870 - 2.894\log_{10}\left(\dfrac{D_t}{d_r}\right)} \tag{3}$$

where N_{eqiv} is the equivalent number of pulleys, d_r denotes the diameter of the rope.

For the V-groove angle $\gamma = 40^0$, the equivalent number of pulleys is determined as [4]

$$N_{equiv} = N_{equiv(t)} + N_{equiv(p)} \tag{4}$$

where $N_{equiv(t)} = 10$ and $N_{equiv(p)} = 1$ so that $N_{equiv} = 11$. Consider using a standard rope size, d_r = 13 mm, giving a sheave/rope diameter ratio 43.08. Using $N_{equiv} = 11$ and $D_t/d_r = 43.08$ in (3) the minimum safety factor is determined as S_f = 17.18.

On the other hand the safety factor of the suspension means is defined as the ratio between the minimum breaking load of one rope and the maximum force in this rope, when the car is stationary at the lowest landing, with its rated load [2].

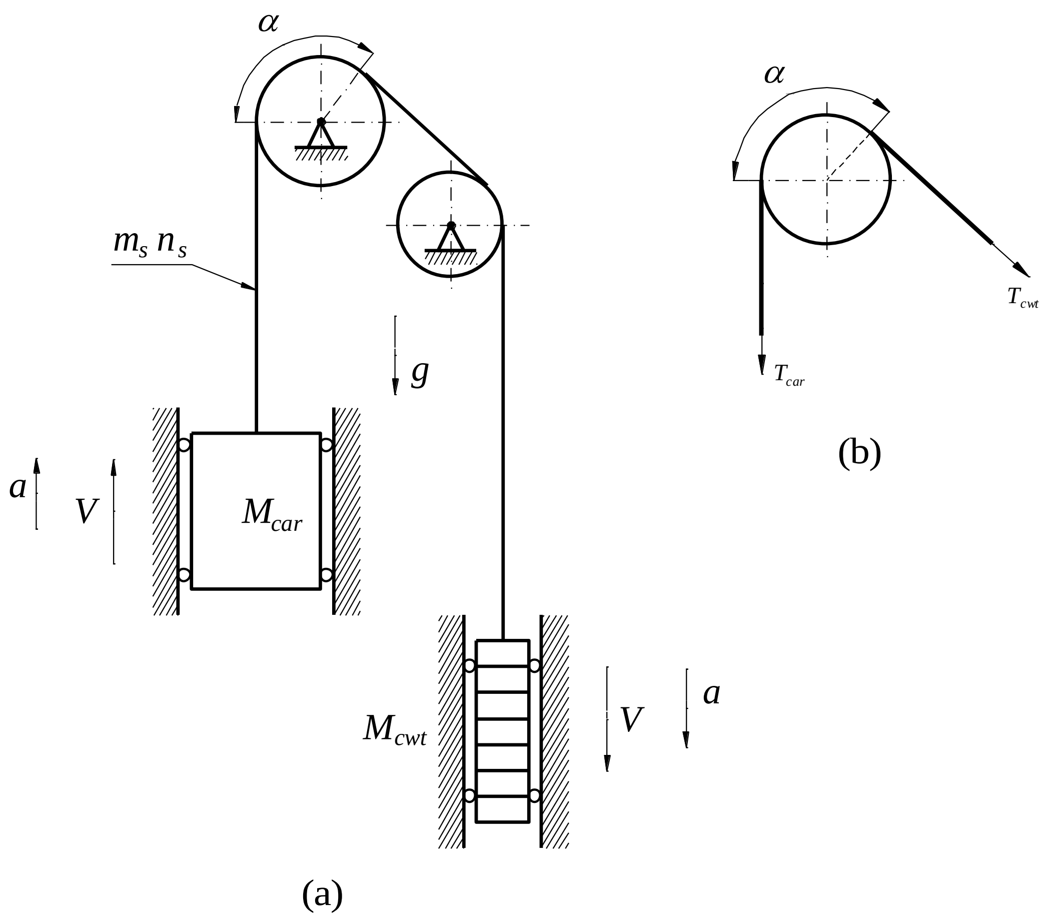

Figure 1: Simplified model of a lift system

The minimum breaking load for a 13 mm 8×19 S - FC [4] is F_{bmin} = 80.2 kN and the corresponding nominal mass per metre is approximately m_{sr} = 0.569 kg/m. The total length of the suspension ropes on the car side when the car is stationary at the lowest landing can be estimated as $L_{sr} = H + l_{head}$ where an additional length in the headroom is added to the travel height. The ‘applied’ safety factor is then calculated as

$$S'_f = \frac{n_{sr} F_{b\min}}{\left(P + Q + n_{sr} m_{sr} L_{sr}\right) g} \tag{5}$$

where n_{sr} denotes the number of ropes. For compliance with EN81-50 clause 5.12.3 the following condition must be satisfied

$$S'_f \geq S_f$$

i.e. (6)

$$\frac{n_{sr} F_{b\min}}{\left(P + Q + n_{sr} m_{sr} L_{sr}\right) g} \geq S_f$$

from which the number of ropes required to give compliance may be calculated. By using $n_{sr} = 4$ ropes and $l_{head} \approx 3.5$ m (L_{sr} = 25 m+3.5 m = 28.5 m in (5)) the applied safety factor S'_f is determined as 17.54 which would be just adequate for the installation, provided subsequent calculations do not require an excessive increase in the well masses (e.g. due to the application of compensation).

Next, the traction calculation should be carried out. In order to determine the critical traction ratio (defined as $e^{f\alpha}$) one needs to apply appropriate values of the friction factor *f*. Consider the case of car loading and emergency braking and that the V-grooves have been submitted to a hardening process. In that case the following formula applies [3]:

$$f = \frac{\mu}{\sin\frac{\gamma}{2}} \tag{7}$$

where the coefficient of friction is determined as

$$\mu = 0.1 \text{ - for normal operation/ loading conditions}$$
$$\mu = \frac{0.1}{1+V/10} = 0.091 \text{ - for emergency braking conditions} \tag{8}$$

The friction factor is then calculated as 0.2924 and 0.2658, for the loading condition and emergency braking condition, respectively. To determine the angle of wrap α let's consider the diagram shown in Fig. 2.

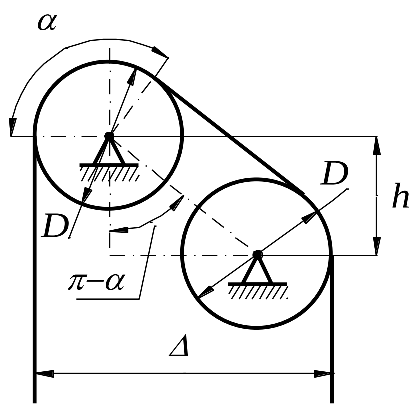

Figure 2: Traction sheave and diverter pulley geometry

If the diameters of the traction shave and the diverter pulley are assumed to be the same $D_t = D_p = D$ with the distance between the rope centres denoted as Δ, the angle of wrap is determined in terms of the vertical separation, *h,* of the sheave – diverter pulley and Δ as $\alpha = \pi - \tan^{-1}\left(\frac{\Delta - D}{h}\right)$ [1]. Consider that the rope centre distance is provided in the installation specification as Δ = 1150 mm whilst the vertical separation is h = 700 mm. The angle of wrap is then determined as $\alpha = 139.87^o$. The critical traction ratios are then calculated as 2.04 and 1.91 for the loading condition and emergency braking condition, respectively.

According to the code requirements [2], the applied static traction ratio should then be evaluated for the worst-case depending on the position of the car in the well with 125 % of the rated load. Consider the static applied traction ratio with the car at the bottom landing. Assuming the balance B = 0.45, the tensile forces in the ropes at the traction sheave end/ diverter pulley end are determined as follows

$$T_1 = \left(P + 1.25Q + n_{sr} m_{sr} L_{sr}\right) g = 20.256 \text{ kN}$$
$$T_2 = \left(P + BQ + n_{sr} m_{sr} l_{head}\right) g = 13.420 \text{ kN} \tag{9}$$

The corresponding applied traction ratio is then determined as $\frac{T_1}{T_2} = 1.51 < 2.04$. Thus, it is evident that traction in this scenario will be maintained.

In the case of emergency braking condition, the applied dynamic ratio is be evaluated for the worst-case depending on the position of the car in the well and the load conditions (empty, or with rated load). The calculation in the case of emergency stop at the deceleration rate of $a_b = a = 1$ m/s^2 near the bottom landing whilst a full car is travelling downwards is given below.

$$T_1 = \left(P + Q + n_{sr} m_{sr} L_{sr}\right)\left(g + a_b\right) = 20.159 \text{ kN}$$
$$T_2 = \left(P + BQ + n_{sr} m_{sr} l_{head}\right)\left(g - a_b\right) = 12.052 \text{ kN} \tag{10}$$

The corresponding applied traction ratio is then determined as $\frac{T_1}{T_2} = 1.67 < 1.91$ so that it is evident that traction will be ensured in this case as well.

3 DYNAMIC TRACTION UNDER ADVERSE DYNAMIC CONDITIONS (RESONANCE VIBRATION)

Consider the longitudina elasticity (stiffness) EA of the suspension rope, where E is the modulus of elasticity and A denotes the metallic cross-sectional area of the rope, and vertical (longitudinal) elastic deflections (vibrations) x_{car} , x_{cwt} of the car and counterweight, respectively, induced by small vertical motions (oscillations) $s(t)$ of the machine/ traction sheave assembly (see Fig. 3). This can be represented as a base motion excitation and an adverse situation arises when the car/ counterweight are excited at their natural frequency and vibrate periodically at large amplitudes. Such adverse resonance condition may occur due to seismic excitations [5], for example.

For the scenario when the base excitation has been introduced when the car with 125 % of the rated load is stationary at the bottom landing (see the system calculation above), a simplified model to represent the dynamic behaviour of the system can then be given by equation (11)

$$M_{eq_{car/cwt}} \ddot{x}_{car/cwt} + c_{car/cwt} \dot{x}_{car/cwt} + k_{car/cwt} x_{car/cwt} = k_{car/cwt} s + c_{car/cwt} \dot{s} \tag{11}$$

where $M_{eq_{car/cwt}}$ represent the well equivalent mass at the car/ counterweight sides. The quantities $k_{car/cwt} = n_{sr} EA / L_{car/cwt}$ denote the coefficients of elasticity, where $L_{car/cwt}$ define the length of the ropes, at the car/ counterweight sides, respectively. Viscous friction model is used to quantify the amount of friction in the well, and $c_{car/cwt}$ represent the coefficients of viscous friction at the car/ counterweight sides, respectively.

Considering that the base excitation is harmonic $s = s_{\max} \sin \Omega t$, equations (11) can be re-written as

$$\ddot{x}_{car/cwt} + 2\zeta\omega_{car/cwt} \dot{x}_{car/cwt} + \omega^2_{car/cwt} x_{car/cwt} = s_{\max}\left(\omega^2_{car/cwt} \sin \Omega t + 2\zeta\omega_{car/cwt} \Omega \cos \Omega t\right) \tag{12}$$

where $\omega_{car/cwt}$ denote the natural frequencies of vibrating masses at the car side/ counterweight side and ζ is the damping ratio [6]. Equations (12) can be solved for the dynamic responses (vibrations) $x_{car/cwt}(t)$.

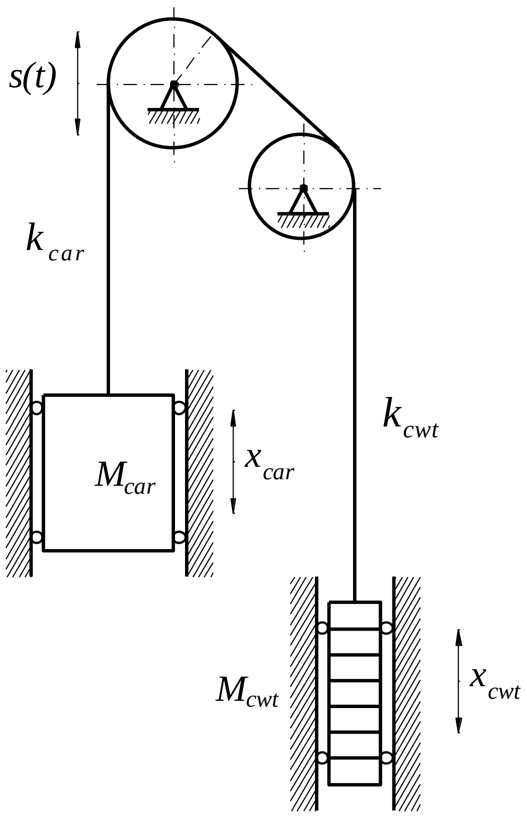

Figure 3: Simplified model of a lift system subjected to base excitation

The vibration effects on the dynamic traction ratio are then evaluated by considering the dynamic tensions in the ropes as

$$T_{car/cwt} = T_{0car/cwt} + k_{car/cwt} x_{car/cwt} \tag{13}$$

where $T_{0car/cwt}$ are the static/ quasi-static tensions in the ropes.

The rope lengths are then determined as $L_{car} = H + l_{head}$, $L_{cwt} = l_{head}$, and the static tensions $T_{0car/cwt}$ are given by equations (9). By considering that the modulus of elasticity of a stranded wire rope with a fibre core lies in the range of (0.7 – 1.0) × 10^5 N/mm^2 the longitudinal elasticity of one rope is determined as $EA = 5040.5$ kN where E = 0.85 × 10^5 N/mm^2 and A = 59.3 mm^2 (for 13 mm 8×19 S - FC rope [4]) are used. The damping ratio is assumed to be $\zeta = 0.1$ so that equations (12) can be solved to determine the dynamic responses, followed by calculation of the dynamic tensions from (13).

The dynamic response is determined from equations (12) by numerical integration. Fig. 4 then shows the dynamic tensions in the suspension ropes when the amplitude of base excitation is s_{max} = 0.15 mm and the frequency of base excitation is 10 Hz. It should be noted that this frequency is close to the natural frequency of the suspension ropes at the counterweight side, which results in vibrations that may compromise traction leading to counterweight jumps [1]. A plot of the corresponding dynamic traction ratios is shown in Fig. 5.

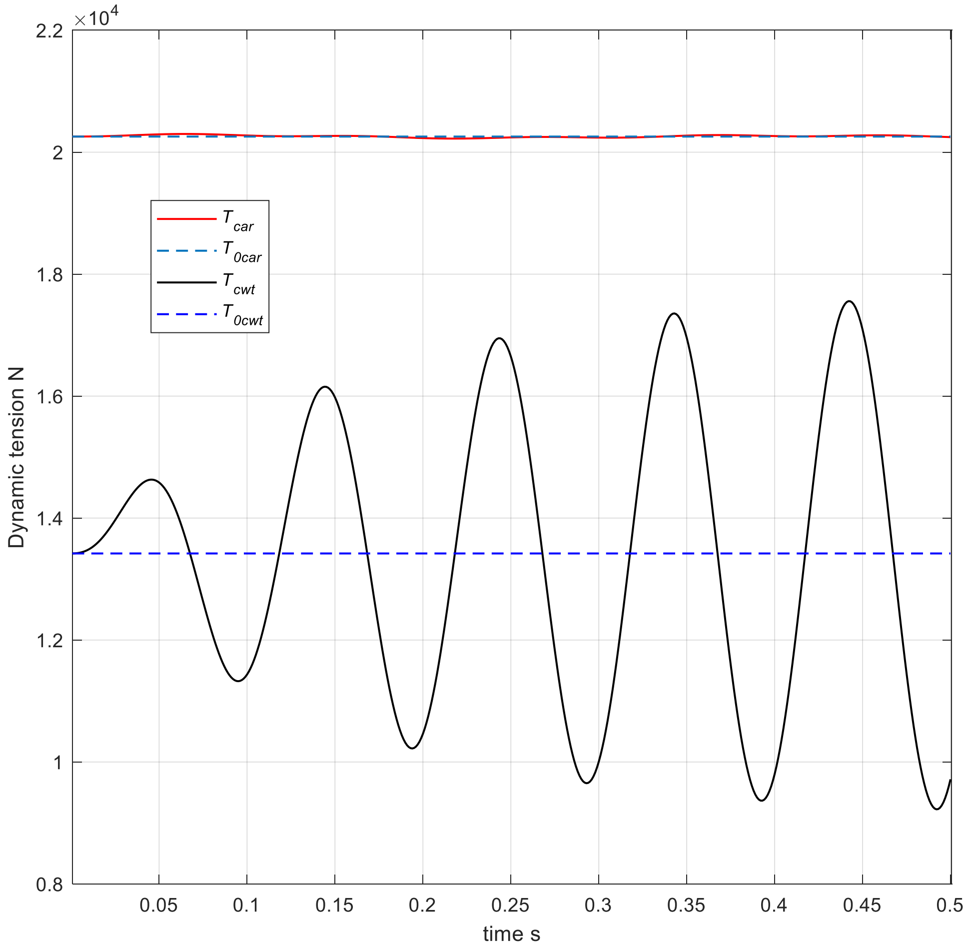

Figure 4: Dynamic tension in the suspension ropes

It is evident from Fig. 5 that after about 0.29 s the dynamic traction ratios reach the critical value and the system might instantaneously be subjected to traction problems, despite the fact that the standard system analysis predicted that traction is maintained.

4 CONCLUDING REMARKS

The system analysis involves calculations that follow the safety code requirements. These calculations are essential to design a system which complies with accepted safety standards. With a number of commercial/custom-designed software tools/programs to automate the calculations available, the designer is able to arrive at desired results for standard scenarios. However, correct understanding of engineering principles and the assumptions applied in the safety standard formulae is essential to understand the limitations of the results. This aspect is demonstrated through the analysis of resonance condition scenario when the dynamic traction, to comply with European safety standards, needs to be evaluated by rigorous engineering procedure.

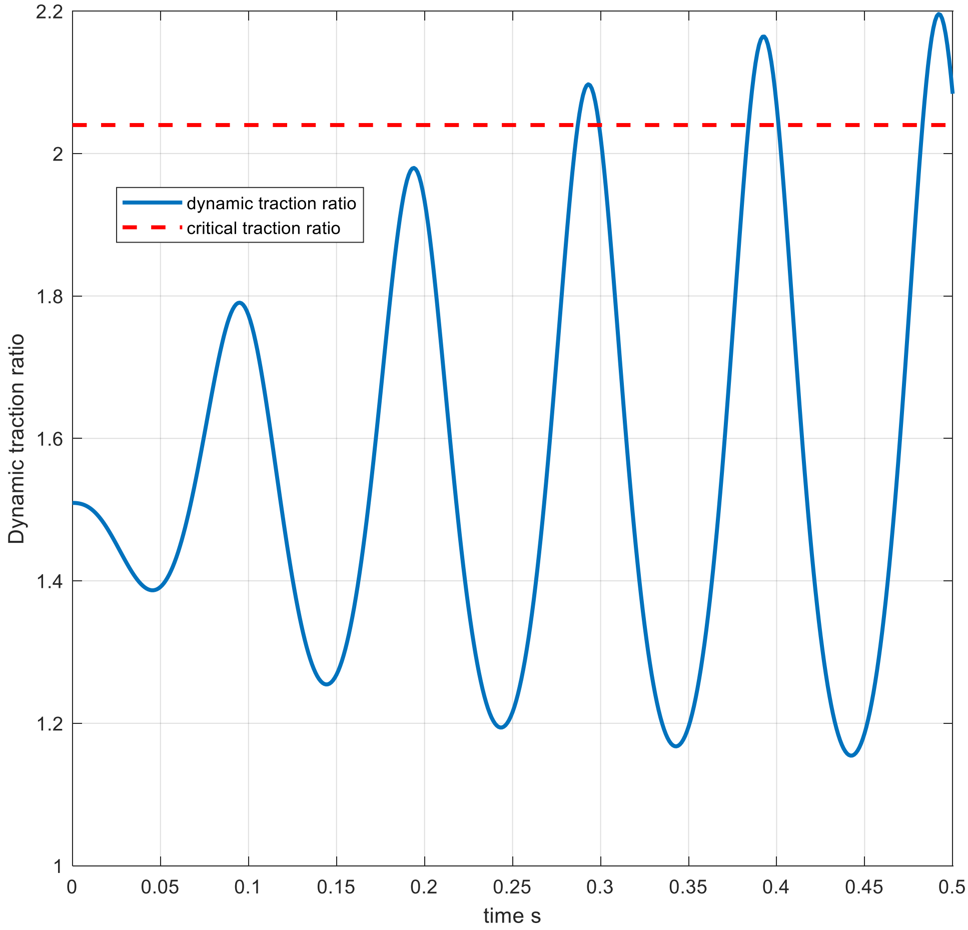

Figure 5: Traction ratios

REFERENCES

[1] J.P. Andrew and S. Kaczmarczyk, *Systems Engineering of Elevators*. Elevator World, Mobile, AL (2011).

[2] British Standards Institution, *Safety rules for the construction and installation of lifts — Lifts for the transport of persons and goods Part 20: Passenger and goods passenger lifts.* BS EN 81-20:2014.

[3] British Standards Institution, *Safety rules for the construction and installation of lifts — Examinations and tests Part 50: Design rules, calculations, examinations and tests of lift components.* BS EN 81-50:2014.

[4] Pfeifer DRAKO *Elevator Products* https://www.pfeifer.info/out/assets/PFEIFER-DRAKO_ELEVATOR-PRODUCTS_BROCHURE_EN.PDF (Accessed 24 Jun 2019).

[5] S. Kaczmarczyk, "The modelling and prediction of dynamic responses of long slender continua deployed in tall structures under long period seismic excitations". *Proceedings of the 7th Symposium on Mechanics of Slender Structures*, Mérida, Spain, 14-15 December 2017.

[6] S.S Rao, *Mechanical Vibration.* Prentice Hall, Singapore (2005).

BIOGRAPHICAL DETAILS

Stefan Kaczmarczyk has a Master's degree in Mechanical Engineering and he obtained his doctorate in Engineering Dynamics. He is Professor of Applied Mechanics and Postgraduate Programme Leader for Lift Engineering at the University of Northampton. His expertise is in the area of applied dynamics and vibration with particular applications to vertical transportation and material handling systems. Professor Kaczmarczyk has published over 100 journal and international conference papers in this field. He is a Chartered Engineer, a Fellow of the Institution of Mechanical Engineers and a Fellow of the Higher Education Academy.

Phil Andrew has a Master's Degree in Control Systems Engineering from the University of Warwick. He joined the Express Lift Co. Ltd in 1978 where, over the next 18 years he held a range of senior engineering positions with the company. In 1996 he joined the lift engineering group at the University of Northampton. He led the team who developed the Northampton MSc in Lift Engineering, and then the Foundation Degree in Lift Engineering. In 2003 he took over as Divisional Leader for Engineering in the School of Technology and Design. From the year 2000 until his retirement in 2004, he served on the National Interest Review Committee for the ASME/ANSI A17 Code Committee and represented the University on Committee MHE/4 of the British Standards Institution.

Understanding GB/T 24476 – 2017 China's Technical Specifications for Internet of Things For Lifts, Escalators And Moving Walks

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Keywords: Remote monitoring, codes and standards, IoT.

Abstract. The People's Republic of China has a new code that requires all new or modernized lifts, escalators and moving walks to be equipped with a remote monitoring system. The Standard specifies every detail of the standardized monitoring system.

The data from the monitoring system is transmitted via the internet to a Safety Monitoring Platform. This Safety Monitoring Platform is operated by regional governments.

The system and the data that it acquires is explained. Additionally, the potential effects of this system on safety and the lift industry are explored.

1 INTRODUCTION

The Chinese Standard, GB/T 24476, requires all new or modernized lifts, escalators and moving walks to be equipped with remote monitoring equipment that sends data to a safety Monitoring Platform operated by government agencies [1].

The Standard specifies every detail of the monitoring system. It defines the performance of the hardware and software, details the system architecture, describes what data will be collected and defines the format of the data.

This Standard is far more than a standard to promote safety. It is a strategic initiative to improve the status of the Chinese lift industry. It is important for the global lift industry to understand this Standard and to consider how it has the potential to change the industry.

2 LIST OF ACRONYMS

1. API: Application Programing Interface
2. ATD: Acquisition and Transmission Device
3. CPS: Controller Protocol Converter
4. EAP: Enterprise Application Platform
5. IoT: Internet of Things
6. LMAP: Lift Manufacturer's Application Platform
7. ML: Machine Learning

3 THE GOALS OF THE STANDARD

The goals of the Standard are stated in its Introduction. The following is a summary of those goals:

1. Improve the long-term competitiveness of the lift industry.
2. Improve products, service and management of the lift industry.
3. Increase passenger satisfaction.
4. Improve products and service by acquiring and analyzing data.
5. Reduce the time that passengers spend entrapped in lifts.
6. Create a method of providing remote technical support for field personnel.
7. Create a platform to improve supervision efficiency.

8. Improve the efficiency of the Chinese lift industry.
9. Improve the status of the Chinese lift industry by being the first country to apply the Internet of Things (IoT) on all lifts, escalators and moving walks.

4 SYSTEM ARCHITECTURE

Two system architectures are defined in the Standard. One is oriented for large lift companies who manufacture, install and maintain lifts. The alternative architecture is for lift companies that purchase lift packages from suppliers and then install and maintain these lifts.

Fig. 1 is an architecture diagram for the larger, vertically integrated lift companies.

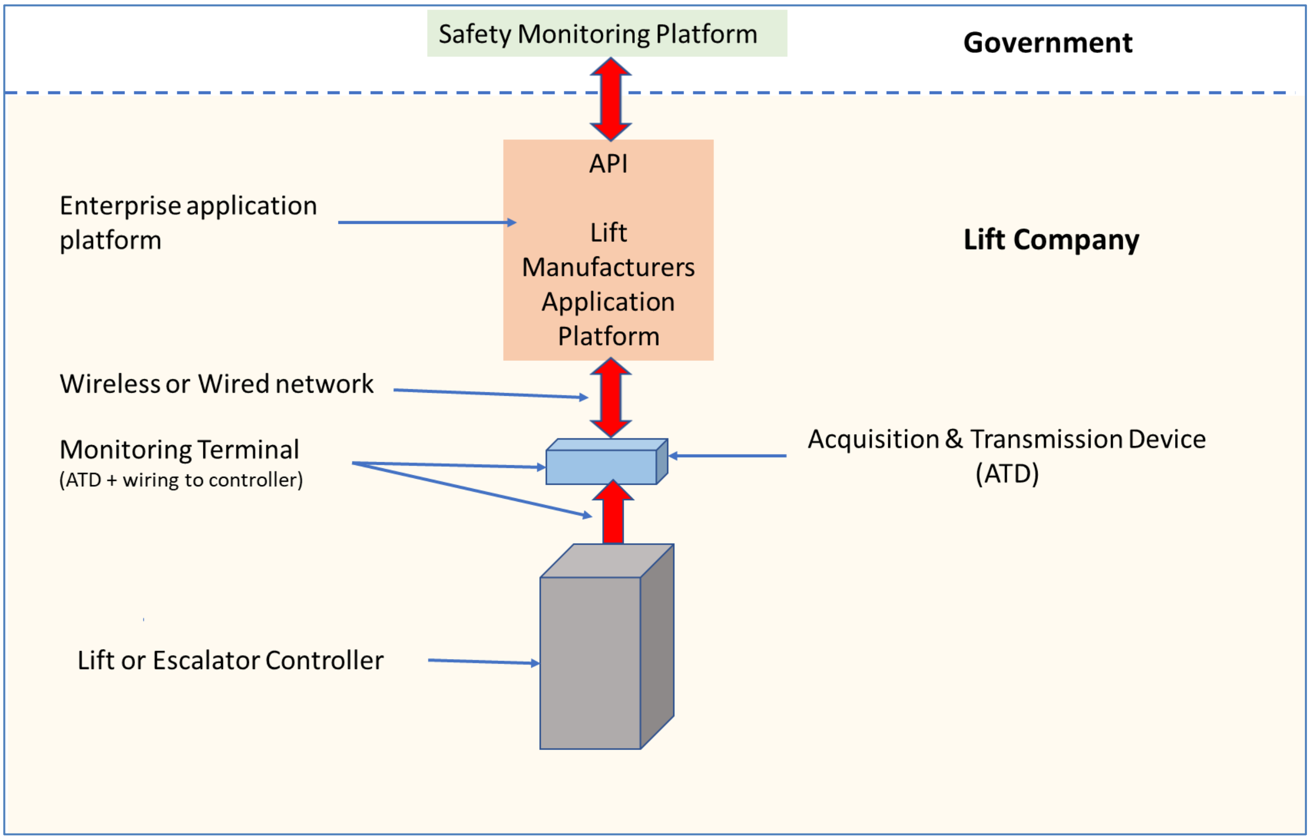

Figure 1: Architecture for vertically integrated lift companies

The Standard refers to the wiring between the controller and the Acquisition and Transmission Device (ATD) as the Monitoring Terminal. The ATD receives data from the controller and sends it to the Lift Manufacture's Application Platform (LMAP). In most cases this device is a cellular modem with the ability to process the data. In some cases, where the device is wired, the device sends the data using RS-485 communication.

Note that the data only flows from the controller to the ATD. No commands can be sent to the controller.

The LMAP has an Application Programing Interface (API) that allows the government's Safety Monitoring Platform to communicate with the LMAP using the internet.

The yellow-shaded lower portion of the diagram represents the portion of the architecture that is the responsibility of the lift manufacturer. The upper portion is the responsibility of the government.

Fig. 2 is an architectural diagram of the system for smaller companies who can out-source the transmission of data to the government. Please note that this diagram has three layers. The blue-shaded lowest layer is the layer provided by the controller manufacturer. The middle, yellow-shaded layer is the out-sourced layer that processes the data from the controller and makes it available to the government's Safety Monitoring Platform through an API.

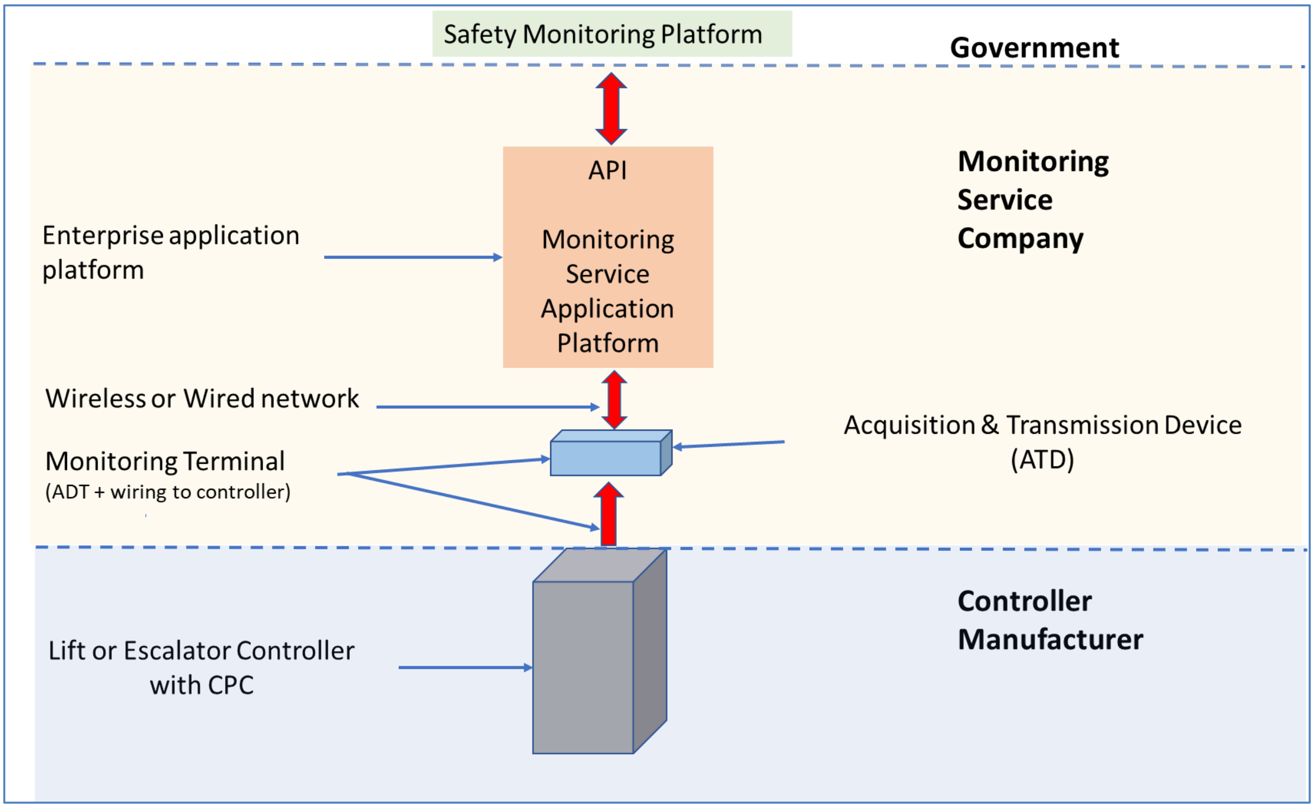

Figure 2: Architecture with outsourced monitoring

The controller has a Controller Protocol Converter (CPC) that converts the data from the controller to a common format that the Monitoring Service Application can utilize.

5 MONITORING TERMINAL

The monitoring terminal has the following requirements:

1. The monitoring terminal must be isolated from the controller in such a way that it does not affect the normal running of the lift, escalator or moving walk.
2. The monitoring terminal must continue to operate for a minimum of 1 hour in the event of a power failure.
3. If the monitoring terminal is provided by a vendor, the power for the terminal must be connected on the line side of the controller.
4. The real time clock in the ATD must be synchronized to the real time clock in the application platform. All clocks will use Beijing time.
5. The memory in the monitoring terminal shall be large enough to store at least the last 100 event records.

6 DATA

The Standard requires several types of data be sent ultimately to the Safety Monitoring Platform. The data types are the following:

1. Static data.
2. Real-time operation status.
3. Statistical data.
4. Faults, event alerts and alarms.

6.1 Static Data

The following static data for each lift, escalator or moving walk is stored in the Enterprise Application Platform (EAP):

1. Identification Number. The number assigned to lift, escalator or moving walk by the EAP.
2. Installation ex-factory number. The number that appears on the certificate of conformity.
3. Registration Number. The number assigned to the lift or escalator when the installation is registered.
4. Installation variety. The variety number assigned by AQSIQ, a government quality agency [2].
5. Installation type. Product type assigned by the manufacturer.
6. Product installation address.
7. Installation internal number. The name that the building management uses, such as "High Rise Car 2".
8. Installation Manufacturer.
9. Dealer of the imported installation. Only applies to units not produced in China.
10. Installation ex-factory date. The date that appears on certificate of conformity.
11. Modernization company of installation.
12. Modernization date of installation.
13. Product installation company.
14. Product installation date.
15. Name of maintenance company.
16. Emergency rescue phone number. Phone number of maintenance company or building engineer.
17. Name of user entity.
18. Lift data:
    a. Landing number. Number of stops.
    b. Rated speed.
    c. Rated load.
    d. Landing names. Floor designations as displayed on the car position indicator.
19. Escalator data:
    a. Nominal speed.
    b. Hoisting height. Distance between floors.
    c. Angle of inclination.
    d. Nominal width.
20. Moving walk data:
    a. Nominal speed.
    b. Hoisting height. Distance between floors.
    c. Angle of inclination.
    d. Nominal width.

6.2 Real-time operation status

Real-time operation status information is available in the API. The Safety Monitoring Platform, the Government, can access the API in the EAP to remotely monitor any lift in the country.

The following is the real-time data that the Standard requires be sent to the EAP:

1. Data generation time stamps. The "BACnetDateTime" format must be used.
2. Lift data:
    a. BACnetLiftServiceMode data is used as follows:
        i. Out of service.
        ii. Normal operation.
        iii. Inspection. (Faults, events and alarms are not generated while in this mode).
        iv. Fire return.
        v. Firefighters operation.
        vi. Emergency power operation.
        vii. Earthquake mode.
        viii. Unknown.
    b. Car status. Stopped or in motion.
    c. Car direction. No direction, Up, or Down.
    d. Door Zone:
        i. True: Car is in the door zone.
        ii. False: Car is outside the door zone.
    e. Car position. Position is by floor.
    f. Door status:
        i. True: Door is closed.
        ii. False: No door closed signal.
    g. Car occupied:
        i. True: Passengers in car.
        ii. False: No passengers in car.
3. Escalator and Moving Walk Data:
    a. BACnetEscalatorServiceMode
        i. Out of service.
        ii. Normal operation.
        iii. Inspection. (Faults, events and alarms are not generated while in this mode).
        iv. Unknown.
    b. Operation status. Stopped or travel.
    c. Operation direction. No direction, Up, or Down.

6.3 Statistical Data

Two types of statistical data are sent by the Acquisition and Transmission Device (ATD) to the Enterprise Application Platform (EAP):

1. Total running time. This is the cumulative time when the unit was in motion.
2. Motor starts.

6.4 Faults event alerts and alarms

This Standard requires control systems to be capable of generating a prescribed list of faults, event alerts and alarms. These faults, event alerts and alarms must be forwarded to EAP by the ATD.

6.5 Lift faults

The following is a list of the required lift faults:

1. No fault.
2. Safety circuit is interrupted while lift is running.
3. Door closing fault.
4. Door opening fault.
5. Unintended movement.
6. Actuation of motor run limiter.
7. Loss of position.

6.6 Lift events

The following is a list of event alerts:

1. Lift returns to automatic mode.
2. Power failure.
3. Lift enters inspection mode.
4. Lift enters out of service mode.
5. Lift enters fire return mode.
6. Lift enters firefighter’s mode.
7. Lift enters emergency power operation.
8. Lift enters earthquake mode.

6.7 Lift alarm code

When the emergency alarm button is activated, an alarm notification must be sent to the EAP.

6.8 Fault codes for escalators and moving walks

The following is a list of the required faults:

1. No Fault. This fault is issued when the unit exits a fault mode.
2. Safety circuit interruption.
3. Overspeed.
4. Unintentional reversal of direction.
5. Missing step or pallet.
6. Other fault. Any other fault that prevents the unit from starting or running.

6.9 Event codes for escalators and moving walks

The following is a list of the required event alerts:

1. Unit returns to automatic mode.
2. Unit enters inspection mode.

6.10 Alarms for escalators and moving walks

There are no alarms for escalators and moving walks.

7 OBSERVATIONS

7.1 Machine Learning

This Standard requires a large amount of data be sent to the EAP and this data is available to the government. The hardware required by the standard could easily and inexpensively be used to gather much more data. The required data and the additional data that can be collected could be used for Machine Learning (ML). ML evolved from Artificial Intelligence (AI). The goal of AI is to develop computers and software that mimic human intelligence. One of the goals of AI is learning. Machine Learning involves making predictions based on properties learned from data [3].

Machine learning on a larger data set than the minimum required by the Standard, is in the spirit of the goals of the Standard. ML can have the ability to identify product deficiencies, it can identify the strengths and weaknesses of a service program, improve customer satisfaction and most of all, ML can improve safety.

7.2 Transparency

This Standard will create a new level of transparency.

It will be possible to rank companies by such things as call backs per unit per year, injuries per unit per year and maintenance hours per unit per year.

It will be possible to identify problem products and problem companies.

If the government makes their findings available to the public, it will have a great impact on the industry. The impact will be positive for companies that have good reports. It could be disastrous for a company with a poor safety record.

8 LOCAL VARIATIONS

The cities of Hangzhou, Nanjing, Ningbo, Shanghai, Suzhou, and Wuxi have all developed their own variations of the GB/T 24476 code [4].

Shanghai is one of four municipalities governed directly by the central government and the largest city in China [5]. Because of Shanghai's prominent position in China it is widely believed that the Shanghai variation of the code will be adopted nationally [4].

The Shanghai variation of the GB 24476 code is known as DB 31/T 1123-2018 [6]. This code is essentially the GB 24476 standard with additional requirements that include video monitoring.

9 CONCLUSIONS

The GB/T Standard has the possibility to achieve the goals stated in its Introduction. One of those goals is to improve the international status of China's lift industry. One should remember what Japan's adoption of W. Edwards Deming's quality philosophy did for Japanese industry [7].

Proper implementation of the Standard will improve safety and customer satisfaction.

The Standard will change the industry. Those members of the industry who take advantage of this Standard to improve products and operations will be successful. Those who do not, will not fare as well.

10 LITERATURE REFERENCES

[1] Standardization Administration of the Peoples Republic of China GB/T 24476-2017 *Technical Specifications for Internet of Things for Lifts, Escalators and Moving Walks.* Beijing

[2] *What is AQSIQ* Available from: https://www.aqsiq.net/what-is-aqsiq.htm Last accessed 6 June 2019

[3] Machine learning Available from: https://en.wikipedia.org/wiki/Machine_learning Last accessed: 30 June, 2015

[4] Discussions with Emilio Manzano, Director of Service Operations, thyssenkrupp Elevator, Asia Pacific. June, 2019.

[5] Shanghai Available from: https://en.wikipedia.org/wiki/Shanghai Last accessed 18 June, 2019

[6] Shanghai Municipal Market Supervisory Authority DB31/T 1123-2018 *Smart Elevator Monitoring Terminal Technical Requirements.* Shanghai

[7] *W. Edwards Deming* Available from: https://en.wikipedia.org/wiki/W._Edwards_Deming Last accessed 7 June, 2019.

BIOGRAPHICAL DETAILS

Rory Smith is Visiting Professor in Lift Technology at the University of Northampton. He has over 50 years of lift industry experience during which he held positions in research and development, manufacturing, installation, service, modernization, and sales. His areas of special interest are robotics, machine learning, traffic analysis, dispatching algorithms, and ride quality. Numerous patents have been awarded for his work.

Using Monte Carlo Simulation in Lift Traffic Systems to Compile the Probability Density Function (PDF) for the Car-Load Data and Drive-Motor System Loading

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Keywords: Monte Carlo Simulation; probability density function; cumulative distribution function; car capacity; car-load; lift traffic analysis; lift traffic analysis.

Abstract

The Monte Carlo Simulation (MCS) method has been successfully applied in lift traffic systems to evaluate a number of different parameters such as the round-trip time and the average travelling time; and under different conditions, such as sectoring control and for multiple lift cars running in the same shaft. Using the MCS methods is particularly effective in cases where the number of possible combinations becomes too complicated for analytical equation-based calculation methods to deal with.

This paper attempts to extend the applications of the MCS method in two areas: Car capacity and drive-motor system sizing. It uses this method to compile the probability density functions (PDF).

In the first area, MCS is used in order to compile the statistical description of the number of passengers in the lift car whenever it departs from a floor. This is concisely presented in the form of a PDF of the number of passengers in the car when it departs from a floor. Such a PDF can be used to make judicious decisions regarding the suitable car capacity.

The second area involves using the same data in order to compile a load profile of the number of passengers inside the lift car when it stops at a certain floor and when it departs from the that floor, along with the probability of the lift car stopping at that floor. This provides a strong input to simulate the drive-motor system and evaluate the temperature rise in the windings and the power electronic devices.

A numerical example is given for a single lift car to illustrate the application of the method.

1. INTRODUCTION

The Monte Carlo Simulation method has been successfully used in a number of applications in lift traffic analysis and design, such as the evaluation of the round-trip time under conventional group control [1], the average travelling time [2], evaluating the round-trip time for double decker lifts [3], evaluating the round-trip time under sectored group control [4, 5], in multi-car lift systems [6] and other applications [7, 8]. The MCS method is effectively one of the calculation methods employed in lift traffic engineering.

At the heart of the MCS method is the generation of representative passenger traffic that reflects the prevailing traffic in the building. The prevailing traffic conditions are one of the most important elements of lift traffic demand [9].

Based on the expected mix of traffic, the so-called origin-destination (OD) matrix can be developed that concisely describes the probability of a passenger travelling from one floor in the building to another floor. Well established procedures have been developed that allow the compilation of an OD matrix from the floor population percentages, the entrance bias and the mix of prevailing traffic [10, 11]. A more generalised procedure that allows any floor to simultaneously be an entrance floor and an occupant floor has been recently published [12]. Research has also been carried out on the reverse procedure (i.e., estimating the traffic mix from the lift movements resulting from passenger origin-destination pairs) as shown in [13, 14, 15, 16].

The most important application of the OD matrix is in the random generation of passenger origin-destination pairs within simulation software packages or for the purposes of MCS. The full procedure is clearly documented in [17] as an integrated framework. When using the MCS methods to simulate a full round-trip, a number of passengers, denoted as P passengers, are generated (denoted as P_{gen}). Generating a passenger in this context involves finding the origin-destination pair for that passenger.

It is also possible to generate random arrival times for passengers (i.e., generating passengers in time) assuming a Poisson passenger arrival process [18]. However, this is beyond the scope of this paper. Potentially, this could further affect that probability density function (PDF) as the additional randomness of the arrival time of the passengers is considered (i.e., too many passengers arriving in a period of time, or too few).

In this paper, the MCS method is used in order to develop a detailed description of the car-load in the lift car at every start or within the whole round-trip under conventional group control but assuming general traffic conditions. As the car-load is a random variable (especially under general traffic conditions) then it is best described as a probability density function (PDF). The advantage of describing the car-load in the car in consecutive round-trips, using a PDF, is that it is possible to understand the scatter of the values of the car load in units of passengers and then make an informed decision on the car capacity (CC).

A similar comment can be made regarding the sizing of the drive system. A detailed understanding of the load inside the car at different positions in the shaft, can help the designer make an informed assessment of the temperature of the electrical drive system and the traction motor.

When the prevailing traffic is incoming traffic (e.g., 100% incoming traffic), the car-load is obviously equal to the number of generated passengers in a round-trip (Pgen). However, under general traffic conditions, the prevailing traffic could be any mixture of incoming traffic, outgoing traffic, inter-floor traffic and even inter-entrance traffic. Under these conditions, the effective car-load would be smaller than the number of generated passenger (P_{gen}) and this presents an opportunity to increase the handling capacity of the lift system.

It is worth noting that the definition of the type of traffic as incoming, outgoing, inter-floor or inter-entrance assumes that any floor can be classified as either an entrance/exit floor or an occupant floor, although the procedure followed in this paper has made the simplifying assumption that any floor is either an occupant floor or an entrance/exit floor.

Section 2 discusses the motivation for developing this paper. The random nature of the passenger generation process is discussed in Section 3. Section 4 reviews in detail the procedure for preparing the cumulative distribution function (CDF) from the probability density function (PDF) and then using it to randomly generate passenger journey origin-destination pairs. A detailed numerical scenario is analysed in Section 5. Section 6 contains some PDF results for the car loading and the drive loading at different floors (up and down). Conclusions are drawn in Section 7.

2. MOTIVATION FOR THIS PAPER

It has been noted that the car capacity is not fully exploited when the traffic is not fully incoming or not fully outgoing. A good example of this problem can be seen under the following conditions: The maximum car capacity is 8 persons, the traffic is 50% incoming and

50% outgoing, and 8 passengers are generated per round-trip. Under these conditions, on average, 4 passengers travel in the up direction and 4 passengers travel in the down direction.

It is recognised that as the traffic mix becomes more balanced between incoming traffic and outgoing traffic, an opportunity exists to exploit this balance by increasing the number of passengers generated in one round-trip

The question that this exercise answers is formulated below:

"When the traffic in the building is not purely incoming or purely outgoing, but a mix of different modes (i.e., incoming, outgoing, inter-floor, inter-entrance), what is the effective car load in a consecutive round-trip, and the effective car load every time it starts and what is the car load inside the car at different positions in the shaft?"

Answering the first part of the question helps the designer decide on the suitable car capacity for a certain mix of traffic. Ultimately, it could allow the designer to keep the car capacity at its value but scientifically deal with larger handling capacities under balanced mixes of traffic.

3. AN IMPORTANT NOTE ON THE RANDOM NATURE OF THE PASSENGER GENERATION PROCESS

When expressing the car-load, the term 'on average' is used here, because the passenger generation process is truly random. For example, if 8 passengers are to be generated in one round trip and the traffic is exactly balanced between incoming traffic and outgoing traffic, the 8 passengers are generated randomly, and it could be that 5 of them are incoming passengers and 3 of them are outgoing passengers in one round trip. Under certain rare round-trip scenarios, the random generation of passengers could result in 7 incoming passengers and one outgoing passenger, or even (in rare cases) 8 incoming passengers and no outgoing passengers or 8 outgoing passengers and no incoming passengers.

However, after generating a very large number of round-trip passengers, the average of the number of incoming passengers will approach 4 passengers and the number of outgoing passengers will also approach 4 passengers.

This random generation of passenger origins and destinations ensures that the final value of the round-trip time is a faithful representation of the true value for the round-trip time as it better represents the real-life conditions of random passenger movements. *The value of the round-trip time obtained at the end represents all of the possible combination, and more importantly, in the correct ratio.*

4. GENERATING THE PASSENGER ORIGIN-DESTINATION PAIRS FROM THE CDF

As discussed in Section 1, the passenger origin-destination pairs should be representative of the traffic in the building. This is done in accordance with a systematic methodology that uses the origin-destination (OD) matrix. The systematic method involves the following steps:

1. Obtaining the nature of the floors in the building as follows:

    a) Whether a floor is an occupant floor, an exit/entrance floor or both.
    b) The percentage of passenger arrivals/departures from an entrance/exit floors (sometimes referred to as "entrance bias").
    c) The ratio of the populations of the occupant floor (the actual number is not required; simply the relative strength).

d) The mix of traffic, expressed as percentages of decimal fractions adding up to 1, as follows: incoming traffic, outgoing traffic, inter-floor traffic and inter-entrance traffic.

2. Building the OD matrix.

3. Converting the origin-destination from a PDF to a CDF by integration. An example of a CDF for the building used as an example in this paper is shown in Figure 1. This building has 8 occupant floors with equal populations and 2 entrance floors with ratio of 30%:70% for the basement and the ground respectively. The traffic mix is representative of lunchtime traffic (45% incoming: 45% outgoing: 10% inter-floor).

		Destination Floors									
		Basement	**Ground**	**1st**	**2nd**	**3rd**	**4th**	**5th**	**6th**	**7th**	**8th**
Origin Floors	**Basement**	0.00000	0.00000	0.01688	0.03375	0.05063	0.06750	0.08438	0.10125	0.11813	0.13500
	Ground	0.13500	0.13500	0.17438	0.21375	0.25313	0.29250	0.33188	0.37125	0.41063	0.45000
	1st	0.46688	0.50625	0.50625	0.50804	0.50982	0.51161	0.51339	0.51518	0.51696	0.51875
	2nd	0.53563	0.57500	0.57679	0.57679	0.57857	0.58036	0.58214	0.58393	0.58571	0.58750
	3rd	0.60438	0.64375	0.64554	0.64732	0.64732	0.64911	0.65089	0.65268	0.65446	0.65625
	4th	0.67313	0.71250	0.71429	0.71607	0.71786	0.71786	0.71964	0.72143	0.72321	0.72500
	5th	0.74188	0.78125	0.78304	0.78482	0.78661	0.78839	0.78839	0.79018	0.79196	0.79375
	6th	0.81063	0.85000	0.85179	0.85357	0.85536	0.85714	0.85893	0.85893	0.86071	0.86250
	7th	0.87938	0.91875	0.92054	0.92232	0.92411	0.92589	0.92768	0.92946	0.92946	0.93125
	8th	0.94813	0.98750	0.98929	0.99107	0.99286	0.99464	0.99643	0.99821	1.00000	1.00000

Figure 1: Cumulative Distribution Function (CDF) for the passenger origin-destination pairs.

4. Carrying out random sampling in order to generate the origin-destination pairs. The random sampling consists of generating uniformly distributed random numbers between 0 and 1 and applying them to the CDF produced in the previous step (shown in Figure 1).

5. Sorting the origins and destinations into the up-part of the round-trip and the down-part of the round-trip.

6. Finding the stops during the round-trip.

7. Calculating the number of passengers in the lift car when it departs from the floor at which a stop occurred. This number represents the load inside the lift car.

8. The largest number of passengers inside the car during the round-trip will be taken as representative of the maximum car-load for a round-trip. This value is stored in an array. In addition, a note is taken of all the values of the numbers of passengers inside the car when it started at each floor.

9. Steps 4 to 8 are repeated for a large number of times (the number of trials in the Monte Carlo Simulation, e.g., 10,000 trials).

10. The values of the car loading from each of the ‘n’ trials are then analysed in order to produce a PDF for the maximum car loading in a round-trip, the load in the car when it starts at each floor.

It is worth noting that when looking at the number of passengers inside the car, the assumption is that passengers inside the car will alight first and then waiting passengers at the landing will board. This is more representative of reality. By taking the number of passengers inside the car, when it departs from a floor at which a stop occurred (as suggested in point 7 above), ensures that this is the case.

5. NUMERICAL EXAMPLES/SCENARIOS

As an example, on the above, taking a lift with a car capacity of 9 passengers and assuming that the passengers will be willing to fill it up with 9 passengers where possible. It will be insightful to examine the following two different cases:

The first case is pure incoming traffic (i.e., 100% incoming traffic: 0% outgoing traffic: 0% inter-floor traffic). As the building has two contiguous entrances, then the 9 passengers will originate at one of the two entrance floors (basement and ground in this case). Thus, as the lift car departs from the ground floor, it will have 9 passengers on board, regardless of the origins or destinations of the passengers. Therefore the lift car will fill up to its maximum capacity in every round-trip. There is nothing to be gained from analysing the various random scenarios, as the car will fill up with 9 passengers in every round-trip.

An alternative scenario is where the traffic in the building is mixed (e.g., lunchtime traffic: 45% incoming: 45% outgoing: 10% inter-floor). In this case, the maximum load in the car will vary from one round-trip to the next and will rarely attain the value of 9 passengers.

Table 1: The origins and destinations of the 9 passengers.

Passenger #	Origin floor	Destination floor	Type of Passenger
P1	3	2	Inter-floor
P2	G	5	Incoming
P3	B	3	Incoming
P4	8	6	Inter-floor
P5	7	G	Outgoing
P6	1	7	Inter-floor
P7	4	B	Outgoing
P8	G	5	Incoming
P9	5	8	Inter-floor

As can be seen in the table, there are 4 inter-floor passengers, 2 outgoing passengers and 3 incoming passengers. The full journey is now analysed in terms of stops and passengers in the car throughout the round-trip as shown in Table 2.

Table 2: Analysis of one full round-trip to obtain car loading.

Segments of the journey	Passengers in the car	Passengers boarding	Passengers alighting
Stopped at B		1	0
B to G	1		
Stopped at G		2	0
G to 1	3		
Stopped at 1		1	0
1 to 3	4		
Stopped at 3		0	1
3 to 5	3		
Stopped at 5		1	2
5 to 7	2		
Stopped at 7		0	1
7 to 8	1		
Stopped at 8		1	1
8 to 7	1		
Stopped at 7		1	0
7 to 6	2		
Stopped at 6		0	1
6 to 4	1		
Stopped at 4		1	0
4 to 3	2		
Stopped at 3		1	0
3 to 2	3		
Stopped at 2		0	1
2 to G	2		
Stopped at G		0	1
G to B	1		
Stopped at B		0	1

The same round-trip analysis is also shown in a diagrammatic format in Figure 2.

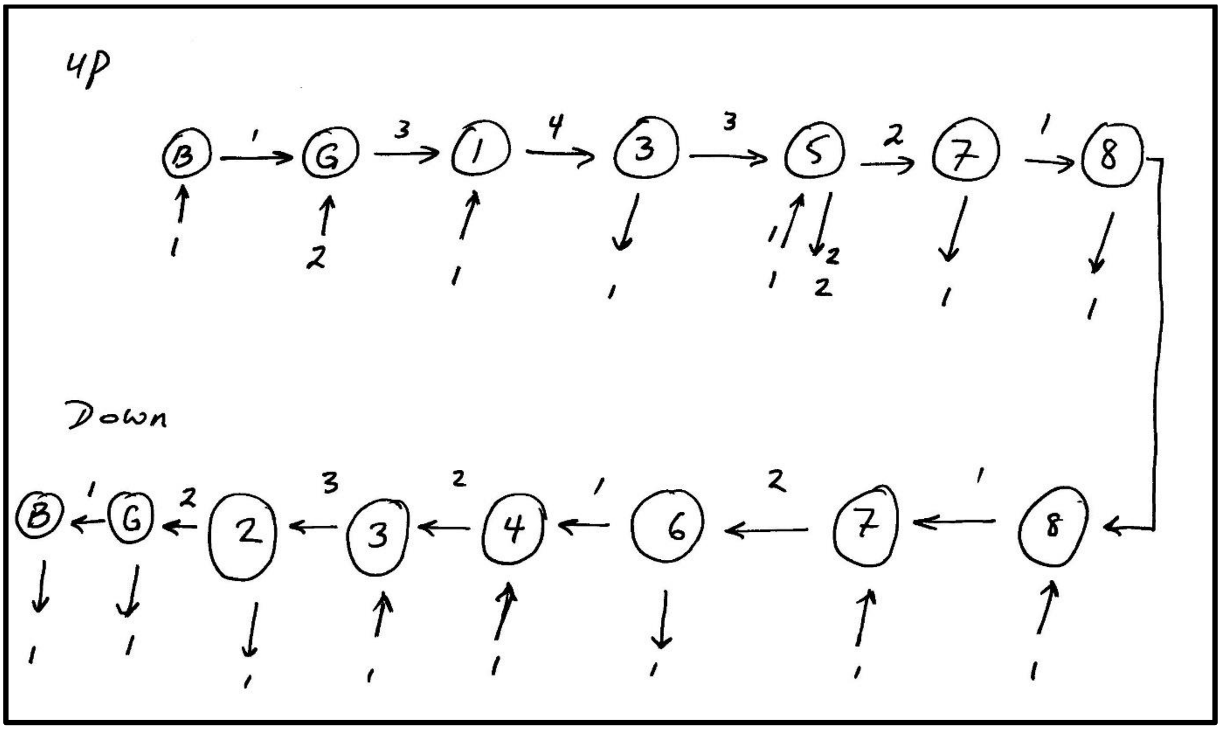

Figure 2: Diagrammatic representation of one round-trip.

When examining the load inside the car at the moment it starts at every stop, there are cases when the car starts with zero passengers inside. The probability density function for the number of passengers inside the car when it starts could either include 0, 1, 2, 3…. passengers or 1, 2, 3, …. passengers. It has been decided to exclude the case where there are no passengers inside the car, as this does not contain any meaningful data. Thus, the probability density function has random variable values running from 1 to P (and does not include 0).

6. RESULTS

In this section, a sample of the results that are obtained from the MATLAB software are reviewed.

A sample building that has 8 occupant floors above ground and two entrance floors (basement, ground) is used. It is assumed that the occupant floors have equal populations. It is worth noting that the software does not require the actual floor population; it simply needs the ratio of the floor populations. The software also needs the entrance bias for the two entrance floors (in this case assumed to be 30%:70% for the basement passenger arrival rates). The traffic mix is assumed to be a typical lunchtime traffic (45% incoming: 45% outgoing: 10% inter-floor).

The Monte Carlo Simulation was run for 1000 trials, with 8 passengers generated in each round-trip. The number of passengers in the car at every start at each floor was recorded to be later processed. The data was then processed to produce the following:

- The number of passengers inside the car when it starts. This was then converted to a probability density function (PDF). The resulting PDF is shown in Figure 3.

- The maximum number of passengers in the car during a round-trip. This was then converted to a PDF. The resulting PDF is shown in Figure 4.

- The number of passengers inside the car when it starts at each floor.
    - A distinction is made between the start at a floor in the up direction and the down direction. This is compiled into an average load inside the car when it starts in a certain direction. This is shown in a tabular format in Figure 5. It is worth noting that the four cells highlighted in yellow have zero values in them. As expected, the car cannot start at the topmost floor when travelling in the up direction, and it cannot stop at the lowest-most floor when travelling in the up direction. A similar argument applies when travelling in the down direction.

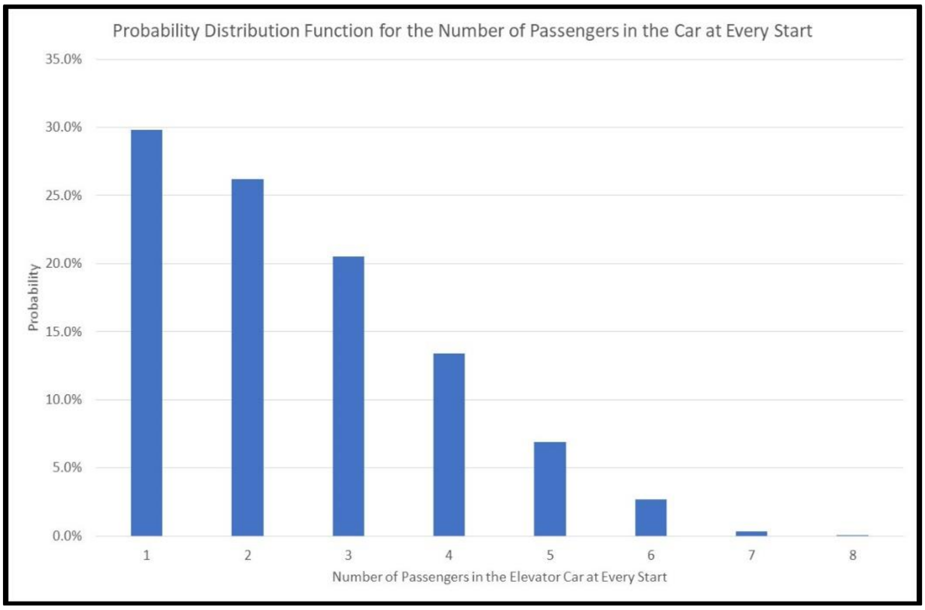

Figure 3: The PDF results for the number of passengers inside the car at every start, in units of passengers and at a lunchtime traffic (45% incoming: 45% outgoing: 10% inter-floor).

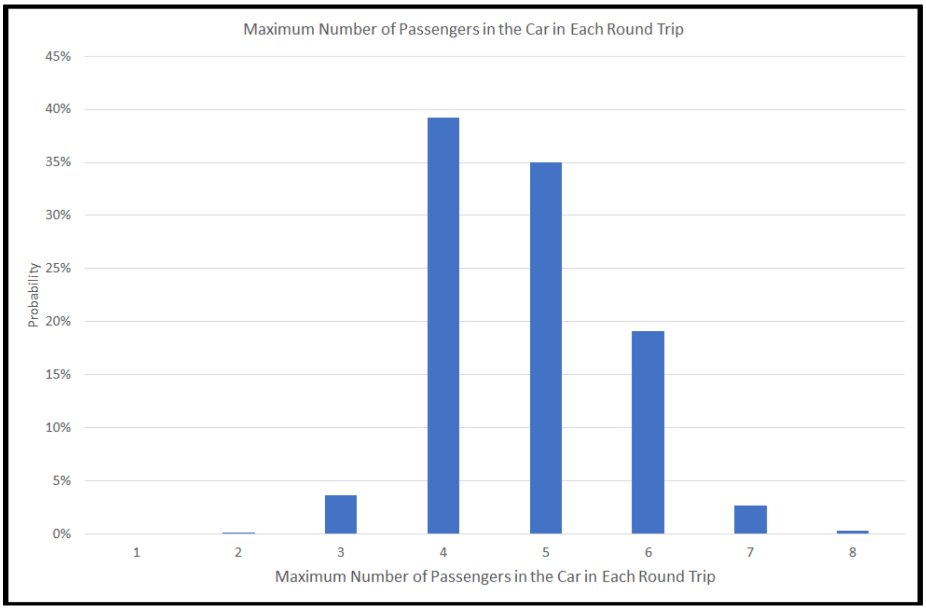

Figure 4: The PDF results for the maximum car-load for 8 generated passengers in a round-trip and lunchtime traffic (45% incoming: 45% outgoing: 10% inter-floor).

Direction	Floor	Probability stopping at this floor in this direction	Load in the car when starting at this floor (units of passengers)	Load in the car when stopping at this floor (units of passengers)		Direction	Floor	Probability stopping at this floor in this direction	Load in the car when starting at this floor (units of passengers)	Load in the car when stopping at this floor (units of passengers)
Up direction	8	41.3%	0.00	0.52		Down direction	8	46.8%	0.58	0.00
	7	43.0%	0.20	0.72			7	42.6%	0.76	0.23
	6	42.7%	0.42	0.93			6	42.2%	0.95	0.47
	5	43.5%	0.63	1.08			5	43.8%	1.10	0.64
	4	44.0%	0.82	1.23			4	42.6%	1.25	0.81
	3	42.4%	0.95	1.37			3	43.1%	1.38	1.00
	2	44.2%	1.21	1.57			2	44.7%	1.61	1.23
	1	43.9%	1.36	1.73			1	42.9%	1.70	1.36
	Ground	94.3%	3.46	0.99			Ground	95.0%	1.01	3.54
	Basement	67.1%	1.09	0.00			Basement	69.5%	0.00	1.08

Figure 5: The Drive Load results for 8 passengers in a round-trip and lunchtime traffic (45% incoming: 45% outgoing traffic: 10% inter-floor traffic).

7. CONCLUSIONS

The Monte Carlo Simulation method has been successfully used in order to extract the load inside the car when it started at each floor and the maximum car-load in the lift car under general traffic conditions. This relied heavily on the origin-destination matrix probability density function (PDF) which was converted into a cumulative distribution function (CDF) and then used to randomly sample passenger origin-destination pairs.

Over a large number of Monte Carlo Simulations, the values of the car-load at each start was stored. The values were then processed to obtain the car-load when it starts, the maximum car-load in a round-trip and the average car-load at each floor in both directions. The results were then compiled into appropriate PDFs and an average load in the car at each floor table.

The results can be used to assess the suitable car capacity under mixed traffic conditions. They can also be used to simulate and model the thermal performance of the drive system and the traction motor.

REFERENCES

[1] Al-Sharif L, Aldahiyat H M and Alkurdi L M. The use of Monte Carlo Simulation in evaluating the elevator round trip time under up-peak traffic conditions and conventional group control. *Building Services Engineering Research and Technology* 2012; 33(3): 319–338. doi:10.1177/0143624411414837.

[2] Al-Sharif L, Abdel Aal O F and Abu Alqumsan A M. Evaluating the Elevator Passenger Average Travelling Time under Incoming Traffic Conditions using Analytical Formulae and the Monte Carlo Method. *Elevator World* 2013; 61(6): 110-123. June 2013.

[3] Al-Sharif L, AlOsta E, Abualhomos N and Suhweil Y. Derivation and Verification of the Round Trip Time Equation and Two Performance Coefficients for Double Deck Elevators under Incoming Traffic Conditions. *Building Services Engineering Research and Technology* 2017; 38(2): 176-196.

[4] Al-Sharif L, Jaber Z, Hamdan J and Riyal A. Evaluating the performance of elevator group control algorithms using a three element new paradigm. *Building Services Engineering Research and Technology* 2016; 37(5): 597–613. 10.1177/0143624416652182.

[5] Al-Sharif L, Yang Z S, Hakam A and Abd Al-Raheem A. Comprehensive analysis of elevator static sectoring control systems using Monte Carlo Simulation. *Building Serv. Eng. Res. Technol.* 2018; DOI: 10.1177/0143624417752644

[6] Gerstenmeyer S. Traffic Analysis for a Multi Car Lift System Used as Local Group. Proceedings of the 9th Symposium of Lift and Escalator Technologies, September 2018, The University of Northampton, United Kingdom, 23.1 – 23.10.

[7] Powell B. The role of computer simulation in the development of a new elevator product. Proceedings of the *1984 Winter Simulation Conference*, page 445-450, November 1984, Dallas, TX, USA, published by INFORMS, Catonsville, MD 21228, United States.

[8] Tam C M and Chan A P C. Determining free elevator parking policy using Monte Carlo Simulation. *International Journal of Elevator Engineering* 1996; 1:24-34.

[9] Al-Sharif L. Introduction and Assessing Demand in Elevator Traffic Systems (METE I). *Lift Report* 2014; 40(4): 16-24. July/August 2014.

[10] Al-Sharif L and Abu Alqumsan A M. Generating the Elevator Origin-Destination Matrix from the User Requirements Specification under General Traffic Conditions. Elevator Technology 2016; 21: 1-13. Proceedings of Elevcon 2016. Madrid/Spain: The International Association of Elevator Engineers.

[11] Al-Sharif L. Building the Origin-Destination Matrix under General Traffic Conditions and Using it to Generate Passenger Origin-Destination Pairs (METE XII). *Lift Report* 2016; 42(3):24-33.

[12] Al-Sharif L. The Universal Origin-Destination-Matrix with Dual Designation Floors as Entrances and Occupant Floors. *Lift Report* 2018; 44(2):36-45.

[13] Basagoiti R, Beamurgia M, Peters R and Kaczmarczyk S. Origin destination matrix estimation and prediction in vertical transportation. *2nd Symposium on Lift and Escalator Technologies*, University of Northampton, Northampton, U.K., 27th September 2012.

[14] Basagoiti R, Beamurgia M, Peters R and Kaczmarczyk S. Passenger flow pattern learning based on trip counting in lift systems combined with on-line information. *3rd Symposium on Lift and Escalator Technologies,* University of Northampton, Northampton, U.K., 26th - 27th September 2013.

[15] Kuusinen J M, Sorsa J, Siikonen M L. The elevator trip origin-destination matrix estimation problem. *Transportation Science*, 2015; 49(3): 1-18.

[16] Kuusinen J M, Malapert A. The effect of randomisation on constraint based estimation of elevator trip origin-destination matrices. 4th Symposium on Lift and Escalator Technologies, University of Northampton, 25th to 26th September 2014.

[17] Al-Sharif L and Abu Alqumsan A M. An Integrated Framework for Elevator Traffic Design under General Traffic Conditions Using Origin Destination Matrices, Virtual Interval and the Monte Carlo Simulation Method. *Building Services Engineering Research and Technology* 2015; 36(6): 728-750.

[18] Al-Sharif L. Generating Elevator Passengers in Time (METE XIII). *Lift Report* 2017; 43(3): 21-31.

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When is a Lift not a Lift?

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Keywords: Lifts, lifting platforms, stairlifts, lifting tables, slow speed lifts, goods hoists, Lifts Directive, Machinery Directive.

Abstract.
Over the last 10 years many types of lifting devices found in buildings have started to look and act the same. This blurring of products has implications for suitability, safety and equipment reliability - particularly where the underlying driver for this is cost. This paper examines the types of devices available, the standards which should apply to their design, manufacture and installation and proposes guidelines to the recommended selection criteria for each type of device.

1 INTRODUCTION

Industry outsiders often mistake the complex array of vertical transportation equipment currently available. Lifting Platforms, Goods Hoists, Slow speed lifts are widely seen as all being just lifts. Those within the industry are, however, aware of the different standards [1] applicable to different classes of devices and the performance and limitations of those devices. It is perhaps a useful exercise therefore, to examine how, why and when, this confusing situation arose. We will then also consider the scope of suitability of application of each different member in the vertical transportation family and thus help avoid outcomes which can range from user disappointment to fatal critical failures.

2 A HISTORY OF VERICAL TRANSPORTATION

2.1 From Ancient Greece to New York City

If we accept as a starting point, the definition of a lift as, “a carrier that can move people and objects up and down”, then the history of lifts is a long one. Rudimentary lifts are known to have been in use in ancient Greece as far back as 266 B.C., with the first reference of one built by Archimedes.

These early lifts had open carriers rather than enclosed ones and consisted of a carrier with a mechanism that would enable the carrier to move vertically or up inclines. These hoists were typically worked manually, either by people or animals - though sometimes water wheels were used. The Egyptians, Greeks and Romans continued to use these simple lifts for many years, usually to move water, building materials, or other heavy items from one place to another.

Henry VIII had a simple early type of stairlift installed in Whitehall castle in the 16th century. The device was powered by servants using a block and tackle system borrowed from the Navy to pull a throne up a ramp laid over 20 steps.

Dedicated vertical passenger lifts were created in the 18th century, with one of the first used by King Louis XV in 1743. He had a lift constructed at Versailles that would carry him from his apartments on the first floor to his mistress' apartments on the second floor. This lift was not much more technologically advanced than those used in Rome. To make it work, men stationed in a chimney pulled on the ropes. It was known as the "flying chair."

It wasn't until the 1800s that lift technology really started to advance. In 1823, two British architects Burton and Hormer built a steam-powered "ascending room" to take tourists up to a platform for a view of London. Several years later, their invention was expanded upon by architects Frost and Stutt, who added a belt and counterweight to the steam power.

Soon after, hydraulic systems began to be created as well, using water pressure to raise and lower the lifts carrier. This, however, was not practical in some cases - pits had to be dug below the lifts shaft to enable the piston to pull back. The higher the lifts went, the deeper the pit had to be. Thus, this wasn't a viable option for taller buildings in big cities.

Despite the hydraulic systems being somewhat safer than steam-powered/cabled lifts, the steam powered ones, with cables and counterweights, stuck around. They had just one major drawback: the cables could snap, and sometimes did, which sent the lifts plummeting to the bottom of the shaft, killing passengers and damaging building materials or other items being transported.

In 1853 Elisha Otis, with the invention of his safety brake, mitigated the risks associated with rope failure and made passenger lifts and skyscrapers the reality they are today. Thus, human ingenuity in devising and improving a transportation system called lifts, has shaped not only how we live and work, but where we live and work.

In the high-rise world, few would disagree that lifts are essential and only the right capacity, number and speed of lifts will provide an adequate transportation system. This however is largely true of all types of buildings.

2.2 The evolution of the definition of lifts and other types of lifting devices.

The starting definition of a lift as a carrier that can move people and objects up and down, was broadly based and with the invention of cranes and other lifting devices and so it was inevitable that a clearer definition was required. It is beyond the scope of this paper to examine all the changes in accepted definitions, but it is important to demonstrate the differences cited in various documents over the last 30 years: -

- In BS 5655-2 1988, EN81-2 1987 a lift is defined as "*permanent lifting equipment serving defined landing levels, comprising a car whose dimensions and means of construction clearly permit the access of persons; running at least partially between rigid vertical guides or guides whose inclination to the vertical is less than 15 degrees".*

  SI 831 The Lifts Regulations 1997 defines a lift as *"an appliance serving specific levels, having a car moving:*

(a) Along guides which are rigid; or

(b) Along a fixed course or along a fixed course even where it does not move along guides which are rigid (for example a scissor lift), and inclined at an angel of more than 15 degrees to the horizontal and intended for the transport of:

- *Persons*

- *Persons and goods*

*Goods alone that is to say, a person may enter it without difficulty, and fitted with controls situated inside the car or within reach of a person inside."*In EN 81-2 1998 the inclusion of a definition was removed but the scope stated *"1.1 permanent installed new hydraulic lifts serving defined landing levels having a car designed for persons or persons and goods, suspended by jacks, ropes or chains and moving between guide rails inclined not more than 15 degrees to the vertical".*The statements of additional requirements in 1.2 and exclusions in 1.3 of the scope are the precursors for the development of new standards or the revision of existing standards. This in 2014 therefore, formalised a process where the changes in the scope of one standard, opened the door for the development of another standard. A process which began in the late 20th Century and has become the EN81 family of standards. By 2025 the whole family will migrate into the ISO 8100 family of world standards for lifts. There is of course a lot of work to be done to get to this position as all draft standards will have to be completed and agreed at a global level.

Standards covering other types of lifting devices, also use the scope of the standard, as a means of providing a definition of the device:

- Service Lifts EN81-3

"1.1 This standard specifies the safety rules for the construction and installation of permanently installed new electric service lifts with traction or positive drive, or hydraulic service lifts defined as lifting equipment, serving defined landing levels, having a car, the interior of which is regarded as inaccessible to persons on account of its dimensions and means of construction, suspended by ropes or chains or supported by a ram and moving between rigid vertical guide rails or guide rails whose inclination to the vertical does not exceed 15° and driven electrically or hydraulically.

This standard covers service lifts with rated load not exceeding 300 kilograms and not intended to move persons."

- Accessible Goods Only Lifts EN81-31

"1.1 This European Standard applies to new electric accessible goods only lifts with traction or positive drive and new hydraulic accessible goods only lifts, permanently installed in restricted areas and/or only used by authorised and instructed persons (users), serving fixed and permanent landing levels, having a load carrying unit made of a single load carrying area, designed for the transportation of goods only, moving along a fixed path (e.g. scissor lifts, lifts with guide rails) and inclined not more than 15° to the vertical, with rated speed not exceeding 1 m/s.

This European Standard covers accessible goods only lifts with rated load exceeding 300 kg and not intended to move persons.

This standard deals with all significant hazards, hazardous situations and events with the exception of those listed in 1.3 below, relevant to accessible goods only lifts, when they are used as intended and under the conditions foreseen by the manufacturer (see Clause 4).

1.2 For the purpose of this European Standard, a goods only lift is regarded as accessible where one of the following conditions is satisfied:

> *a) floor area of the load carrying unit is greater than 1,0 m2;*
>
> *b) depth of the load carrying unit is greater than 1,0 m;*
>
> *c) height of the load carrying unit is greater than 1,20 m.*

In case of a platform, it is considered accessible when the height of the landing doors is more than 1,20 m.

1.3 Two types of accessible goods only lifts are addressed:

> *a) Type A, where the intended use is bound to the following two simultaneous conditions:*
>
> > *1) maximum rated speed: 0,30 m/s;*
> >
> > *2) maximum travelling height: 12 m;*
>
> *b) Type B, where one of the conditions mentioned above is not fulfilled."*

- Stairlifts EN 81-40

"1.1 This European Standard deals with safety requirements for construction, manufacturing, installation, maintenance and dismantling of electrically operated stairlifts (chair, standing platform and wheelchair platform) affixed to a building structure, moving in an inclined plane and intended for use by persons with impaired mobility:

- *travelling over a stair or an accessible inclined surface;*
- *intended for use by one person;*
- *whose carriage is directly retained and guided by a guide rail or rails;*
- *supported or sustained by rope (5.4.4), rack and pinion (5.4.5), chain (5.4.6), screw and nut (5.4.7), friction traction drive (5.4.8), and guided rope and ball (5.4.9)."*

- Lifting Platforms EN81-41

"1.1 This European Standard deals with safety requirements for construction, manufacturing, installation, maintenance and dismantling of electrically powered vertical lifting platforms affixed to a building structure intended for use by persons with impaired mobility:

- *travelling vertically between predefined levels along a guided path whose inclination to the vertical does not exceed 15°;*
- *intended for use by persons with or without a wheelchair;*
- *supported or sustained by rack and pinion, wire ropes, chains, screw and nut, friction/traction between wheels and the rail, guided chain, scissors mechanism or hydraulic jack (direct or indirect);*
- *with enclosed lift ways;*
- *with a speed not greater than 0,15 m/s;*
- *with platforms where the carrier is not completely enclosed."*

- Lifting Tables serving 2 fixed levels EN1570-1

"1.1 This European Standard specifies the safety requirements for industrial lifting tables for raising and/or lowering goods and the operator(s): — where the lifting table does not pass a fixed landing; — serving not more than 2 fixed landings.

1.2 This European Standard deals with all significant hazards pertinent to lifting tables when they are used as intended by the operating instructions and under the conditions foreseen (including foreseeable misuse) with the operating instructions (see Clause 4). This European Standard specifies the appropriate technical measures to eliminate or reduce the risks arising from the significant hazards.

1.3 Both power operated and manually operated lifting tables are included whether stationary or mobile.

1.4 This European Standard does not apply to the following equipment:

— lifting tables, serving more than 2 fixed landings of a building, for lifting goods with a vertical travel speed not exceeding 0,15 m/s (EN 1570-2);

— lifting tables, serving more than 2 fixed landings of a building for lifting operators, with a vertical travel speed not exceeding 0,15 m/s (EN 1570-3);

— lifting tables carrying operators and installed in full enclosures (EN 1570-3);

— permanently and temporarily installed lifting tables, serving specific levels of a building for lifting operators, with a vertical travel speed exceeding 0,15 m/s (EN 81-1 and EN 81-2);

— lifting tables with flat or toothed belts lifting systems for the carrying of operators;

— lifting tables whose vertical travel speed exceeds 0,15 m/s (unless safe by position and non person carrying);

— power operated lifting platforms for persons with impaired mobility (EN 81-41);

— mobile lifting tables for airport ground support equipment (EN 1915-2 and EN 12312-1);

— lifting tables which are designed as part of a lift according to Directive (95/16/EC);

— lifting tables used on ships; — mobile elevating work platforms (EN 280);

— static elevating work platforms; — vehicle lifts for maintenance (EN 1493);

— mobile lifting tables used for fire fighting (EN 1777);

— mobile lifting tables used as fork lift trucks and order pickers;

— mobile lifting tables with a horizontal travelling speed of more than 1,6 m/s;

— rail dependent storage and retrieval equipment (EN 528);

— theatre stage lifts intended to move performers;

— scissor lift pallet trucks (EN ISO 3691-5);

— suspended lifting tables;

— lifting tables operated by pushing chains.”

- Lifting tables serving more than 2 fixed levels EN1570-2

“1.1 This European Standard specifies the safety requirements applicable to lifting tables presenting

the following characteristics:

— serving more than two fixed landings of a construction;

— able to pass landings;

— designed exclusively for lifting or lowering goods and not persons;

— only accessible to persons during the loading/unloading phases;

— with a travel speed of no more than 0,15 m/s;

— permanently installed.

1.2 This European Standard deals with all significant hazards pertinent, with the exception of noise, to lifting tables when used as intended and under the conditions foreseen by the manufacturer (see Clause 4). This European Standard specifies the appropriate technical measures for eliminating and reducing the risks arising from the significant hazards.

1.3 This European Standard does not apply to the following equipment:

> *— permanently installed lifting tables, serving specific levels of a construction, with a vertical travel speed exceeding 0,15 m/s (EN 81-31);*
>
> *— lifting tables serving not more than two fixed landings of a construction (EN 1570-1);*
>
> *— lifting tables, serving more than 2 fixed landings of a construction for lifting operators, with a vertical travel speed not exceeding 0,15 m/s;*
>
> *— lifting tables carrying operators and installed in enclosures with a vertical travel speed not exceeding 0,15 m/s;*
>
> *— lifting tables used on ships;*
>
> *— lifting tables designed for artists and stage set features during artistic performances;*
>
> *— lifting tables driven by pusher chains.”*

EN81-21 2018 3.1 defines an existing building as “*a building, which is used or was already used before the order for the lift was placed*” and clarifies this “*Note 1 to entry: A building whose internal structure is completely renewed is considered as a new building*”. Where there is a new lift shaft constructed within an existing building which retains some of its internal structure the alternative safety measures defined in EN81-21 can be utilised.

The position set by the European Commission’s Lift Committee 0n 9th September 2004 [2] and used by HSE guidance in the UK is that any lift in an existing lift shaft would be classed as a new lift if only the guide rails or the guide rail fixings were retained. This may in time have major ramifications for the industry. If any new lift in an existing building can offer the equivalent safety measures, outlined in EN81-21, to the traditional refuge spaces in the headroom at the top of the lift shaft and pit at its base - why can this not be the case in new buildings? New buildings can have the same unavoidable limitations on pit depth, caused say by an underground railway as the existing building next door. The only solution currently available for new lifts in a new building with restricted pit or headroom is to utilise a slow speed lift, which is currently certified under the Machinery Directive previously cited. EN81-42 will, when published, codify this type of device. It is a concern that this type of device may not be suitable for the overall requirements of the building viz. traffic handling, suitability for use as a firefighter’s lift, vandal resistance, reliability and longevity.

Table 1 shows the standards which apply to various types of Vertical Transportation. Some of the standards listed are at the planning stage or are in preparation. Others refer to components common to lifts and other types of lifting devices.

Table 1: Standards for different types of Vertical Transportation and associated equipment

Type of Lift or Component	**Applicable Standard**
Electric and hydraulic service lifts	EN81-3

Lifts for the transportation of persons and goods	EN81-20
New passenger and goods passenger lifts in existing building	EN81-21
Electric lifts with inclined path	EN81-22
Remote alarm on passenger and goods passenger lifts	EN81-28
Accessible goods only lifts	EN81-31
Stairlifts and inclined lifting platforms	EN81-40
Vertical lifting platforms	EN81-41
Slow speed lifts	EN81-42
Lifts in cranes	EN81-43
Lifts in wind turbines	EN81-44
Design rules, calculations, examinations and tests of lift components	EN81-50
Type examinations of lifts	EN81-51
Landing door fire test	EN81-58
Technical file and instruction for use special lifts for persons and goods	EN81-60
Technical file and instruction for use Goods only lifts	EN81-61
Remote monitoring of lifts	EN81-68
Accessibility for persons with disability	EN81-70
Vandal resistant lifts	EN81-71
Fire fighters' lifts	EN81-72
Behavior of lifts in the event of fire	EN81-73
Lifts subject to seismic conditions	EN81-77
Improvement of safety of existing lifts	EN81-80
Modernisation of lifts	EN81-81
Accessibility improvement of existing lifts	EN81-82
Vandal resistance improvement of existing lifts	EN81-83
Escalators and Moving walks	EN115-1
Improvement of safety to existing escalators and moving walks	EN115-2
Builders hoists goods with accessible platforms	EN12158-1
Inclined hoists for goods non accessible	EN12158-2
Builders hoists for persons and goods	EN12159
Transport platforms	EN16719
Lifting tables for up to 2 landings	EN1570-1
Lifting tables for more than 2 landings	EN1570-2

2.3 Other standards for Lifts

The main types of lift missing from the above standards are:

- Evacuation Lifts formerly covered in the UK by BS5588 part 8 and now covered by BS9999 and BS9991 for evacuation lifts in residential buildings. These standards define the additional features required for lifts to be used for the evacuation of building occupiers.

- Goods only lifts with attendant control - these devices are usually manufactured as slow speed lifts and may be designed to EN81-42 once the standard is issued. They are currently manufactured to the Machinery Directive.

- Home lifts colloquially known as "Through the floor" lifts are covered by in the UK BS5900
- None enclosed or partly enclosed lifting platforms (or step lifts as they may be known colloquially) are covered in the UK by BS6440.

The format of the testing and final inspection of lifts is currently set down in the BS8486 series of standards. Other types of lifting devices such as lifting platforms, lifting tables, goods only lifts, stairlifts and home lifts do not have an equivalent set of testing and inspection documents.

3 LEARNING FROM HISTORY – SUFFICIENT SAFETY?

Lifts installed under the Lifts Directive are subject to a design and installation procedure, which is approved and monitored by a Notified Body and in the UK, are subject to a comprehensive final inspection based on the BS8486 series of standards. Devices supplied and certified under the Machinery Directive may not be as carefully selected, risk assessed, designed, installed or tested. There is a body of opinion which holds that there may not be equivalent safety in Machinery Directive Devices (when compared to lifts installed under the Lifts Directive), but there is sufficient safety. I do not hold with that body of opinion. There cannot be enough safety if there are accidents and incidents occurring. Of the LEIA safety notices issued in the last 20 years [3], over 30% have related to lifting appliances other than lifts. The HSE have reported that here have been a series of incidents involving lifting platforms with landing doors that have opened when the carrier in not at that floor [3]. There have also been instances of premature drive nut failures on lifting platforms including those designed to transport goods [3]. These types of event sadly have occurred before with tragic consequences.

3.1 Case study: The High Claire Rochdale Incident 1985

BS5900-1980 "Specification for Powered Home lifts" was intended to be a domestic home lift standard. It assumed that there would be very low usage on a device installed in a private residence and hence partly to save space (and cost), small worm wheel gear boxes with 75mm centers were utilized. Several manufacturers supplied very similar products during the early 1980's. Sadly this type of lift started to be sold into local authority and private residential care homes, where usage was far more extensive. On 2nd September 1985, the gearbox of the lift at High Clare Rochdale, designed to BS5900, failed whilst carrying passengers. Two of the elderly passengers died from their injuries. This, much to the concern of the Health and Safety Executive (HSE), was not an isolated incident. On 11th September 1985, the Manchester Area Director wrote to all HSE Area Directors [4] advising of the issue. It was discovered that there had been several fatalities in other areas. Over the next 6 years, various modifications to Home Lifts designed to BS 5900 were attempted, aiming to prevent further accidents. None of the preventative measures applied or alternative machines supplied were able to limit the accelerated wear in the worm wheel gearboxes. Ultimately, the lifts were replaced either by hydraulic bore hole solution lifts or lifting platforms intended for a commercial application. One of the last of this type of home lift was replaced in Barnsley in June 2019. What lessons can history teach in this case - where a design was utilized outside of the scope of its design?

3.1.1 Lessons we can learn for the suitability of other types of lifting devices

Case specific lesson:

> The maximum number of trips per annum and starts per hour should be considered by the designer - as well as wear due to over loading, misalignment of guides, and poor maintenance. Load bearing components should have a sufficient factor of safety to allow for

these adverse factors. The design parameters for maximum number of trips per annum and starts per hour should be included in sales literature and in O & M manuals.

General lessons for other types of lifting devices:

a) Where there are open carriers and/or where hold to run controls are deployed on lifting platforms, the motor and other related components should be rated at least 30 starts per hour - as inexperienced users will often fail to maintain the momentary contact of the control and as a result the motor may have several starts in a single journey. Many screw-driven lifting platforms are rated at less than 20 starts per hour and this can lead to entrapment caused by the operation of thermal overload devices. Failure of this type of device can leave elderly or disabled passengers stuck above ground floor level until the device is repaired or alternative rescue means established.

b) The maximum travel for lifting platforms and slow speed lifts should be limited by the maximum time to destination analysed by simulation. The maximum time to destination should be less than 180 seconds in residential applications, and in commercial applications, 120 seconds. This would probably reduce the maximum travel for slow speed lifts to 9 meters in residential and 6 meters in commercial applications. Otherwise, it may be that a person with disability could argue that they were being discriminated against, due to the poor service provided by the access arrangements.

c) The vertical transportation system should be designed with an arrival rate for persons with a disability of at least 8% of the building population per 5 minutes, in both residential and commercial applications. For residential nursing homes, where the arrival rate may need to be higher, a conventional passenger goods lift should always be considered instead.

d) Lifting platforms are usually not designed to transport goods but can often be found in retail mezzanine applications and used regularly for that purpose. Using a device outside of the scope of its design is potentially dangerous. For example, a designer of a stairlift may reasonably not identify risks associated with it being used to carry liquid nitrogen. The event would be considered very unlikely, were it not for the fact that the British Compressed Gas Associations Code of Practice CP30, recommends the installation of a stairlift for that very purpose. Where goods are to be regularly carried a disabled lifting platform should not be used.

e) Lifting Platforms and Slow speed lifts should follow the same rules for the relationship of available area to rated load as defined in EN81-20.

f) The definition of rated speed should be the maximum speed in either direction of travel for all types of lifting appliances.

4 CONCLUSION

Our brief review of the history of lifts revealed "necessity is the mother of invention". The meaning of this anonymous proverb is that innovations are chiefly driven by human need. In the construction industry, cost reduction can sometimes be the strongest necessity. Equipment supplied to internationally recognised standards, that are based on risk assessments, carried out by teams of experts in their respective field, guiding experienced designers, consistent manufacturers and competent installers and testers will be safer, more reliable and fit for purpose. They may well be more expensive than devices which have not gone through such a rigorous process. Other devices supplied by a different route may be sufficiently safe but may well fail to perform or last as the end user expects.

Just because an alternative to a conventional passenger and goods lift can be installed, does not mean that it should be installed, as it may not be suitable to handle the traffic flow of the building. "Buy cheap and buy twice" is another proverb and is based on common sense.

5 REFERENCES

[1] Standards will be referred to in this paper presented to an international audience as EN ** and ISO ** rather than BS EN **. All standards cited other than those in preparation can be found on the BSI online website:

https://shop.bsigroup.com/?utm_campaign=MS-UPD-MEMB-usonline1205-1205&utm_medium=PMAG&utm_source=UPDA&utm_content=us1205

[2] European Commission Enterprise Directorate-General Ref. Ares(2016)699730

[3] https://www.leia.co.uk/technical/product-information/

[4] VT Consult archive https://documentcloud.adobe.com/link/track?uri=urn%3Aaaid%3Ascds%3AUS%3A332da449-86f4-4bd4-bef8-91df5c1913ca

6 BIOGRAPHICAL DETAILS

Michael Bottomley joined the lift industry in 1981. He worked for Gregson & Bell Lifts for 21 years and MovvéO (formerly Lerch Bates) for 17 years. He is currently a Lift and Escalator Consultant and Authorising Engineer for lifts with VT consult. He holds a degree, with honors, in Engineering and Marketing from the University of Huddersfield, and has over 38 years' experience in lift engineering and lift design. In 1999 he was the second lift designer in the UK to achieve Notified Body approval under the Lifts Regulations 1997. He is an affiliate member of the Chartered Institute of Building Service Engineers (CIBSE) and is currently Vice Chairman and a Past Chairman of the CIBSE lifts group. He is a contributory Author to the 2015 edition of HTM 08-02 and is currently assisting with the 2020 edition of CIBSE Guide D.