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## FOREWORD

It is with great pleasure that we present the proceedings of the 16th Symposium on Lift and Escalator Technologies, 24-25 September 2025, 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 involve the 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 postgraduate students.

The papers are listed alphabetically by first author surname. The requirement was to prepare an extended abstract, but full papers were accepted where the speakers 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

# Using machine learning in order to estimate the traffic mix in a building from the stops data

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**Keywords**: The Round Trip; elevator; lift; incoming traffic; outgoing traffic; interfloor traffic; occupant floor; entrance floor, machine learning.

**Abstract.** Previous work has established that the average number of up stops and down stops in a building during a round trip, as well as the ratio between them, could be used to estimate the mix of traffic prevailing in the building and its intensity.

Further work has used basic correlation methods to derive the mix of traffic in the building, finding the ratios of incoming traffic, outgoing traffic, and inter-floor traffic. These studies have assumed that inter-entrance traffic is zero.

This paper builds on the methodologies developed in the earlier work by introducing machine learning techniques to model the relationship between stop types and their locations within a building. The methodology requires knowledge of the types of floors in the building (occupant floors or entrance/exit floors).

The data required for machine learning will be generated in larger amounts in a reasonable time and with modest processing power, whereby the data is representative of a specific building.

## 1 INTRODUCTION

This paper is a continuation of a series of pieces of research that attempt to infer the type of traffic in a building based on the number and type of stops that the lift makes. The following is a historical summary:

- As a simple example, the ratio of the up stops to the down stops can be used to detect the presence of an up-peak condition [1].
- A follow-up piece of work used artificial neural networks to assess the type of prevailing traffic in the building, such as up peak, down peak, two-way traffic or off peak [2].
- The concept of attempting to infer traffic data based on the number of stops was first suggested in 1992 [3] in what was then called the I-S-P method.
- Further work on this concept was carried out in 2022 [4], whereby the tables relating the expected number of stops in the up direction and the down direction were generated based on large amounts of data generated using the Monte Carlo Simulation (MCS) method.
- Basic single-dimensional regression was applied in special limited traffic cases (e.g., where incoming traffic and outgoing traffic are equal) to try to determine simple ways that can be used to find the mix of traffic based on the number of stops [5].

This paper relies heavily on the definition of a floor in a building as either an entrance/exit floor (to be referred to later as an entrance floor) or an occupant floor [6]. It further extends the work in [5] by systematically using two-dimensional regression to find specific equations that allow the user to find the incoming traffic and the outgoing traffic percentages from the four types of stops in a round trip.

Section 2 generates the data for the number of stops in a round trip based on the mix of traffic. This results in a triangular data table, ready to be used in the machine learning process. Section 3 plots four surfaces that allow the reader to visualise the relationship that is contained in the triangular table, against the x and y axes (incoming traffic percentage and outgoing traffic percentage, respectively). Section 4 carries out the two-dimensional regression and presents the two resultant equations. Section 5 draws conclusions and discusses the next important step that will allow this methodology to become universal and allow it to be used for any size and arrangement of building.

## 2 GENERATING THE TRIANGULAR STOPS DATA

In order to implement the machine learning process, it is first necessary to generate sufficient data. The data will link the different scenarios of the traffic mix with the average number of stops in any round trip.

The ideal method for generating such data is to employ the Monte Carlo simulation (MCS) method.

In the previous piece of research [5], the approach of generating data points at different mixes of traffic was selective, rather than systematic. To understand the data and be able to come up with a suitable approach, two sets of scenarios were generated:

- The first set of scenarios attempts to keep the ratio between the incoming traffic and the outgoing traffic constant, while varying the percentage of the inter-floor traffic.
- The second set of scenarios keeps the percentage of the inter-floor traffic constant at 40%, while varying the ratio of the incoming traffic to the outgoing traffic.

In all cases, the inter-entrance traffic is kept at 0%.

Such an approach was very limited and only concentrated on a specific number of cases. This paper adopts a more systematic approach by continuously varying the incoming traffic and the outgoing traffic in increments of 10% (or 0.1) from 0% to 100% (i.e., from 0 to 1.0). When the incoming traffic attains values of 60% or more, the value of the outgoing traffic must be restricted (to prevent the total traffic values exceeding 100%). Such a restriction means that a table that has column heading of outgoing traffic ranging from 0% to 100%, and row headings of incoming traffic from 0% to 100%, can only be a "triangular" table, as the lower part of the triangular would have values the sum of which exceeds 100%, and thus must be disallowed. A resolution smaller than the value of 10% is not necessary for this exercise, as the resultant surface (which will be seen in the next section) is very smooth.

An overview of the resultant data table is shown in Figure 1 below. The figure aims to show the shape of the table (as the numbers in it are too small to read!).

| incoming traffic % | outgoing traffic % | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | | | 10 | | | 20 | | | 30 | | |
| | interfloor % | | | interfloor % | | | interfloor % | | | interfloor % | | |
| | 100 | up stops | down stops | 90 | up stops | down stops | 80 | up stops | down stops | 70 | up stops | down stops |
| 0 | entrance floors | 0.000 | 0.000 | | 0.0000 | 0.9367 | | 0.0000 | 1.4119 | | 0.0000 | 1.6601 |
| | occupant floors | 6.590 | 6.591 | | 6.3068 | 6.5885 | | 5.9684 | 6.5891 | | 5.5678 | 6.5886 |
| | 90 | | | 80 | | | 70 | | | 60 | | |
| 10 | entrance floors | 0.9384 | 0.0000 | | 0.9378 | 0.9373 | | 0.9371 | 1.4126 | | 0.9386 | 1.6603 |
| | occupant floors | 6.5909 | 6.3043 | | 6.3059 | 6.3025 | | 5.9653 | 6.3036 | | 5.5669 | 6.3052 |
| | 80 | | | 70 | | | 60 | | | 50 | | |
| 20 | entrance floors | 1.4107 | 0.0000 | | 1.4116 | 0.9376 | | 1.4107 | 1.4127 | | 1.4109 | 1.6602 |
| | occupant floors | 6.5888 | 5.9663 | | 6.3044 | 5.9675 | | 5.9673 | 5.9657 | | 5.5665 | 5.9665 |
| | 70 | | | 60 | | | 50 | | | 40 | | |
| 30 | entrance floors | 1.6596 | 0.0000 | | 1.6602 | 0.9371 | | 1.6605 | 1.4111 | | 1.66049 | 1.65929 |
| | occupant floors | 6.5902 | 5.5662 | | 6.3067 | 5.5647 | | 5.9664 | 5.567 | | 5.56582 | 5.56462 |
| | 60 | | | 50 | | | 40 | | | 30 | | |
| 40 | entrance floors | 1.7967 | 0.0000 | | 1.7955 | 0.9363 | | 1.7967 | 1.4117 | | 1.7966 | 1.6592 |
| | occupant floors | 6.5899 | 5.0973 | | 6.3056 | 5.0955 | | 5.9664 | 5.0972 | | 5.5671 | 5.098 |
| | 50 | | | 40 | | | 30 | | | 20 | | |
| 50 | entrance floors | 1.8756 | 0.0000 | | 1.8757 | 0.9383 | | 1.8756 | 1.4127 | | 1.8755 | 1.66 |
| | occupant floors | 6.5886 | 4.5415 | | 6.3039 | 4.5424 | | 5.9673 | 4.5417 | | 5.5656 | 4.5444 |
| | 40 | | | 30 | | | 20 | | | 10 | | |
| 60 | entrance floors | 1.9242 | 0.0000 | | 1.9239 | 0.9373 | | 1.9237 | 1.4112 | | 1.9237 | 1.6595 |
| | occupant floors | 6.5903 | 3.8939 | | 6.3027 | 3.8945 | | 5.9657 | 3.8937 | | 5.5659 | 3.8933 |
| | 30 | | | 20 | | | 10 | | | 0 | | |
| 70 | entrance floors | 1.9531 | 0.0000 | | 1.9533 | 0.9373 | | 1.9531 | 1.4116 | | 1.9534 | 1.6597 |
| | occupant floors | 6.5899 | 3.1311 | | 6.3041 | 3.1321 | | 5.9677 | 3.1321 | | 5.5683 | 3.1329 |
| | 20 | | | 10 | | | 0 | | | | | |
| 80 | entrance floors | 1.9719 | 0.0000 | | 1.9723 | 0.9370 | | 1.9719 | 1.4118 | | | |
| | occupant floors | 6.5898 | 2.2425 | | 6.3058 | 2.2429 | | 5.9660 | 2.2428 | | | |
| | 10 | | | 0 | | | | | | | | |
| 90 | entrance floors | 1.9832 | 0.0000 | | 1.9832 | 0.9385 | | | | | | |
| | occupant floors | 6.5893 | 1.2055 | | 6.3042 | 1.2075 | | | | | | |
| | 0 | | | | | | | | | | | |
| 100 | entrance floors | 1.9904 | 0.0000 | | | | | | | | | |
| | occupant floors | 6.5887 | 0.0000 | | | | | | | | | |

| incoming traffic % | 40 | | | 50 | | | 60 | | | 70 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | interfloor % | | | interfloor % | | | interfloor % | | | interfloor % | | |
| | 60 | up stops | down stops | 50 | up stops | down stops | 40 | up stops | down stops | 30 | up stops | down stops |
| 0 | | 0.0000 | 1.7965 | | 0.0000 | 1.8756 | | 0.0000 | 1.9235 | | 0 | 1.9534 |
| | | 5.0940 | 6.5909 | | 4.5438 | 6.5876 | | 3.8915 | 6.5895 | | 3.1349 | 6.5899 |
| | 50 | | | 40 | | | 30 | | | 20 | | |
| 10 | | 0.9371 | 1.7969 | | 0.9368 | 1.8755 | | 0.9373 | 1.923 | | 0.9377 | 1.9526 |
| | | 5.096 | 6.3031 | | 4.5433 | 6.3048 | | 3.8939 | 6.3054 | | 3.1337 | 6.3055 |
| | 40 | | | 30 | | | 20 | | | 10 | | |
| 20 | | 1.4115 | 1.7966 | | 1.4121 | 1.8757 | | 1.4114 | 1.9236 | | 1.4126 | 1.9533 |
| | | 5.0975 | 5.9673 | | 4.544 | 5.9673 | | 3.8907 | 5.9671 | | 3.1337 | 5.9671 |
| | 30 | | | 20 | | | 10 | | | 0 | | |
| 30 | | 1.6602 | 1.7964 | | 1.6594 | 1.8754 | | 1.6598 | 1.9234 | | 1.6596 | 1.9532 |
| | | 5.0976 | 5.5648 | | 4.5411 | 5.5691 | | 3.8952 | 5.5673 | | 3.1313 | 5.5667 |
| | 20 | | | 10 | | | 0 | | | | | |
| 40 | | 1.79595 | 1.79553 | | 1.7964 | 1.8755 | | 1.796 | 1.9234 | | | |
| | | 5.09899 | 5.09513 | | 4.5447 | 5.0958 | | 3.8915 | 5.0966 | | | |
| | 10 | | | 0 | | | | | | | | |
| 50 | | 1.875 | 1.7959 | | 1.8754 | 1.8760 | | | | | | |
| | | 5.0956 | 4.5414 | | 4.5414 | 4.5429 | | | | | | |
| | 0 | | | | | | | | | | | |
| 60 | | 1.9229 | 1.7961 | | | | | | | | | |
| | | 5.096 | 3.8935 | | | | | | | | | |

| incoming traffic % | 80 | | | 90 | | | 100 | | |
|---|---|---|---|---|---|---|---|---|---|
| | interfloor % | | | interfloor % | | | interfloor % | | |
| | 20 | up stops | down stops | 10 | up stops | down stops | 0 | up stops | down stops |
| 0 | | 0 | 1.9717 | | 0 | 1.9835 | | 0 | 1.9904 |
| | | 2.2423 | 6.5897 | | 1.2063 | 6.5895 | | 0 | 6.5896 |
| | 10 | | | 0 | | | | | |
| 10 | | 0.9377 | 1.9714 | | 0.9377 | 1.9834 | | | |
| | | 2.2447 | 6.3027 | | 1.2065 | 6.3058 | | | |
| | 0 | | | | | | | | |
| 20 | | 1.4108 | 1.9717 | | | | | | |
| | | 2.2429 | 5.9666 | | | | | | |

**Figure 1 The triangular data table that contains the stops data against the values of incoming traffic and outgoing traffic.**

Figure 2 shows an enlarged view of the table. As can be seen, a highlighted group of cells contains the values of four types of stops (up on entrance floors; up stops on occupant floors; down stops on entrance floors; down stops on occupant floors) under the values of 10% outgoing traffic, 10% incoming traffic, and 80% inter-floor traffic. The values of the stops are absolute here, but they will be normalised later in the process by dividing by the number of entrance floors and the number of occupant floors as appropriate. The values of the stops under this scenario of traffic (i.e., 10%; 10%; 80%; 0%) are: At the entrance floors, 0.9378 up stops per round trip and 0.9373 down stops per round trip; at the occupant floors, 6.3059 up stops per round trip and 6.3025 down stops per round.

| entrance floor | Occupant floors |
|---|---|
| 2 | 8 |

| incoming traffic % | outgoing traffic % | | | | | |
|---|---|---|---|---|---|---|
| | 0 | | | 10 | | |
| | interfloor % | | | interfloor % | | |
| | 100 | up stops | down stops | 90 | up stops | down stops |
| 0 | entrance floors | 0.000 | 0.000 | | 0.0000 | 0.9367 |
| | occupant floors | 6.590 | 6.591 | | 6.3068 | 6.5885 |
| | 90 | | | 80 | | |
| 10 | entrance floors | 0.9384 | 0.0000 | | 0.9378 | 0.9373 |
| | occupant floors | 6.5909 | 6.3043 | | 6.3059 | 6.3025 |

**Figure 2 An enlarged view of the data table, showing stops data in detail against the value of traffic components.**

Figure 3 shows part of the reorganised table of data that has been prepared for the machine learning process, with three input variables (two of which are independent) and the four output variables.

| A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|
| i/c | o/g | interfloor % | u/s ent | d/s ent | u/s occ | d/s occ |
| 0 | 0 | 100 | 0 | 0 | 6.59 | 6.591 |
| 10 | 0 | 90 | 0.9384 | 0 | 6.5909 | 6.3043 |
| 20 | 0 | 80 | 1.4107 | 0 | 6.5888 | 5.9663 |
| 30 | 0 | 70 | 1.6596 | 0 | 6.5902 | 5.5662 |
| 40 | 0 | 60 | 1.7967 | 0 | 6.5899 | 5.0973 |
| 50 | 0 | 50 | 1.8756 | 0 | 6.5886 | 4.5415 |
| 60 | 0 | 40 | 1.9242 | 0 | 6.5903 | 3.8939 |
| 70 | 0 | 30 | 1.9531 | 0 | 6.5899 | 3.1311 |
| 80 | 0 | 20 | 1.9719 | 0 | 6.5898 | 2.2425 |
| 90 | 0 | 10 | 1.9832 | 0 | 6.5893 | 1.2055 |
| 100 | 0 | 0 | 1.9904 | 0 | 6.5887 | 0 |
| 0 | 10 | 90 | 0 | 0.9367 | 6.3068 | 6.5885 |
| 10 | 10 | 80 | 0.9378 | 0.9373 | 6.3059 | 6.3025 |
| 30 | 10 | 60 | 1.6602 | 0.9371 | 6.3067 | 5.5647 |
| 40 | 10 | 50 | 1.7955 | 0.9363 | 6.3056 | 5.0955 |
| 50 | 10 | 40 | 1.8757 | 0.9383 | 6.3039 | 4.5424 |
| 60 | 10 | 30 | 1.9239 | 0.9373 | 6.3027 | 3.8945 |

**Figure 3 Part of the data in the table following reorganisation to prepare the data for machine learning (the matching data shown in Figure 2 is highlighted here in yellow).**

As was mentioned earlier, the raw data was generated using the Monte Carlo Simulation method. The MCS method can be used to faithfully generate a large amount of round-trip data [7, 8, 9, 10]. The MCS employs random sampling methods that ensure that the resultant data is a faithful representation of the parameters of the building. The MCS tool was used to generate round trip stops based on the following (similar to what is used in [6]):

- The specific number of passengers per round trip (P=13 passengers in this case).
- A predefined mix of traffic showing the relative strength of the incoming traffic, outgoing traffic, inter-floor traffic and inter-entrance floor.
- The number of occupant floors and the number of entrance/exit floors (8 and 2, respectively, in this case)
- The relative populations of the occupant floors.
- The relative arrivals at the entrance/exit floors.

The MCS methodology does not need to generate the kinematics of the lift system or produce the speed-time profiles. Moreover, it does not need to carry out any allocation of landing calls to the cars. This makes the method independent of the dispatching algorithm. But more importantly, this is an excellent example of the abstraction capability of the MCS method, where it only generates the data that is needed for the case in question, rather than spending time generating kinematic curves or allocation calls. This approach speeds up the generation of the raw data.

## 3 VISUALISING THE FOUR SURFACES

Prior to moving to try to find the best fit for the four surfaces, it is very insightful to better understand the nature of the relationships in a visual manner.

There are three independent variables: the percentage of incoming traffic, the percentage of outgoing traffic, and the percentage of inter-floor traffic. However, only two of these three are independent, as the sum of all three values must add up to 100% (or to 1.0). Thus, in reality, there are only two independent variables (e.g., incoming traffic percentage and outgoing traffic percentage), as the third value will be dependent on the values of the other two. This is assuming that the inter-entrance traffic percentage is always zero.

In addition, there are four dependent variables. These are the average number of stops in a round trip. These four variables are:

- Stops in the up direction on entrance floors.
- Stops in the down direction on the entrance floors.
- Stops in the up direction on occupant floors.
- Stops in the down direction on occupant floors.

As there are two dependent variables, it is very convenient to plot each of the four variables as a "surface" against the two dependent variables. This results in four "surfaces" for each of the four dependent variables that have been plotted against the two dependent variables. In this case, it has been assumed that the two independent variables are the incoming traffic percentage and the outgoing traffic percentage. So, in the plots that have been shown below, the x-axis and the y-axis are the incoming traffic and the outgoing traffic percentages, respectively.

As can be seen in the four figures (Figure 4, Figure 5, Figure 6, and Figure 7), they all show a "triangular" surface that has been "curved". In two cases, the base of the triangle is at zero, either parallel to the x-axis or parallel to the y-axis, and the upper vertex of the triangle ends up at the other side. In the two other cases, the base of the triangle is at the top, either parallel to the x-axis or parallel to the y-axis, with the vertex near the zero. The limiting number of stops is the car size and the number of occupied floors. Here, the number of stops saturates at about 6.3-6.6 stops per round trip, which is about 78.8%-82.5% of the number of occupied floors.

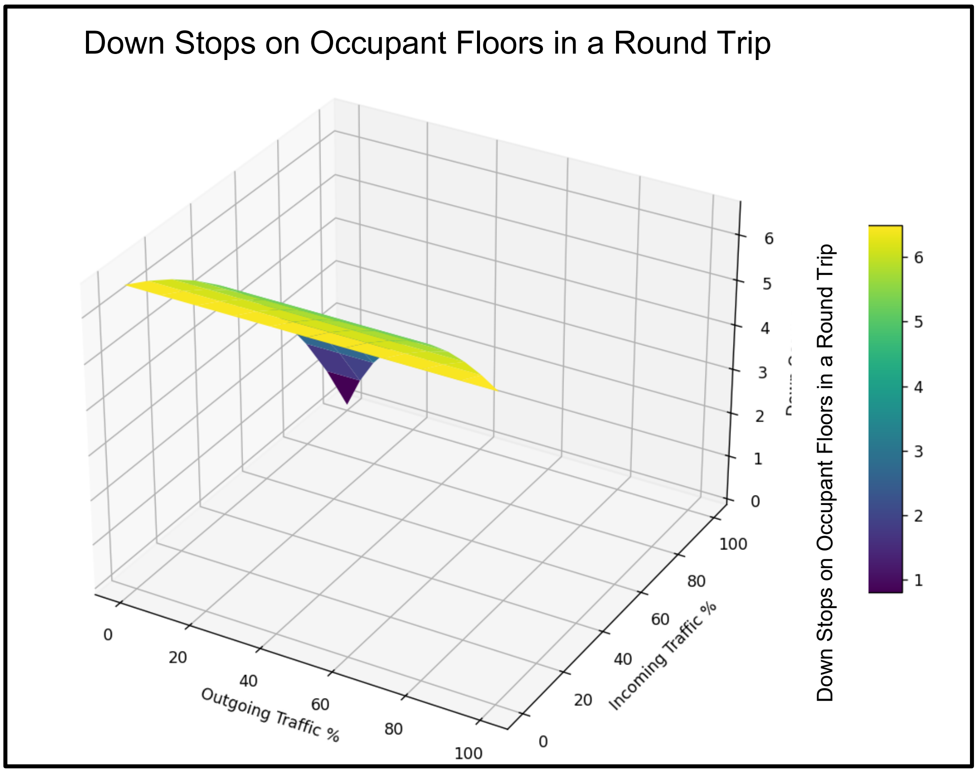


**Figure 4 The plot of the surface that shows the number of down stops on the occupant floors during a round trip, plotted against the incoming traffic percentage and the outgoing traffic percentage.**

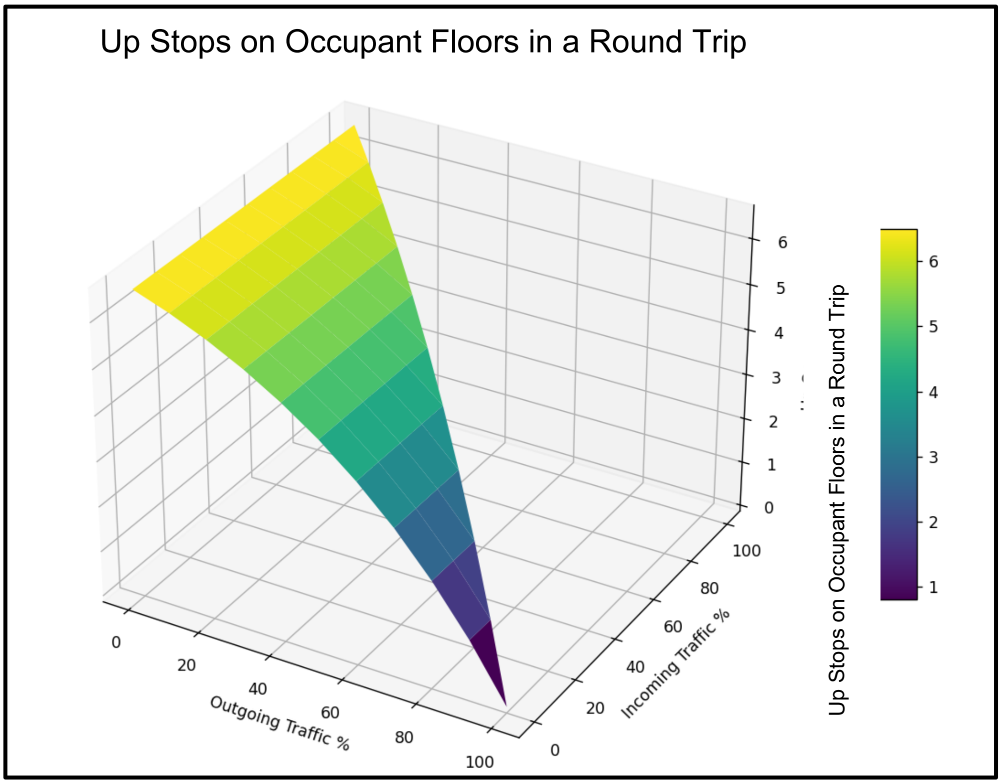


**Figure 5 The plot of the surface that shows the number of up stops on the occupant floors during a round trip, plotted against the incoming traffic percentage and the outgoing traffic percentage.**

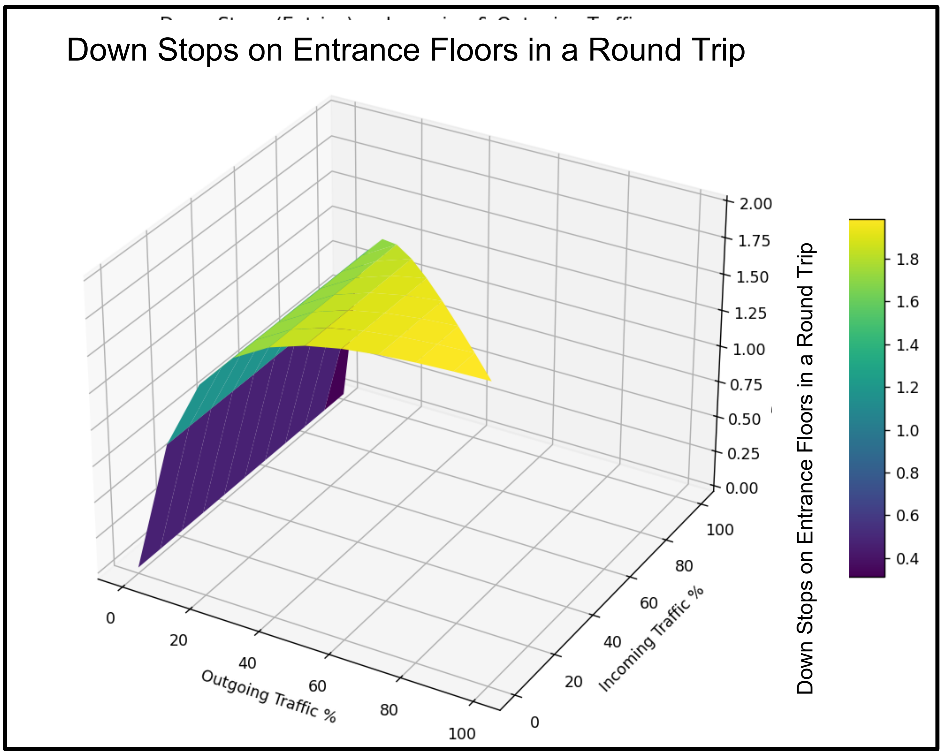


**Figure 6 The plot of the surface that shows the number of down stops on the entrance floors during a round trip, plotted against the incoming traffic percentage and the outgoing traffic percentage.**

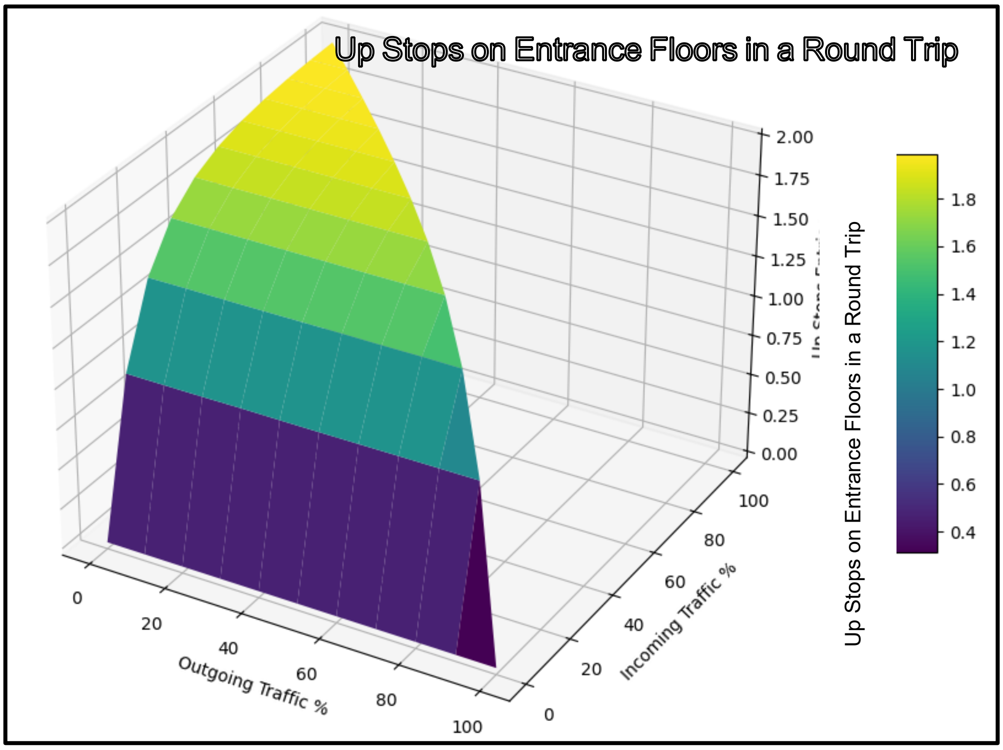


**Figure 7 The plot of the surface that shows the number of up stops on the entrance floors during a round trip, plotted against the incoming traffic percentage and the outgoing traffic percentage.**

It is also worth noting that the z-axis in all four cases (i.e., the average number of stops in a round trip) has not been normalised and has been shown in absolute number of stops. Using further processing (as will be seen in the next section), the number of stops can be normalised by dividing the maximum possible number of stops in the entrance floors (in this case, 2) and by dividing by the maximum number of stops in the occupant floors (in this case, 8). This will produce a "cube" that is normalised and in which each of the three sides is equal to 1 (or 100%).

## 4 TWO-DIMENSIONAL REGRESSION

Using MATLAB, two-dimensional regression tools were used to find the best fit equation that allows the user to find the percentage of the incoming traffic (i/c%), the percentage of outgoing traffic (o/g%), and the percentage of the inter-floor traffic (i/f%) based on the four types of stops that take place on average during a round trip. The equations below were developed using two-dimensional regression tools. It is worth noting that these equations use the normalised values of the stops data, by dividing the average number of stops in a round trip by the maximum number of possible stops. The following is a list of the variables used in the equations below:

- i/c: incoming traffic (number between 0 and 1).
- o/g: outgoing traffic (number between 0 and 1).
- i/f: inter-floor traffic (number between 0 and 1).
- u/s (ent): The average number of up stops on the entrance floors in a round trip, normalised by dividing it by the number of entrance floors in the building.
- u/s (occ): The average number of up stops on the occupant floors in a round trip, normalised by dividing it by the number of occupant floors in the building.
- d/s (ent): The average number of down stops on the entrance floors in a round trip, normalised by dividing it by the number of entrance floors in the building.
- d/s (occ): The average number of down stops on the occupant floors in a round trip, normalised by dividing it by the number of occupant floors in the building.

Having done the regression, these are the following two equations that resulted. The first is the resultant regression equation to find the value of the incoming traffic:

$$i/c = 85.1098 + (22.0421 * u/s\ ent\ (norm)) + (1.6454 * d/s\ ent\ (norm)) + (3.4023 * u/s\ occ\ (norm)) + (-109.0788 * d/s\ occ\ (norm)) \quad (1)$$

The second equation is the resultant regression equation to find the value of the outgoing traffic:

$$o/g = 85.0430 + (1.8327 * u/s\ ent\ (norm)) + (21.8450 * d/s\ ent\ (norm)) + (-109.2628 * u/s\ occ\ (norm)) + (3.7193 * d/s\ occ\ (norm)) \quad (2)$$

The correlation coefficient from the two regression analysis results is very high and nearly close to one, showing an excellent correlation between the number of stops and the mix of traffic parameters:

i/c equation: $R^2$ Score: 0.9908616713660177

o/g equation: $R^2$ Score: 0.9908560432436128

As the inter-entrance traffic has been assumed to be equal to 0, then the inter-floor traffic can be found by subtracting the incoming traffic and the outgoing traffic from 1, as shown below:

i/f = 1 – i/c – o/g (3)

For example, if we calculate that incoming traffic is equal to 10% and outgoing traffic is equal to 30%, then the interfloor traffic would be equal to 1-0.1-0.3 = 0.6= 60%.

It is worth noting that this methodology has assumed the inter-entrance traffic is always zero for simplicity. Future work will remove this constraint and allow the inter-entrance traffic to take on non-zero values. However, in such a case, the number of independent variables will rise to three (e.g., incoming traffic, outgoing traffic, and inter-floor traffic that do not add to one, as the inter-entrance traffic will not be equal to zero in this case). As such, it will not be possible to visualise the resultant "hyper-surface", because it will have four dimensions. Nevertheless, the fact that it cannot be visualised does not prevent finding the equation that links the mix of traffic to the value of the four types of stops. In such a case, three equations will be found for the incoming traffic, the outgoing traffic and the inter-floor traffic. The inter-entrance traffic will be found by simply subtracting the three resultant values of traffic from 1.

## 5 CONCLUSIONS AND FURTHER WORK

This paper has presented a systematic methodology to attempt to find a deterministic relationship between the mix of traffic in a building (i.e., incoming traffic, outgoing traffic, and inter-floor traffic), and the number of stops on entrance/exit floors in the up direction, the number of stops on entrance/exit floors in the down direction, the number of stops on occupant floors in the up direction, and the number of stops on occupant floors in the down direction. Before processing, the number of stops in each round trip was normalised by dividing the number of stops in a round trip by the maximum possible number of stops. The maximum possible number of stops is the number of occupants, floors and/or the number of entrance floors.

Data was first generated using MCS for a specific building. For each of the 66 different combinations of mixes of traffic, one million scenarios were generated, resulting in 66 million scenarios. Each scenario represents one round trip. In each case, the number of stops in the up direction and the down direction, on both the occupant floors and the entrance floors, was recorded. The average number of stops for each type of stop was found by taking the average of all one million scenarios.

This resulted in a "triangular" data table. This table was then used to perform a machine learning exercise, to find the two equations that allow the user to find the values of incoming traffic and outgoing traffic from the four types of stops data. A very high value of correlation coefficients was obtained in both cases, giving a high level of confidence in the accuracy of the resultant equations.

The normalisation of the stops data was critical in attempting to find a universal solution. The most important piece of research that must follow this research is to attempt to carry out the same exercise that has been done in this paper on other types of buildings. If the resultant equations for the incoming traffic and outgoing traffic are identical to those found in this paper, this leads to the important conclusion that these equations are universal. This would mean that these equations can be used for any building without the need to do prior analysis on it. This would be an important breakthrough in lift traffic engineering.

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# Why Escalators Require Safety Gear Similar to Lifts

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**Keywords**: Escalator, Auxiliary Brake

**Abstract.** As outlined in European standards, safety gear (commonly referred to as "parachutes") is mandatory for lift cabins where uncontrolled descent is possible but required for escalators under three specific conditions, particularly when the escalator height exceeds 6 meters. This study begins by examining the historical development of parachutes, lift safety regulations, and the requirements established by European standards. It then analyses escalator incidents where the primary braking system failed to stop the escalator, highlighting the necessity of auxiliary brakes even for escalators under 6 meters in height. Finally, the research advocates for making auxiliary brakes mandatory across all escalators. By equipping escalators with safety mechanisms similar to those in passenger lifts, a secondary system can effectively prevent accidents, significantly enhancing passenger safety.

## 1 INTRODUCTION

The history of parachutes dates back to the 18th and 19th centuries. Initially, parachutes were used to reduce the speed of falling balloons, aeroplanes, etc., and sometimes they were used for recreational purposes.

### 1.1 Parachutes in lifts

After the invention of the lift safety brake by Elisha Otis, it was also called a parachute in lifts. However, just as a parachute includes components such as the pilot chute, bridle, apex, canopy, skirt, suspension lines, links, risers, control lines, harness and container, bag, and manual activator mechanism, the parachute in a lift also does not mean only the safety brake. It includes the governor, tension sheave, governor wire rope, rope clamp, governor engagement microswitch, safety brake engagement microswitch, safety brake, synchronisation lever, etc., which ultimately create safety similar to an aeroplane parachute for the lift. With this definition, an upward parachute does not make sense; rather, the correct term is the safety mechanism to prevent upward overspeed or upward safety brake. Installing a parachute is mandatory for all passenger cabins and, under certain conditions, for the counterweight as well.

**Figure 1 Conceptual photo of a parachute in an elevator**

### 1.2 Parachute requirement in escalators

Unlike lifts, the parachute mechanism for preventing passenger accidents is not mandated for escalators under EN115-1:2017 [1]. According to sub-clause 5.4.2.2.1 of the standard, auxiliary brakes (similar to parachutes in lifts) are only mandatory under three conditions:

a) the connection between the operational brake and the driving sprockets is not accomplished by shafts, gear wheels, multiplex chains, or more than one single chain, or
b) the operational brake is not electro-mechanical, or
c) the escalator rise exceeds 6 meters.


**Figure 2 Conceptual photo of a parachute in an escalator**

### 1.3 Naming of escalator parachutes

Since parachutes are not always mandatory in escalators, they are called “auxiliary brake” in the standard. Therefore, the term "safety brake", which is sometimes used, is incorrect because if this component is not installed (which is optional for heights less than 6 meters), the escalator is not safe, which contradicts the standard's interpretation.

## 2 SAFETY BRAKE REQUIREMENTS IN STANDARDS

### 2.1 When should the escalator parachute operate in EN115-1?

As outlined in sub-clause 5.4.2.3 of the EN standard, the parachute system operates in two scenarios:

- Protection against excessive speed
- Unintentional reversal of the direction of travel

While the standard mandates parachute activation in these cases, sub-clause 5.4.2.2.1 specifies that auxiliary brakes are required only under three specific conditions. Given that chains and electro-mechanical brakes are used in approximately 90% of escalator designs, does the standard suggest that only escalators with a rise exceeding 6 meters pose a safety risk necessitating auxiliary brakes?

Would an escalator with a rise of 5.95 meters not also be susceptible to overspeed or unintended reversal?

If a height above 6 meters is deemed hazardous, it stands to reason that an escalator just below this threshold would share similar risks.

**Figure 3 A simulated image depicting loss of balance due to a sudden change of direction**

# 3 CONCEPTUAL CONTRADICTION IN THE STANDARD

## 3.1 Accidents of overspeed and unintended direction reversal

According to sub-clauses 5.12.2.7.2 and 5.12.2.7.3: A device shall be provided to detect excessive speed before the speed exceeds a value of 1.2 times the nominal speed. If unintentional reversal of direction of travel occurs, a device shall detect it immediately.

Table 8 of EN 115-1:2017 identifies both direction reversal and overspeed as hazardous conditions, necessitating intervention. In addition to completely shutting down the equipment, a skilled technician must investigate the cause. These incidents may occur in escalators of any height, from the smallest model at 0.83 meters to systems as tall as 6 meters. However, the only mandated response mechanism remains cutting off motor power and engaging the mechanical brake.

## 3.2 Causes of overspeed and unintended direction reversal accidents

An analysis of multiple accident cases reveals that the most common and significant causes of these incidents are:

a) Main chain failure – In most cases, the brake is integrated into the motor, and chain breakage results in the inability to support the escalator steps.

**Figure 4 Main chain breakage**

b) Sprocket failure or chain derailment – The breaking of the sprocket or the main chain slipping off its intended path.

**Figure 5 Simulation of sprocket failure by broken teeth**

c) Step chain failure (breakage or derailment) – Step chains breaking or falling off the sprocket, disrupting the escalator's operation.

**Figure 6 Step chain**

d) Main brake failure – Issues such as brake pad wear, oil contamination, or brake disc malfunction that impair the braking system.

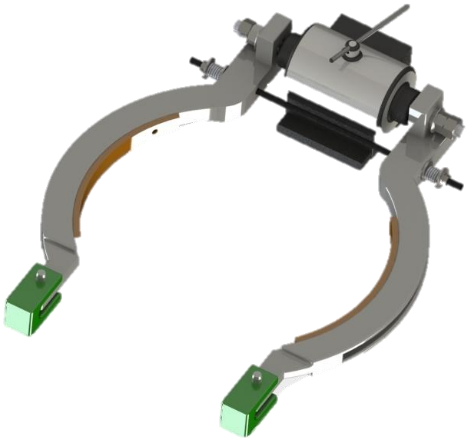

**Figure 7 Main brake failure**

e) Flange failure – In certain motor designs, flanges are used to prevent gearbox damage from affecting the motor shaft and to facilitate part replacement. In one documented accident, flange breakage was directly responsible for failure. Notably, in 90% of cases, the main brake is mounted on the motor. Consequently, flange breakage can lead to gearbox disengagement, rendering the main brake ineffective in stopping the system.

**Figure 8 Flange breakage**

f) Gearbox failure – shaft or gear

**Figure 9 Gearbox breakage**

### 3.3 When should the escalator parachute operate in ASME A17.1?

In version 2019, clause 6.1.5.3.2 [2]: If the escalator driving-machine brake is separated from the main driveshaft by a chain used to connect the driving machine to the main driveshaft, either

a) A mechanically applied or permanent magnet brake capable of stopping and holding a down-running escalator with brake rated load shall be provided on the main driveshaft, or
b) Multiple and separate chains, each with an individual drive-chain device in accordance with 6.1.6.3.4 and each with connection to the escalator driving-machine brake(s) and/or other brake(s) with capacity capable of stopping and holding a down-running escalator with brake rated load, shall be provided.

**Figure 10 A simulated image depicting loss of balance due to the overspeed of the escalator**

In the American standard, auxiliary braking is required even for moving walkways, but in the European standard, it is only for those over 6 meters, and 90% of conventional moving walkways have a lower height.

In version 2010, clause 6.1.5.3.2 [3]: Main drive shaft brake. If the escalator driving-machine brake is separated from the main drive shaft by a chain used to connect the driving machine to the main drive shaft, a mechanically or magnetically applied brake capable of stopping a down-running escalator with brake rated load (see 6.1.3.9.3) shall be provided on the main drive shaft. If the brake is magnetically applied, a ceramic permanent magnet shall be used.

### 3.4 When should the escalator parachute operate in the Japanese code?

In MOC-N (No.1424–2000): The escalator shall be provided with the following safety devices and shall be stopped depending on the detection of the operation of these safety devices.

The step chain safety device stops the escalator rapidly and surely when the step chain stretches excessively or breaks.

Although not stipulated in this regulation, for escalators that use the chain (called the main drive chain) to transmit the driving force from the driving machine to the step chain sprocket, it is required to furnish the escalator with the mechanical brake to prevent the step from descending and the safety switch to stop the driving motor when the main drive chain brakes.

In this case, it needs to rapidly stop the stopping distance of the escalators allowed to over the value obtained by the formula described in the item.

### 3.5 Identifying root causes of overspeed and reversal in escalators: a complex challenge

Numerous reports indicate accidents where even auxiliary brakes have failed to function with full reliability. Moreover, detecting issues such as an increase in the length of the main chain and step chain requires highly specialised measurement techniques, while structural failures like flange breakage or cracks in the brake arm often go unnoticed.

## 4 CONCLUSION

A technical standard is typically a defined set of requirements, so why does it incorporate recommendations when addressing critical safety matters? (refers to [1] Annexe H, part H.2 “it is recommended to install auxiliary brakes also for rises $h_{13}$ less than 6 m.”)

Given that auxiliary brakes could be mandated for all escalators at a minimal cost (just as they are for passenger lift cabins), it stands to reason that all escalators should be equipped with parachutes (secondary brakes), similar to the ASME standard. Implementing this measure would ensure a secondary safety mechanism is always available to prevent accidents and enhance passenger protection.

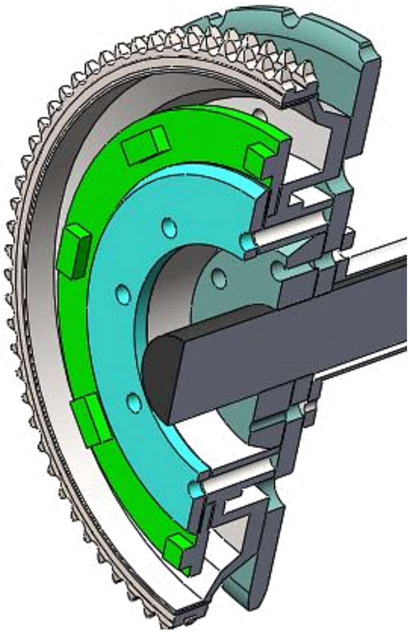

**Figure 11 Schematic parts of a usual auxiliary brake**

It must also be emphasised that, unfortunately, the recommendation for mandatory use of auxiliary braking systems in all escalators – a conclusion also drawn in other studies presented at the 10th and 12th Lift and Escalator Symposiums (such as [5] and [6]) – has still not been formally adopted, even after five years. It is hoped that, through the convergence of expert opinions, we will eventually reach a point where the inclusion of a secondary stopping mechanism for escalators, under all conditions, becomes a mandatory requirement in official standards.

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## BIOGRAPHICAL DETAILS

Anthony Andon, a graduate in Industrial Engineering, began his career in the Lift and escalator industry in 2010.

Among his many accomplishments, Andon has authored 12 specialised books on Lifts and escalators, one of which was published by the prestigious Lift World Press in the USA. In addition, he has delivered over 145,000 hours of advanced training, served on multiple standardisation committees, and presented at numerous safety seminars.

Building on these achievements, his robust research background and success in obtaining official certification as a standardisation expert have enabled him to serve as a consultant and inspector. To date, he has applied his expertise to more than 624 escalators and 45 Lifts.

# Artificial Intelligence in Lift Systems

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**Keywords:** Artificial Intelligence, Elevator systems, Dispatching, Preventive maintenance, Expert design, System modelling

**Abstract.** Artificial Intelligence (AI) is playing an increasingly significant role in the lift industry, offering the potential to enhance efficiency, reliability, and passenger experience. This paper examines the application of AI across five core areas: dispatching, preventive maintenance, traffic pattern recognition, expert design, and system modelling.

In addition to reviewing existing research and practical implementations, it explores potential future developments, considering how AI could reshape the operational landscape of vertical transportation.

The ethical implications of AI adoption are also discussed, with particular attention to privacy concerns, workforce impacts, and the challenge of balancing parameter optimisation. This paper highlights the transformative potential of AI within the lift industry while emphasising the importance of ethical and sustainable implementation.

## 1 INTRODUCTION

### 1.1 Background

For thousands of years, humans have been automating work. Automation is the use of technology to perform tasks with minimal human intervention. Historically, the work being automated was routine manual labour that did not require intelligence. Artificial intelligence (AI) refers to machines' ability to perform tasks typically associated with human intelligence.

AI has impacted many industries and will continue to do so in the next few decades, changing how people work. One of the industries that has been and will continue to be impacted is the vertical transportation industry. There are a few areas in which researchers have attempted to apply AI in this industry with varying success.

### 1.2 Forms of AI

#### 1.2.1 Knowledge-based system

A KBS is a computer system that uses logical reasoning and knowledge to solve problems. The system uses a repository of facts, rules and procedures, and an inference engine that applies the rules to make decisions.

#### 1.2.2 Fuzzy logic

FL is a computational approach to dealing with uncertainty. Unlike the well-defined knowledge of a KBS, FL deals with uncertain or changing knowledge. FL works by converting crisp input values into fuzzy values between 0 and 1. Rules are then applied to the fuzzy inputs and a fuzzy output is generated. The fuzzy output is converted back to a crisp value which will determine an action.

#### 1.2.3 Artificial neural networks

ANNs work by passing inputs through a set of artificial synapses and neurons with associated weighting to find an output. Based on the output, the weighting is changed to improve its accuracy. Unlike FL, ANNs use machine learning based on training data to improve.

#### 1.2.4 Genetic algorithms

GAs also use machine learning, but instead of simulating a brain, they simulate biological evolution. An initial population of random solutions all try to solve the same problem; those that do better are used to create the next generation of solutions. Each generation makes slight random adjustments to the most successful solutions from the previous generation. Over multiple generations, better solutions are created.

## 2 LITERATURE REVIEW

This literature review summarises the existing research on using Artificial intelligence in lift systems.

### 2.1 Dispatching

Dispatching is the process of allocating lifts to calls. While simple rules can be used for dispatching, AI can potentially improve performance. [1]

Researchers first started looking at applying AI to lift dispatching in the early 90s when Deven and Chengdong [2] proposed using Fuzzy Logic (FL) to optimise multiple parameters when assigning cars to calls. Two years later [3] implemented and verified this approach in simulation.

A few years after that, researchers began investigating Artificial Neural Networks (ANN) for lift dispatching [4]. As ANN technology advanced, so too did its use in lift-dispatching [5] [6] [7].

Researchers have also experimented with using Genetic Algorithms (GA) to dispatch in more complicated lift systems, such as systems with double-deck lifts [8] [9] [10].

Basagoiti, et al. [11] proposed using data about past traffic flow to predict future traffic and thus improve the dispatcher. This study was based on simulated passengers and was not implemented in a real system.

Peters [1] published a paper discussing existing AI research on dispatching and evaluated which aspects of AI were most useful for a dispatcher. Peters implemented AI logic into a dispatcher which worked in both simulation and in real-world lift systems. This AI logic was carried forward to 'The Global Dispatcher' [12], which is a single dispatching algorithm capable of dispatching complex lift systems such as double-deck and two cars per shaft.

### 2.2 Preventive maintenance

As with all physical machinery, lifts must be regularly maintained to prevent failure during peak usage. All potential break points must be tested as just one break point could cause the system to fail. If monitoring systems could predict failures before they occur and accurately identify damaged components, maintenance could become less frequent and more targeted.

Researchers started discussing AI in preventive maintenance in the early 1990s [13] but little progress was made due to the complexity of the hardware needed to monitor a moving lift car and feed data back to a central computer. As other technologies such as IOT, big data, cloud computing and sensor fusion began to emerge, preventative maintenance became a practical possibility from the 2010s onwards. [14] [15] [16].

Kaczmarczyk et al. [17] developed an AI model that used vibration data to detect and classify damage in lift doors. The model used ANN with supervised learning and consistently demonstrated a 97.9% accuracy in damage classification. The following year, the same authors published a paper specifically on roller-bearing damage [18]. While the 2022 model classified existing damage, the 2023 model could also predict damage during the early stages, facilitating preventive maintenance. Data-driven preventive maintenance using this technology could transform the way that service personnel do their job, as Smith [19] predicts.

Most research on preventive maintenance has used vibration data but some researchers have explored the use of other sensors to monitor component health. Seyyedi et al. [20] used high-speed cameras to gather data about lift rope fatigue. The researchers trained an AI image processing system to classify different types of broken wires. Four cameras, each covering a 90-degree rope segment, continuously took pictures and sent them to a computer with an AI image processing module.

Sensor fusion is the process of reducing uncertainty by combining data from multiple sources [21]. Smans [22] suggested fusing data from optical sensors, accelerometers and barometric pressure sensors to detect failures in lift doors. By combining data from these diverse sensors, Smans demonstrated that the accuracy and reliability of door failure detection improved significantly compared to using single-sensor methods.

### 2.3 Traffic pattern recognition

A car call does not always correspond to one passenger, as groups of people going to the same floor might only register one call. Accurately measuring passenger traffic can improve dispatching and preventive maintenance logic.

Siikonen & Kaakinen [23] discuss using carload, calls and time of day to estimate the passenger flow. Siikonen wrote a further paper explaining how the system works using FL and how it can improve dispatching [24]. So, et al. [25] proposed a similar idea using ANN which they implemented in a Hong Kong building. However, its accuracy was less than 35% due to the training not being comprehensive enough.

Guidotti [26] described the use of AI to process data from infra-red beams in the lift doors which counts passengers in and out of a lift. This gathers information about passengers by processing data from a light curtain, a technology already essential for safety. The accuracy of the information can be improved when processed in conjunction with accelerometer data from the lift. This data-gathering method is less intrusive than a camera as the scanned image doesn’t show people in sufficient detail to identify them.

The I-S-P (Inverse Stops to Passengers) method [27] predicts the number of passengers based on the number of stops and can be used to estimate the building's traffic flow. The I-S-P method can use traditional methods such as a rearranged form of the uppeak calculation or the Monte

Carlo Simulation as described by Al-Sharif et al. [28]. The I-S-P method can also use AI by training a model with simulation data. Al-Sharif et al. [29] demonstrated that a regression model can be trained to do an I-S-P analysis. However, further research is needed to demonstrate that the AI I-S-P method offers improvements when compared to the traditional I-S-P method.

### 2.4 Expert design

An essential step in building design is determining what sort of lift system is needed to lift a building with a given population and number of floors. This historically required an expert in traffic analysis.

An expert system is a computer system designed to model the knowledge of human experts. An expert design system is an expert system which designs lift systems. ISO 8100 – 32 [30] and CIBSE Guide D [31] each provide a set of rules, based on practices from industry experts, which can be used to design a lift system.

Prowse, et al. [32] describe an approach to lift system design using KBS. They also suggested a solution using an ANN.

Peters & Dean [33] used CIBSE guidance in a KBS to create an expert system which designs buildings to the CIBSE specification. Peters & Dean suggested in this paper's conclusion that applying fuzzy rules is an alternative to investigate in the future.

### 2.5 System modelling

Some attempts to use AI in the lift industry have been more successful than others. Sometimes, this is because the technology doesn't yet exist to make it work, and sometimes, it is because the problem doesn't lend itself to an AI solution.

Tolosana, et al. [34] applied ANN to lift system modelling. A model was trained on simulation data and could predict the round-trip time. The study demonstrated that under narrow constraints, there was a correlation between the simulated results and the ANN results. Although there was a correlation, there was too much variance between the ANN model and the simulation to rely on the ANN model for building design.

## 3 FUTURE DEVELOPMENT

The previous section of the paper investigated existing concrete research on the use of AI in lift systems. Instead, this section speculates on the trajectory of the lift industry based on current trends.

### 3.1 Dispatching

Dispatching systems are likely to use more sophisticated machine learning algorithms to adapt dynamically to complex passenger behaviours and building-specific traffic patterns.

Historical traffic data coupled with real-time analysis from multiple IoT sensors on the lift car will enable dispatchers to make better decisions. Predictive dispatching that anticipates demand spikes or reduces bottlenecks as well as passenger-specific dispatching which accounts for accessibility needs or priority handling can improve passenger satisfaction.

AI systems may be used to optimise the dispatcher for energy efficiency, balancing operational costs with environmental sustainability. Providing the dispatcher with real-time data about the energy consumption of the lift could help to improve dispatcher decisions over time.

## 3.2 Preventive maintenance

As sensors become more reliable and AI tools grow more adept at identifying faults, preventive maintenance is expected to become increasingly accurate, precise and timely. Technologies such as advanced vibration analysis, high-speed image recognition, and sensor fusion will play a key role in detecting faults early and classifying damage with greater precision. When combined with real-time operational data, these insights will allow future systems to anticipate failures and understand their potential ripple effects, enabling proactive and targeted interventions. A scalable IoT ecosystem will support this by continuously gathering and processing sensor data, ensuring that issues are identified and addressed in real time. AI systems could also recommend cost-effective maintenance schedules based on component wear rates and usage patterns, reducing downtime and resource wastage.

## 3.3 Traffic pattern recognition

Intelligent dispatching and preventive maintenance sensors will collect vast amounts of data. AI may be able to process this data, achieving near-perfect accuracy in counting passengers and predicting flow. Future systems might use historical traffic data and contextual data, such as weather, public holidays or events, to predict passenger demand more accurately. These predictions can feed into dispatching algorithms, ensuring lifts operate at peak efficiency while minimising passenger waiting times and energy consumption.

## 3.4 Expert design

Expert design systems currently use a KBS and a set of uppeak calculations to design a lift system based on a basic building design. Some authors have suggested using more advanced AI models such as FL or ANN. However, these advanced models are less transparent and less accountable for the design decisions they make.

So long as expert design systems rely on uppeak calculations, it will not be possible to use expert design for advanced buildings, such as those with a mixed traffic flow. The inclusion of general analysis calculations or simulations in an expert design system would have a greater impact on the utility of such a system.

## 3.5 System modelling

Some elements of system modelling can be improved with AI. The improvements to traffic pattern recognition can be used to create more realistic simulated passengers in traffic analysis. As dispatchers improve in real-world lift systems due to AI enhancements, the dispatchers in simulations will also need to improve to accurately model real-world systems.

Other elements, such as ideal lift kinematics, are best performed by computational logic and will remain in the domain of predictable maths equations.

# 4 IMPLICATIONS, RISKS AND ETHICS OF AI IN LIFT SYSTEMS

## 4.1 Dispatching

### 4.1.1 Impact on operators

When lifts were first invented, they were operated by trained employees. Passengers would tell their operator which floor they wanted, and the operator would take them there. By the 1970s, automated lifts had replaced the role of lift operators, and the job became redundant.

Improvements to lift dispatching algorithms can now happen without losing any jobs. The lift operation jobs no longer exist so improvements can be made without the ethical consideration of job redundancy.

### 4.1.2 Optimisation

#### 4.1.2.1 Background

A dispatcher needs to balance various parameters when dispatching lifts to floors and allocating passengers to lift cars. Each decision a dispatcher makes will have an impact on the following parameters.

#### 4.1.2.2 Journey time

The quicker an employee gets to their desk, the more work gets done and the more profits the organisation can make. Therefore, the priority should be to minimise the time between an employee pressing the call button and the lift arriving at the employee’s destination.

#### 4.1.2.3 Waiting time

Passengers are more satisfied when they are in the lift and moving somewhere than when they are waiting for the lift, according to Bird et al. [35]. This means that when a dispatcher sacrifices journey time to reduce waiting times, passengers are happier.

#### 4.1.2.4 Travel time

All research into the correlation between travel time and passenger satisfaction was conducted before the Covid-19 pandemic. As a result, we do not yet know if the pandemic has changed societal expectations and passenger preferences with concerns about enclosed spaces leading to a shift in priority from travel time to waiting time. In such a scenario, passengers may have preferred lower lift occupancy, even if it resulted in longer waiting times.

#### 4.1.2.5 Accessibility

Door dwell times can be reduced to reduce waiting and travel times. Lower dwell times mean the lift spends less time stopping at each floor. On the other hand, reduced dwell time makes the lift less accessible for those with impaired mobility who need longer to get to the lift.

#### 4.1.2.6 Energy

As the impact of the impending environmental crisis becomes more visible, organisations will have to be seen as making a difference. One way to reduce a building's energy consumption is to use a dispatcher that minimises the energy consumption of the lift system.

#### 4.1.2.7 Money

Some building providers have started offering premium prioritisation where clients who pay more get a better lift service. Under this system, when a premium passenger calls the lift, the dispatcher will prioritise getting that passenger to their destination over serving other passengers in the system. Although this would be good for the premium clients, this would increase journey times for the other passengers and would increase the average journey time for the building.

#### 4.1.2.8 Decisions

A dispatcher could minimise waiting times by always sending the nearest car to collect each passenger, but this decision is likely to increase journey time. Conversely, a dispatcher could assign a car per passenger which would reduce journey time, but this decision would increase waiting time. Making the decision to reduce door dwell time might reduce both journey and waiting times, but it is likely to make the system less accessible to some passengers.

The AI logic used in the dispatcher can help balance each decision to meet target outcomes, but AI cannot assess which parameters are more important. Prioritising parameters is an ethical dilemma that should be agreed upon by humans for the AI to obey, not the other way around.

## 4.2 Preventive maintenance

AI can predict and categorise failures in lift systems, enabling intelligent preventive maintenance. Preventive maintenance can be done during off-peak periods, meaning more lifts will be in service during peak usage. Over time, this will reduce the need for system redundancy, so fewer lifts will be needed in new buildings, which could positively impact cost and carbon emissions.

### 4.2.1 Monitoring systems

#### 4.2.1.1 Image-based passenger recognition

AI image recognition has grown massively in the past decade, but ethical concerns are also growing.

AI can now accurately count the number of humans in an image, differentiating between humans, bags, dogs, pushchairs and anything else that might end up in a lift. AI has even reached the point of object permanence, the understanding that if a person goes out of view and comes back into view, they are still the same person. Camera-based analysis can provide more accurate data about traffic flow than can be provided by a weight-based analysis.

On the other hand, having a camera in the lift car will leave some passengers concerned about their personal privacy, especially if the footage is analysed in the cloud by a third party. One of the best ways to ensure object permanence is to use facial recognition. Companies that already track users' actions online for targeted advertisements could use this data to improve their digital user profiles. In the hands of an authoritarian government, facial recognition data could be used for invasive surveillance and control of citizens.

One solution is to use 'fog computing' by analysing the footage close to the source and only uploading the traffic data with no footage or details about specific passengers. This justification might be enough for some, but others would still be concerned by any form of camera in their lift car.

Another solution is to use less detailed data such as the readings from a light curtain over time. This data can be used to generate a 2D map of a person which can be used for passenger counting but it is harder to use this kind of data to count people when their 2D map is irregular. This can happen for a variety of reasons, such as if a person is in a wheelchair or carrying a pushchair or shopping trolley.

#### 4.2.1.2 Accelerometer-based failure recognition

Using a supervised ANN, a model can be trained to recognise damaged components based on the frequency and intensity of vibration data. This model can detect damage, locate the damage, classify the type of damage, assess the extent of the damage, and predict the residual life before the damage becomes critical. Most lift installation faults occur in the doors, so identifying door damage is the priority. Eventually, an array of accelerometers could monitor the entire system.

If this is monitored accurately, the data can be used to aid preventive maintenance. When preventive maintenance is assisted by AI data analysis, this is known as data-driven preventive maintenance and could have a massive impact on the whole industry.

The data gathered from monitoring lift health could be used to improve lift simulation. If a simulation could provide an approximate maintenance frequency with and without data-driven preventive maintenance, it would help building providers calculate whether the additional sensor costs are worth the investment.

### 4.2.2 Impact on technicians

Preventive maintenance is when a lift is inspected or serviced even if it is not out of service. This means lifts will spend less time out of service during peak usage times as servicing can be scheduled for off-peak times. Currently, technicians are given a list of lifts to be inspected (looked at) or serviced (actively changed) and will do these maintenance visits at a regular frequency. Technicians must have the skills, parts and tools to assess, adjust or replace anything that is wrong.

With data-driven preventive maintenance, fewer manual inspections must be carried out, as the lift is constantly being inspected by the automatic sensors. AI monitors and analyses the wear on each component in real-time, so replacements only occur when needed instead of regularly replacing components. Technicians will be given a list of tasks to perform on each lift, along with which parts and tools will be needed for the job.

#### 4.2.2.1 Advantages

As a result of data-driven preventive maintenance, lifts will require less manual inspection and will spend less time out of service. Technicians will have more time to focus on fixing the problems as they will spend less time doing unnecessary regular inspections and servicing. This also means that fewer technicians are needed to maintain the same number of lifts thus reducing maintenance costs.

#### 4.2.2.2 Disadvantages

The financial savings from reducing the frequency of routine maintenance must be weighed against the upfront and ongoing costs of installing and managing the necessary sensors and processors. These sensors need to be installed on the lift, a process that may require specialised technical expertise. Furthermore, the data collected must be analysed in real time and stored securely in a format that is both accessible and reliable, typically using internet-based systems.

This shift introduces new demands in terms of infrastructure and cybersecurity, which can increase the overall complexity and cost of the maintenance ecosystem.

A potential downside of adopting data-driven preventive maintenance is the shift in required skills for technicians. While fewer manual inspections mean some traditional technician roles might become redundant, the new system demands technicians become proficient in computer use, data interpretation, and accurately following detailed digital instructions. Technicians accustomed to traditional hands-on roles might find this transition challenging, highlighting a clear need for retraining and reskilling programs. Additionally, reliance on AI guidance may inadvertently lead to deskilling if technicians lose the ability to troubleshoot independently should the technology fail or overlook issues. [36]

### 4.3 Expert design

Lift consultants currently use ISO guidance, calculations and simulations to design lift systems that suit the building. An expert design system would do this automatically but lift consultancy is not at risk from the expert system. A lift consultant's skill is knowing what the results of an analysis mean and feeding back to an architect or structural engineer what changes need to be made. An expert design system will improve the reliability and consistency within the lift consultancy industry as all consultants will be applying the same logical rules.

In the early days of any complex expert system, experts will disagree with some edge case decisions the system produces. Feedback from expert lift consultants is essential for improving an expert system's decision-making process.

## 5 CONCLUSION

AI will impact the lift industry and change the way work is done. This does not necessarily mean fewer jobs, but it will mean different jobs.

In some cases, AI will remove the tedious aspects of the job allowing humans to focus on the complex aspects, such as with lift consultants. In other cases, AI will remove the skilful element leaving humans to do the muscle work, such as with technicians. Without appropriate governance, more data and analytics could result in unethical surveillance or advertising. As dispatching becomes more powerful, prioritising parameters becomes an ethical dilemma. This dilemma could be handed to the building manager by giving them the power to change prioritisation. However, one could argue that manufacturers should take responsibility for the dispatcher and not allow building owners to put money before the environment.

The industry has an ethical responsibility to care for its workers and passengers as well as the environment. As AI pervades the industry, those responsible for making the decisions should put the interests of people over the interests of profit.

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## 7 BIOGRAPHICAL DETAILS

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# The Potential of Digital Out-of-Home Advertising in the Lift Industry

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**Keywords**: Digital Out-of-Home (DOOH), Lift-Based Advertising, Programmatic Content Delivery, Content Management Systems (CMS), Smart Building Communication, Stakeholder Adoption

**Abstract.** This paper analyses the potential of Digital Out-of-Home (DOOH) advertising in the lift environment—a confined, high-dwell space optimally suited to targeted, high-impact digital communication. Based on academic literature, market research, and direct lift stakeholder survey data, this paper explores the technical infrastructure, operational concerns, content models, privacy considerations, and monetisation strategies associated with lift-based DOOH applications.

The paper examines the adoption of modular hardware within the lift and how this integrates into building management systems. The paper then reviews content scheduling through CMS (Content Management System) platforms with AI and programmatic delivery of ads. Special focus is placed on ethical curation of content and GDPR compliance in data use, specific to the lift environment. Findings from a direct lift stakeholder survey show very high interest in DOOH for organisational communication and cost efficiency, but also pinpoint concerns about control, relevance, and aesthetic disruption.

The paper outlines an innovation agenda with smart targeting, responsive display environments, and effective energy use at its centre. It concludes by highlighting lift-based DOOH as a monetisable ad vehicle and strategic communications layer in smart buildings— albeit one which will only be successful if privacy, content regulation, and context are placed at its centre.

## 1 INTRODUCTION

DOOH advertising is dynamic, screen-based media shown in public areas, from roadside billboards and malls to transit points and lifts. While traditional OOH (Out-of-Home) relied on static signage, DOOH transforms this medium by integrating real-time, data-driven content distribution, contextual messaging, and cross-platform engagement via programmatic networks [1, 2]. This evolution has made outdoor advertising an increasingly digitised landscape that leverages AI and behavioural analytics to deliver targeted, responsive campaigns.

The global DOOH market is growing at a high rate. Research by Grand View Research [3] predicts the market will reach USD 39.12 billion by 2030, driven by rising urbanisation, smart infrastructure investments, and demand for real-time, interactive content. Stakeholders are leveraging DOOH technologies more than before to gain optimum audience coverage, maximise return on advertisement spend, and be aligned with digital transformation trends [4].

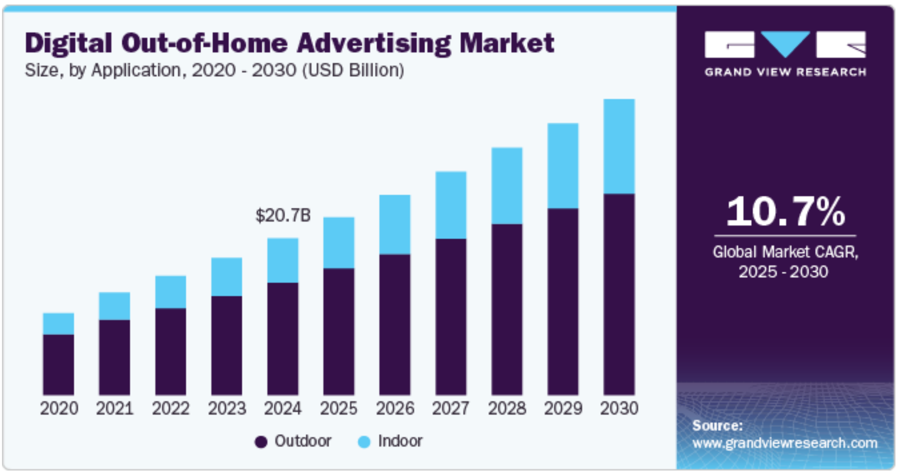


**Figure 1 Digital Out-of-Home Advertising Market [3]**

Lifts provide a new, albeit relatively untapped, environment for the deployment of DOOH. As enclosed and high-frequency transportation areas, lifts provide long dwell times—typically 30–60 seconds—and a captive audience with low distraction. Additionally, lift screens offer the advantage of contextual relevance, allowing content to be customised to suit the specific building environment and audience needs. These features make the inside of lifts a perfect space for hyper-targeted, time-sensitive communication [5]. In addition, the repetitive use of lifts ensures multiple exposure, developing brand awareness and internal communications.

For lift asset owners and building managers, there are numerous advantages to the installation of DOOH screens. Beyond monetisation potential via advertising, screens can modernise interior aesthetics, enable real-time user communication, and elevate emergency messaging systems [6,7]. In a post-pandemic era where digitisation and contactless information are a priority, such systems also enhance real-time user experience and build competitiveness.

Likewise, this paper examines the operational and technical viability of lift-based DOOH advertising, founded in academic literature, market research, and primary stakeholder response.

## 2 TECHNICAL INFRASTRUCTURE OF DOOH SYSTEMS IN LIFTS

### 2.1 Hardware integration and display technologies

Installing digital screens in lifts requires careful consideration of space constraints, constant movement, and visibility. The lift environment is compact and subject to frequent use, vibration, and varying temperatures, demanding robust and resilient hardware.

Screen placement is critical in lift environments. Displays must not interfere with control panels, emergency buttons, or passenger movement. Ultra-thin, flush-mounted designs integrated into wall panels offer a discreet and practical solution, maintaining both safety and usability. Beyond function, these installations enhance the overall passenger experience and project a modern, high-tech image – a valuable asset for commercial offices and premium residential buildings.

### 2.2 Power Supply and Network Connectivity

Reliable power and connectivity are key to lift-based DOOH. Lifts do not typically enjoy simple access to building LAN infrastructure, and small metal cabins interfere with wireless signals. The Outdoor Advertising Association of America [8] adds that most operators resort to cellular connectivity—typically via 4G/LTE modems utilising external antennas fixed outside the lift shaft. Redundant power systems need to be implemented in order to prevent power outages, with UPS backup suggested to maintain service during short-duration power loss.

In addition, to keep latency and service interruption under control, content must be stored locally on embedded flash storage or edge media devices, such as SD cards, ensuring smooth playback in the event of temporary network disruption. Remote screen health monitoring and content updating via cloud-based CMS platforms provide scalability and assurance for building managers and advertisers, ensuring seamless management across multiple locations.

Another critical challenge in lift-based DOOH systems is electromagnetic noise, particularly in modernisation projects. Older motors, legacy wiring, and pre-existing electrical infrastructure can generate high-frequency electromagnetic interference, disrupting network signals and causing inconsistent data transmission. These disruptions can lead to unstable connections, content loading delays, or even complete signal loss. To mitigate these issues, shielded networking cables are deployed to insulate data transmission lines from external interference, ensuring a clean, uninterrupted connection. Managing electromagnetic interference will be essential for ensuring the long-term reliability of lift-based DOOH systems. Future installations may integrate signal filtering technologies and improved grounding mechanisms to further stabilise transmission, reinforcing the viability of lift-based digital signage as a robust communication platform within modern buildings.

### 2.3 Integration with Building Management Systems (BMS)

Top-tier DOOH implementations are facilitated through integration with BMS, allowing content to respond automatically to real-time inputs. Quinn et al. [9] describe how IoT sensors linked to Facility Management enabled Building Information Models (FM-BIM) platforms are able to update content triggers—e.g., occupancy rates, time-of-day, or alert messages. During peak traffic during mornings, for example, screens can show fast-scrolling headlines or offers geared towards professionals; during evenings, content can shift to leisure or lifestyle programming.

Lift-specific integrations may also integrate lift controllers or Programmable Logic Controllers (PLC). These integrations cause screen content to change with the floor level or destination context of the lift—providing hyper-relevant messages. Though more complex, this multi-layered use case makes DOOH a component of a building's digital architecture, and not a standalone system.

### 2.4 Modular Design and System Upgradability

As DOOH media landscapes continue to develop at a fast pace, the systems have to be capable of simple upgrading. D'Ambrosio et al. [10] identify modular system design as good practice—whereby display units, controllers, and CMS software can be upgraded separately. This reduces maintenance expenses, future-proofs the installation, and prevents the downtime of total system revamps.

In retro-fit applications and pre-wired modular packs allow screens to be more readily installed without heavy infrastructure renewal. This is particularly advantageous in older buildings which wish to improve their internal communications and income streams without extensive lift refurbishments.

Modular buildings also lend themselves to scalable content strategies—where multiple units across different floors or elevations can be tracked from a single dashboard. This is valuable for business property managers with portfolios of office towers, hotels, or apartment complexes.

# 3 CONTENT MANAGEMENT AND PROGRAMMATIC ADVERTISING

## 3.1 Content scheduling and CMS requirements

The adoption of content management systems (CMS) for DOOH is typically driven by the perceived usefulness and ease of use—key constructs of the Technology Acceptance Model (TAM). As Shinde et al. [4] elaborate, stakeholders will adopt CMS tools that have intuitive interfaces and automatic scheduling functionality for numerous endpoints. In the context of lift-based DOOH, this is the ability to program short-format, context-sensitive content that changes dynamically based on time, building type, or user profiles.

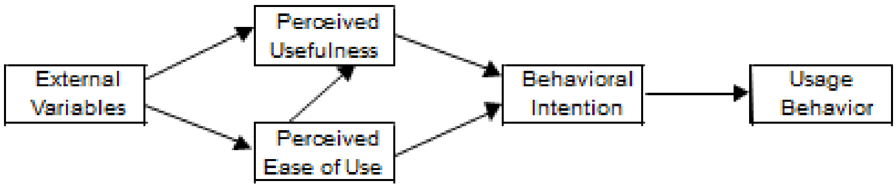


**Figure 2 Technology Acceptance Model [11]**

Sayoh [7] also adds that AI-powered integration with CMS enables content to respond to real-time input, such as environmental factors or audience traffic. This capability is especially required in lifts, where audiences are subjected for limited durations, and messaging must be concise, dynamic, and immediately relevant. Scheduling through CMS effectively reduces operational overhead while optimising content impact.

## 3.2 Programmatic and automated ad delivery

With programmatic infrastructure becoming inherent to DOOH networks, the lift environment can benefit from more targeted and efficient delivery of advertisements. Häglund and Björklund [1] explain programmatic DOOH as connecting advertisers with screen networks via real-time bidding platforms, with the capability of data-driven control of when and where content is displayed. Shinde et al. [4] explain how such automation improves campaign agility – ads can be changed in a space of minutes, depending on real-time data feeds.

In lifts, this ability delivers time-of-day programming, weekday-vs-weekend targeting, and floor-level messaging according to commercial or residential audiences. Programmatic delivery also offers ad inventory that is sold with minimal or no human involvement, which scales while continuing to maintain relevant content.

## 3.3 Interaction and cross-channel integration

Beyond visual messaging, lift-based DOOH can extend its impact through interactive touchpoints and cross-channel efforts. Sayoh [7] discusses that AI-powered DOOH networks use ambient cues—such as crowd density or motion detection—to adjust content in real time. QR codes, near-field communication (NFC), and Bluetooth Low Energy (BLE) beacons can serve as bridge points between lift-based screens and users' mobile devices, enabling deeper engagement and interaction.

This level of interaction strengthens campaign recall and allows for deeper conversion funnels, especially when paired with broader omni-channel efforts. In the lift ecosystem, where real estate is minimal but dwell time is abundant, these digital cues can solicit strong action without physical engagement, maximising each passenger's journey to its highest utility.

# 4 PRIVACY, AUDIENCE MEASUREMENT AND ETHICS

## 4.1 Privacy, consent and data protection

The use of DOOH advertising in lift environments demands a rigorous data privacy and protection strategy. Because of the enclosed nature of lifts, any data collection mechanisms, such as sensors or cameras, must be fully compliant with data privacy regulations such as the General Data Protection Regulation (GDPR). The GDPR mandates explicit user consent for data collection and processing, such that the individuals are aware of how their data is being used and can opt out if they choose to do so [12].

To counter these demands, advertisers are increasingly relying on anonymised data collection methods. For instance, sensors can log the presence of individuals without noting personally identifiable information, thus adhering to compliance while still offering targeted content [13]. This not only safeguards users' privacy but also facilitates trust between consumers and advertisers.

## 4.2 Ethical content and contextual sensitivity

Responsible use of DOOH content extends beyond data privacy to encompass the content and context of the advertising itself. In lift environments, where audiences are captive and exposure is unavoidable, it is critical that the content is appropriate and not invasive. Advertising needs to avoid leveraging sensitive topic areas or displaying content that will offend or cause discomfort for those exposed to it.

Moreover, the use of adaptive advertising technologies that tailor content based on real-time data raises ethical issues about the potential for manipulation, along with the perpetuation of biases. It is the advertisers' duty to make sure that such technologies are used responsibly, with regulatory frameworks existing to prevent abuse as well as maintain the integrity of the content of the advertisements [14].

# 5 STAKEHOLDER INSIGHTS: SUPPORTING EVIDENCE FROM INDUSTRY SURVEY

To gain a clearer understanding of perspectives on digital modernisation within lift spaces, we conducted a targeted industry survey. The survey aimed to explore stakeholder interest in replacing traditional pinboards with digital solutions, assess attitudes towards advertising in lifts, and identify key considerations for content relevance and operational management. By gathering insights from respondents across residential, commercial, and hospitality sectors—including lift contractors, consultants, and building owners—we were able to capture a comprehensive view of the current landscape and future opportunities.

## 5.1 Current adoption landscape

The adoption landscape for building lift digital screens is evolving extremely rapidly, with pioneers being primarily commercial real estate and high-end residential buildings. What our survey reveals is that while 63% of respondents indicated they have digital screens installed somewhere within their buildings, only as low as 38% affirm deployment in lifts as well. This divergence depicts a huge growth opportunity. Academic papers confirm the same observation. Babu and Lakshmaiah [6] pointed out that lift lobby digital screen advertising continues to be a high-recall and cost-efficient option that aligns perfectly with residents' routines. They emphasise the hyper-local coverage of such media, which is reinforced by repeated exposure and physical proximity to decision-making spaces like offices and homes.

Furthermore, Bah and Haba [15] found that positive attitudes towards DOOH are strongly correlated with familiarity and frequent exposure frequency—a natural advantage of lift environments, where individuals are often captive and recurrently exposed to screens.

### 5.2 Operational management & content governance

One of the recurring themes in the survey answers was the importance of content management and control. Over 67% of the respondents answered that their screens are not refreshed more than once a month, indicating the challenge of maintaining a steady stream of new and appropriate content.

Additionally, 75% underscored the importance of maintaining local control of screen content. Governance becomes even more relevant within local environments. Respondents were reluctant to give away content control to third-party sponsors, complaining about the possibility of brand misalignment, lack of relevance, or visual clutter. This is in line with Shinde et al. [4], who highlight that successful DOOH campaigns within cluttered or semi-private environments are extremely dependent on a successful Technology Acceptance Model (TAM) strategy centred on perceived ease of use and usefulness by operators and inhabitants.

The research tells us that owners of buildings are open to adopting DOOH systems, but only in facilities that enable selective filtering of material and relevance enforcement—particularly if user attitudes and building brand identity are at stake.

### 5.3 Cost sensitivity and monetisation

The most significant point of our industry poll was the financial incentive for DOOH installation. A full 58% of the respondents said they were open to third-party ads on lift displays—provided it would help cover operational or installation costs and if they would retain some editorial discretion over the ads. A few suggested that openness to monetising would depend on reducing intrusiveness and increasing contextuality. This reflects how the broader market feels. Kishore Babu [6] clarifies that as lift real estate becomes increasingly digitised, brands perceive it as an opportunity to reach audiences during moments of unbroken attention and the best possible platform for branded content. Nevertheless, he also warns that excessive commercialisation in the absence of thematic and aesthetic alignment has the risk of diminishing user experience and trust levels.

Therefore, the path forward appears to be hybrid monetisation models, where a percentage of screen time is spent on building-related announcements or community content, and a selection pool of advertisers is given limited access, subject to strict guidelines.

## 6 FUTURE-PROOFING AND INNOVATION ROADMAP

### 6.1 Smart targeting and responsive displays

Among the most groundbreaking developments of DOOH advertising is the application of AI in real-time targeting. Smart targeting allows screens to dynamically react to context—e.g., weather, day/part of day, or demographic information—displaying more relevant and effective content. Sayoh [7] describes how AI may screen consumer demographics, behaviours, and environmental context to personalise content on-the-fly, maximising consumer experience and enhancing brand recall.

As urban spaces get packed, the lift becomes more and more a hub of online interaction. Research conducted by Babu [6] demonstrates the high dwell time and typical use of lifts, revealing that screens in these confined spaces can maintain sustained contact and cement brand remembering. Beyond advertising, buildings are increasingly adopting digital signage as an integral communication tool, facilitating tenant updates, community notices, and real-time building-wide messaging.

In the long term, DOOH in lifts may shift from passive advertising to a platform for building-wide communication infrastructure—used not just for marketing purposes but also for community engagement, building notices, and personalised user experiences. The wider applicability reinforces the strategic importance of such installations over the long term.

### 6.2 Consumer behaviour and ROI: Further research suggestions

While academic papers and marketing research point towards high recall and interaction rates with DOOH, more quantitative academic studies are required to measure consumer behavioural shifts in particular lift environments. Upcoming studies would then be able to examine how repeated exposure in these environments affects loyalty to a brand, intention to buy, or tenant satisfaction.

Besides, an awareness of the psychological impact of screen proximity and use frequency in such cramped areas might be a useful input for content design and organisation.

### 6.3 Energy-efficient resilient technologies

Future-proofing DOOH networks also entails the adoption of energy-efficient technology. LCDs with LED backlight and the next-generation E-ink display offer power-saving alternatives without compromising visibility. Moreover, heat-resistant and vibration-resistant hardware ensures uninterrupted performance in changing lift environments.

These innovations reinforce advocacy for a holistic, future-oriented approach to lift-based DOOH in which technical competence is weighed against functional building integration as well as user-centric design.

## 7 CONCLUSION

Digital Out-of-Home advertising is coming of age, and especially in the built environment. The lift industry, with its inherent captive-audience environment and habitual use patterns, offers an engaging environment for novel, interactive DOOH systems. This paper has discussed the technical infrastructure necessary, the changing stakeholder environment, and the way forward for lift-based digital screens.

Evidence from industry reports and scholarly research indicates that while take-up is growing, success will depend on balancing technological innovation with governance, content suitability, and user trust. The convergence of AI-driven targeting, modular and energy-efficient hardware, and programmatic content delivery offers lift operators and advertisers a strategic moment for both communication and monetisation—provided that privacy and contextual integrity are guaranteed.

Moving ahead, the task is not merely to install DOOH infrastructure, but to ensure its integration assists broader stakeholder objectives, from operational efficiency to resident happiness. With thoughtful installation, lift-based DOOH can be a central component of smart building ecosystems and a highly effective ad touchpoint.

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## BIOGRAPHICAL DETAILS

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Gemma Moore is an Account Manager at Dewhurst Ltd, where she manages a portfolio of key clients and supports the delivery of tailored lift solutions across the UK. She holds a BA in International Marketing and a BA in Business Management from Teesside University. With over eight years of experience in technical sales and customer relationship management, she plays a central role in driving new business development and ensuring long-term client satisfaction. Gemma brings a customer-focused approach to the lift industry, with a strong emphasis on service excellence, market insight, and collaborative growth.

# Statistical Investigation of Lift Damages after Large Earthquakes in Turkey

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**Keywords**: Lift, Earthquake, Structural Damage, Fieldwork, Damage Statistics.

**Abstract.** Lifts are expected to continue their services after earthquakes, especially in critical and strategic public buildings such as hospitals. However, from investigations carried out in the field after earthquakes, it is known that lifts are out of service due to damage to critical components. In this study, after large earthquakes in Turkey, field investigations carried out on lift installations are discussed, and the structural elements of the lifts are classified and statistically expressed. The results obtained are shown graphically, and the distribution of the damages in critical components is given. It is aimed to reveal which components should be focused on in lift design for earthquakes and the points to be taken into account in lift design for seismic test suit. Although the EN 81-77 standard was introduced in Turkey in 2014, it has been observed that the standard is not mandatory, and the structural characteristics of the damaged lifts during the period are the same.

## 1 MAJOR EARTHQUAKES IN TURKEY

Turkey is a seismically active country, with large earthquakes recorded throughout history. Since 1900, 22 earthquakes with a magnitude greater than 7 have occurred. These earthquakes and their details are displayed in Table 1 [1, 2]. There were 269 earthquakes in Turkey between 1900 and 2023 that resulted in fatalities or damage. The 2023 Kahramanmaraş earthquake, the 1939 Erzincan earthquake, and the 1999 İzmit earthquake were the most destructive and fatal earthquakes [3].

According to the Earthquake Hazard Map of Turkey, which was published in 2018 and depicts Turkey's earthquake hazard, the majority of Turkey's territory is located in earthquake-prone areas. Figure 1 shows Turkey's seismic hazard map [4].

**Table 1 Earthquakes with magnitude over 7 in Turkey (1900-2023)**

| | Earthquake Name | Date | Time (UTC) | Longitude (°) | Latitude (°) | Depth (km) | Magnitude (AFAD) | Magnitude (Kandilli) | Loss of Life | Damaged Building |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1912 Tekirdağ | 09.08.1912 | 01:29:00 | 27.2 | 40.75 | 10 | 7.4 | 7.3 | 216 | 5540 |
| 2 | 1914 Burdur | 04.10.1914 | 22:06:00 | 30.1 | 37.6 | 10 | 7 | 6.9 | 300 | 6000 |
| 3 | 1916 Tokat | 24.01.1916 | 06:55:15 | 36.83 | 40.27 | 10 | 7.1 | 7.3 | | |
| 4 | 1919 Balıkesir | 18.11.1919 | 21:54:50 | 26.71 | 39.26 | 10 | 7 | 7 | | |
| 5 | 1926 Datca | 26.06.1926 | 19:46:38 | 27.33 | 36.54 | 100 | 7.7 | 7.7 | | |
| 6 | 1930 Near Persian | 06.05.1930 | 22:34:32 | 44.48 | 37.98 | 70 | 7.6 | 7.6 | 2514 | |
| 7 | 1939 Erzincan | 26.12.1939 | 23:57:21 | 39.51 | 39.8 | 20 | 7.9 | 7.9 | 32968 | 116720 |
| 8 | 1942 Tokat-Erbaa | 20.12.1942 | 14:03:08 | 36.47 | 40.87 | 10 | 7 | 7 | 3000 | 32000 |
| 9 | 1943 Çankırı-Ilgaz | 26.11.1943 | 22:20:41 | 33.72 | 41.05 | 10 | 7.2 | 7.5 | 4000 | 40000 |
| 10 | 1944 Bolu-Gerede | 01.02.1944 | 03:22:36 | 32.6 | 40.9 | 10 | 7.3 | 7.2 | 3959 | 20865 |
| 11 | 1948 Mediterranean | 09.02.1948 | 12:58:19 | 27.2 | 35.41 | 30 | 7.2 | 7.2 | | |
| 12 | 1953 Çanakkale | 18.03.1953 | 19:06:16 | 27.36 | 39.99 | 10 | 7.2 | 7.2 | 265 | 6750 |
| 13 | 1957 Mediterranean | 25.04.1957 | 02:25:45 | 28.68 | 36.42 | 80 | 7.1 | 7.1 | 67 | 3200 |
| 14 | 1957 Düzce-Bolu | 26.05.1957 | 06:33:35 | 31 | 40.67 | 10 | 7.1 | 7.1 | 52 | 5200 |
| 15 | 1964 Bursa | 06.10.1964 | 14:31:23 | 28.23 | 40.3 | 34 | 7 | 7 | 23 | 5398 |
| 16 | 1970 Kütahya | 28.03.1970 | 21:02:24 | 29.51 | 39.21 | 18 | 7.2 | 7.2 | 1086 | 19291 |
| 17 | 1976 Van | 24.11.1976 | 12:22:16 | 44.029 | 39.08 | 8.6 | 7 | 7.5 | 3840 | 9232 |
| 18 | 1999 İzmit | 17.08.1999 | 00:01:39 | 30.004 | 40.77 | 15 | 7.6 | 7.8 | 17480 | 73342 |
| 19 | 1999 Düzce | 12.11.1999 | 16:57:21 | 31.226 | 40.806 | 11 | 7.1 | 7.5 | 763 | 35519 |
| 20 | 2011 Van | 23.10.2011 | 10:41:00 | 43.4657 | 38.689 | 19.02 | 7.1 | 7.2 | 644 | 17005 |
| 21 | 2023 Kahramanmaras-Pazarcık | 06.02.2023 | 01:17:32 | 37.043 | 37.288 | 8.6 | 7.7 | 7.7 | 50000 | 500000 |
| 22 | 2023 Kahramanmaras-Elbistan | 06.02.2023 | 10:24:47 | 37.239 | 38.089 | 7 | 7.6 | 7.6 | | |

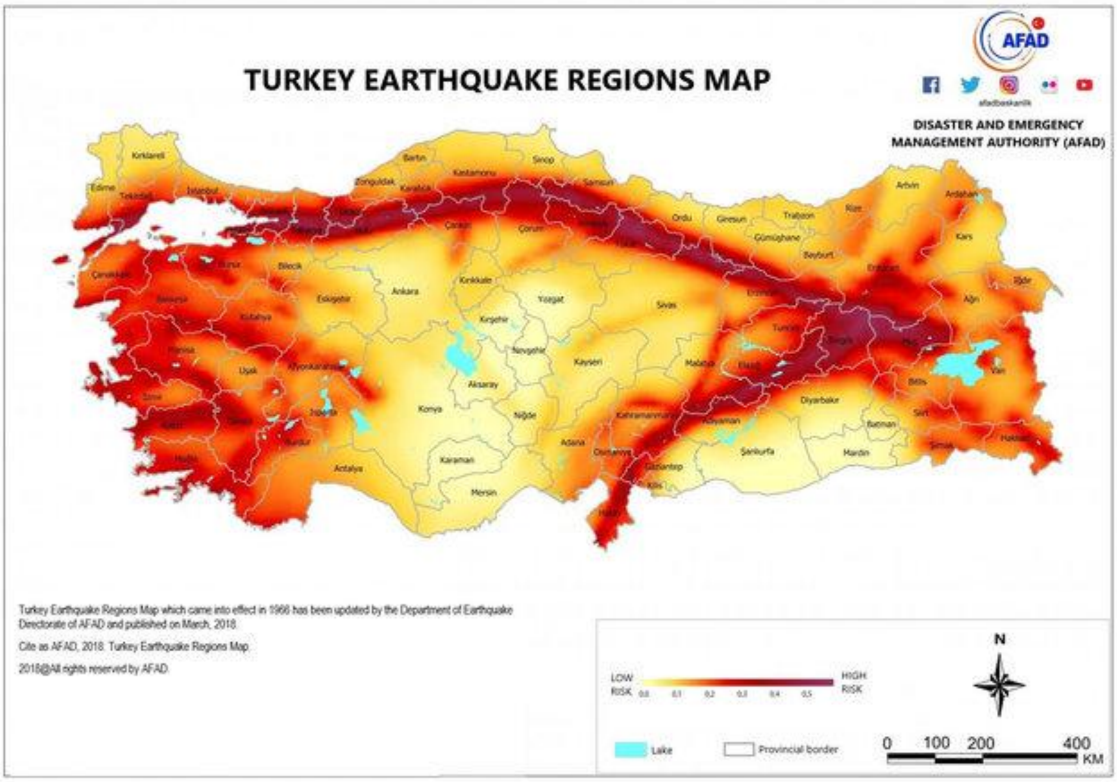



**Figure 1 Earthquake hazard map of Turkey [4]**

# 2 LIFT DAMAGE (STATISTICS) AFTER EARTHQUAKES

Lifts are expected to continue operating after earthquakes, particularly in crucial and strategic public buildings like hospitals. However, post-earthquake investigations revealed that the lifts' mechanical elements were damaged and rendered inoperable. This study examines the damage to lift structural elements following large earthquakes in Turkey. In this context, the 1999 İzmit earthquake, 2011 Van earthquake and 2023 Kahramanmaraş earthquakes will be analysed. Figure 2 shows the centres of earthquakes on the map of Turkey.


**Figure 2 Centres of selected earthquakes on the map of Turkey**

## 2.1 The 1999 İzmit Earthquake

On August 17, 1999, at 00:01:39 in coordinated universal time (UTC) (03:01:39 local time), the İzmit earthquake took place. The earthquake's depth was 15.0 kilometres, its epicentre was located at 40.77°N 30.004°E, and its magnitude was 7.6. The earthquake killed roughly 18000 individuals and damaged around 75000 buildings [1, 2].

The following damage was caused to lifts by the İzmit earthquake. Some counterweights came out of the rails and hit the cabin, hoisting ropes were damaged or came out of their sheaves, rail brackets were broken or damaged, governor ropes that were cut, roller guides that were broken or loose, compensating cables that were damaged or came out of their grooves, some hoistways that collapsed, and cabins that stayed at the bottom and were crushed [5].

## 2.2 The 2011 Van Earthquake

On October 23, 2011, at 00:01:39 10:41:00 in UTC (13:41:00 local time), the Van earthquake took place. The earthquake's depth was 19.02 kilometres, its epicentre was located at 38.689°N 43.4657°E, and its magnitude was 7.1. The earthquake killed roughly 750 individuals and damaged around 20000 buildings [1, 2].

İmrak studied the sorts of damage to lifts following the Van earthquake. The following damage types have been observed: the counterweight derailment, the guide shoes of the counterweight frames breaking, the guide rails on the counterweight side bending, the bracket element bending, the landing doors jamming, the rope dislocating from the pulleys and becoming damaged, the carrier ropes snagging on the bracket elements, and the falling of the counterweight weights on the car. Lift damage following the earthquake is depicted in Figure 3 [6].

**Figure 3 Lift damage of the Van Earthquake [6]**

After 25 lifts were examined in Van, it was observed that the counterweights came out of their guide rails, and brackets were bent, resulting in counterweight derailments and guide rails forced to break their guide shoes, as shown in Figure 3.

### 2.3 The 2023 Kahramanmaraş Earthquakes

Two consecutive large earthquakes occurred in Turkey. The first earthquake was Kahramanmaras-Pazarcık on February 06, 2023, at 01:17:34 in UTC (04:17:34 local time). The earthquake's depth was 8.6 kilometres, its epicentre was located at 37.288°N 37.043°E, and its magnitude was 7.7. The second earthquake was Kahramanmaras-Elbistan on February 06, 2023, at 10:24:48 in UTC (13:24:48 local time). The earthquake's depth was 7.0 kilometres, its epicentre was located at 38.089°N 37.239°E, and its magnitude was 7.6. The earthquakes killed roughly 50000 individuals and damaged around 500000 buildings [1, 2].

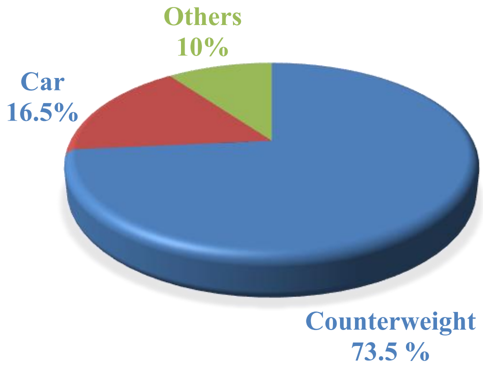
According to the report following the Kahramanmaraş earthquakes, the following types of damage were recorded in lifts. Some lift shafts collapsed, cabins sank to the bottom, roller guides were loose or broken, regulator ropes were damaged, rail brackets were broken, balancing cables were out of their slots or damaged, counterweights were coming out of their rails, and some of them were hitting the cabins. Lift damage following the earthquake is depicted in Figure 4 [7].

**Figure 4 Lift damage of the Kahramanmaraş Earthquakes [7]**

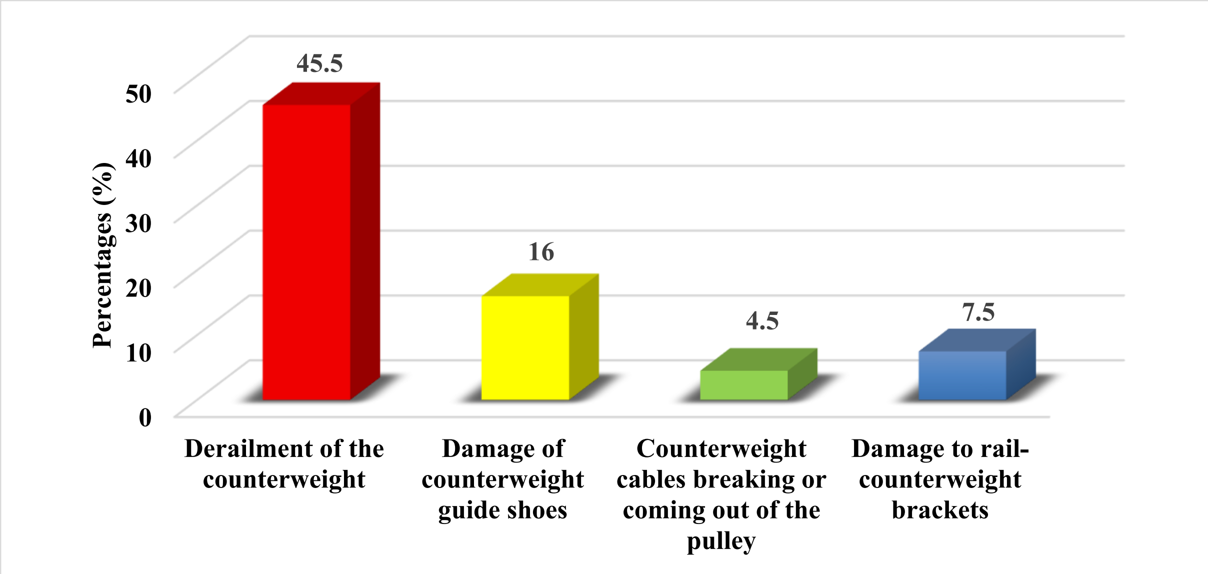
Field work was carried out in Malatya, one of the provinces affected by the Kahramanmaraş earthquakes. Although the hospital lifts examined were installed after the EN 81-77 standard was implemented, it was observed that the brackets were not specially designed for earthquake zones. Many of them had structural damage, and the counterweight was displaced, caused by the effects of the earthquake, as shown in Figure 4.

### 2.4 Statistics of Lift Damage After Earthquakes

As a result of the research and observations made in the field after the major earthquakes in Turkey, the percentage distribution of damage to lifts is shown in Figure 5. While examining the statistical data, the lift system is divided into the car part, counterweight part and others (Figure 5 (a)). The counterweight part consists of rail, shoes, bracket, cables and counterweight, and the part that includes all the elements here can be referred to as the rail-counterweight system. When the earthquake statistics are examined, it is seen that the total damage rate of the rail-counterweight system is 73.5%. According to statistical data, the most common type of damage is derailment of the counterweight (Figure 5 (b)).




**(a)**




**(b)**

**Figure 5 Percentage of damage types in lifts**

Although the EN 81-77 standard was introduced in Turkey in 2014, it has been observed that the standard is not mandatory, and the structural characteristics of the damaged lifts during the period are the same. Although the lifts damaged in the Van earthquake correspond to the period before this standard was applied, and the lifts damaged in the Kahramanmaraş earthquake correspond to the subsequent period, it is understood that there is a lack of awareness and supervision on this issue.

It is known that building seismic-proof conditions and the lift seismic-proof condition minimise the lift damage after earthquakes. The classification and evaluation of lift damage after earthquakes is useful for understanding the damage and effectiveness of seismic proofing procedures.

## 3 COUNTERMEASURES TO REDUCE EARTHQUAKE DAMAGE

In the event of an earthquake, countermeasures should be taken to ensure that lift systems receive the least possible damage. In the reports prepared as a result of field studies conducted after earthquakes, the following countermeasures were recommended.

Imrak said that seismic switches should be used in lifts, box brackets should be used to strengthen the counterweight rails to prevent displacement of the counterweight, guide rails of sufficient size should be used, retaining plates are required under the roller guide assemblies, and anti-tripping guards are required in the lift track to prevent tripping of ropes and travelling cables [6].

Çelik et al. suggested that seismic switches should be used, measures for counterweight tie rods and electrically charged wire with displacement ring should be taken, an appropriate size guide rail should be used, structural support frames for seismically isolated buildings, and rope guards should be used [7].

## 4 CONCLUSIONS

Observations and assessments of large earthquakes in Turkey reveal repeating types of damage to lift systems. These damages are counterweight derailments, hoistway component damage, cable dislocation, and shaft structural failures. Statistical analyses show that the most common damage is in the rail-counterweight system, and within this system, the most common is derailment of the counterweight. When the statistical analysis is evaluated, it shows that lift designs should focus on the rail-counterweight system. Recommendations such as the installation of seismic switches, reinforced guide rails, box brackets, retaining plates, and anti-tripping mechanisms are critical for increasing lift resilience and further reducing the risk of failure during earthquakes.

These findings, and the implementation of advanced seismic design standards and regular maintenance protocols, are essential. These measures can ensure the functionality and safety of lift systems in earthquake-prone regions, reducing operational downtime and protecting human lives.

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## BIOGRAPHICAL DETAILS

Yakup Artun has been working as a Research Assistant at Yıldız Technical University (YTU). He received his bachelor's degree in Mechanical Engineering from Bozok University in 2014. He completed his master's degree at YTU, Department of Mechanical Engineering. In 2022, he started his PhD education in the field of Construction, Department of Mechanical Engineering at YTU and is still continuing his PhD education. Machine design and machine elements, materials handling and especially lift systems, mechanical vibrations are among the areas of study and research.

C. Oktay Azeloglu has been employed as a full-time associate professor at Yıldız Technical University (YTU). Associate Professor Azeloglu received the B.Sc., M.Sc. and Ph.D. degrees in Mechanical Engineering from YTU, respectively. He was a postdoctoral researcher at the Kandilli Observatory and Earthquake Research Institute, Bogazici University. Machine design and machine elements, materials handling and especially crane and lift systems, design for vibration/earthquake-induced vibration are among the areas of study and research.

C. Erdem İmrak has been employed as a full-time Professor at Istanbul Technical University (ITU). Professor Imrak received the B.Sc., M.Sc. and Ph.D. degrees in Mechanical Engineering from ITU in 1990, 1992, and 1996, respectively. He has carried out research into computer-aided engineering, CAD/CAM, numerical analysis, materials handling and especially lift systems. Currently, his activities include: an Honorary Member of ASYAD; a Member of the Safety, Education & Training Committee of ELA; a Member of the ASME; a Member of the OIPEEC; a Member of the IAEE; and a Member of the Chamber of Mechanical Engineers in Turkey.

Ahmet Sagirli has been employed as a full-time Professor at Yıldız Technical University (YTU). Professor Sagirli received the B.Sc., M.Sc. and Ph.D. degrees in Mechanical Engineering from YTU in 1988, 1990, and 1997, respectively. Construction and manufacturing, machine design and machine elements, computer-aided design and manufacturing, materials handling, machine theory and dynamics, and modelling and simulation of dynamic systems are among the areas of study and research.

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Hamit Kenan completed his BSc degree in Mechanical Engineering at Uludağ University and Yıldız Technical University (YTU) between 2006-2011, his MSc degree at Istanbul Technical University in 2015 and his PhD degree at YTU in the Construction Program in 2022. His research interests include the behaviour of cranes under earthquake effects, finite element analysis, mechanical performance of functionally graded auxetic structures and machine design. Dr. Kenan worked as a research assistant at YTU between 2014-2022 and has been working as a faculty member at Antalya Bilim University, Department of Mechanical Engineering since 2022.

Caner Yüksel has been working as a Research Assistant at Doğuş University, Department of Mechanical Engineering, since 2019. He received his bachelor's degree in Automotive Engineering from Karabük University in 2016. He completed his master's degree at Yıldız Technical University, Department of Mechanical Engineering. In 2022, he started his PhD education in the field of Construction, Department of Mechanical Engineering at Yıldız Technical University and is still continuing his PhD education. Machine design and machine elements, materials handling and especially lift systems, mechanical vibrations are among the areas of study and research.

# Advances in Technical E-Learning in the Lift Industry

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**Keywords**: Continuous training, e-learning, online training, 3D, simulations

**Abstract.** This paper will discuss e-learning training applied to the construction sector, with a specific focus on the lift industry.

## 1 INTRODUCTION

The need to update knowledge, skills, and competencies is becoming increasingly essential to meet the demands of a rapidly evolving labour market. The COVID-19 pandemic, as well as digital and ecological transitions, pose new challenges and a shift in the way we learn and work. Traditional formal education and training are not sufficient to address these challenges, leading to the emergence of new learning methods that are impacting company-funded training.

As these new methods are implemented in businesses and their practical results are assessed, considering the physical, mental, and emotional well-being of employees, we are likely to witness a significant transformation in continuous training within the next decade. This transformation is already underway, but it requires changes in how companies manage training.

## 2 CURRENT SITUATION OF COMPANY-FUNDED TRAINING IN THE UK, SPAIN, FRANCE AND ITALY: A BRIEF OVERVIEW

### 2.1 United Kingdom

Since the introduction of the Apprenticeship Levy in 2017, large companies in the United Kingdom with an annual payroll exceeding £3 million are required to contribute 0.5% of their wage bill to this fund. The accumulated funds can only be used to finance apprenticeship training and assessment programs and expire if not used within 24 months.

However, the effective use of these funds has been limited. According to a 2024 survey conducted by the Institute of Student Employers (ISE), companies spent on average only 41% of their levy funds, down from 45% the previous year. Moreover, only 4% of employers managed to fully utilise their available levy budget [1].

Levy utilisation varies significantly across sectors. For example, the construction sector used approximately 69% of its funds, while the healthcare, pharmaceutical, retail, and tourism sectors used only around 25%.

The main barriers identified by employers to fully using the funds include the bureaucratic complexity of the system, the rigidity of training requirements (such as the minimum 12-month duration and the obligation to dedicate 20% of working time to off-the-job training), and the lack of training programs tailored to the specific needs of companies.

It is estimated that over £3.3 billion in unused levy funds have been returned to the Treasury, sparking criticism regarding the system's overall efficiency.

In response to these concerns, the government has implemented reforms aimed at increasing flexibility. Since April 2024, companies have been allowed to transfer up to 50% of their unused funds to other businesses—especially SMEs—to support training programs. Additional reforms are being considered to transform the Apprenticeship Levy into a "Growth and Skills Levy", which would allow companies to use the funds for a broader range of training programs, not limited exclusively to formal apprenticeships.

Continuing Professional Development (CPD) is widely implemented and, in many cases, mandatory within the UK construction sector. While not a legal requirement across the board, CPD is a formal obligation for professionals affiliated with key regulatory and chartered institutions, such as the Chartered Institute of Building (CIOB), the Royal Institution of Chartered Surveyors (RICS), and the Institution of Civil Engineers (ICE). For example, RICS members are required to complete a minimum of 20 hours of CPD annually, and several types of Construction Skills Certification Scheme (CSCS) cards now require ongoing CPD to remain valid. Major construction firms—such as Balfour Beatty and Kier Group—also run internal CPD programmes focusing on health and safety, regulatory compliance, digital tools like BIM, sustainability, and leadership on site.

According to the 2023 CIOB Skills Survey, 87% of chartered construction professionals report completing CPD each year. Furthermore, the 2024 UK Construction Training Trends Report reveals that 63% of medium and large construction companies have formalised CPD frameworks. The Construction Industry Training Board (CITB) highlights CPD as a critical strategy for talent retention and skills development in a sector facing significant labour shortages. As such, CPD is increasingly seen not only as a compliance requirement but also as a quality standard and a competitive advantage for firms bidding on complex or public projects.

In recent years, the delivery of Continuing Professional Development (CPD) in the UK has seen a marked shift towards online formats. A 2023 survey showed that 69% of learners in the UK preferred online CPD due to its flexibility, compared to just 31% who favoured in-person training [2]. This trend is reflected in the workplace, where 44.7% of employees reported engaging in online training courses, compared to 50.9% who attended in-person sessions [3]. Furthermore, the 2023 Adult Participation in Learning Survey revealed that nearly half of UK adults had participated in learning activities in the previous three years, with a significant increase in self-directed and online formats [4].

Regarding the effectiveness of delivery methods, studies have consistently shown that online CPD can be as effective as face-to-face training when interactive elements are incorporated. These include live sessions, breakout rooms, and collaborative exercises [5]. A systematic review focusing on science educators concluded that there is no significant difference in impact between online and in-person CPD formats [6].

In summary, online CPD has become increasingly prevalent across UK sectors due to its adaptability and accessibility. However, the success of any CPD programme is largely determined by its pedagogical design and engagement mechanisms, rather than its delivery mode.

### 2.2 Spain

According to the latest report from Fundae [6], in Spain, where companies are required to contribute to training schemes, only 53% of the available credit is utilised. This means that approximately €571 million available for workforce training goes unused by Spanish companies.

These figures contrast with widespread complaints about the lack of qualified personnel prepared to handle the unprecedented changes in workplace organisation and today's highly competitive market.

Both young people coming from vocational training and experienced employees require short training courses to improve and update their existing knowledge.

Company-funded training in the construction sector primarily focuses on occupational health and safety (H&S), accounting for half of the total training hours per year and 60.4% of participants. H&S training is also prevalent in the manufacturing industry, although to a lesser extent, involving 37.5% of participants and accounting for 27% of total training hours. H&S training is a legal requirement, yet it often lacks practical relevance to specific job roles and does not sufficiently develop the soft skills necessary for risk prevention.

H&S training is the most prominent across all economic activities, accounting for 16.6% of training hours, encompassing both general and construction-specific training. The second most common type of training is English language training, accounting for 7.3% of total training hours. Other types of funded training are highly diverse but represent only a small share.

Regarding training formats, most training is delivered in person, with 3,339,973 participants in 2022. This growth has come at the expense of virtual classrooms[1], which saw a surge during the COVID-19 pandemic but had 778,462 participants in 2022. Online training[2] continues to show an upward trend, with 1,935,261 participants, although its growth rate has slowed. Satisfaction with online training is low, with a Net Promoter Score (NPS[3]) of -29, according to Gamelearn [7].

Lastly, according to Fundae, the average contribution per participant made by companies towards training costs is €167. Given that the gross annual salary, according to the Spanish Tax Agency in 2022, was €22,781, the investment in training represents 0.73% of wage costs. When adding an average of €106 per employee, the total average training cost per participant in company-funded training is €273.

Globally, the average investment in training is €167 per employee per year, according to the Annual Leadership Development Survey by *Training Magazine* [8], which also revealed that training expenditure increased by 27% in 2022 compared to the previous year. The average number of training hours is 13.5 per employee, accounting for 0.7% of the total annual working hours.

### 2.3 France

Companies in France are legally required to contribute between 1.23% and 1.68% of their payroll to national training funds through the Contribution Unique à la Formation Professionnelle et à l'Alternance (CUFPA**)**. These funds are managed by *France Compétences* and distributed via sectoral bodies known as *OPCOs*.

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[1] A virtual classroom is defined as a learning environment where the tutor/instructor and students interact concurrently and in real-time through a synchronous telematic communication system. Training delivered via a virtual classroom must be structured and organised in such a way that ensures continuous synchronised connectivity between instructors and participating students, as well as bidirectional communication at all times.

[2] Online training is conducted through a virtual learning platform that enables interaction between students, tutors, and resources located in different places. It ensures content management, a structured learning process for participants, continuous real-time monitoring, and the evaluation of the entire process.

[3] The Net Promoter Score (NPS) is a widely used metric that measures customer satisfaction and loyalty by asking how likely individuals are to recommend a product or service on a scale from 0 to 10.

While this system has enabled a high overall participation rate in continuous training, various international reports have identified challenges in how efficiently and equitably these resources are allocated.

According to UNESCO-UNEVOC [9], despite reforms aimed at ensuring sustainability and better coordination among stakeholders, there remains a need to improve transparency and synergies, as well as align training content with labour market needs.

Similarly, CEDEFOP [10] notes that, although efforts have been made to regionalise and adapt training provision, implementation gaps persist, particularly in personalising training pathways and aligning skills development with ecological and digital transitions.

The participation rate of construction workers in continuing training is relatively low. In 2023, only 27% of employees in the sector received at least one training activity organised by their employer [11]. This level is below the national average (41% of employees trained annually). Historically, the construction sector has fluctuated around one-third of workers receiving training annually (35.6% in 2020) [12]. Still, the most recent figures confirm that fewer than one in three employees access training courses each year.

The prevalence of small enterprises is a key factor: the construction sector in France is primarily composed of microenterprises, which tend to train their workers less frequently. For example, in firms with fewer than 10 employees, the training rate can be as low as 15%, whereas in large companies (≥1000 employees), it exceeds 60% [13]. This contributes to the lower participation rate of construction compared to other sectors, which have a more concentrated business structure.

Training delivery methods in the construction sector have undergone significant changes, particularly since the COVID-19 pandemic. Traditionally dominated by in-person training, the sector has seen a decline in classroom-based courses and a rise in alternative formats. Increasingly, companies have adopted remote training and blended learning models, integrating digital tools and self-directed learning into their training strategies.

In 2020, 50% of training providers offered online courses, up from 16% in 2015 [14]. Additionally, 26% of firms funded self-learning modules (asynchronous e-learning), compared to only 12% five years earlier. Work-based learning (FEST format) also expanded considerably, as it was used by 39% of firms in 2020, up from 24% in 2015. These figures highlight the sector's rapid shift toward online and hybrid models, combining virtual learning with on-site practice.

Despite this shift, in-person courses remain important. In 2020, 47% of trained employees continued to receive traditional classroom instruction. However, blended approaches are increasingly popular, especially for combining online theory with hands-on safety or equipment training. Overall, the sector's training approach is now more hybrid, supported by digital tools without completely replacing traditional in-person training.

Construction companies invest proportionally less in continuing training than the national average. In 2023, the construction sector's spending on professional training amounted to only 2.9% of its total payroll, compared to a national average of 3.7%. This investment level is lower than in other leading sectors: for instance, the manufacturing industry invests 4.7% of its payroll in training, while the finance sector exceeds 5%.

In terms of training content, the top priorities are on-site activity, safety, and market-driven demands. Sectoral observatories report that occupational safety and health training ranks first. In small construction businesses, safety training accounts for nearly 50% of all training sessions, making it the leading subject area. Technical training (methods, materials, regulations) follows at around 36%, and management skills (project leadership, site coordination) represent 14%.

Construction lags behind most other sectors in France in terms of training coverage. With a 27% annual employee training rate, it falls well below the national average of 41%, ranking ahead of only sectors such as agriculture (17%) and hospitality (14%). In contrast, manufacturing industries train over 55% of their staff, while finance and insurance sectors exceed 77%.

Training investment rates mirror this gap. Construction allocates 2.9% of payroll to training, compared to 3.7% nationally. Leading sectors invest significantly more: manufacturing spends 4.7%, and finance tops the chart with 5.6% of payroll. As a result, construction workers receive fewer training hours and resources: around 33 hours per trained employee per year, compared to 35 hours in health/education or 34 in finance.

### 2.4 Italy

In Italy, companies can voluntarily allocate a portion of their mandatory social security contributions (0.30% of gross payroll) to inter-professional training funds (*Fondi Paritetici Interprofessionali*), which are managed by joint employer–union bodies. These funds are designed to finance continuing vocational training for employees.

Although the system offers flexibility and is widely accessible, several reports point out significant disparities in participation and fund utilisation, particularly among small and medium-sized enterprises (SMEs). Many companies—especially microenterprises—are either not aware of the funds or lack the administrative capacity to access them.

According to UNESCO-UNEVOC [15], despite the system's potential, access remains uneven across sectors and company sizes, and coordination among national and regional actors is still insufficient.

Furthermore, CEDEFOP notes that structural weaknesses limit the strategic use of training by companies and that participation in formal training remains low by European standards, especially among low-qualified workers [16].

Employee participation in CVT in Italy's construction sector is relatively robust. In 2020, about 49.3% of all construction employees (in firms with 10+ workers) took part in training courses [17]. This rate is higher than the national average of 44.6% across all sectors. The training provision by employers is also high, with 82.1% of construction firms offering training to staff, rivalling the information technology and finance sectors. This is mainly due to mandatory safety requirements and the prevalence of short, cost-effective training formats.

Traditional in-person training remains the predominant method in the construction industry. However, by 2020, nearly one-third of companies had adopted online learning formats. Blended approaches, which combine on-site practical training with virtual modules, have become common. Digital delivery saw notable growth in southern regions, such as Abruzzo and Sardinia. The sector increasingly uses a mix of in-person, remote, and work-based learning methods.

Italian companies spent €6.2 billion on training in 2020. Construction firms showed strong participation, with 49% of workers receiving training. However, the average cost per hour was about €50—below the national average of €56—due to shorter course formats. Larger construction firms account for the majority of spending, investing in both compliance certifications and skill development.

High-demand skills include energy-efficient construction methods, digital design (e.g., BIM), and sustainable practices. There is also a continued need for traditional trade skills (bricklaying, carpentry) and transversal skills (problem-solving, teamwork, project management). Safety training remains a cornerstone of continuing education in the sector [18].

Construction exceeds other sectors in training incidence, outperforming manufacturing and retail. However, it lags in per-capita training investment and advanced skill development. The dominance of micro-firms limits deep training capacity, though broad participation is maintained through sector-wide mandates. Finance and high-tech industries invest more per worker and target different competencies.

## 3 CRITICAL PERSPECTIVES AND INNOVATIONS IN E-LEARNING IMPLEMENTATION

### 3.1 Limitations of e-learning

Based on the authors' experience, online training has significant limitations, which can be grouped into several categories:

- Excessive workload preventing training participation: Even when training could help reduce workloads, employees often struggle to allocate time for learning, creating a vicious cycle that is difficult to break.
- Training schedules: A common complaint from employees participating in company-sponsored training is that it must be completed outside working hours.
- Lack of dedicated training spaces in offices: A minority of employees face difficulties in completing online training due to a lack of access to a computer at home.
- Cultural resistance to e-learning: Many still perceive e-learning as lower quality than face-to-face training. This perception stems from widespread use of low-quality online courses that rely on outdated, generic, and non-interactive content, often presented in static PDF formats.

Several studies have highlighted that learning outcomes in traditional classrooms and e-learning environments can be very similar [19] [20]. Below, we will examine common misconceptions about e-learning.

### 3.2 Barriers to the adoption of e-learning

Based on the authors' experience, primarily in Spanish-speaking countries, some assumptions act as barriers to e-learning. One assumption is that in-person training automatically guarantees practical learning. Simply being physically present in a classroom (as is the case in 62.9% of corporate training) does not ensure hands-on training. The presence of an instructor alone does not necessarily provide learners with practical knowledge.

Likewise, there is a misconception that online training is impractical. Ironically, one of the most high-risk professions, airline pilots, undergo extensive practical training using flight simulators.

While certain tasks require on-site, hands-on training, many of these tasks can be complemented or even replaced by high-quality e-learning. In fact, e-learning can simulate scenarios that are difficult or impossible to replicate in real-world training environments. For example, it can simulate the downward movement of a lift cabin while a technician is in the pit, a situation that would be unsafe to recreate in a physical setting.

Another common confusion is between distance learning and e-learning. Distance learning (which might still be based on pdf documents) and online blended learning offer different experiences for learners, with the differences not being fully understood.

Unlike traditional classroom training, modern e-learning platforms typically are able to track the time spent on each activity, can integrate assessments between topics, and can require successful completion before progressing. Identity verification systems using IP (Internet Protocol) tracking can be used to check that the registered user is the one completing the course, without posing privacy concerns.

## 3.3 Advanced E-Learning Proposal

Experience gained with technological advancements in learning methodologies over the last 20 years enables observations to be made on designing, implementing, and evaluating e-learning or blended learning policies in industrial sectors, such as the lift industry.

### 3.3.1 Blended Learning Methodology

Blended learning, which combines face-to-face sessions with asynchronous online training, has been used by the authors in leadership development programmes, training for supervisors and sales professionals, technical fault detection courses, and introductory lift training.

The key components of blended learning are:

#### 3.3.1.1 The "Physical Presence" Factor

Traditional face-to-face training sessions, where learners meet and interact in person, offer significant value to the learning experience. They foster rich interpersonal connections, encourage spontaneous exchanges, and create strong group cohesion—benefits that often extend beyond the training programme itself.

However, in-person training also presents logistical and economic challenges. Requiring learners to be physically present at a specific location and time can limit access and participation, particularly for full-time employees who work far from the training venue or operate within demanding schedules.

While the opportunity to network and engage with peers in person is undeniably beneficial, the associated travel time and costs can become prohibitive for both learners and providers.

These constraints are particularly relevant in specialised industries such as the lift sector. In such niche markets, ensuring the minimum number of participants needed to run a commercially viable in-person programme can be difficult. This is even more pronounced in training aimed at senior professionals, whose numbers are limited and whose availability is often constrained.

On the provider side, sourcing qualified instructors locally or covering travel expenses adds further complexity. Recruiting trainers with the necessary industry expertise and teaching capability becomes even more challenging when sessions are tied to a physical location.

Our experience in highly geographically concentrated lift markets, such as Spain, shows that while traditional methodologies remain valuable, relying on them exclusively is no longer sustainable. A blended or fully online approach, when well-designed, can offer both pedagogical quality and commercial viability, making advanced, industry-specific training accessible to a wider professional audience.

#### 3.3.1.2 The "Online Presence" Factor

This is where technology plays a crucial role. It enables training to take place in the same time frame but without requiring a shared physical location. With the rise of videoconferencing platforms, instructor-student interactions have become commonplace, allowing training programmes to be delivered to participants thousands of kilometres apart.

The COVID-19 pandemic significantly accelerated the adoption of online learning, though many of these practices were already becoming part of professional life beforehand. While online presence offers clear advantages—such as flexibility, accessibility and scalability—it also requires a different set of conditions and behaviours compared to traditional in-person learning. Notably, it is increasingly common for participants to keep their cameras turned off or to engage less actively than they would in a face-to-face setting. These behaviours can limit interaction and reduce the sense of group cohesion, which is typically stronger in physical environments.

Therefore, the success of online training depends not only on the technology itself but also on the intentional design of strategies that foster engagement, encourage participation, and maintain accountability throughout the session.

#### 3.3.1.3 Asynchronous Online Participation

Whether present physically or online, a tutor and learner must both be present at the same time (synchronous). E-learning also allows for asynchronous learning, where the learner can access content and progress at their own pace. This flexibility offers a significant advantage over traditional methods: immersive learning experiences that integrate seamlessly into a learner’s professional and personal life.

With the support of virtual learning platforms, students can independently track their progress in acquiring new knowledge, skills, and competencies. Modern digital training solutions even enable learners to interact with training content hands-on, completing practical exercises without the need for specialised hardware.

## 4 E-LEARNING IN THE LIFT INDUSTRY

The lift industry typically needs to train technicians on equipment from several manufacturers. In 2014, to address this need, the authors set up a one-day traditional workshop-based training programme using real lift controllers. Initially, they developed a traditional, in-person training programme based in a workshop in Seville, where technicians could work directly with real lift control panels. Each training session lasted six hours.

Participants came from various European lift companies, many of whom had to travel the day before or early in the morning. This travel burden affected their ability to remain fully attentive during the course.

Although the programme was successful, it raised questions about whether the benefits of the training could be realised without physical presence.

Consequently, in 2018, the authors trialed an online fault detection course that utilises advanced programming and high-poly multimedia models. This allows technicians not only to identify and familiarise themselves with lift components but also to use a virtual multimeter to measure voltages, whether from the control panel at floor level or from the cabin roof.

Each participant works through the course on their personal computer, using an individual account, progressing at their own pace. Most importantly, they undergo practical assessments that test their ability to diagnose real faults.

**Figure 1 Online practice in fault detection using a multimeter on the safety series**

### 4.1 Training Methodologies Based on 3D

Another example demonstrating that online training can be just as practical as in-person training is the preventive and corrective maintenance course for lift doors, which employs an interactive methodology based on 3D models.

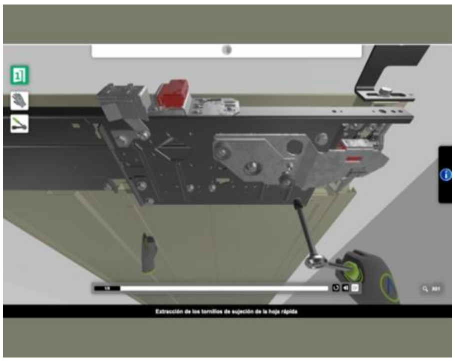

**Figure 2 Online practice of maintenance operations on automatic lift doors**

Following a gamified introduction to the theoretical fundamentals of lift doors, students go through each of the recommended routines for proper preventive maintenance of doors.

To achieve this, through observational learning (or vicarious learning), students follow each task to be performed, moving between different floors of the building and the lift cabin roof.

Once the procedures have been reviewed, the student, now positioned on the floor immediately below, must perform each task independently, selecting the appropriate tools from a virtual toolbox available within the course.

Subsequently, students must diagnose and resolve the most common faults in lift doors using the same 3D-based methodology.

### 4.2 Training Methodologies Based on Simulations

Another methodology employed is simulation-based learning. Through computer simulations or virtual reproductions of real system operations, students learn how to work with equipment such as hydraulic power units and frequency converters.

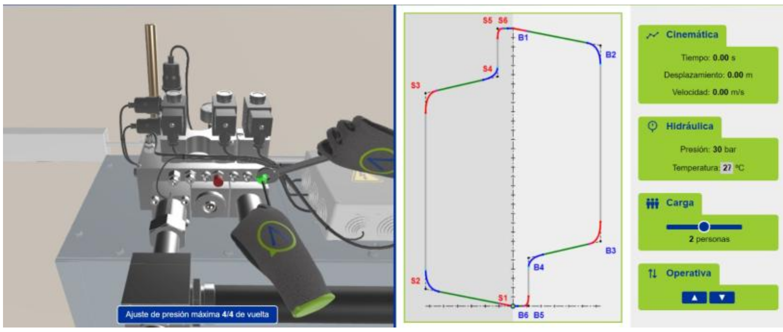


**Figure 3 Sample of simulation-based learning on a hydraulic power unit**

These are interactive learning activities, where students learn practically through discovery and hypothetical scenarios, developing mental agility and problem-solving skills through hands-on interaction.

The virtual simulator enables students to experience real-life scenarios as if they were in a laboratory, with a guided structure that provides step-by-step orientation throughout the learning process.

## 5 CONCLUSION: THE EVOLVING ROLE OF ONLINE AND BLENDED LEARNING

The increasing maturity of e-learning tools has significantly expanded what online and blended training can achieve compared to a decade ago. Our experience confirms that these approaches are particularly effective in addressing knowledge-based learning, especially when combined with structured assessment systems. These enable companies to verify that technicians have acquired the required knowledge of specific control systems and can identify faults effectively.

Online delivery also enhances the commercial viability of training providers, who can form groups with technicians from different countries and languages. At the same time, we acknowledge that in-person training remains valuable, particularly in situations where hands-on skills, behavioural training, or peer interaction are central to the learning goals.

For this reason, we advocate for blended learning, combining the flexibility and reach of digital tools with the depth of human interaction that face-to-face formats can offer. Technology should be seen as a means, not an end: the success of any training programme depends on thoughtful instructional design, high-quality content, and the expertise of trainers and tutors.

According to feedback from our courses, online programmes that include specialised content using audiovisual tools—such as 3D models, simulations, and games—receive a Net Promoter Score (NPS) of +44, compared to -29 for generic e-learning formats. While these figures indicate strong learner satisfaction, we acknowledge that this is a relatively new area and that more longitudinal data is needed to assess the long-term impact on operational outcomes.

Finally, given the workload constraints in many companies, shorter and modular training formats are preferred. A well-balanced combination of clear, engaging theory and practical exercises that reflect real-life situations has proven particularly effective and well-received.

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**BIOGRAPHICAL DETAILS**

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# A Chronology of the Life of Howard Marryat

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**Keywords:** Marryat & Place, Marryat & Scott, Dewhurst & Partner, pioneer, philanthropist, horologist

**Abstract:** This paper presents the life of Howard Marryat (1871-1944), who founded Marryat & Place at the age of 20 and subsequently Marryat & Scott in 1919, which went on to become one of the most successful lift companies in the world and is now owned by KONE. He was also a founding partner with Dewhurst. His work rate and charitable giving were phenomenal, and this paper will demonstrate how his surname became synonymous with the lift industry.

## 1 INTRODUCTION

Howard Marryat was a hardworking and talented engineer, philanthropist, family man, watch expert and mentor. His effect on the lift industry in the UK is very much understated, and he can only be described as "a giant of the industry".

Howard was a successful and well-liked businessman. His friends affectionately called him "HM", and he had a great capacity for friendship. He worked fastidiously hard, creating what eventually became an electrical engineering company specialising in the design, manufacture and installation of lifts in buildings all over the world. He was a pioneer in the field of electrical engineering and wrote and lectured on the subject. His offices were in Hatton Garden, London.

His family life is of equal interest to his working life, with consistent themes of integrity, hard work and philanthropy. Unfortunately, it wasn't without tragedy along the way.

A portrait of Howard, which was painted by his daughter, was lost when his offices in London were damaged by bombs during the war. Of his four children, his youngest daughter (Mary Kent Harrison, nee Marryat) became an accomplished artist and exhibited at The Royal Academy [1] [2].

**Figure 1 The lost portrait of Howard Marryat**

## 2 UPBRINGING & EARLY YEARS

Howard was born on 26th August 1871 in Elham, a village in the district of Folkestone and Hythe, Kent. His parents were Charles and Jessie Marryat (nee Druary) from his birth certificate, although the family believe that Charles never married her and that Howard was an illegitimate son.

It seems Jessie was something of a mystery. She is missing from the census of 1871 [3] when Howard was born, and there is no evidence of a marriage other than the birth certificate where her surname is listed as Marryatt (with two T's) and formerly known as Druary. For some unknown reason she had several aliases, but Mootham is probably her real surname. Mant was also a surname that she used. The Moothams fell upon hard times financially [1], and this may be a reason for the different names used by the family. The matter was never discussed in the Marryat family. There is no evidence linking Jessie with a Charles Marryat, but Howard's son, Robert, recalled a conversation with Howard in which it was made clear that his father was a Marryat.

Jessie brought Howard up single-handedly and in great hardship. It was she who supported him through his early years, which must have been very hard financially. There was no state help for single mothers like there is nowadays. There was also no Marryat money to help. Jessie improved herself and, prior to Howard's birth, found friends among the upper echelons of Victorian society who helped her to educate herself and, in turn, educated Howard and sparked his interest in the finer things of life, such as art and opera [1]. It was a tough upbringing. Much was kept secret, and it seems there is no way of finding out much more. People took liberties with birth and death certificates and census returns in those days.

The hardship of Howard's early years resulted in Howard becoming very ambitious to better himself. It could easily have gone the other way, and Howard would have stayed poor. He was clearly very grateful for Jessie's endeavours in bringing him up. Howard had an impressive headstone with the word 'Angel' carved at the bottom of it under her name, which shows how much he was indebted to her [1].

He was educated privately at Richmond College, leaving there in the midsummer of 1887. This is not the same Richmond upon Thames College that exists today in Twickenham, which wasn't founded until 1937.

As a young man, Howard was a keen swimmer and cyclist. He once walked from Richmond to Exeter and back, accompanied by his dog. Richmond, it seems, provided the right environment where outdoor pursuits could be enjoyed, yet all the benefits of the capital city were within easy reach.

## 3 APPRENTICESHIP & EDUCATION

In 1886, at the age of 15, he started an apprenticeship at the Acton Electric Light and General Engineering Works, founded by Captain Ronald Augustus Scott. Scott was one of the Institution of Electrical Engineers (IEE) Victorian members, and it is suspected that he was very influential in mentoring Howard to join such organisations, promote and work tirelessly for them. Scott's work during the latter years of the 19th century was at the forefront of technology in supplying arc searchlights, generators and switchboards for military and naval use. He later diversified into the novel field of the projection of advertisements onto the sides of buildings. Unfortunately, he became insolvent, and his business collapsed [4].

Howard studied at Finsbury Technical College, which was formally opened on 19th February 1893 and is now recognised as having been the first technical college in England. The College was set up as a result of a meeting of 16 of the City of London's livery companies held in 1876, where it was agreed to form the City and Guilds of London Institute for the Advancement of Technical Education (CGLI). The aim of the CGLI was to improve the training of craftsmen, and the two main strategies devised were to create a Central Institution in London, and to conduct a system of qualifying examinations in technical subjects. No single site could be found immediately for this Central Institution, so evening classes were held at a school in Cowper Street, off City Road, enabling instruction in chemistry and physics to be provided to those who wished to continue their education after working during the day. The school proved such a success that new premises had to be found in nearby Leonard Street, which became Finsbury Technical College in 1893. Its purpose was to be a 'model trade school for the instruction of artisans and other persons preparing for intermediate posts in industrial works'. The college offered opportunities for daytime and evening study, and subjects included building, design, drawing, engineering, mathematics and science. In 1926, Finsbury Technical College closed and was incorporated into Imperial College.

## 4 MARRYAT & PLACE

In 1891, Howard, at the age of only 20, established the firm of Marryat and Place, who were an industrial electrification and maintenance contractor. It is rumoured, and requires further investigation, that there was no "Mr Place" and Howard alluded to this in his application to a professional engineering institution in later years.

In the 1891 census, it appears that Howard was living at 102 Sea Road, Boscombe, Dorset and stated his profession as being a "private secretary". Interestingly, his name is spelt with two "T's" on the census, suggesting that it wasn't he who created the entry.

The head of the household was Alice Helena Thompson (widow), who is listed as a boarding house manageress, so it may be that Howard was lodging there for work. Although, his soon-to-be wife, Maude, lived nearby.

In 1910, Marryat and Place acquired lift manufacturers Joseph Richmond and Co, who had installed a 134 ft travel hydraulic lift in the Columbus Monument in Barcelona in 1876 [5].

Marryat and Place were based at 28 and 29 Hatton Garden, London [6]. During 1926, these properties were being partially rebuilt, and the offices were relocated to 40 Hatton Garden, London EC1. Howard co-authored "The romance of Hatton Garden" [6] with Una Broadbent (published 1930), and within that book there is a reference to floor levels changing. In the book, there are sketches of the streetscape of Hatton Garden.


**Figure 2 View showing 28 & 29 Hatton Garden from Howard's book.**

**Figure 3 28 Hatton Garden in December 2024**

Sadly, 40-42 Hatton Garden has been demolished and replaced with a modern building.

In 1930, Marryat and Place Ltd was converted into a private limited company and operated alongside Marryat & Scott (a company founded by Howard in 1919 and the subject of a separate chapter in this paper).

## 5 MARRIAGE & FAMILY LIFE

On 5th August 1899, at the age of 28, Howard married his cousin, Maude Mootham, in Richmond, Surrey. They remained married until his death in 1944. Marrying a cousin was quite common in those days, and Howard knew the implications of what he was doing by marrying a cousin.

Maude was born in Bournemouth on 2nd July 1869 to Orby & Caroline Mootham (nee Bradfield) who married in Marylebone on 27th October 1868. Orby and Jessie were siblings.

Howard and Maude had four children, two girls and two boys, these being Cecily (1903), John (1907), Robert (1910) and Mary (1915).

In the 1911 census, he is listed as an electrical engineer and married to Maude with children Mary Cecily (8), John (4) and Robert (7 months). Mary Cecily must have been the child known as Cecily, as Mary wasn't born until 1915. Their address was listed as Thames Dene, Hartington Road, Chiswick.

On 29th December 1915, his daughter Mary Marryat (who became Mary Kent Harrison) was born and subsequently became an artist. At the time, Howard was 44 and Maude 46.

Howard's life was not without pain, and his beloved eldest daughter, Cecily, had a tragic early death from Hodgkin's disease, having been born in 1903 in Hammersmith and passing away on 28th July 1935 at the age of just 32. She is buried in Petersham in the same grave as her mother and father. Mary gave the name Cecily to her first daughter [1].

Mary Marryat, Howard's daughter, grew up in Richmond at the family house at 1 The Terrace. Mary had her first romantic attachment with a local curate, but the relationship ended because of his insistence that Mary should abandon any artistic career. Howard sought to help heal the emotional wounds by sending her off on a tour of the Middle East in 1936. In 1939, she married George Kent Harrison, a Canadian, just before the outbreak of war, at St Matthias Church, followed by an impressive wedding reception in the garden at The Terrace [1].

John Marryat, Howard & Maude's youngest son, passed away in 1965.

Mary Kent Harrison (nee Marryat) passed away on 25th May 1983 in London at the age of 67. Her ashes were scattered in the churchyard of St Mathias Church in Richmond, Surrey [2].

## 6 MID CAREER STAGE & INDUSTRY INVOLVEMENT

In 1903, at the age of 32, he founded the "Electrical Contractor Magazine", a publication. It became the official journal of the Electrical Contractors Association (ECA) in the following year, and Howard acted as its Honorary Editor for some 25 years.

In 1904, aged 33, Marryat was an indefatigable worker in any cause likely to benefit the electrical industry. He was a founding member of the aforementioned Electrical Contractors' Association, serving on its Council from its inception in 1904 until the time of his death, and was twice elected President in 1922/3 and 1934/5.

In 1905, he joined The Royal Institution as an Associate Member and was elected a full member in 1907.

In 1912, at the age of 41, his passion for sharing information came to the fore again when he founded his own house journal, "The Engineering Gazette".

On 12th July 1917, at the age of 46, he was made a member of the IMechE, being proposed by a Mr. James Garratt (of Singapore) and Mr. Arthur Patey (London), plus three supporters, Thomas Rice, Hugh Seabrook and Horace Darwin. He gave his address as 28 Hatton Garden and his birthday as 26th August 1870 (it is not known who entered this record, as all other documents suggest that Howard was born in 1871). He described his subsequent career post-Scott's as follows:

"I am the sole proprietor and manager of Marryat & Place, having no partner. The business, in normal times, is principally concerned in lift making, together with self-delivering hoists and allied machinery. We also construct lifting magnets. We have some connection in the optical trade and make various patterns of lens surfacing and grinding machines. We are sole agents for the Reid Gear Co, of Linwood, which is rather more than a buying and selling agency, as we undertake to get out schemes of gearing and the erection of same. During the war, we have been principally engaged in factory equipment and millwrighting, for munition works, such as R & J Beck Ltd., G R Watts & Sons Ltd etc. We have also done a considerable amount of engineering for the London Electron Works, a German concern now taken over by the New London Electron Works, which is a British company, the business of which is to recover tin and solder etc, from old tin cans; a very interesting proposition and one containing many novel problems. With regard to the staff, we are now employing about 104, of which some 46 are skilled fitters and electrical fitters. Normally, we employ five draughtsmen, but at the moment these are reduced to three.” 1891-1917 (he was still employed; this was just the date of the application)

As previously mentioned, his reference to being the sole proprietor is of interest, as rumour has it that there was never anyone called Place, and the business was solely Howard’s.

As part of his work with the IEE, Howard served on the Council from 1927 to 1930 and on the Benevolent Fund Committee from 1938 to 1941.

## 7 MARRYAT & SCOTT

In 1919, at the age of 48, a private company called Marryat and Scott was formed by Howard Marryat and Murray D. Scott to acquire the lift and hoist business of Marryat and Place. Little is known of Murray Scott, but he is not believed to be linked to the Scott under which Howard served his apprenticeship.

Howard was dedicated to the training of young engineers, and Marryat & Scott were responsible for the training of many well-known industry names.

In 1927, a co-operative agreement between Marryat and Scott and competitor John Bennie was signed. The original Bennie business was formed in 1865 by John Bennie (1849-1906), and in 1890 they fitted passenger and luggage lifts at the South Station Hotel in Glasgow. In 1899, a local building firm led by Archibald Fergusson constructed an outside lift shaft at Strachur Manor House for the Plowden family. Bennie was engaged to supply the lift machinery, but due to an untimely death in the Plowden family, the job was abandoned. Whether the lift was installed and subsequently taken out again, or whether it was never installed at all, is unclear. Eventually, floors and ceilings were made in the shaft on each floor so that it became a stack of walk-in cupboards. In the early years of this century, the doors and door frames were removed, and the openings were bricked up so that there is now no access to the shaft. It stands empty, still in place at the back of the house to this day.

NALM (National Association of Lift Makers) was formed in 1932 [7], and Marryat & Scott were founder members with Howard representing them.

In 1934, Messrs. Marryat, Scott and Fletcher formed John Bennie Ltd to acquire that lift business following the 1927 co-operative agreement mentioned earlier.

In 1950, a private company was incorporated to acquire Marryat and Scott Ltd (which also owned John Bennie Ltd) and Marryat and Place Ltd (industrial electrification and maintenance contractors) and was converted into a public company.

In 1979, the Marryat & Scott name was changed to “Kone, Marryat & Scott” when it was acquired by the KONE Corporation from Finland. The names Marryat & Scott no longer feature in the UK market but still remain strong in Kenya.

## 8 DEWHURST & PARTNER

1919 was a busy year for Howard. Dewhurst and Partner (note the singular) of Hounslow, Middlesex, was formed with Melbourne Dewhurst being the Managing Director and Howard Marryat the Chairman. Melbourne Dewhurst was thought to be a former apprentice of Marryat and Place [8]. In 2019, Dewhurst published a book commemorating their 100 years in business. Within the book, it is stated that Melbourne placed an advertisement in the national press for a business partner and as a result became in touch with Howard, who had already formed several companies. The book names both Marryat & Place and Marryat & Scott, but doesn't mention others. The nominal share value of Dewhurst & Partners was £5000 (Calculated as £379,000 in 2024). What took longer to agree on was the name of the business. Howard proposed Marryat & Dewhurst; however, this was rejected as one of Howard's companies had gone into liquidation recently. They toyed with the idea of Marrydew as a name, but eventually settled on Dewhurst & Partner. The formal agreement was signed on the 3rd of November 1919, and the company was formally incorporated 2 days later. Howard remained on the Board until his death in 1944.

In 1922, Dewhurst & Partner moved to Inverness Road in Hounslow, and Murray Scott also joined as director and shareholder.

## 9 1 THE TERRACE, 134 RICHMOND HILL

In 1923, Howard and Maude moved into 1 The Terrace, 134 Richmond Hill, Richmond, Surrey.

**Figure 4: Howard with his daughter, Mary, at the front door of 1 The Terrace.**

The house at 1 The Terrace was full of valuable and delicate objects. A family member recalls two suits of armour in the drawing room that were 'never to be touched'. Such reverence for the collections would have tempered the tone of the house for its occupants, especially one with small children. They also recall further that Howard had a very large telescope on the landing that must have been particularly vulnerable. It was no ordinary telescope. It was one of five telescopes made by William Herschel (1738–1822). Howard Marryat bought it in 1927, but presented it to Robert Whipple in 1944, after Whipple's gift of 2000 scientific instruments and books to the University of Cambridge. It is currently on display at the Whipple Museum of the History of Science in Cambridge. One cannot imagine how panic-stricken the relative must have been when, after playing with it, a part came off and the boy was called to see Howard in his study the next day to 'discuss' the matter!

Thanks to Howard's business acumen, the family were able to live relatively comfortably, at least in the period before the Second World War. They had a staff room in the basement and a huge Aga in the kitchen. There was a live-in maid called Beatrice, and a chauffeur and gardener who were not in permanent residence.

It is said that the house was usually fairly sombre and strict. Everyone was expected to dress formally for the evening meal, and they were served by Beatrice (the maid), who went around the long dining room table, starting with Maude and finishing with Howard. There were fun and games, but only at specific times and in the right place, and such humorous moments would have complemented other times of intense study and reverence. There was a handsome hand-painted rocking horse in the ballroom, on the first floor. It was set up by the window with a view over the River Thames. The rocking horse also featured in a painting by Mary Kent Harrison.

No. 1 The Terrace (134 Richmond Hill) was considerably larger during Howard's tenancy and was made up of two internally joined properties. The house, with an annexe added over the carriageway on the left-hand side in the late 19th Century, was sold to developers in 1953, and four flats were made in the right-hand one. Intriguingly, the two front doors of the original 18th-century buildings were retained when rebuilt in 1873. This is verified in a painting by Leonard Knyff in the Museum of Richmond. Howard did not own the freehold according to the current owner (2024), who advises that it would have been very gloomy and cold, especially during wartime, as there is very little daylight, and the obsolete central heating system relied on a coal-fed boiler in the basement. The Aga cooker was on the ground floor and was converted to oil, kept in one of two large coal cellars under the road.

Maude was very supportive of her husband's career, and she took a keen interest in the welfare of the firm's employees. She arranged Christmas parties in the house for Howard's staff and their families. She also supported the staff on a personal level in times of need or distress. Their home was certainly large enough for such entertaining.

In the 1939 census [2], he is listed as being at 134 Richmond Hill (Also known as 1 The Terrace), and by this time, it was only their son Robert who was still living at home.

## 10 TRAFFIC ANALYSIS FOR LIFTS

In 1924, Howard presented a paper to the Institution of Electrical Engineers (IEE) [9] that included a more substantive glimpse into the lift industry's approach to traffic analysis, from the British perspective. For this, he was awarded The Paris Premium, which was set up to commemorate the Paris Electrical Exhibition of 1881. In 1924, it was listed as a premium of £10 for a paper published in the IEE Journal on any subject. Dr Gina Barney referenced this paper in her paper entitled "My Story of Lift Traffic Analysis, Design and Control 1960 – 2020", presented to the annual Lift Symposium in Northampton in 2017 [10].

In the paper [9], Howard claimed that "given the necessary particulars of a building, the lift engineer will be able to calculate the probable traffic". However, he also noted: "It must be admitted … that the lift engineer himself does not usually employ any scientific method in arriving at the number of passengers per minute which will require lift service on each particular floor during the busy part of the day". Instead of relying on a "scientific method" the typical lift engineer drew "upon his own experience and home-made formulae". At this point Howard opined that, if the various "home-made formulae" used by British lift manufacturers "could be collated, the general advantage would be served and many mistakes avoided". In his paper Howard reported that the "only English pronouncement" he could find on lift traffic was found in "a paper read recently by Mr. C.H.J. Day [11] before the Association of Engineers-in-Charge, in which he says … that in buildings where tests have been made, the rate of traffic flow at the busiest time of the day has been found to be such as to include the equivalent of the entire population of the building in 45 minutes, and that the passenger traffic can be predetermined by allowing for a period of rush from 15 to 20 minutes, during which time a number equal to one-third of the population of the building is dealt with". While Howard stated that his observations did not align with Day's, he also noted that "although I have been investigating the subject for some considerable time I have not yet amassed sufficient data to permit of my making an authoritative pronouncement" Howard's paper (the first draft was completed in July 1923), addressed a wide range of topics concerning electric lifts and in his introduction he noted that it was “remarkable that so little has been written or published upon the subject in this country, although there are a large number of works dealing with cranes, conveyers, etc.” In 1923, British engineer Ronald Grierson (1886-1955) published Electrical Lift Equipment for Modern Buildings [12]. Howard's comment on lift publications reflected his lack of awareness of Grierson’s forthcoming book. However, had he known, he might have questioned the decidedly American bias reflected in much of the book’s content.

Such was Howard’s interest in lift passenger traffic analysis that he invented the lift calculating rule, which took the form of a slide rule. An original example can be found in the archives of the Science Museum in London.

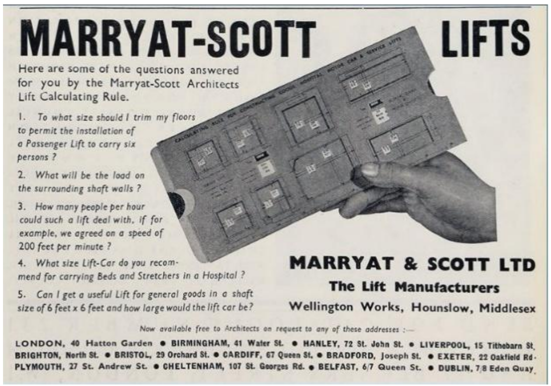



**Figure 5 Howard’s lift calculating rule.**

## 11 THE HOROLOGIST

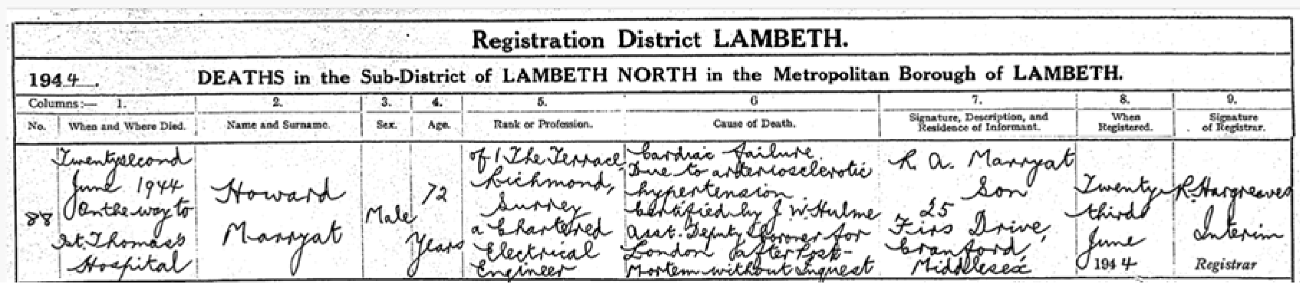
On 12th October 1936, Howard received the Freedom of the City of London and took the Livery of the Worshipful Company of Clockmakers on the same day. It is not known who Howard's sponsors were, but the typical steps of becoming a Liveryman are Sponsorship (where a candidate typically needs to be sponsored by two or more Liverymen). This is followed by the application process, and once the application is approved by the Court, the candidate receives the Freedom of the Company. This then allows the candidate to apply for the Freedom of the City of London. The Freedom of the City is received in one of three ways: Servitude, Patronage and Redemption. Servitude is when you have served as an apprentice under a Freeman of the City (it is not known if Ronald Scott was a Freeman). Patronage is when your father is a Freeman of the City, and Redemption is when you essentially pay to become a Freeman. Once you have obtained the Freedom of the City, you are entitled to become a Liveryman of your Company.

Howard loved watches and was a collector. In 1938, he authored a book entitled “Watches – Henlein to Tompion” [13]. In March 1944, he delivered a lecture on the evolution of watchmaking before the Royal Institution. He was also an enthusiastic collector of Faraday "relics," including a Bible with marginal annotations in Faraday's hand. He presented to The Royal Institution the portrait of Dr. S. Z. de Ferranti, which hangs in the Lecture Theatre there.

His watch collection was left to one of his sons and often appears on auction sites such as Sotheby’s.

## 12 DEATH

Howard Marryat died on the 22nd of June 1944 [14], at the age of 72, while on his way from London to attend a meeting of the Devon and Cornwall Sub-Centre in Exeter, at which he was to have read his paper on "Standardization of Motor Dimensions." According to reports, he suffered a heart attack at Waterloo Station. His death certificate [2] cites the cause of death as cardiac failure due to arteriosclerotic hypertension and states that he died on the way to St Thomas's Hospital. He is buried in St Peter's Church, Petersham, Surrey, in the same grave as his wife Maude and daughter Cecily.



Registration District LAMBETH.

1944. DEATHS in the Sub-District of LAMBETH NORTH in the Metropolitan Borough of LAMBETH.

| Columns:— | 1. | 2. | 3. | 4. | 5. | 6 | 7. | 8. | 9. |
|---|---|---|---|---|---|---|---|---|---|
| No. | When and Where Died. | Name and Surname. | Sex. | Age. | Rank or Profession. | Cause of Death. | Signature, Description, and Residence of Informant. | When Registered. | Signature of Registrar. |
| 88 | Twentysecond June 1944 On the way to St. Thomas's Hospital | Howard Marryat | Male | 72 Years | of 1 The Terrace Richmond, Surrey a Chartered Electrical Engineer | Cardiac failure Due to arteriosclerotic hypertension Certified by J. W. Hulme Asst. Deputy Coroner for London after Post-mortem without Inquest | R. A. Marryat Son 25 Firs Drive, Cranford, Middlesex | Twenty third June 1944 | R. Hargreaves Interim Registrar |

**Figure 6 Death certificate of Howard Marryat**

His estate was valued at £269,452 (which would be £14,974,518 by 2025 standards)

**Figure 7 Final resting place for Howard, Maude & Cecily Marryat.**

## 13 LIFEBOAT LEGACY

The legacy of Howard was to live on, though. In 1957, a lifeboat was provided out of a legacy left by Howard and a gift from his son, Mr. Robert Anthony Marryat, of London. The boat, named "Howard Marryat", was a 46 ft 9 Watson class lifeboat and was built in the same year. She served at Fishguard from 1957 to 1981 and then at Barrow from 1982 to 1986 and thereafter at Moelfre on Anglesey, where she then served as a relief boat until 1989. She is no longer registered as the Howard Marryat; her name is now Jozef de Waey and lies at Blankenburg in Belgium.

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**BIOGRAPHICAL DETAILS**

David Cooper MBE is the CEO of UK based consultants LECS (UK) Ltd and LECS (UAE). He has been in the lift and escalator industry since 1980. 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 Engineering.

He is the co-author of "The Elevator & Escalator Micropedia" and "Elevator & Escalator Accident Investigation & Litigation" as well as being a contributor to a number of other books including CIBSE Guide D. He is also the founder of the Elevator Academy which provides free training for apprentices and trainees and is a Founding Trustee of the UK's Lift Industry Charity.

In 2012 David was awarded a CIBSE silver medal for services to the Institution, in 2021 he was awarded the Sir Moir Lockhead award for 30 years dedication to safety in the lift & escalator industry and in 2023 he was awarded an MBE for services to lift & escalator engineering.

He is a member of the CIBSE Lifts Group Committee. He also serves on the Board of CIBSE and is currently Vice President. He is also an Honorary Visiting Professor at The University of Northampton.

# Mass Migration of Lift Alarm Connections – A Case Study

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**Keywords:** lift alarm, autodialler, emergency communication, PSTN, PSTN switch off, hotels, batteries, UPS, GSM, cellular, digital telephone line, digital switch

**Abstract.** The paper will take the form of a case study detailing the migration of 1100 lift alarms, owned by Premier Inn (a major hotel chain in the UK), from obsolete PSTN telephone lines to a managed service. The case study will cover four key areas:

- The scale of the problem faced by the lift owner/duty holder
- The selection criteria for alternative connectivity solutions
- Challenges with migrating a diverse lift portfolio covering the UK, the Republic of Ireland, the Isle of Man and the Channel Islands
- Additional insight gained into the lift alarm estate during and after the migration

The authors were closely involved with the migration from start to finish, so their records will form the basis for the material. In addition, direct testimony from the end client will be sought in order to present the perspective of the lift owner/duty holder.

## 1 INTRODUCTION

Across the globe, legacy analogue telephone line networks, based on copper cabling, are being retired and replaced with modern digital networks which utilise fibre optic cables. Our ever-increasing demand for internet access, and specifically the upload & download speeds available over those internet connections, has meant that the old analogue networks are no longer fit for purpose [1].

In the UK, the analogue switch-off began in 2018 and has rapidly gathered pace, with a final switch-off date of January 2027 confirmed as the hard stop for all analogue services. This poses a challenge for lift owners/duty holders as the vast majority of emergency alarms (autodiallers) installed on lifts in the UK are analogue devices. Digital telephone lines, therefore, present two key risks:

1. Support for Analogue Signalling: Analogue autodiallers rely on dual tone multi-frequency (DTMF or "touch tone") signalling for their machine-to-machine communication needs. Support for legacy analogue signalling varies between digital telephone line providers and, even then, tends to be unreliable. This can affect the operation of an existing analogue autodialler and even prevent the units from dialling out in some cases.
2. Power Resilience: Copper telephone lines carried their own power (~48VDC) and operated separately from the mains power grid. Because fibre optic cable is unable to carry power, digital telephone lines rely on a separate mains power supply to operate. This means that during a mains power failure event, the telephone line will also fail unless backed up. Previously, failure of the telephone line itself was an extreme event and presented a low risk. With a digital telephone line, even a breaker tripping in the building could result in a loss of the line. A mains power failure event is also a key time for a lift entrapment to occur.

Premier Inn Limited (the client), a subsidiary of Whitbread, is a hotel chain headquartered in the UK, with operations in the UK, the Isle of Man, the Channel Islands, the Republic of Ireland, Germany, Austria, the United Arab Emirates, and Qatar. The UK's largest hotel chain, as of January 2025, the client was able to offer over 85,000 hotel rooms in the UK [2]. Across a diverse estate of buildings, the client has a portfolio of 1100 passenger carrying lifts in the UK, Republic of Ireland, and the UK Crown Dependencies of the Channel Islands and the Isle of Man. In addition, many of the client's sites have platform lifts and other lift appliances.

VerticA Consulting Limited (the consultant) have been working with Whitbread since 2007, beginning with new hotel site projects and later adopting modernisation and replacement projects within existing hotels. They also developed the model specification for all new lifts installed at the client's Inn sites and also provide full maintenance supervision and project management to the client for their entire lift estate.

Beginning in 2018, the consultant highlighted the risk posed by the analogue switch-off and engaged with the client to begin planning the transition for the lift alarms on all 1100 lifts.

## 2 FINDING THE RIGHT SOLUTION

The first port of call was to discuss with the incumbent communication provider (CP) potential solutions to replace the existing analogue lines. Keen to try and keep such a large number of lines with a key client, the CP looked at a number of solutions.

However, the CP was unable to find a workable solution to reliably support the required analogue signalling and did not want to provide the required number of uninterrupted power supply (UPS) units to ensure lines would continue to operate in a power failure. The CP's main concern was how they could maintain the UPS units once they were installed.

Finally, it was agreed that the CP would step away from provisioning the "lift lines" and the transition would be handled as a separate project.

When evaluating solutions, the consultant set out a list of key evaluation criteria:

- Reliability – Whatever replaced the copper lines needed to have at least the same level of reliability and address the analogue signalling & power resilience concerns
- Management – The ongoing management of telephone lines with the existing CP had experienced some challenges, and this was an opportunity to also address those concerns. Key amongst these challenges/concerns were:
  - The lack of an asset list for telephone lines
  - Telephone lines serving lift alarms being cancelled
  - Telephone lines serving lift alarms being re-allocated
- Established Providers – Providers needed to show that they had experience working with lift autodiallers and were able to support work across the required territories
- Fixed Costs – Where possible, work should be on a fixed cost basis for the whole project
- Project Delivery – An end-to-end solution for the whole project across the full portfolio was required, with a minimum number of providers

The concerns about how a solution would be managed bear further discussion:

Whilst a true failure of a copper telephone line was an extreme event, typically involving physical damage to the copper cable itself, there were other ways a copper telephone line could be rendered inoperative.

Issues with telephone lines being cancelled in error, typically due to a perceived lack of usage or being re-allocated to serve other applications, had been a problem across the portfolio. Likewise, the telephone line serving the lift alarm being seized and re-allocated to other building services had been a recurrent problem. In both cases, this was done in error by telecoms engineers who were unclear how a line was being used.

Remedying these issues became a time-consuming process as the issues would often be misreported as a "failed autodialler", only for the lift contractor to test the autodialler and find nothing wrong and report a "line failure". This would typically lead to a drawn-out process of trying to coordinate the CP, the telephone line provider, and the lift contractor to confirm where the fault lay and provide a resolution.

After reviewing a number of potential providers for the transition, the field was narrowed to two options, and the consultant produced a paper outlining the various options explored and making a recommendation.

The consultant chose to recommend the Memco (the supplier) Sentinel Service (managed service) for the whole project, as it fulfilled all of the criteria previously set forth:

- Reliability – replaces the previous fixed telephone line with a 4G VoLTE[1] gateway and a non-steered roaming SIM card, so alarm calls are now placed over the mobile network. The SIM allows the gateway to connect to any of the UK mobile networks, to maximise the chances of getting a strong signal. The gateway has an onboard battery capable of operating the connection for four hours after a mains power failure. Last but not least, the gateway can support the required analogue signalling for autodiallers either directly through the voice channel or by converting to a digital signal & transmitting as data.
- Management – all connections are monitored, so if any faults occur, the client is alerted, whilst remote diagnostics and fault finding are undertaken by the monitoring team. If a fault cannot be resolved remotely, then a site visit is arranged in partnership with the relevant lift contractor. Key connection monitoring criteria: mains power status, battery status and mobile signal strength. Batteries are changed a minimum of every three years in line with the battery manufacturer's stated lifetime or as needed if recharge cycles or environmental conditions have shortened cell life. The management platform allows for a complete digital list of all assets and provides a digital audit trail for all connections.
- Established Providers – the supplier, having been in business since 1972, is a well-known name in the lift industry and was able to demonstrate how they could support both the deployment of services & coordinate with multiple lift contractors.
- Fixed Costs – supports a flat monthly fee to the end client and handles all costs with lift contractors, both for initial deployment of services and in life support (e.g. battery changes). This meant the client could accurately forecast costs for both the initial deployment and ongoing support of the connections.

[1]VoLTE = Voice over Long-Term Evolution, the technology by which voice calls are made over 4G mobile networks.

- Project Delivery – By using the client's incumbent lift maintenance contractors, the supplier could coordinate deployment of services across all sites. The consultant also agreed on an installation specification for the equipment needing to be deployed to the site, to ensure consistency across the portfolio.

This managed service option was presented to the Whitbread board along with a commercial proposal from the supplier, and the project was approved in April 2024.

At the time of writing, the managed service also provides a 25% cost saving when compared to the cost of provisioning a digital telephone with voice (many commercial digital lines are internet only as standard) and a UPS. The authors are not aware of any digital telephone line options in the UK market with management or monitoring services. If these services were to be offered by a CP, it would almost certainly be an additional cost to the end client.

## 3 DEPLOYMENT

The first step in deploying services across the portfolio was to establish a single asset list split both by site and by incumbent lift maintenance contractor. The main asset list held by the consultant included all lifts and lifting appliances, so it needed to be edited down to only include the passenger-carrying lifts. Platform lifts were then accessed on a case-by-case basis, as not all platform lifts in the UK require an alarm device to be fitted. Those platform lifts with alarms fitted were then incorporated into the asset list. This asset list was then used as the tracking document for the progression of the deployments over the course of the project.

Incumbent lift maintenance contractors were informed that the project was going ahead, and rate cards were agreed upon between contractors and the supplier for installing and configuring equipment on site. An agreement was also reached on how lift contractors would go about installing the equipment. Some chose to use dedicated teams for installations, and others opted to do this as part of their monthly service visits.

All installs had to comply with the installation specification agreed with the consultant:

- Gateway to be installed in the motor room or, in the case of MRL installs, at the top of the lift shaft or within the MRL panel if space allows
- Gateway to be powered by a dedicated 230VAC supply, isolated only by the main breaker switch

Where required, additional training was provided to lift engineers who were unfamiliar with the supplier's equipment or gateways in general.

Once a gateway had been installed, lift engineers were able to use an app on their smartphone to test the connection before leaving the site. Each lift contractor was issued additional high-gain antennas to be used with the gateways on sites where mobile signal was a challenge. As part of the planning process, the client was asked to flag any sites where they were aware mobile signal was a problem.

Each new connection was placed onto a '7-Day Check List' by the managed service's monitoring team. The connection was checked each day for seven days to ensure that both the mobile signal and power status remained stable. At the end of the seven-day check period, connections with no issues were moved to the main monitoring pool and the lift contractor was paid for the installation work. Any connections that did not pass the check were flagged, and it was arranged with the contractor that they revisit the site to remedy the faults identified.

## 4 CHALLENGES

The most common issue found during the seven-day check period was connections which exhibited problems with mains power to the gateway.

After investigation on different sites, this was found to be due to lift engineers connecting to a mains power supply, which they believed was only isolated by the main breaker switch, but was in fact switched with the lift shaft lighting.

This issue was a challenge to diagnose because, whilst working on the installation, the shaft lights would be switched on and only switched off once work was completed. When returning to the site to try and fault find, one of the first things a lift engineer would do was switch the shaft lights on (as is standard practice), which also restored the mains power to the gateway. This situation meant that the power issues at first looked like intermittent faults. Once this issue had been correctly diagnosed, further installation advice was issued to all contractors.

The client's hotel site at Heathrow Airport Terminal 4 proved to be a unique challenge as the site exhibited particularly low mobile signal levels. This had not been flagged at the start of the project, and it was later found that the client did not record mobile signal issues as part of their maintenance and repairs data, and it was instead recorded as part of their 'guest satisfaction' data.

A site survey using a mobile signal scanner showed that there were 4G mobile cells on towers nearby, but the recorded signal levels within the building and especially within the lift shafts were extremely low. It was noted that the site is located on the opposite side of the street to one of the airport surveillance radar (ASR) towers, and the working theory was that this ASR tower somehow interfered with or blocked the mobile phone signal.

The solution that was finally developed was to use directional antennas for the gateways, mounted in redundant pockets at the top of the lift shafts, installed facing in the opposite direction to the ASR. This allowed the gateways to receive a strong signal across all five lifts on the site (four front-of-house lifts and one back-of-house staff lift).

The client's site at Canary Wharf Westferry also proved a challenge as the mobile signal above the ground and first floors was extremely low. The building is a 26-storey block, and it was difficult to ascertain why the signal was so low in the upper storeys. Investigation of the local area did note a major Metropolitan Police station nearby and, right next to the site, an elevated section of the Docklands Light Railway (DLR). It was speculated that the police facility might have some form of signal blocker installed, which affected mobile signal in the area, or the DLR blocked signal from local towers to higher floors.

The solution in the end was a simple but time-consuming one – run a mains power cable and communication cable from the MRL panel on the 26$^{th}$ floor, inside the lift shaft, and down to the gateway located on the wall of the lift shaft at the ground floor. This solution was used for all four lifts on site.

## 5 PROJECT PROGRESSION, ADDITIONAL INSIGHTS AND WAYS OF WORKING

The project scope was for 1100 connections across 570 sites, being deployed by six different lift contractors.

Deployments began in July 2024 on the mainland UK, then Northern Ireland, the Republic of Ireland and finally the Isle of Man and the Channel Islands.

By November 2024, 80% of the connections had been deployed; this rose to 90% by March 2025, and project completion is (at the time of writing) projected for the end of July 2025.

As mentioned in Section 2, the client had been unable to obtain an asset list for telephone lines from their CP. So as part of the deployment process, it was agreed with the client that lift engineers would record the current telephone line numbers which served the lifts (this data could also be captured in the app which was used to test each connection). This would then allow the client to cancel the old telephone lines as the managed service was deployed.

An additional benefit which the client was able to realise from the managed service was a log of activity recorded by the gateway and transferred to the monitoring platform. This included logs of when alarm calls had been placed from the autodialler and autodiallers which had become faulty over time and were dialling out unnecessarily. Previously, the latter would not have been detected and would have incurred unnecessary call costs. The fact that this call activity could now be identified allowed the consultant to highlight to lift contractors where autodiallers needed to be investigated for faults and potentially replaced.

Whilst the move away from landlines eliminated the need for coordination with a CP, it became apparent that new ways of working needed to be established with lift contractors. Several callouts for lift autodialler faults were reported back as being “issues with the line”, despite the fact that the connections showed no faults on the managed service’s platform. A new ‘ways of working’ document was produced on how to fault find when the client sites reported autodialler issues and, once approved by the consultant, was discussed and agreed with the lift contractors. The document covered four key areas:

1. Perimeters of responsibility: the supplier being responsible for the gateway, and the lift contractor being responsible for the autodialler on the lift car
2. Fault Finding Process:
    1) Gateway – remote and on-site
    2) Autodialler – on-site
3. Escalation process for faults which could not be rectified and authorisation process for site visits
4. Invoicing for work carried out

## 6 CONCLUSION

The project has been an example of how clients, lift consultants, lift contractors, and suppliers can work together to deliver a major transition in a short timescale.

The client now has fully managed connections for their autodiallers and is proactively alerted of any issues. The backup batteries for all connections are fully monitored and tracked for when they need changing, eliminating a key risk posed by digital phone lines and a common fault seen on autodialler systems [3].

Fault resolutions are co-coordinated with lift contractors to ensure only qualified persons are working on site. The consultant is now using the managed service's monitoring data as part of their maintenance surveillance for the client, and in particular when assessing defects related to autodiallers on insurance reports.

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## BIOGRAPHICAL DETAILS


Matt Davies is the Business Development Manager for digital products and services at Memco (a brand of Avire). In addition to his responsibilities at Memco, Matt is a member of the BSI committee 'MHE/4 Lifts hoist and escalators', CEN TC10 WG1 Working Team 4 responsible for revising EN81-28, the European Lift Association 'Telco Working Group' and the American Society of Mechanical Engineers 'A17 Ad Hoc Committee on Door Protection'.

Chris Holmes is the Technical Director at VerticA Consulting Limited, having started in the lift industry as an apprentice engineer, Chris has worked in the field on Installations, Modernizations, Servicing and Project Management before becoming UK Bases Site Technical Support for a Global Supply Chain, which led to a Sales Manager role before his journey at VerticA began when he joined as Technical Consultant in 2016.

# Identifying and Addressing the Causes of Excessive Wear in Lift Suspension Means Through Rope Load Analysis

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**Keywords**: Rope, Belt, Suspension Maintenance, Equalising

**Abstract.** Excessive wear on suspension means in lifts, particularly in machine-room-less (MRL) systems, has become a growing concern in recent years. A key factor influencing wear is the load distribution within the rope set. According to Prof. Feyrer's well-known studies at the University of Stuttgart, the lifespan of the entire rope set can be reduced by up to 40% if a single rope deviates by just 15% from the average load within the set.

While standards such as North America's Safety Code for Elevators and Escalators, ASME A17.1/B44, are trying to impose limits on static rope tension differences, the dynamic load behaviour during lift operation is often even more critical. Factors such as worn traction sheaves, misaligned deflection/diverter pulleys, or twisted ropes can lead to significant variations in rope tension, which directly equate to load. A detailed analysis of the load progression during the travel allows for a precise identification of such irregularities, enabling targeted implementation of corrective measures, optimising system performance and extending the lifespan of the suspension means and drive sheaves.

This paper presents real-world measurements of rope tensions and demonstrates how simple calculations and considerations can help derive effective measures to improve the performance and longevity of lift systems.

## 1 INTRODUCTION

Developments in the lift market have led to the loss of validity in today's lifts of the time-honoured 'rule of thumb' for the lifetime of rope sets between 10 and 20 years. A lifetime which was formerly only not achieved in cases of poor maintenance and/or assembly or extreme ambient conditions.

The demand for lift systems to minimise space requirements as much as possible is continuing unabated; the advantages for architects and building owners are highly apparent. These systems, generally designed as traction lifts without machine rooms, possess several special features related to their means of suspension:

- Multiple suspension (2:1 or higher)
- Small traction sheave diameters
- Small rope or belt diameters, which permit as small a bending radius as possible

These features, produced according to customers' wishes and design, have negative effects on the lifetime of suspension means when we compare to the direct-suspended lift systems with rope diameters larger than 8 mm and large traction sheaves.

The multiple suspension, for which the drive is frequently positioned directly in the shaft to save space, requires more deflecting sheaves. This means more bending points for the suspension means, generally also with counter bending (aka reverse bends), which substantially increases the wear on the steel ropes.

To reduce the required construction space even further, it is expedient to also reduce the diameters of the traction sheave and the deflection pulley. At the same time, this permits the application of inexpensive drives which have a high speed but only a relatively low torque. Because the suspension means does not permit as small bending radii as might be required, i.e. the ratio between the traction sheave diameter and the suspension means diameter (D/d) permitted by Code is too small, the diameters of the suspension means also have to be reduced. Therefore, rope diameters of approximately 6 mm are found in lifts without a machine room.

The smaller the rope diameter, the smaller the load capacity of these ropes will become; more ropes are then required (which substantially increases the possible bending capacity), or ropes of a higher strength are used so that the quantity of ropes required does not become too high. High-strength ropes then demand higher traction sheave hardness in order to minimise wear on these, and therefore also wear on the ropes. Other solutions can be plastic-coated ropes, which cause hardly any or no wear on the traction sheaves, but which do cause other problems, including debates over the discard criteria.

Without trying to describe the individual relationships between the parameters in too much detail, it can be determined that a balanced mix must be found between the boundary conditions, which does not excessively increase the wear on suspension means, wherever space-saving lift systems without machine rooms are required.

## 2 WAYS TO REDUCE THE SUSPENSION MEANS WEAR

The above-mentioned design conditions for lifts without machine rooms all cause increased rope wear, with a limited chance to compensate for the cause of this wear:

- Every deflection of the suspension ropes increases wear on these ropes.
- Counter or reverse bending massively increases the wear on the ropes
- As the diameter ratio D/d is reduced linearly, the rope wear increases exponentially
- As the rope safety factor decreases linearly, the rope wear also increases exponentially

In order to compensate for the factors which are detrimental to the rope's lifetime, and yet to continue to uphold a high running performance, all the remaining ambient conditions for the suspension means must be optimally achieved in operation. In this way, the number of bending cycles can be increased once more.

### 2.1 Rope Maintenance

Almost all rope manufacturers offer an appropriate care agent for their steel ropes to reduce corrosion and abrasion. The ropes are pre-lubricated, but dust and abrasion can bind the lubricant so that the lubrication effect is continuously reduced. The rope maintenance must be undertaken in accordance with the manufacturer's information to prevent unnecessary lifetime restrictions at this point, too.

### 2.2 Installation of new Suspensions

In part, rope manufacturers issue detailed instructions on how to install new ropes and what should always be observed in the interests of a long rope lifetime. In addition to rather obvious comments, such as that the ropes should not be kinked during installation, some manufacturers have also applied a marking on the ropes; the so-called "i-line" or surface line. This line, applied in the suspension direction, makes it easy to ensure that the ropes are not twisted during installation, a mistake which can occur very easily as lift ropes, with one-directional construction, tend to twist by themselves. When, despite this, the ropes are twisted at installation (either closed or open) and then fastened onto the counterweight and cabin or in the shaft head in such a way that they can no longer untwist, then this would have severe negative effects on the lifetime, as additional and above all unnecessary wear takes place inside the rope during every lift movement.

### 2.3 Load distribution between the suspension means

Twisting ropes also causes load capacity differences in the ropes during lift movement, but this is only a small part of the problem. Far more serious is the actual adjustment of the ropes to each other.

The load distribution within the rope set is significantly determinant for the lifetime of the ropes. An equation is stated in the decisive standard work on wire ropes in lift construction by Prof. Dr. Feyrer [1]. By using this equation (1), the bending capacity of wire ropes can also be determined, dependent on the rope tension.

$$lg\,N = b_0 + \left(b_1 + b_4 lg\,\frac{D}{d}\right)\left(lg\,\frac{Sd_0^2}{d^2 S_0} - 0,4\,lg\,\frac{R_0}{1770}\right) + b_2 lg\,\frac{D}{d} - 0,32\,lg\,\frac{d}{d_0} + \frac{1}{b_5 + lg\,\frac{l}{d}} \quad (1)$$

**Expected number of bending cycles N as a function of various parameters including the individual rope tension, according to Prof. Feyrer, Equation 3.76. [1]**

If all the parameters in this equation (such as ambient conditions, mechanical rope parameters etc.) are kept the same, and only the difference in the rope tension is considered, astonishing effects by the load distribution on the rope lifetime are revealed, as has also been published by Pfeifer DRAKO in a technical document from 23.11.2009 [2], based on the formula stated by Prof. Feyrer:

- A reduction in load difference between the suspension ropes by 5% increases the lifetime by 11%
- A reduction of the load difference between the suspension ropes by 10% increases the lifetime by 23%
- A reduction of the load difference between the suspension ropes by 15% increases the lifetime by 38%

For some years now, aids in the form of rope tension measuring devices have been available, using which, in addition to the absolute cabin weight, the individual rope loads can also be determined and adjusted. This is of course very useful, but still insufficient, as we explain next.

### 2.4 Varying load distribution during travel

Naturally, it is only possible to adjust the ropes manually when the lift system is at a standstill. This means that a particular position of the cabin in the shaft must be decided upon, and the ropes must be adjusted at this position. This generally must mean, in the case of 2:1 suspended systems without a machine room, that the cabin is positioned at the uppermost stop, so that the end fastenings of the ropes can actually be reached for adjustment purposes.

Depending on the design of the rope tension measuring devices, it is possible to measure the progressions of the individual rope tensions in advance during lift movement in order to determine the optimum setting of the ropes for subsequent adjustment. This is necessary as the individual rope tensions constantly alter during lift movement, frequently to a substantial extent. This is caused, for example, by slight deviations between the grooves and ropes, out-of-round running-in of traction sheave grooves, and deflection rollers which do not align absolutely horizontally to each other, etc.

In the case of a 2:1 suspended system with a traction sheave of 240 mm in diameter and a travel height of 20 m, a 1/10 mm groove depth deviation or rope diameter difference immediately affects a 17 mm rope diameter difference between the individual ropes during movement across the entire travel height. It is thus easy to imagine how much more an individual rope bears, which is 17 mm shorter than the other ropes. The result is excessive wear on the rope. This effect can occur due to the abovementioned causes even on new 2:1 suspended lifts. This effect can also be found to an equal extent on 1:1 suspended systems.

The following example shows a measurement on a 1:1 suspended system which has a rope tension difference of up to 200% during lift movement. It is also clear to see how the individual rope tensions are displaced during lift movement.

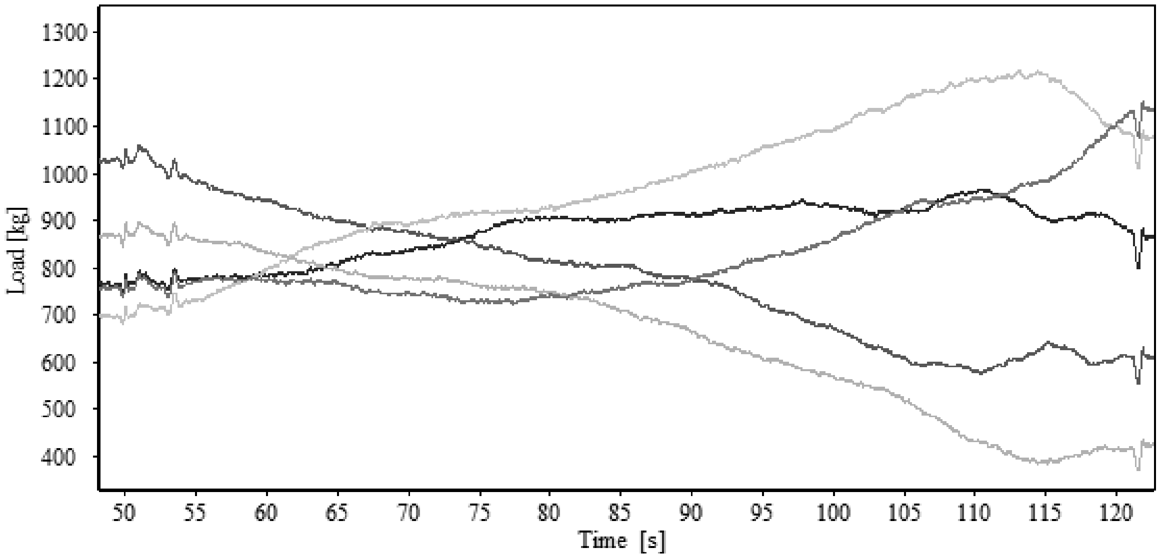


**Figure 1 Progression of the individual rope tensions during upwards lift travel of a 1:1 suspended lift**

Correct adjustment of the rope tension is essential for such a lift system, if the theoretical lifetime of the ropes is to be exploited as much as possible. The typical “spot check” adjustment of ropes during each maintenance procedure is an initial and important step, but is, in this view, not at all sufficient, as the adjustment can only take place at certain points referring both to time and position. As soon as the lift starts to move after such a rope adjustment, the rope adjustment will once again prove insufficient for the new position in the shaft.

In addition to excessively large manufacturing tolerances already present in new systems, the cause for varying rope tension can also develop during operation—e.g., if the ropes were not properly aligned with each other. This often results in individually worn grooves of a traction sheave. Once this situation occurs, it worsens over time and leads to the rope set needing to be replaced well before the usual service life is reached. The actual root cause usually goes unidentified, leading to frequent replacement of the rope set, while the actual cause—the traction sheave—is neither replaced nor repaired. We can note here that attempting to repair a traction drive sheave is almost always ill-advised. Either the cost or the level of tolerance needed is an imprudent decision.

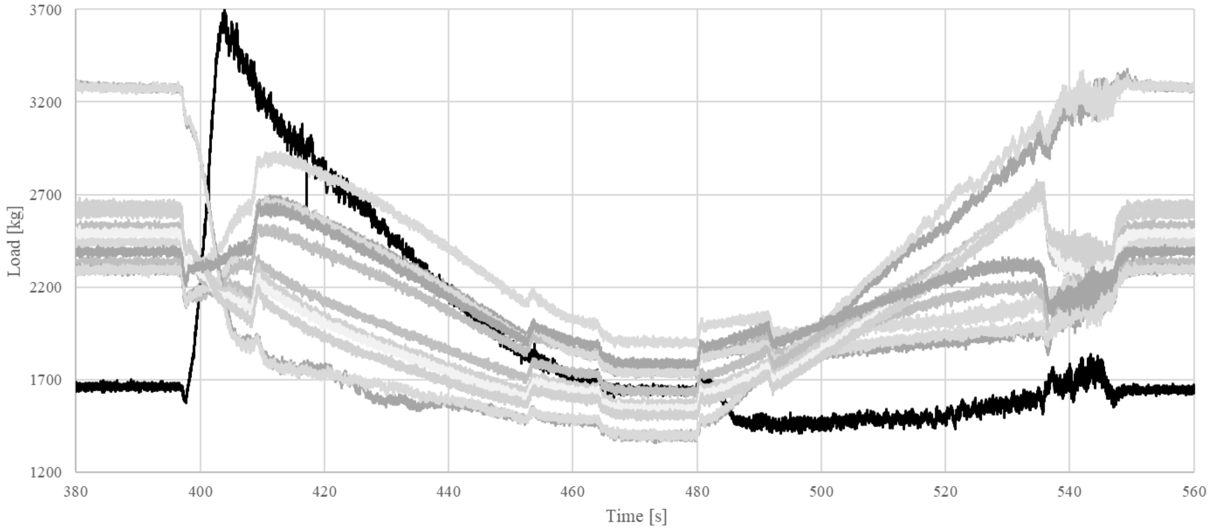


**Figure 2 Rope tensioning during a downward and upward ride with a worn-out traction sheave**

In Figure 2, the rope tensions of a lift with tie-down compensation are shown: between 395 and 470 seconds during the downward ride, and between 480 and 550 seconds during the upward ride. Rope tensions vary between 1700 kg and 3700 kg, although during the standstill phase at the lowest floor, the rope tensions are relatively even between 1500 kg and 1900 kg. Particularly noteworthy is the black line in the figure, showing the tension of one suspension rope. While at a standstill at the top floor, this rope carries the least load, but it abruptly becomes the rope carrying the most load when starting to move downward. During the upward ride, it consistently carries the least load. The explanation for this clear and significant behaviour is that the affected rope sits in a worn groove of the traction sheave.

During a down run, what happens if a groove or rope has a much smaller diameter than the others? For every rotation of the traction sheave, this damaged rope/groove travels less than the other ropes. This results in increasing rope tension, because it carries more load than the other ropes until there is enough force to exceed the traction force. During an up run, all other ropes move further per rotation of the traction sheave than the damaged rope/groove. The other ropes now carry more load, and the damaged rope/groove loses tension ("it slackens"). As the tension force difference between the traction friction force and the equalising spring force exceeds a value, the rope slips and equalises.

Another common cause of uneven rope tensions during operation is one or more twisted ropes. The ropes are twisted within themselves, meaning they "open" or "close" during each ride, which leads to elongation or shortening. This, in turn, results in fluctuating rope tensions. Depending on the degree of twist, this can be a precursor or even the root cause of worn traction sheave grooves. The following figure shows the rope tension profile for such a system. Again, the ride begins with a downward movement (8 s – 33 s), followed by an upward ride (38 s – 63 s).

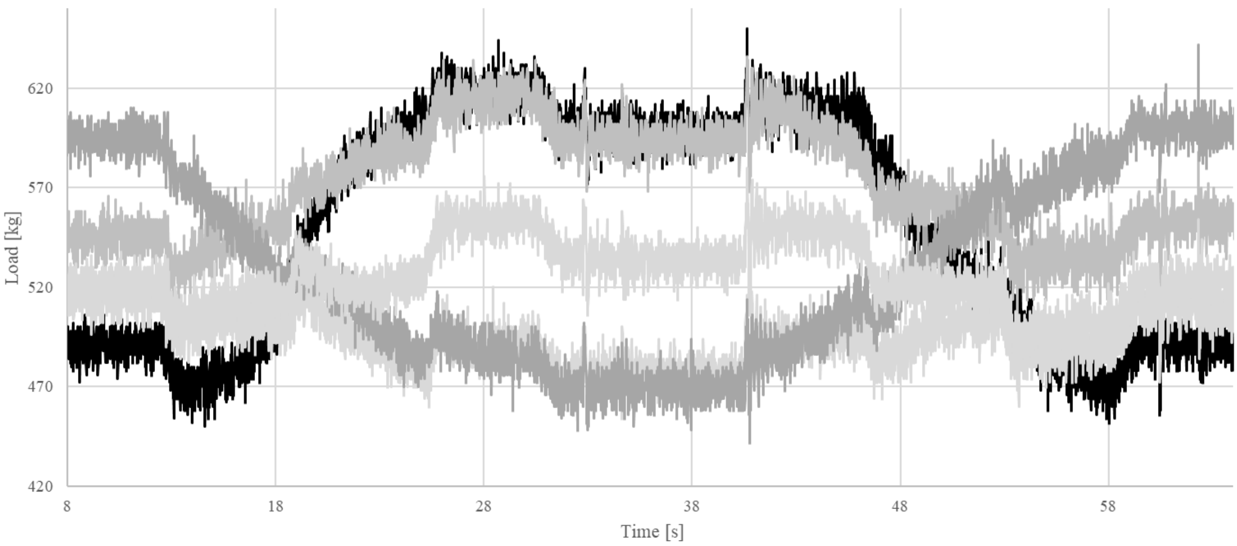


**Figure 3 Rope tensioning during a downward and upward ride with twisted ropes**

Here too, the rope tensions fluctuate significantly during travel, by approximately 30% of the average load. During the downward ride, some of the ropes take on load uniformly and together with other ropes, while others lose load to the same extent. The upward ride is a mirror image of the previous movement, so that the initial condition is restored after both trips. In contrast to a worn traction sheave, no rope stands out visibly here. The rope that loses the most load during the downward ride—and therefore builds up the most tension during the upward ride—is the one that is most twisted. A visual inspection of the i-line during operation will show the most rotations for this rope.

## 3 CONCLUSION

Decisive for the lifetime of suspension ropes, after their correct dimensioning and after ruling out avoidable errors in installation and rope maintenance, is above all, optimum rope tension in every position within the shaft. The trend toward multiple suspensions is affecting comparatively small lift systems, which were formerly seen only on high-rise lifts featuring a travel height of several hundred meters. Deviations of less than 1/10 mm in the traction sheave grooves and rope diameters lead to major differences in individual rope tensions, as the small traction sheaves of lifts without machine rooms carry out a similar quantity of rotations as the traction sheaves in high-rise lifts.

Even if the individual rope tensions are adjusted with scrupulous care using high-precision measuring technology, wear on the rope cannot be prevented, as adjustments can only be undertaken for one position of the cabin within the shaft.

Dedicated software solutions exist that evaluate rope tension measurements—such as those presented in this paper. An optimised target rope tension profile, which can subsequently be applied and adjusted on-site, is needed. While this approach represents a practical compromise for minimising rope tension imbalances, it does not constitute an ideal or comprehensive solution. Rather, it serves primarily to mitigate excessive wear but does not restore the rope set to conditions consistent with standard or expected wear behaviour.

A sustainable and technically sound solution requires precise and balanced rope tensioning to be established from the initial installation of the lift system. This worthwhile goal must be subject to continuous monitoring and periodic recalibration to maintain optimal performance and extend the service life of the suspension components.

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## BIOGRAPHICAL DETAILS

Tim Ebeling has been employed since 2003 as head of development with Henning GmbH & Co. KG. In this capacity, he has established the R&D center in Braunschweig (Germany). A team of employees is now working there on the development and production of electronic and measurement components for lifts.

Since 2012, the author has also been the managing director and a shareholder. One of his particular focal points is measurement technology. Especially in this area, the author looks back on many years of experience in the development of acceleration and rope load measuring systems. The author's professional goal is to enrich the lift market with innovative lift components.

In addition to his role as a board member of the German Elevator Association (VFA), he is active in working groups of the European Lift Association (ELA) and serves on the advisory boards of LiftJournal and the Center for Elevator Technology in Roßwein (ZFA).

# Dynamic Rope Loads and Traction Ratios Under Adverse Lift Operating Conditions

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**Keywords**: Rope tension, Dynamic traction ratios, Environmental conditions.

**Abstract.** The lift safety codes demand that the dynamic traction conditions must be investigated in addition to the static conditions. This includes evaluation of the traction ratios under emergency braking conditions. For safety reasons, the systems calculations involve the evaluation of dynamic suspension rope tensions on the car and counterweight sides of the traction sheave and seek to guarantee that during normal operation/car loading and emergency braking conditions, slippage between ropes and traction sheave does not occur. In this paper the determination of tensions under dynamic loads arising due to sway of tall buildings caused by diverse environmental issues such as strong wind and earthquake conditions is discussed. The tensions during the lift travel are computed and the corresponding dynamic traction ratios for the worst cases depending on the position of the car in the well are assessed. The additional dynamic effects are analysed, and it is demonstrated that to make an accurate estimate of the applied traction conditions these effects should be assessed.

## 1 INTRODUCTION

The design of a lift involves system calculations that consider a range of parameters, such as the frictional characteristics of the traction system, the rated load and speed, the masses/inertias of the various components in the well, and the maximum accelerations to be expected to occur under normal and emergency conditions [1]. The requirements to avoid slippage between the ropes and the driving sheave under defined conditions are then determined. For safety reasons, the systems calculation also seeks to guarantee that under certain circumstances slippage between ropes and traction sheave must occur [2].

The diagram in Figure 1 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 $\alpha$. In considering the system calculation the procedure prescribed in EN81-50 clause 5.11.2 [3] is to be followed so that the following inequality formulae, that originate from the Eytelwein-Euler equation, are applied as follows:

$$\frac{T_1}{T_2} < e^{f\alpha} \tag{1}$$

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). In Equations (1) – (2) the expression $e^{f\alpha}$ represents the critical traction ratio (or available traction), where $e$ is the natural logarithm base, and $f$ is the friction factor which depends on the coefficient of friction $\mu$ as well as on the geometry of the rope sheave contact configuration. $T_1$ 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).

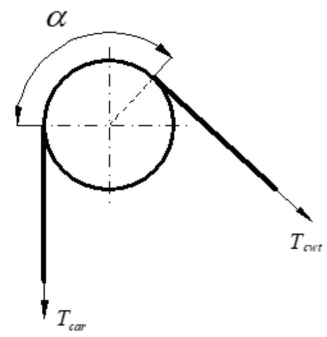


**Figure 1 Rope tension forces at a traction sheave**

Responses of tall buildings to wind and seismic long-period excitations are sensitive to the structural dynamic properties such as the building natural frequencies and damping ratios. The national and international regulations provide specific design guidance and safety measures to be applied for tall and slender structures that operate under return period wind conditions and seismic zones [4,5]. The determination of traction requirements is the fundamental consideration in lift system calculations. In this paper the calculation of hoist rope tensions under dynamic loads arising due to sway of tall buildings caused by diverse environmental issues such as strong wind and earthquake conditions is discussed. A computer simulation model is developed to determine the dynamic tensions during the lift travel. The dynamic resonance effects are analysed to make an estimate of the applied traction conditions.

## 2 TRACTION DRIVE LIFT SYSTEM WITH COMPENSATION

### 2.1 Dynamic model

Figure 2 shows a diagram of a dynamic model of a traction drive lift system with compensation, installed in a cantilever vertical host/building structure subjected to bending deformations resulting in displacements $v_0(t)$ and $w_0(t)$ that occur at level $Z_0$. The structure is subject to the fundamental bending mode resonance conditions. The fundamental mode shape of the structure is approximated by a polynomial shape function $\Psi = 3\eta^2 - 2\eta^3$ where $\eta = z/Z_0$ [6].

The system comprises rigid body discrete masses $M_1$, $M_2$ and $M_3$ that represent the lift car, counterweight and compensating sheave assembly (CSA). These masses are constrained by long slender continua (cables/ropes) of length $L_i(t)$, with their spans varying in time with the position of the car in the shaft (denoted as $l_{car}$). The spans denoted by $i$ = 1,4 correspond to the compensating cables and the spans corresponding to $i$ = 2,3 represent the hoist (suspension) ropes. The compensating cables, suspended from the beneath of the car to the beneath of the counterweight are used to reduce, or eliminate the effect of the suspension rope mass transfer during the lift travel.

The car speed and acceleration/deceleration are denoted as $V$ and $a$, respectively. The ropes/cables have small bending stiffness represented by $EI_{cable}, EI_{rope}$, their longitudinal elastic properties are characterised by the stiffness coefficients $EA_{cable}, EA_{rope}$, and their masses per unit length are $m_{cable}$ and $m_{rope}$, respectively. $I_3$ is the second moment of inertia of the compensating sheave, with its rotational degree of freedom represented by the angular coordinate $\theta_3$. A viscous damping tie-down element can be applied to constrain vertical motions of the CSA. Such an element is schematically shown in Figure 2, represented by the coefficient of damping $c_3$ on the diagram.

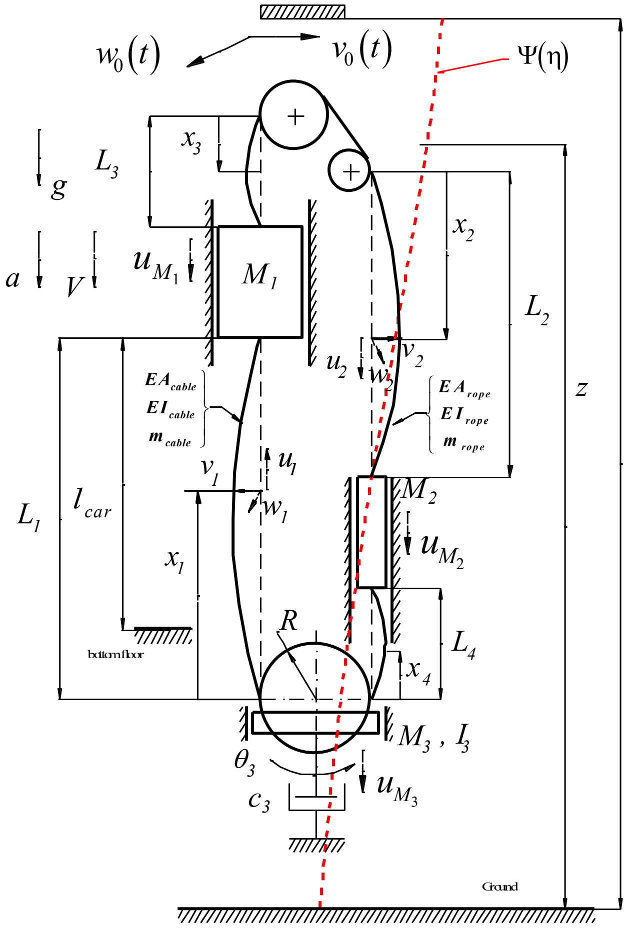


**Figure 2 Model of a traction drive lift system with compensation**

## 2.2 Equations of motion

The dynamic response of the lift system involves the longitudinal and lateral motions of the compensating cables and suspension ropes that are coupled with the dynamic displacements of the discrete masses constrained to move vertically. The dynamic displacements of the car, counterweight and CSA are denoted by $u_{M_1}(t), u_{M_2}(t)$ and $u_{M_3}(t)$, respectively. The lateral in-plane and out-of-plane displacements of the ropes and cables are denoted as $v_i(x_i,t), w_i(x_i,t)$, and their longitudinal displacements are represented by $u_i(x_i,t)$, where $i = 1, 2\ldots, 4$, respectively. The longitudinal and lateral responses of the ropes/cables are governed by the following set of coupled non-linear equations of motion:

$$
\begin{aligned}
&m_i\left(u_{itt} + 2V_i u_{ixt} + V_i^2 u_{ixx} + a_i u_{ix}\right) - EA_i \varepsilon_{ix} = 0 \\
&m_i\left(v_{itt} + 2V_i v_{ixt} + V_i^2 v_{ixx}\right) + EI_i v_{ixxxx} + \left[m_i\left(g - a_i\right)x_i - \bar{T}_i\right]v_{ixx} + m_i g v_{ix} - EA_i\left(\varepsilon_i v_{ix}\right)_x = 0 \\
&m_i\left(w_{itt} + 2V_i w_{ixt} + V_i^2 w_{ixx}\right) + EI_i w_{ixxxx} + \left[m_i\left(g - a_i\right)x_i - \bar{T}_i\right]w_{ixx} + m_i g w_{ix} - EA_i\left(\varepsilon_i w_{ix}\right)_x = 0
\end{aligned}
\tag{3}
$$

where $0 \le x_i \le L_i(t)$, the quantities represented by $\varepsilon_i$ denote the quasi-static axial strains in the rope/cable components given as:

$$
\varepsilon_i = u_{ix} + \frac{1}{2}\left(v_{ix}^2 + w_{ix}^2\right) \tag{4}
$$

Furthermore, $g$ represents the acceleration due to gravity, $V_1 = V_2 = -V$, $a_1 = a_2 = -a$, $V_3 = V_4 = V$, $a_3 = a_4 = a$. The bending stiffness and the longitudinal stiffness parameters are identified as $EI_1 = EI_4 = EI_{cable}$, $EA_1 = EA_4 = EA_{cable}$, and $EI_2 = EI_3 = EI_{rope}$, $EA_2 = EA_3 = EA_{rope}$, respectively $m_1 = m_4 = m_{cable}$, $m_2 = m_3 = m_{rope}$, and the subscripts $(\ )_t, (\ )_x$ represent partial derivatives with respect to $t$ and $x_i$, , and

$$\begin{aligned} \bar{T}_1 &= T_0 + m_1 L_1 (g - a_1) \\ \bar{T}_2 &= T_0 + (M_2 + m_2 L_2 + m_4 L_4)(g - a_2) \\ \bar{T}_3 &= T_0 + (M_1 + m_1 L_1 + m_3 L_3)(g - a_3) \\ \bar{T}_4 &= T_0 + m_4 L_4 (g - a_4) \end{aligned} \tag{5}$$

where $T_0 = M_3 g/2$. The dynamic responses of the discrete masses are defined by the following equations of motion:

$$\begin{aligned} & M_1 \ddot{u}_{M_1} - EA_1\, \varepsilon_1\big|_{x_1 = L_1} + EA_3\, \varepsilon_3\big|_{x_3 = L_3} = 0 \\ & M_2 \ddot{u}_{M_2} - EA_4\, \varepsilon_4\big|_{x_4 = L_4} + EA_2\, \varepsilon_2\big|_{x_2 = L_2} = 0 \\ & M_3 \ddot{u}_{M_3} + EA_1\, \varepsilon_1\big|_{x_1 = 0} + EA_4\, \varepsilon_4\big|_{x_4 = 0} + F_d = 0 \\ & I_3 \ddot{\theta}_3 - REA_1\, \varepsilon_1\big|_{x_1 = 0} + REA_4\, \varepsilon_4\big|_{x_4 = 0} = 0 \end{aligned} \tag{6}$$

The damping force provided by the hydraulic tie-down is represented in Equation (6) by $F_d$ and is defined as:

$$F_d = c_3 \dot{u}_{M_3} \left| \dot{u}_{M_3} \right|^{\lambda - 1} \quad 0 < \lambda \le 1 \tag{7}$$

where an over dot denotes the derivative with respect to time $t$.

### 2.3 The solution and dynamic tensions

It is evident that in the formulation presented above the domains for the spatial coordinates $x_i$ are time-varying which would lead to computational complexities. Therefore, the time-varying domains are transformed to time-invariant domains by suitable transformations of variables. The Galerkin method can then be applied to discretize Equations (3) and solved together with Equations (5) by numerical simulation techniques. The effects of friction losses are accommodated in the model through the introduction of modal damping ratios (1% for the lateral modes and 5% for the vertical modes are used) and the dynamic interactions when the frequency of the building is tuned to the natural frequencies of the lift system are investigated.

It should be noted that for steel wire ropes/cables, the ratios between their longitudinal wave speeds and lateral wave speeds are very high (several hundreds), Thus, their longitudinal natural frequencies are much higher than their lateral frequencies. Furthermore, long-period excitation frequencies are within an order of magnitude of the lateral frequencies of the ropes. Therefore, the longitudinal inertia terms in the first equation in (5) can be neglected. The resulting equation is then integrated to yield the following result:

$$u_{ix} + \frac{1}{2}\left(v_{ix}^2 + w_{ix}^2\right) = e_i(t) \tag{8}$$

where $e_i(t)$, $i = 1, \ldots, 4$ represent the quasi-static axial strain in the rope and cable elements. Equation (8) can be integrated so that when the boundary conditions are applied the following results:

$$e_i(t) = e_{0i}(t) + \frac{1}{2L_i(t)}\int_0^{L_i}\left(v_{ix}^2 + w_{ix}^2\right)dx_i \tag{9}$$

where

$$e_{01} = \frac{u_1(0,t) - u_{M_1}(t)}{L_1(t)},\ e_{02} = \frac{u_{M_2}(t)}{L_2(t)},\ e_{03} = \frac{u_{M_1}(t)}{L_3(t)},\ e_{04} = \frac{u_4(0,t) - u_{M_2}(t)}{L_4} \tag{10}$$

Once the solution is obtained the dynamic tensions at the car and at couterweight side are computed by using the following equations:

$$\begin{aligned} T_{cwt}(x_2,t) &= T_2^{ini}(x_2,t) + EA_2e_2(t) \\ T_{car}(x_3,t) &= T_3^{ini}(x_3,t) + EA_3e_3(t) \end{aligned} \tag{11}$$

where $T_2^{ini}$ and $T_3^{ini}$ represent the initial quasi-static tension forces given as

$$\begin{aligned} T_2^{ini} &= T_0 + \left[M_2 + m_4L_4 + m_2(L_2 - x_2)\right](g - a_2) \\ T_3^{ini} &= T_0 + \left[M_1 + m_1L_1 + m_3(L_3 - x_3)\right](g - a_3) \end{aligned} \tag{12}$$

in the counterweight and car hoist rope sections, respectively. The dynamic tensions given by Equations (11) can then be used to determine the applied traction ratios and to verify the traction conditions by considering the inequalities given by Equations (1) - (2).

## 3 NUMERICAL EXAMPLE AND RESULTS

Having developed a suitable approach a numerical example is presented to investigate how the dynamic phenomena arising due to the sway of a tall building may affect the rope tensions, and the corresponding dynamic traction ratios, during the operation of a high-rise lift system. A parametric study has been conducted for a high-rise lift system comprising a car of mass 3915 kg which carries a rated load of 1588 kg. The travel height is 172 m and the car and the counterweight, balanced at 50%, are suspended on 9 steel wire ropes (SWR) of mass per unit length 1.1 kg/m each. The installation is equipped with 8 compensating ropes with mass per unit length 1.26 kg/m each, and the CSA mass is 2835 kg. The horizontal (bending mode) natural frequencies of the building structure are given as 0.175 Hz (1st mode) and 0.220 Hz (2nd mode), in the in-plane and out-of-plane directions, respectively. The maximum displacements of the building are specified at the height of $Z_0$ = 287 m as 0.2 m (corresponding to the 1st mode) and 0.15 m (corresponding to the 2nd mode) under 10-year return wind conditions. The scenario considered is when the car with rated load is moving from the top landing level downwards at the rated speed of 5 m/s and stopping under electromechanical braking. The braking deceleration is 1.2 m/s$^2$ (see the kinematic profile diagrams shown in Figure 3).

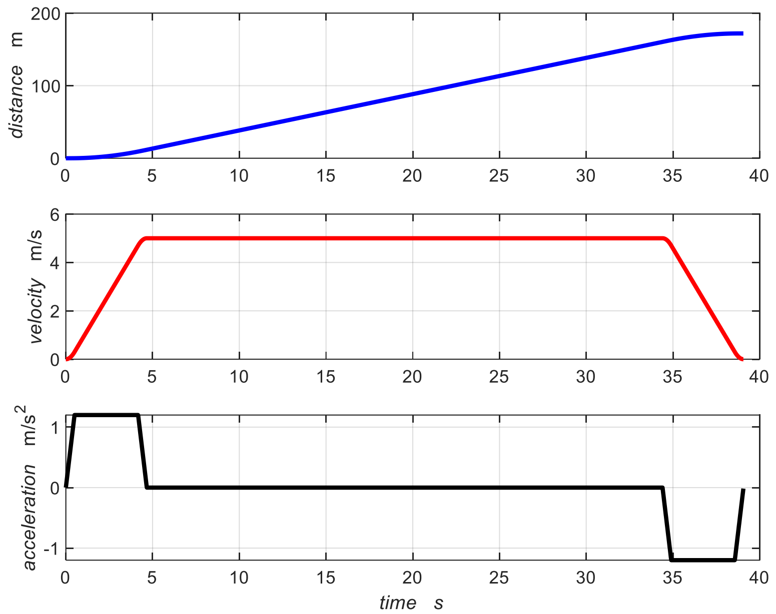


**Figure 3 Kinematic profiles of the lift**

Figures 4 (a-c) show the variation of the natural frequencies of the ropes/cables and the frequencies of the vertical modes (note the higher values of the vertical frequencies in comparison with the sway frequencies). The dynamic displacements of the car, counterweight and CSA assembly are presented in Figure 5. The plots demonstrate adverse dynamic interactions under the resonance conditions when the frequencies of the building sway excitation (represented by horizontal red solid/dashed lines) become close and tuned to the natural frequencies of the system. In the scenario considered in this example the resonance phenomena strongly affect the compensation cables (see the regions marked in Figure 4(b)).

In Figure 6(a), (b) the dynamic tensions at the car side and counterweight side are presented, computed from Equations (11) – (12) with no tiedown applied. The dynamic traction ratios are then shown in Figure 6(c). It is evident that in the resonance regions the tensions increase and fluctuate, which results in the fluctuation of the traction ratios in the second part of the lift travel. It is evident that the traction ratio reaches its instant maximum value of about 2.4 at approximately $t = 32.7$ s.

To assess the traction conditions the minimal critical traction ratios need to be determined. As discussed above, the evaluation of the critical traction ratios involves $\alpha$, the angle of wrap, and $f$, the friction factor. The friction factor $f$ is dependent upon the coefficient of friction $\mu$ and the geometry of the grooves in the traction sheave. Consider that the lift's traction sheave has semi-circular (U) groove profiles with an undercut. The friction factor is then determined from the following equation [3]:

$$f = 4\mu \frac{\cos\frac{\gamma}{2} - \sin\frac{\beta}{2}}{\pi - \gamma - \beta + \sin\gamma - \sin\beta} \tag{12}$$

where $\beta$ is the undercut angle, and $\gamma$ denotes the groove angle.

For the undercut angle $\beta = 105°$ (1.83 rad), the groove angle $\gamma = 25°$ (0.44 rad) the friction factor and the corresponding critical traction ratios are calculated for the minimum angles of warp assumed as 160° (single wrap) and 320° (double wrap), respectively (see Table 1). It is evident that the instant maximum value of the applied traction ratio exceeds the critical traction ratios and under the dynamic conditions considered the host rope slip might occur and traction is compromised. Thus, appropriate mitigating measures should be considered.

Various options could be considered to improve the traction conditions and to achieve traction throughout the lift travel. As discussed above, the lift system under consideration can be equipped with a tie-down device to limit the dynamic displacements of the CSA. Figure 7 shows the effects of application of a hydraulic tiedown device with the coefficient of viscous damping $c_3$ = 193.42 kN m/s and $\lambda = 1$ (linear damping) selected.

**Table 1 The critical traction ratio (undercut U groove)**

|   | | | Min. critical traction ratio $e^{f\alpha}$ single wrap ($\alpha = 160^o$) | Min. critical traction ratio $e^{f\alpha}$ double wrap ($\alpha = 320^o$) |
|---|---|---|---|---|
| Breaking conditions (v=5.0 m/s) | $\mu = \frac{0.1}{1+\frac{v}{10}} = 0.067$ | f = 0.1477 | 1.5106 | 2.2821 |

It is evident that the application of the tie-down reduced the adverse effects of dynamic interactions in the system. The maximum value of the traction ratios throughout the lift travel is determined as 1.4933 which is within the limiting values of the critical traction ratios shown in Table 1 (both for single and double wrap configuration). Another option to improve traction would be to consider the application of a traction sheave with hardened V-grooves. This would increase the friction factor and the minimum critical traction ratios would be higher.

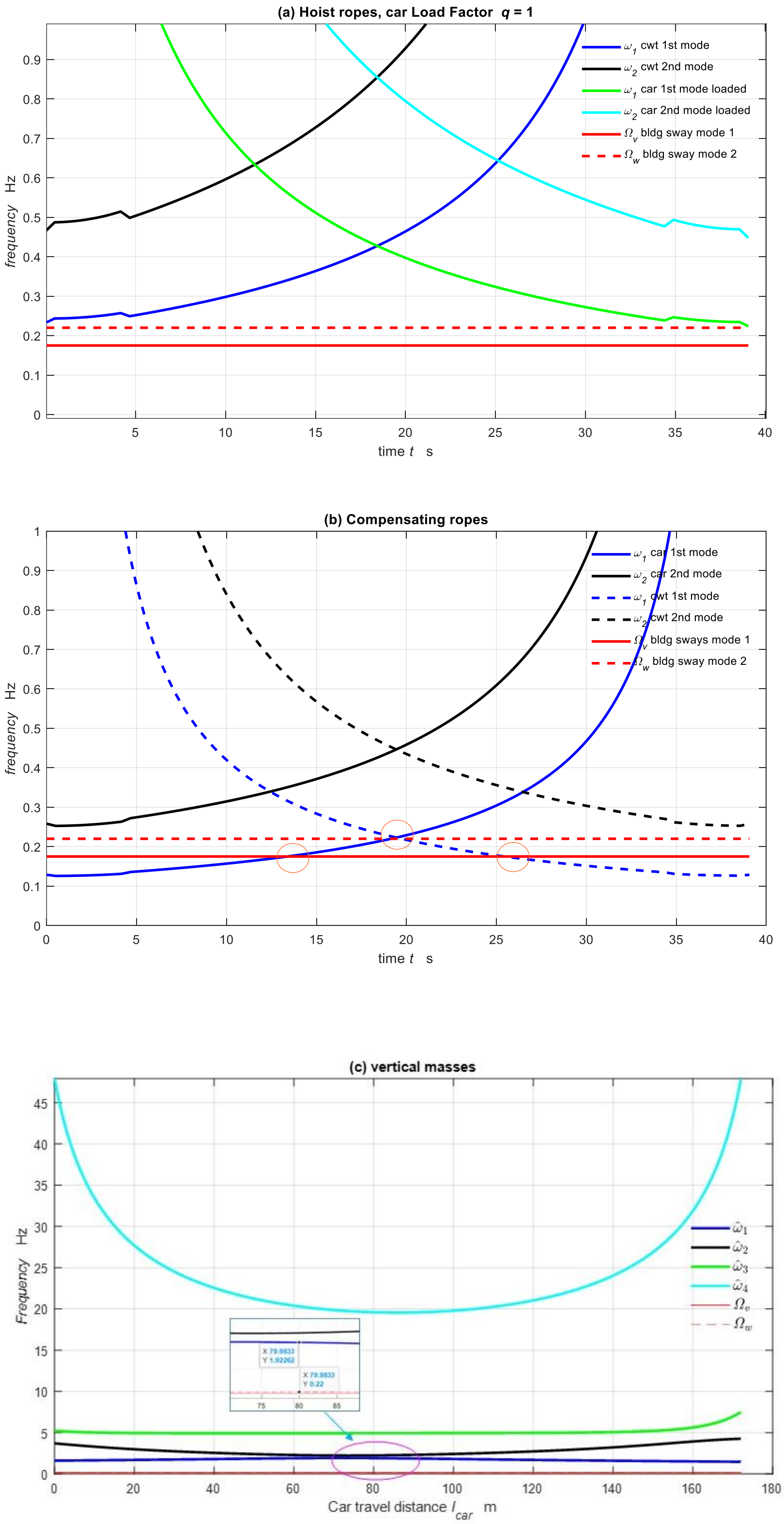


**Figure 4 Variation of the natural frequencies of the lift system**

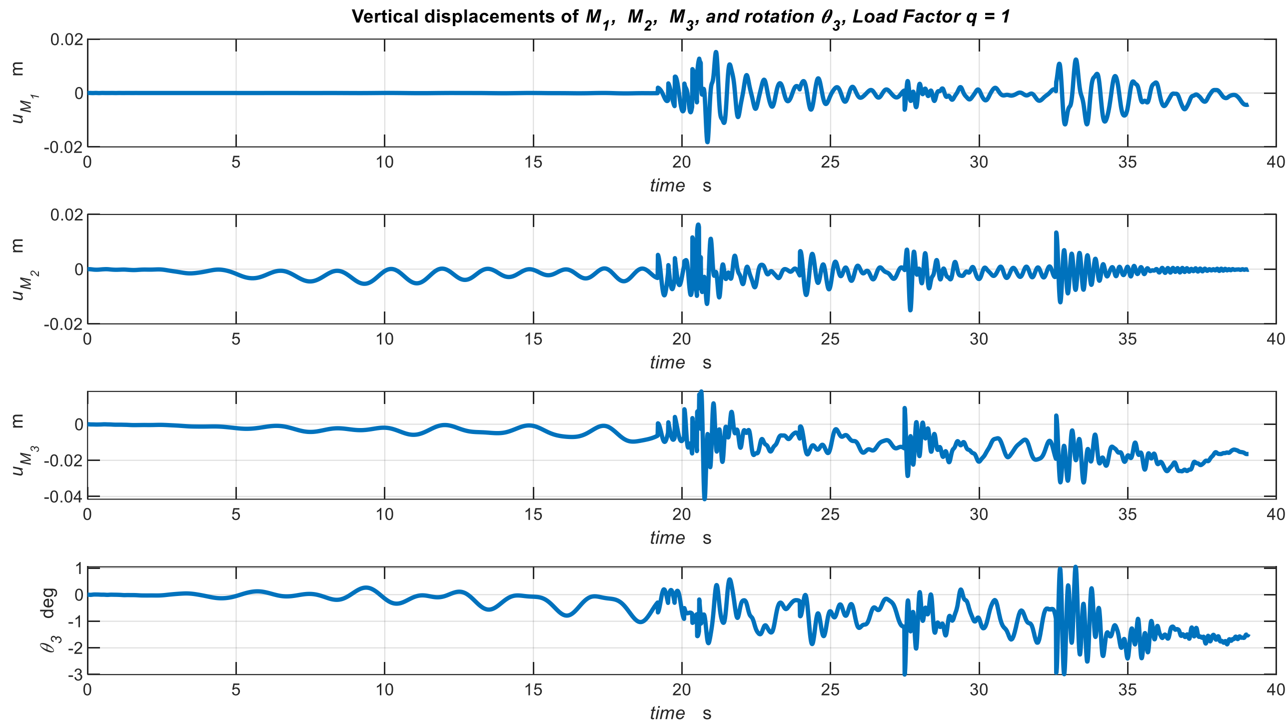


**Figure 5 Dynamic displacements of the car, counterweight and CSA assembly**

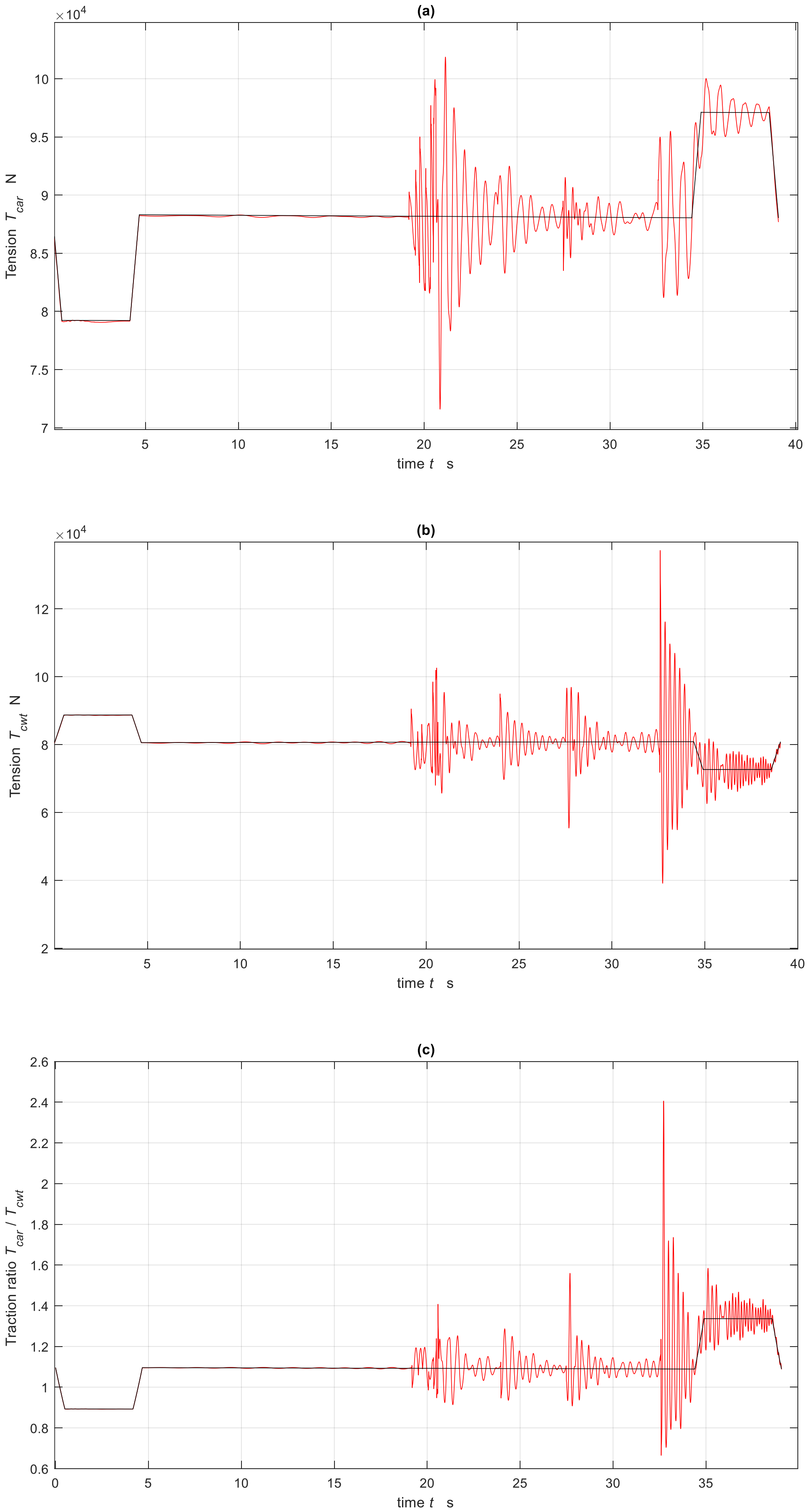


**Figure 6 Variation of tension forces and the applied traction ratio**

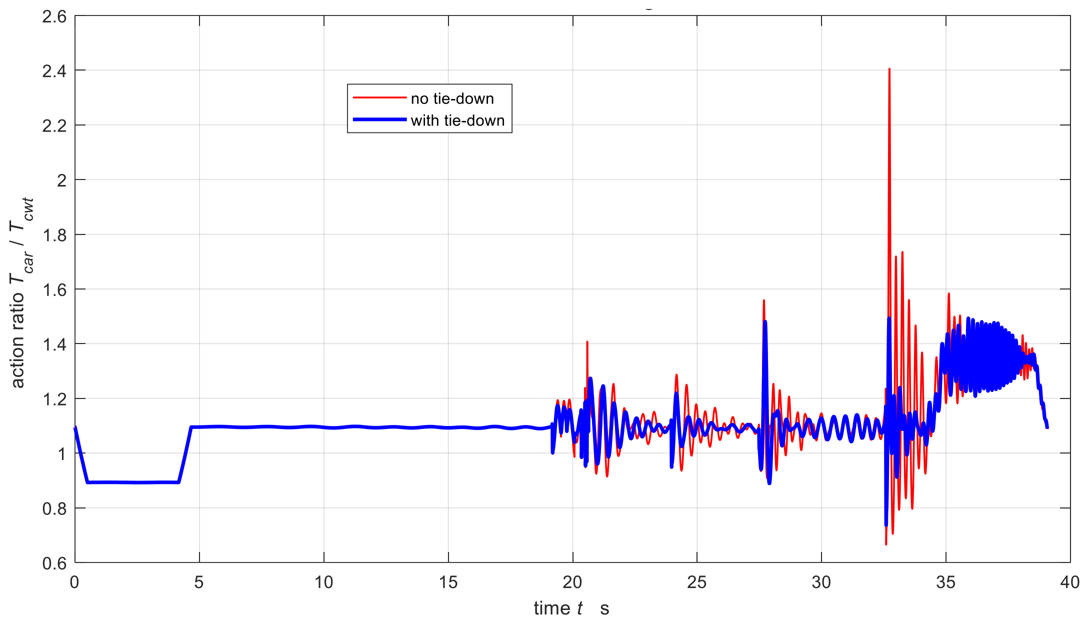


**Figure 7 Applied traction ratios with/without tie-down**

## 4 CONCLUSIONS

The tractive forces developed between the sheave and the hoisting ropes are the fundamental consideration in the design of a traction lift system. To complete a traction design of a lift system one must evaluate the values of the critical traction ratios and ensure that the applied traction ratios do not exceed these values during the operational normal conditions unless the car or counterweight is resting on the buffers.

It is evident from the discussion presented in this paper that the dynamic conditions arising in high-rise lift installations due to sway of tall buildings may affect the hoist rope tensions. This in turn might compromise traction.

It is demonstrated that to make an estimate of the applied traction during the sway conditions appropriate dynamic simulation models can be developed and applied in the design calculations. Once the simulation results are available appropriate mitigating measures can be considered to avoid any potentially hazardous traction scenarios.

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## BIOGRAPHICAL DETAILS

Professor Stefan Kaczmarczyk has a master's degree in mechanical engineering and a doctorate in engineering dynamics. His expertise is in applied mechanics/dynamics and mathematical modelling, with applications to vertical transportation systems. He has over 45 years' research experience in these areas, and he taught mechanical engineering/engineering dynamics courses at all levels. Professor Kaczmarczyk is a Chartered Engineer, a Fellow of the Higher Education Academy, and a Fellow of the Institution of Mechanical Engineers.

# Improving Maintenance with Technology

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**Abstract.** The paper will discuss the tremendous equipment improvements that electronic maintenance control programs and IoT can provide to owners. Tailoring maintenance provides optimum performance with minimal costs. An ideal program provides for contractual reimbursement when maintenance is not performed per contract, the financial benefits finally in favor of the building. Examples of documented 70% reduction of callbacks, reduction of unexpected equipment failure, elimination of incidents, preservation of capital equipment, and improved elevator personnel morale are possible. The current trends of overloading mechanics have swung too far to the detriment of owners.

## 1 INTRODUCTION: TECHNOLOGICAL EVOLUTION IN ELEVATOR MAINTENANCE

One can't be unaware that maintenance practices have changed in the last 30 years in the lift industry. Technological improvements have been applied, moving from relay logic to computer controllers, solid state motor control, and the use of sealed bearings. As these changes have occurred, maintenance demands have changed. Certainly, the need to meg and blow out the carbon dust in a motor-generator is no longer there; however, there still exists the ever-present degradation of mechanical components such as gibs and rollers in a dirty environment and rope stretch. Regular housekeeping maintenance remains unchanged. Older equipment is still in service, where much more maintenance is still required; it is critical not to apply a maintenance control program from a modern system to these older systems.

## 2 THE RISKS OF OVER-REDUCING PREVENTIVE MAINTENANCE

Reductions in maintenance time and frequency in the lift industry may have some legitimacy given technological improvements in the equipment. The question is, how much reduction in maintenance can a lift system endure before reduced performance and hazards are created? This must be examined objectively. In the US and Canada, the ASME A17.1/CSA B44 Code has a maintenance section that allows companies to determine intervals between maintenance visits. There is ample evidence that maintenance companies have stretched the interval limits hazardously, and without questioning these intervals, it will likely continue further.

## 3 KEY INDICATORS: CALLBACKS AND CUY

The first key performance indicator when determining if adequate preventive maintenance is being done is the number of equipment-related callbacks a lift or escalator has in a year. Six or more equipment-related callbacks in one year is direct evidence of a lack of adequate maintenance in a very busy building, such as a hospital or an extremely under-elevated building. For a correctly elevatored building of normal use with adequate maintenance, 4 equipment-related "Callbacks per Unit per Year" (CUY) is easily achieved. Injury incidents are typically associated with a high number of equipment-related callbacks, infrequent visits, short duration of maintenance visits, and insufficient training of mechanics on older equipment.

## 4 CASE STUDY: UNIVERSITY SYSTEM PERFORMANCE WITH LIFT EMCP

A real-world example is an account with 669 lifts at a large university in the United States using eMCP, now known as Lift eMCP after acquisition by LiftAI in late 2024. Before providing an enforceable contract with true transparency using Lift eMCP, the average callback rate was over 6.5 equipment-related CUY. After accountable maintenance was contractually imposed, the equipment-related callbacks plummeted to 1.5 equipment-related CUY, and after ten years, the average remains at 2.1 CUY consistently with no injury incidents reported. For a large University with primarily traction elevators, this is a stunning result.

| | # | % | OSU MC | % | FOD | % | SL | % | BA | % | ATH | % | Out | % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total OSU Units | 651 | 100% | 150 | 100% | 294 | 100% | 105 | 100% | 24 | 100% | 23 | 100% | 50 | 100% |
| Units With Any Callbacks | 469 | 72% | 89 | 59.3% | 176 | 59.9% | 91 | 86.7% | 12 | 50.0% | 5 | 21.7% | 4 | 8.0% |
| Total Callbacks | 3,090 | 100% | 548 | | 1452 | | 1043 | | 32 | | 5 | | 9 | |
| Equipment Related CBs | 1,379 | 45% | 248 | 45.3% | 523 | 36.0% | 581 | 55.7% | 14 | 43.8% | 2 | 40.0% | 2 | 22.2% |
| Non-Equip Related CBs | 1,711 | 55% | 300 | 54.7% | 929 | 64.0% | 462 | 44.3% | 18 | 56.3% | 7 | 140.0% | 7 | 77.8% |
| Units with 0 Callbacks | 277 | 43% | 61 | 40.7% | 118 | 40.1% | 14 | 13.3% | 15 | 62.5% | 23 | 100.0% | 46 | 92.0% |
| Units with 1- 4 Callbacks | 259 | 40% | 70 | 46.7% | 141 | 48.0% | 35 | 33.3% | 9 | 37.5% | 0 | 0.0% | 4 | 8.0% |
| Units with 5 - 8 Callbacks | 80 | 12% | 16 | 10.7% | 28 | 9.5% | 36 | 34.3% | 0 | 0.0% | 0 | 0.0% | 0 | 0.0% |
| Units with 9 - 13 Callbacks | 19 | 2.9% | 2 | 1.3% | 5 | 1.7% | 12 | 11.4% | 0 | 0.0% | 0 | 0.0% | 0 | 0.0% |
| Units with 14 - 18 Callbacks | 6 | 0.9% | 1 | 0.7% | 2 | 0.7% | 3 | 2.9% | 0 | 0.0% | 0 | 0.0% | 0 | 0.0% |
| Units with 19 - 25 Callbacks | 5 | 0.8% | 0 | 0.0% | 0 | 0.0% | 5 | 4.8% | 0 | 0.0% | 0 | 0.0% | 0 | 0.0% |
| Entrapment Callbacks | 273 | 8.8% | 75 | 14% | 92 | 6% | 105 | 10% | 1 | 3% | 0 | 0% | 0 | 0% |
| Running on Arrival Callbacks | 1,565 | 51% | 236 | 43% | 814 | 56% | 493 | 47% | 18 | 56% | 3 | 60% | 1 | 11% |
| Equip Related - C/U/Y | 2.1 | | 1.65 | | 1.78 | | 5.53 | | 0.58 | | 0.09 | | 0.04 | |
| All Callbacks - C/U/Y | 4.7 | | 3.65 | | 4.94 | | 9.93 | | 1.33 | | 0.22 | | 0.18 | |

**Figure 1 2023 Callbacks**

| | # | % | OSU MC | % | FOD | % | SL | % | BA | % | ATH | % | Out | % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total OSU Units | 669 | 100% | 154 | 100% | 305 | 100% | 115 | 100% | 22 | 100% | 23 | 100% | 50 | 100% |
| Units With Any Callbacks | 463 | 69% | 107 | 69.5% | 219 | 71.8% | 107 | 93.0% | 11 | 50.0% | 4 | 17.4% | 15 | 30.0% |
| Total Callbacks | 2,851 | 100% | 689 | | 967 | | 1,096 | | 63 | | 9 | | 27 | |
| Equipment Related CBs | 1,407 | 49% | 327 | 47.5% | 396 | 41.0% | 590 | 53.8% | 42 | 66.7% | 1 | 11.1% | 16 | 59.3% |
| Non-Equip Related CBs | 1,444 | 51% | 362 | 52.5% | 571 | 59.0% | 506 | 46.2% | 21 | 33.3% | 8 | 88.9% | 11 | 40.7% |
| Units with 0 Callbacks | 190 | 28% | 38 | 24.7% | 80 | 26.2% | 9 | 7.8% | 11 | 50.0% | 18 | 78.3% | 35 | 70.0% |
| Units with 1- 4 Callbacks | 242 | 36% | 57 | 37.0% | 142 | 46.6% | 24 | 20.9% | 4 | 18.2% | 4 | 17.4% | 15 | 30.0% |
| Units with 5 - 8 Callbacks | 124 | 19% | 24 | 15.6% | 54 | 17.7% | 35 | 30.4% | 4 | 18.2% | 0 | 0.0% | 0 | 0.0% |
| Units with 9 - 13 Callbacks | 39 | 5.8% | 10 | 6.5% | 11 | 3.6% | 15 | 13.0% | 3 | 13.6% | 0 | 0.0% | 0 | 0.0% |
| Units with 14 - 18 Callbacks | 33 | 4.9% | 8 | 5.2% | 8 | 2.6% | 14 | 12.2% | 0 | 0.0% | 0 | 0.0% | 0 | 0.0% |
| Units with > 18 Callbacks | 26 | 3.9% | 7 | 4.5% | 4 | 1.3% | 18 | 15.7% | 0 | 0.0% | 0 | 0.0% | 0 | 0.0% |
| Entrapment Callbacks | 308 | 10.8% | 103 | 15% | 92 | 10% | 105 | 10% | 7 | 11% | 1 | 11% | 0 | 0% |
| Running on Arrival Callbacks | 1,620 | 57% | 277 | 40% | 814 | 84% | 493 | 45% | 21 | 33% | 9 | 100% | 6 | 22% |
| Equip Related - C/U/Y | 2.1 | | 2.12 | | 1.30 | | 5.13 | | 1.91 | | 0.04 | | 0.32 | |
| All Callbacks - C/U/Y | 4.3 | | 4.47 | | 3.17 | | 9.53 | | 2.86 | | 0.39 | | 0.54 | |

**Figure 2 - 2024 Callbacks**

The numbers shown in Figures 1 and 2 illustrate how monthly site visits improve performance and prove the obvious point: maintenance frequencies and durations are critical to keep even the oldest equipment operating hazard-free and operating with maximum uptime. The University is clearly elated, and additionally, the total cost of vertical transportation maintenance did not increase, with the exception of inflation and labour rate escalation. Even in this ideal environment, the number of "Running on Arrival" (ROA) callbacks remains over

50% of the total callbacks. Some of these callbacks required repairing a component. Because the lift was running, there was still a corrective action to some component. Most records, however, had no corrective action at all, just “Checked Operation” without finding any problems requiring a corrective action.

## 5 UNDERSTANDING ROA CALLBACKS AND TELEMETRY OPPORTUNITY

ROA callbacks are a waste of labour, they interrupt maintenance to answer a phantom call, and are a nuisance to the University. From researching ROA callbacks, the evidence suggests that very conservative behaviour by the owner is partially responsible. They respond to the general public perceiving a problem, and they request the maintenance company check out the lift, typically without their own review of the lift by someone onsite. If there is a place for utilising IoT telemetry systems that can provide enough data to determine if the lift is operating correctly and safely, it is in this area, where there is an actual financial return on investment for the telemetry equipment. If the telemetry system can safely determine the elevator is operating correctly, then the response to the callback is logged: “Telemetry shows all is OK, call again if the problem returns.” When this information is available on the mechanic's smart device, he can continue with his maintenance tasks without interruption. This concept is valid with intelligent telemetry, the kind of intelligence available with many systems today.

## 6 IOT: FROM REACTIVE TO INTELLIGENT MAINTENANCE

For example, in this implementation, the telemetry can detect accelerations known to be hazardous, such as an emergency stop, the lift not getting to full speed, or overspeeding. Vibration analysis can determine if door cycle times are substantially increased, indicating debris in the sills or impacted doors with bent gibs. When using IoT devices to simply notify the maintenance company that a failure has occurred, in lieu of the maintenance company actually regularly visiting the unit and observing a developing failure, it allows the failure to occur. It is reactive maintenance, otherwise known as “callback maintenance”, when scheduled maintenance visits are three, four, or six months apart, a failure is detected, and that is what brings repair personnel to correct the issue.

Intelligent use of IoT telemetry systems must be an adjunct to preventive maintenance, not replace preventive maintenance. For example, the telemetry should provide notice of a new vibration in a roller indicating a deleterious change in its condition, an irregular vibration in the floor open and close cycle indicating debris in the sill. Such events should be evaluated, a degree of importance assigned, and levels based on the customer's ability to sense the failure and schedule a new task to immediately generate a maintenance request, regardless of the next scheduled maintenance visit. These things should be noticed before the guide roller material shredding off and allowing a full speed clipping of an interlock, causing injury or rope stretch, which trips a buffer or compensation sheave switch, causing an injury. These conditions should be observed by an on-site mechanic who should visit the lift more than 3 times a year.

## 7 MAINTENANCE FREQUENCY STANDARDS – THEN AND NOW

In the 1980s, traditional maintenance in the United States and Canada was monthly, with some exceptions. Very low-use lifts could be quarterly, for example, in a church or a water treatment plant, where the usage is very low. Very high-use lifts in critical areas sometimes have every two-week visitation requirements in their contract, for example, international airports. In practice today, many large companies have what seems to be a one-size-fits-all schedule, regardless of the price, and claim that one major reason is due to a shortage of labour. One has to ask if you own a business and take on too many clients to the point they all suffer a reduction in service, wouldn't it be better to not take the job on until it could be properly manned, so the existing customers don't suffer?

## 8 INDEPENDENT VS. MAJOR FIRMS: INCIDENT DISPARITY

Juxtaposed with this is the practice of independent maintenance companies that do monthly maintenance. Since 2008, when I began doing forensic analysis of incidents, the major companies have had a significantly higher number of incidents than independent companies. Out of over 200 incidents, only 12 were independent company incidents, while the major companies had over 180 incidents. In my experience with the University, requiring monthly site visits bears this out, and there have been no incidents in over 10 years. Major companies have 60% to 65% of the estimated total of 1.2 M units in the US and Canada. One would expect a similar ratio of incidents, but this is not the case. There is no reason my cases should statistically bias against independent company incidents. This was confirmed by my consulting peers - all had similar percentages.

## 9 CONTRACT ENFORCEMENT: LEGAL AND OPERATIONAL IMPACT

There seems to be no limit to how little maintenance a company can do, with only the injuries bringing the inadequate maintenance to light. This is what appears to be the driver in the marketplace today. When the bar is as low as reducing preventive maintenance to the point of occasional injury incidents, this practice should not be allowed to continue. The purpose of Codes and Standards is to assure that there are few injuries, to protect life and limb, where act-of-God-type failures are the only acceptable types of incidents. This should be the lowest bar, and mandates to reduce preventive maintenance should be left to technical engineers and former mechanics, not to financiers and shareholder interests.

## 10 LIFTAI AND LIFT EMCP: FULL TRANSPARENCY IN ACTION

This kind of oversight is the purpose of LiftAI and Lift eMCP: to provide transparency to contractually enforceable duties. For example, if a contract requires monthly maintenance, without some oversight, most customers don't know if they actually received maintenance in the last month. Lift eMCP provides a monthly completion report that is used to illustrate maintenance completion when combined with contractual language to use this reporting system. This excludes all company boilerplate contracts that typically just require "systematic and periodic" visits to the unit. When a contract requiring the use of Lift eMCP is signed, maintenance companies must rationalise why the tasks were not completed. There may be valid reasons, for example, a fire in a building that has left the building unoccupied, or the lifts are being modernised. This leaves either doing 100% of the tasks or rationalising why it wasn't achieved, so owners have full visibility of their maintenance costs and results.

Lift eMCP provides a tool for seeing contract compliance. Our findings after 10 years of successful use at the University include improved morale when the mechanics are told to leave their jobs, as they can report that they are not finished with all the maintenance tasks. When the tasks are left incomplete, the company has money withheld for not completing all the tasks. The net result is that when a mechanic is asked to work off-site, they are now also asked if all the tasks are completed or if they are on track to complete them. If the mechanic says no, the company instructs them to stay and finish the maintenance tasks. This is what regularly occurs at the University, and the condition of the equipment is much improved. Reverting back to the

1980s when the mechanic was much more autonomous and when routes were not so heavily populated with excessive numbers of units.

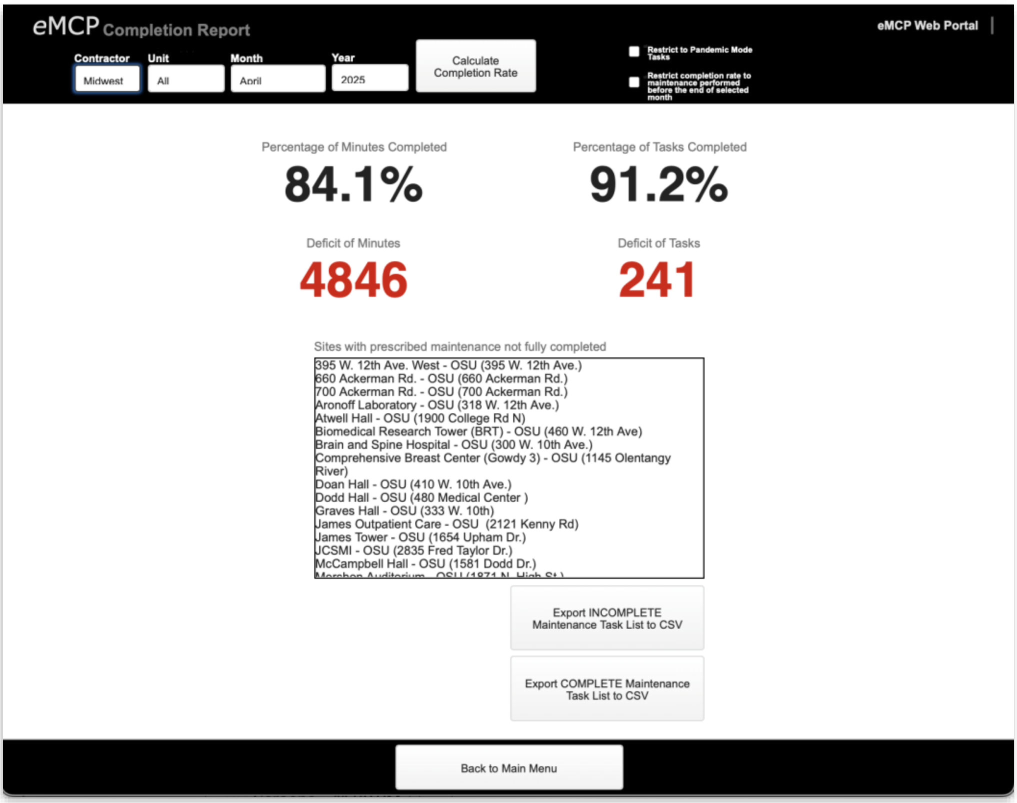


**Figure 3 - Completion Report**

When the tasks are completely identified and a reasonable time is associated with each task, the time can be tallied and the monies recovered by reducing the next payment from the maintenance company in breach of the contract. The refusal to pay was challenged in year two, and the University won when undergoing a legal challenge. The company did not perform, and the lack of maintenance monies was credited back to the university. This was a seminal ruling and has been recognised and adhered to subsequently. One can get what you pay for with systems and contracts in place.

LiftAI has the business of monitoring and auditing all communications: proposals, invoices, parts orders, and verification of pricing per the contract. By acquiring eMCP, rebranding to Lift eMCP, a complete maintenance system allows for total transparency. Their auditing function can be managed by the building or by a consultant who may have many building owners in their business. Errors in billing, unjustifiable proposal amounts, and not following contractual site visits are regularly discovered with this type of auditing. Providing experienced oversight to building managers and owners is commonly done by consultants. LiftAI provides systems for this function so owners and managers can manage their maintenance contracts effectively. By partnering with eMCP, LiftAI has revolutionised lift maintenance, changing the premise of little say because of the complexities of the lift products, by monitoring the money, the value of the spend, and demanding to get what they pay for with systems that illustrate all aspects of their equipment.

## 11 CONCLUSION

Utilising transparent, accountable maintenance systems such as LiftAI and Lift eMCP improves safety, capital preservation, and uptime of lift equipment. Using Lift eMCP has produced optimum performance with minimal costs. Combined with a contract which binds the maintenance company to actually perform to the terms, with control of the maintenance fees at risk to the maintenance company, the owner now controls his equipment in ways not seen in the past. Equipment life, in-service uptime, reduction of callbacks, elimination of incidents, and mechanics who are given the time necessary to actually perform maintenance, which improves morale.

## 12 REFERENCES

## BIOGRAPHICAL DETAILS

John Koshak has worked in the elevator industry since 1980, beginning as an adjuster with major companies before moving into product design, code compliance, and consulting. He patented the LifeJacket safety device, founded Elevator Safety Solutions, LLC in 2008, and later co-founded eMCP LLC to deliver code-compliant Maintenance Control Programs. An author of books, Certified Elevator Technician courses, and numerous technical articles, he also teaches code education for licensing. Koshak has served on the ASME A17 Standards Committee since 2005 and holds leadership roles including President of the International Association of Elevator Consultants (IAEC) and Board Member of Elevator World Magazine.

# Lift Evacuation Communications

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**Keywords**: Lift, emergency, communications, VoIP, evacuation, connected cabin.

**Abstract.** The (imminent) arrival of EN81-76:2025 as a published and applicable new lift standard and the need for implementation of evacuation communications to new and/or modernised lifts is a new challenge for lift companies and extends their responsibilities beyond lift operation. In this paper and symposium presentation, the topic of evacuation communications will be explored in terms of available communication technology, options, and considerations with the goal of providing some foundation for the selection and application of effective solutions. Key findings include the importance of clear communication protocols, the benefits of different technology options, and the necessity of regular testing and training.

## 1 INTRODUCTION

The development of EN81-76:2025 and its release and publishing as a new addition to the EN standard, when it happens, will have profound effects, both in the scope of lift communications technology to be deployed on affected lift projects, and the addition of responsibilities around evacuation and the stakeholders involved and their respective liabilities. The author believes there may also be pressure to explore to what extent existing lift installations can be retrofitted with evacuation communication solutions to meet in full or in part the objective of that new standard, since new lifts and newly modernised lifts represent a small fraction of the UK installed base, leaving that exposed without any action in this regard. The symposium presentation from which this abstract is derived will seek to give an overview of the technology and deployment issues likely to arise within the lift industry and highlight any grey areas which the published standard will hopefully clarify.

### 1.1 Objectives

This paper aims to:

- Provide an overview of evacuation communication systems.
- Compare different communication technology options.
- Highlight the importance of regular testing and monitoring.
- Discuss the necessity of comprehensive training for all stakeholders.
- Outline key compliance points and future research directions.

## 2 EVACUATION COMMUNICATIONS OVERVIEW

In essence, an active communication channel must be established between the designated evacuation lift(s) and a location from which the evacuation will be managed and the instructions as to the routing of the lift picking up evacuees provided to the lift driver(s). In addition, that same location from which the evacuation will be managed should be in communication with all floors from which evacuation might be required, typically all floors above MEEF (Main Elevator Evacuation Floor).

That interaction is critical where the evacuation plan bares some relevance to the tenants/residents on particular floors who perhaps are unable to use the stairs for building egress, or that plan is overridden to some extent by demands coming from landings that somehow do not align to the plan in position or volume of such tenants/residents to be evacuated from that location.

Clear and effective communication during evacuations is paramount to ensure the safety and timely evacuation of all occupants.

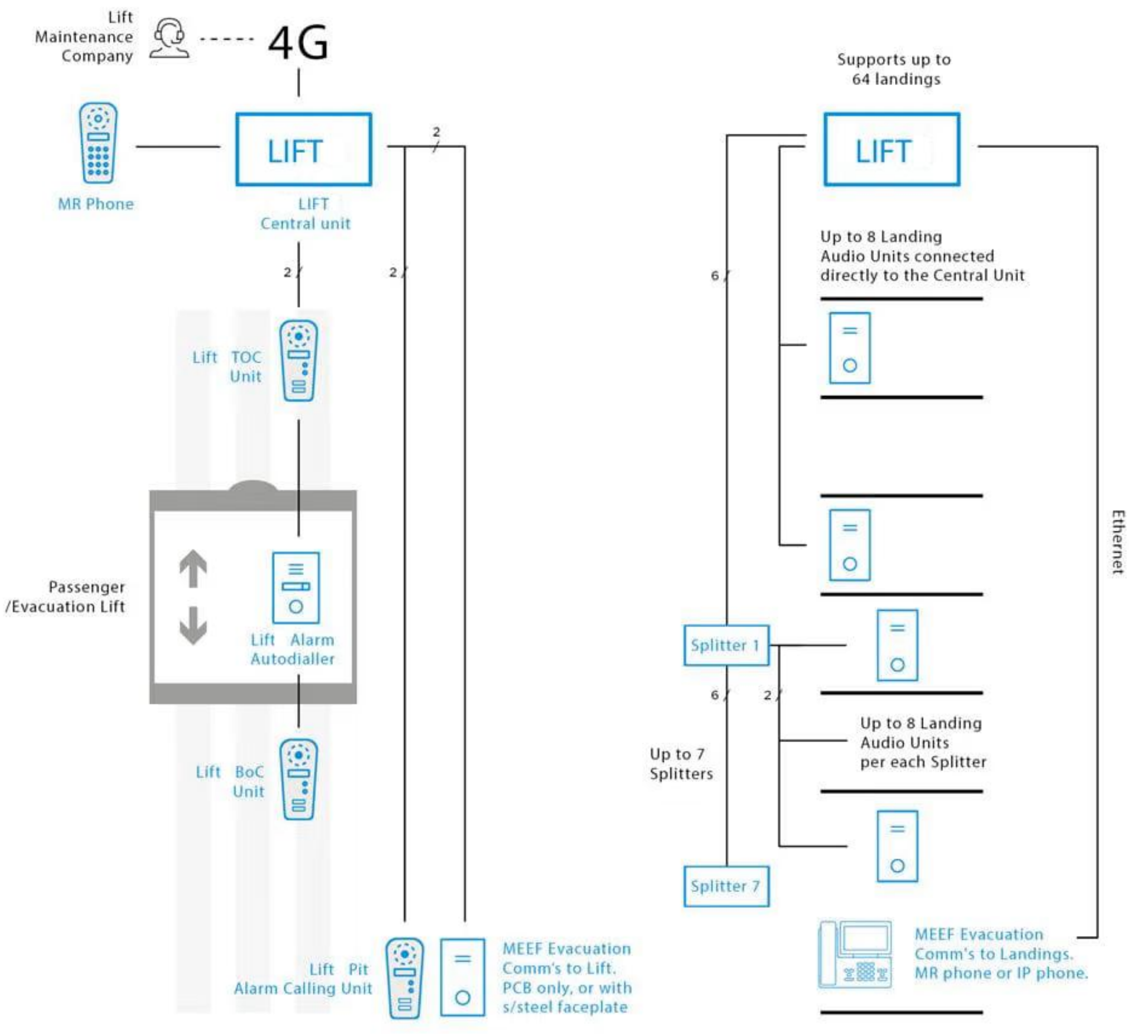


**Figure 1 Communication schematics**

## 3 COMMUNICATIONS TECHNOLOGY OPTIONS

There is typically a choice of Analogue, Digital (multi-wire bus), or IP communications technology, with relative advantages and/or disadvantages of each. Importantly, the technology selection should support the use of just one intercom/phone in the lift cabin for any designated evacuation or evacuation/fireman's lift covering those needs and regular emergency calling by trapped passengers. The use of multiple lift cabin communication devices for different purposes is not ideal.

**Table 1 Comparison of Communication Technology Options**

| Technology | Advantages | Disadvantages |
|---|---|---|
| Analogue | Simple, widely available | Extensive wiring, prone to interference |
| Digital | Minimised wiring, robust | Requires multiplexing |
| IP | Future-proof, scalable | Complex configuration, requires network infrastructure |

## 4 MONITORING & TESTING

It is the opinion of the author that the evacuation communication system should be subject to regular testing, not unlike what EN81-28:2022 provides for lift emergency phone communication. If EN81-76:2025 in published form provides for some form of testing and oversight, then this should be applied. In the absence of guidance, the building evacuation plan should include communications testing on a regular basis by a nominated, responsible party(s).

### 4.1 Functional monitoring

To maintain reliability, systems should implement both passive and active monitoring mechanisms:

- **Line Monitoring**: Continuous supervision of all wired endpoints (lift cabin, landings, MEEF panel) to detect disconnections, short circuits, or device failures.
- **Heartbeat/Ping Signals**: For IP-based systems, regular heartbeat signals between intercom units and control hubs ensure network integrity and device availability.
- **Power Monitoring**: Uninterruptible Power Supply (UPS) units should be monitored for charge level, runtime, and fault conditions, especially for PoE switches and MEEF panels.

### 4.2 Regular testing protocol

A structured testing schedule should be embedded into the building's evacuation preparedness plan:

**Table 2 Regular testing protocols**

| Test Type | Frequency | Responsible Party |
|---|---|---|
| Functional voice test | Monthly | Building manager / Lift tech |
| System self-test log | Weekly or daily | Automated / Remote monitoring |

| Test Type | Frequency | Responsible Party |
|---|---|---|
| End-to-end evacuation drill | Annually | Safety officer / Fire service |
| Battery backup runtime test | Quarterly | Maintenance technician |

### 4.3 Best practices for testing

- Always simulate real conditions — including powered lift shaft, live evacuation mode (if safe), and realistic call sequences.
- Use voice clarity assessments, latency checks (for IP), and verify fallback behaviour if a component fails.
- Document all test results in an evacuation logbook reviewed periodically by facility safety officers.

### 4.4 Remote diagnostics

Modern systems increasingly support remote diagnostics through cloud-connected panels or SNMP-compatible IP intercom systems. This allows manufacturers and service providers to detect and resolve faults proactively and can reduce time-to-repair during faults or inspections.

## 5 TRAINING

It cannot be assumed that communication solutions for evacuation are intuitive to the point of not requiring user training. With the wide variety of solutions and aforementioned technology choices on the market, it is imperative that all stakeholders take an interest in the training and support of nominated, responsible party(s) or person(s) expected to use the solution in the event of an evacuation. In addition, manuals should be provided along with clear instructions at or around the MEEF communication control point(s). Landing intercoms will be engraved with lettering signifying their purpose and directing on how to use those units in case of evacuation.

### 5.1 Who should be trained?

**Table 3 Training guide**

| Stakeholder | Required Knowledge |
|---|---|
| Evacuation Coordinators | MEEF operation, system prioritisation, call routing |
| Lift Operators | Cabin communication usage, responding to MEEF instructions |
| Building Management Staff | System reset, basic fault response, documentation |
| Occupants (esp. vulnerable) | Use of landing intercoms, basic awareness |

### 5.2 Training methods

- **Hands-On Demonstrations**: Periodic live walkthroughs with MEEF equipment and intercoms.
- **Simulated Drills**: Incorporate communication checks into full building evacuation drills.
- **Quick Reference Guides**: Laminated cards at each MEEF location and at landings with usage steps.
- **Digital Training Modules**: Short e-learning modules or videos for building staff and security teams.
- **Onboarding Sessions**: For new employees or tenants, include evacuation communication usage in safety induction.

### 5.3 Training documentation and evaluation

Training logs should be maintained, detailing:

- Date, attendees, instructor
- Systems used
- Scenarios simulated
- Lessons learned and issues identified

Evaluations using checklists or short quizzes can help assess comprehension. Training frequency should align with building type and complexity; for example, quarterly for hospitals or high-rise residential towers.

## 6 KEY COMPLIANCE POINTS

The EN 81-76:2025 draft introduces mandatory requirements for lift-based evacuation communications that are both technically detailed and operationally impactful. In conjunction with EN 81-28:2022, EN 81-72:2020, and BS 9991:2024, these standards define the communication infrastructure, behaviours, and responsibilities for stakeholders during an evacuation.

This section summarises key clauses, offers interpretations based on practical deployment, and highlights unresolved ambiguities. These should be considered as the author's comments.

### 6.1 Two-way communication between the lift car, MEEF, and landings

EN 81-76:2025, Clause 5.4.1 and 5.4.3

**Requirement**: “A remote assisted evacuation lift shall have a communication system for interactive two-way speech communication… allowing communication between the remote panel and the evacuation lift car, each lift landing to be evacuated, and the MEEF.”

**Interpretation**:

- Practical implementation should follow a hub-and-spoke model with the MEEF as the communication hub.
- Direct communication between the lift car and landings is neither required nor practical and should be clarified in the final wording.

- EN 81-72:2020 (Clause 5.2.1) reinforces this hub model for firefighter's lifts, which can be mirrored in evacuation designs.

### 6.2 Use of built-in microphone and speaker (no handset)

EN 81-76:2025, Clause 5.4.4

**Requirement**: "Communication equipment in the car and at the landings shall be a built-in microphone and speaker, and not a telephone handset."

**Interpretation**:

- Supports intuitive, hands-free interaction for passengers during emergencies.
- Does not explicitly prohibit handsets at the MEEF, which may offer operational benefits (e.g., call queue management and privacy).
- EN 81-28:2022, Clause 4.4.1, similarly mandates hands-free operation for emergency call systems in lift cars.

### 6.3 Controlled activation from the MEEF

EN 81-76:2025, Clause 5.4.2

**Requirement**: "The communications from the car and the landings to the remote panel shall individually be switched active from the remote panel."

**Interpretation**:

- Enables the evacuation coordinator to prioritise calls and manage communication traffic.
- Requires selective call handling and queued call displays at the MEEF.
- Aligns with EN 81-28:2022, Clause 5.3.2, which specifies remote activation and acknowledgement of emergency calls.

### 6.4 Permanently active communication from the lift car to MEEF

EN 81-76:2025, Clause 5.4.3 (a)

**Requirement**: "The communication from the car to the MEEF shall be permanently active during any evacuation operation… without pressing a control button."

**Interpretation**:

- A passive system design is required: the communication channel is auto-enabled in evacuation mode.
- Ensures lift drivers or evacuees are immediately reachable and do not need to initiate calls.
- Systems should indicate when the channel is active and log all audio activity for auditability.

### 6.5 Communication with the machine room or the emergency panel

EN 81-76:2025, Clause 5.4.3 (b)

**Requirement**: "…the microphone shall only be made active by pressing a control button."

**Interpretation**:

- Limits activation of technical intercoms (e.g., in machine rooms) to trained users.
- The definition of "control button" remains ambiguous — could include keypad input or GUI command.
- EN 81-72:2020, Clause 5.3.1 defines similar logic for firefighter intercoms.

### 6.6 Optional communication to the central command point

EN 81-76:2025, Clause 5.4.3 (c)

**Requirement**: "Microphones for other locations shall only be made active by pressing a control button on the intercom unit."

**Interpretation**:

- Allows connection to fire control rooms or facility security desks.
- Systems must provide multi-channel routing and role-based access, especially in hospitals, campuses, or airports.

### 6.7 Integration with EN 81-72:2020 firefighter lift requirements

EN 81-76:2025, Clause 5.4.5

**Reference**: "The communication system may be the same as the communication system required in EN 81-72."

**Interpretation**:

- Allows reuse of certified firefighter communication hardware for evacuation purposes.
- Systems must be designed for dual-mode operation with clearly defined role separation (e.g., evacuation vs. fire response).
- EN 81-72:2020, Clause 5.2 outlines audio communication between the lift car and firefighter panel; this can be mirrored for MEEF communication.

### 6.8 Strategy-driven lift role expansion

BS 9991:2024, Clause 10.5.2

**Requirement**: "For buildings with floors over 50m high and a 'stay-put' strategy, every lift should be a firefighter's lift and have the ability to function as an evacuation lift."

**Implications**:

- Expands the number of lifts that may require evacuation communication systems.
- Increases complexity of MEEF coordination and system scalability.
- Necessitates greater integration with fire systems, lift monitoring, and building management systems (BMS).
- Raises the need for enhanced operator training, as discussed in Section 5.

### 6.9 EN 81-28:2022 monitoring applicability

Though EN 81-76:2025 does not (yet) define a comprehensive monitoring protocol, EN 81-28:2022 offers a well-established reference:

- Clause 6.3 requires functional periodic testing of the emergency alarm system.
- Clause 4.7 mandates remote fault detection and alerting.

These concepts should be applied analogously to evacuation communication — especially when powered by shared hardware.

### 6.10 Additional Considerations from Other Standards

- **ISO 8102-20:2023 (Lift IoT and remote management)**: Specifies diagnostic interfaces and smart monitoring — relevant for cloud-based evacuation comms.
- **EN 54-16:2008 (Fire alarm voice communication)**: May provide guidance for public address integration where evacuation announcements and intercoms coexist.

## 7 CONCLUSION

The need for evacuation communications and effective, appropriate evacuation guidance for building occupants was clearly demonstrated by the Grenfell tragedy [1]. Extending responsibilities and understanding the roles and responsibilities of all stakeholders in the evacuation and communication process will be critical. In addition, whilst mandating new standards of evacuation for new buildings or modernised lifts is a big step, that only represents a small fraction of the market and so it begs the questions as to what can or should be done for existing properties and whether discretionary upgrades to facilitate evacuation can and should be retrofitted along with all supporting processes, evacuation plans and award of responsibilities.

### 7.1 Next steps and future research directions

- Explore the feasibility and cost-effectiveness of retrofitting existing lift installations with evacuation communication solutions.
- Develop standardised training programs and certification processes for stakeholders involved in evacuation communications.
- Conduct further research on the psychological and behavioural aspects of evacuation communications to improve user experience and compliance.

## REFERENCES

[1] Grenfell Tower Inquiry, Phase 1 Report (2019)

- BS9991:2024
- EN81-28:2022
- EN81-76:2025
- EN81-72:2020
- ISO 8102-20:2023
- EN 54-16:2008

**BIOGRAPHICAL DETAILS**

Pavel Kotek is the Lift Sales Director responsible for all 2N sales in the elevator sector as well as the OEM partnerships around the globe. With 13 years of experience in the field of elevator emergency communication, he holds expertise in the field and can provide the manufacturer's view as well as experience from implementation in different parts of the world. Pavel holds a Master's degree from the University of Economics in Prague in the field of International Business.

# 80%: Lift Traffic Design's Most Misunderstood Number

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**Keywords**: Car loading, capacity factor, handling capacity, simulation, round trip time, design stability, CIBSE Guide D, ISO 8100-32.

**Abstract.** An 80% capacity factor (car loading) is widely used in lift traffic design; however, it is applied differently in calculations and simulations. In round-trip time calculations, an 80% car factor is typically assumed to determine handling capacity. For consistency, in simulations, cars may be allowed to fill to 100%, with average capacity factor assessed across the peak period to confirm it does not exceed 80%. This paper examines the origin and purpose of the 80% capacity factor, demonstrates its implementation in both calculation and simulation, and explains the importance of using area, not mass, as the basis for these assessments. The paper addresses common misconceptions that incorrectly conflate allowances for passengers occupying more space (e.g. as they are carrying baggage) with the 80% capacity factor. Instead of adjusting the 80% capacity factor, a better approach is to vary the area per person in the analysis to reflect different passenger types. By consistently applying the 80% capacity factor, designers can better communicate their work and ensure realistic and robust lift system designs.

## 1 INTRODUCTION

Lift traffic analysis and simulation involves predicting how effectively a lift system can handle passenger demand, particularly during peak periods. At the heart of these calculations is an assumption about how many people will occupy each car. This is not a straightforward question: although each lift has a rated capacity in kilograms, real-world occupancy depends more critically on how much floor area is available and how that space is used.

A benchmark figure of 80% loading is commonly used across the industry. It serves as a reference in both analytical calculations and simulations to estimate how full a lift car will be at peak times, on average, when in service. However, this value is applied differently depending on the method, and its purpose is often misunderstood.

In calculation-based methods [1] [2] 80% capacity factor typically refers to 80% of the usable car area being occupied. In simulation models, cars are allowed to fill to 100% of their rated area, but their *average* loading is assessed over the simulation period to ensure it remains below 80%. This introductory discussion is necessarily simplified, and the correct interpretation of the 80% figure in relation to the number of passengers is explained in more detail in Section 5.

Despite its widespread use, the 80% figure is often misrepresented. Some practitioners apply it (or adjust it to a lower value) to account for passengers accompanied by items such as luggage, prams, stretchers, hospital beds or wheelchairs that reduce the usable space in the car. Others use it to address the observation that the number of passengers calculated by dividing rated load by an assumed passenger mass often does not fit inside the car. These confusions are problematic: they distort the original intent of the 80% rule and lead to inconsistent results between calculation and simulation methods.

This paper explains how to effectively apply the 80% loading rule to ensure consistency between calculation and simulation, identifies common sources of confusion, and highlights the importance of using area-based measures to determine actual capacity.

# 2 UNDERSTANDING THE 80% CAPACITY FACTOR

The 80% capacity factor is best understood not as a design constraint, but as a performance benchmark. It reflects how much of the available lift car area is typically occupied in real use during peak periods, allowing for variability in passenger arrivals, group sizes, and human factors such as body size and behaviour. As such, 80% is not a maximum capacity but an average target for realistic, stable system performance. Both ISO 8100-32 [2] and CIBSE Guide D [1] emphasise that this figure is included for statistical reasons, reflecting variability in passenger arrivals and groupings rather than a hard physical constraint.

This concept also appears outside of the lift industry. Similar thresholds are used in other fields to indicate the point beyond which system performance becomes unstable or inefficient.

## 2.1 Beyond Lifts: 80% in Other Fields

The 80% utilisation threshold is not unique to lift traffic design. It appears across various engineering disciplines as a pragmatic upper bound for stable system operation. In telecommunications and data networks, capacity planning commonly adopts this figure to ensure reliable performance. For example, network monitoring platforms such as Nile Secure recommend setting alert thresholds around 80% capacity to trigger proactive intervention before user experience is affected [3].

Similarly, VIAVI's Observer platform designates the 60 to 80% utilisation range as a "warning zone," beyond which network congestion and latency begin to rise sharply [4]. These practices reflect a broader engineering principle: systems tend to degrade non-linearly as they approach saturation.

In queueing theory, Harrison and Whitt [5] [6] have shown that under heavy-traffic conditions, service systems, including those with idealised infinite-server assumptions, become increasingly sensitive to variability. Their work demonstrates that performance becomes less predictable and more volatile as utilisation increases, particularly under stochastic arrival and service times.

These parallels suggest that the 80% figure used in lift traffic design is not arbitrary. It represents a well-founded engineering threshold that provides a stable operating margin, helping to preserve consistent performance under peak conditions.

# 3 AREA VERSUS MASS

Lift traffic analysis should be based primarily on the number of people that can physically occupy a lift car, not the total mass they represent. While mass (rated load in kilograms) is important for the mechanical design and certification of lift systems, it is the platform area that determines actual passenger capacity during peak traffic conditions.

ISO defines the maximum allowable car area for a given rated load. These values, however, are not proportional to mass. As the rated load increases, the area per kilogram of rated load decreases. This means that using rated load as a proxy for occupancy can result in misleading conclusions.

To illustrate this, Table 1 shows the maximum car areas permitted by BS ISO 8100-30:2019 for a selection of rated loads (excluding finishes), together with the resulting area per person. The rated passenger capacity has been calculated by dividing the rated load by 75 kg/person and rounding down to the nearest whole number. However, Table 1 below includes an additional column, 'area per person', which demonstrates that the area allowed per person decreases with car size. The rated capacity in persons, based on mass, gets less realistic as the car sizes get larger.

**Table 1 Rated load vs. maximum car area (from BS ISO 8100-30:2019) and resulting area per person, assuming 75 kg/passenger (rounded down to the nearest whole number).**

| Rated load, mass (kg) | Maximum available car area ($m^2$) | Rated passenger capacity (persons) | Area per person ($m^2$/person) |
|---|---|---|---|
| 630 | 1.66 | 8 | 0.21 |
| 800 | 2.00 | 10 | 0.20 |
| 1000 | 2.40 | 13 | 0.18 |
| 1275 | 2.95 | 17 | 0.17 |
| 1350 | 3.10 | 18 | 0.17 |
| 1600 | 3.56 | 21 | 0.17 |
| 1800 | 3.88 | 24 | 0.16 |
| 2000 | 4.20 | 26 | 0.16 |
| 2500 | 5.00 | 33 | 0.15 |

*Note: Values are based on ISO maximum car areas. Installed cars are often smaller due to finishes or shaft constraints.*

Where two lifts with the same rated load in kg have different floor areas, they will appear to have the same handling capacities if only mass is considered, even though their physical capacity to carry passengers differs.

It should be noted that the average areas per passenger shown in Table 1 are derived directly from ISO maximum car areas. In practice, however, larger values are normally adopted in design. For example, CIBSE Guide D [1] recommends 0.21 $m^2$ per person for office traffic.

A practical example illustrates the real-world impact: a 1600 kg lift was observed with a platform area of 2.92 $m^2$, significantly smaller than the 3.56 $m^2$ maximum permitted area. The car had a nominal capacity of 21.3 persons (1600 kg ÷ 75 kg), which yields a rated capacity of **21 persons**. However, based on area and assuming 0.21 $m^2$/person (the office design standard), the car would accommodate only 13.9 persons (2.92 $m^2$ ÷ 0.21 $m^2$/person).

In use, the observed maximum loading was **14 persons**, closely matching the area-based estimate and showing why mass is an unreliable proxy for occupancy. This observed case illustrates the difference between ISO maximums, installed cars, and design practice.

In practice, there is no way to govern the exact number of passengers that will enter a car. Occupancy depends on passenger behaviour, groupings, and comfort preferences, which cannot be controlled precisely. Car area therefore provides the most reliable approximation of capacity for traffic analysis, supported by passenger area allowances. This point is discussed further in Section 4.

This issue becomes even more critical in the context of evacuation analysis. Overestimating lift capacity based on rated load may lead to underestimated evacuation times, providing a false sense of compliance or safety.

In practice, as the 1600 kg case shows, occupancy is set by area, not by load. For realistic and robust lift traffic modelling, the area should be the foundation of both calculation and simulation. Mass may also be considered, but only supplementary to the area, with the lowest calculated car loading applied.

## 4 AVOIDING CONFLATION

While the 80% loading rule is widely accepted in lift traffic design, it is sometimes misunderstood or misapplied.

One of the most persistent misconceptions is that the 80% rule exists to compensate for the mismatch between rated capacity (in kg) and the actual number of passengers a car can fit, as discussed in Section 3. For example, some assume that a lift rated at 1600 kg for 21 persons should be expected to carry 17 passengers, applying 80% to correct a perceived physical shortfall. This reasoning confuses unrealistic mass-based car loading with a threshold intended to allow for a stable operating margin.

Another common error is to conflate the 80% figure with allowances for large or encumbered passengers, such as those carrying luggage, pushing prams, or using wheelchairs. This has led some designers to arbitrarily reduce the 80% value to 70%, 60%, or lower, to reflect such real-world conditions. While well-intentioned, this practice is both unnecessary and counterproductive.

Instead, a better way to account for non-standard passenger types is by adjusting the assumed area per person. CIBSE Guide D [1] recommends:

- 0.21 m² per person for general office traffic,
- 0.3 m² per person for hotels and residential buildings,
- Larger values for healthcare or other environments where luggage or mobility aids are common.[1]

By keeping the 80% average car loading by area constant and varying the area per person, designers can adapt to different use cases without compromising the underlying methodology.

## 5 THE 80% RULE IN CALCULATION

In traditional lift traffic analysis, the 80% rule is applied directly within the round-trip time (RTT) calculation methodology. These calculations estimate handling capacity and interval for a group of lifts by modelling a hypothetical "average" round trip under peak conditions. A key parameter in these calculations is the average number of passengers per car.

To determine this, designers start with the available platform area of the car and divide it by an assumed area per person, such as 0.21 m² for offices. However, to allow for a stable operating margin, the full area is not considered usable. Instead, 80% of the platform area is taken as the practical maximum occupancy; this is the capacity factor.

For example, a 1600 kg car with a 3.56 m² platform and a 0.21 m²/person space allowance would have a theoretical capacity of 3.56 m²/0.21 m²/person = 17.0 persons. Applying the 80% capacity

[1] In practice, effective space requirements can be higher, for example in modern offices where many passengers carry bulky rucksacks, laptops or food trays. In more complex environments such as hospitals or public buildings, it may be more appropriate to model different user groups separately. Wheelchair users, patients in beds and staff moving goods each require different amounts of car area, so treating them as distinct categories rather than applying a single higher average value for the whole population may give a more realistic representation of usage and allow performance to be considered for each group individually.

factor results in an average loading of 80% of 17.0 = 13.6 passengers per trip, which is then used in the round trip time and handling capacity calculations.

This approach has been well established in CIBSE Guide D for decades. It ensures that performance metrics such as handling capacity (% of population served in 5 minutes) and interval (average time between car departures) are based on realistic loading levels, not idealised or extreme ones.

In the calculation method, 80% is not variable. It is not adjusted for building type or user group; instead, such variations are reflected by altering the area per person value. This consistency keeps the method simple, repeatable, and transparent.

### 5.1 Calculations using iterations

The 80% rule also supports calculation methods using iteration, applying techniques such as the enhanced uppeak [7], general analysis [8] and Monte Carlo simulation [9], where the capacity factor is adjusted until the design passenger demand is achieved.

Here, the 80% car loading is being used as a design check. If, to achieve the required handling capacity, the calculated capacity factor exceeds 80%, the design is likely to fall short in practice.

## 6 THE 80% RULE IN SIMULATION

Dispatcher based simulation more accurately reflects real-life operation than calculation methods. Passengers do not arrive at regular intervals [10] or fill lifts evenly, so modelling these variations directly offers a more detailed view of system behaviour. Nevertheless, the 80% loading figure remains key, not as an input but as a validation criterion.

In a simulation, the 80% rule is not applied as a fixed input. Instead, it is used as a performance check on the results. Simulations model individual passenger journeys in detail, accounting for varying arrival times, lift movement, and loading behaviour. Each car is permitted to fill up to its full rated area (and mass if considered), i.e. a capacity factor of 100%, not 80%. However, the average car loading across all trips during any 5-minute period should not exceed 80% to ensure a stable operating margin.

It is important to note that if cars are permitted to load up to 100% in simulation, the assumed area per person must still be chosen carefully. Otherwise, the model may allow cars to fill with more passengers than would be comfortable or physically realistic.

ISO 8100-32 applies the 80% figure in different ways depending on whether car capacity is derived by mass or area, and whether the method is calculation or simulation. When using rated load (mass), ISO introduces the loading factor $F_1$ and recommends that it should not exceed 0.8 (80%). When using car area in the calculation method, the same 0.8 factor is applied inside the equations to determine the average passengers per car ($P_{calc}$). However, in the simulation method, the factor is not applied: the maximum number of passengers per car ($P_{sim}$) is based on the full available area, unless the modeller chooses to set a lower loading limit $F_1$. This creates an inconsistency as calculation methods always embed the 80% assumption, while simulation methods in ISO do not. To maintain alignment, CIBSE Guide D goes further by recommending that cars may load to 100% in simulation, but that the average capacity factor by area should then be checked to ensure it remains at or below 80% over the peak period. This approach reconciles the two methods and avoids the risk of simulation producing results based on unrealistically high average car loadings.

For example, in a simulation of a morning up-peak, a system may achieve acceptable waiting and transit times; however, if cars are on average loaded to 90% of their rated capacity by area, the performance is unlikely to be stable in real-world operation. Such a design would be overly sensitive to fluctuations in arrival rates or unexpected passenger behaviour, leaving little room for variation.

In simulation, this post-analysis check of car loading allows us to ask not only if people are being served within an acceptable time, but also if the system is running too close to saturation. If average car loading consistently exceeds 80%, the system may be fragile and unresponsive to fluctuations in demand.

ISO 8100-32 does not currently include this post-simulation check. Instead, it requires additional simulations at higher traffic densities to test the robustness of the design. While this provides a safeguard, it can involve arbitrary steps in demand and does not directly address whether average car loadings are realistic. By contrast, the approach described in CIBSE Guide D [1] and implemented in popular simulation tools [7] allows for nuanced system analysis without compromising on the core design principle that 80% average car loading should not be exceeded. It also aligns simulation with analytical calculation, providing consistency across methods and clear criteria for assessing system adequacy. As a member of ISO/TC 178/WG 6/SG 5, which develops ISO 8100-32, the author considers this method more robust, as it avoids the instability that arises as system loading approaches saturation, and believes it should be adopted in a future revision of the standard.

### 6.1 Simulation Stability and the 80% Threshold

One of the key reasons for applying the 80% average car loading threshold in simulation is that system behaviour becomes increasingly unstable as this figure is exceeded. At higher loadings, simulation results become more variable between runs, more sensitive to small changes in demand, and more prone to extreme queues or wait times.

This phenomenon occurs because the system does not have sufficient capacity to recover from short-term overdemand (where demand temporarily exceeds capacity) caused by random variations in passenger arrivals. As utilisation approaches 100%, queues no longer clear between peaks, so delays and congestion grow rapidly rather than in a straight line. This is similar to road traffic: a motorway may flow steadily up to a point, but once it becomes saturated, even a small increase in cars can cause long-lasting traffic jams.

A clear demonstration of this can be found by running simulations using ISO 8100-32:2020 traffic templates. These constant demand templates are typically run for two hours, with a passenger demand and traffic mix selected according to the building type and time of day, see Figure 1.

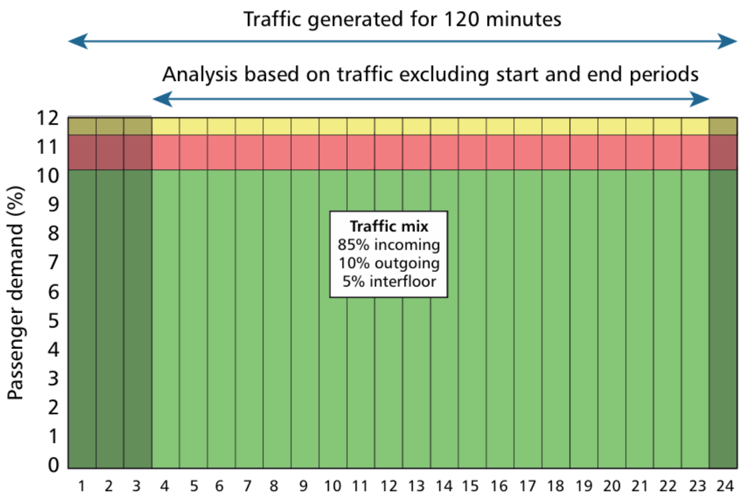


**Figure 1 Example ISO Template for office during uppeak**

When simulations are run at the demand levels defined by the templates, the resulting car loadings should be less than 80% on average. However, if demand is increased further, even slightly, car loading can climb above 80%, and simulation results become less consistent.

For example, consider a simulation of a

- 5 car group, 1275 kg cars (2.95 m² platform area) at 1.6 m/s
- serving 12 floors above ground
- 70 people per floor above ground
- An uppeak passenger demand with traffic mix 85% incoming, 10% outgoing, 5% interfloor

ISO 8100-32:2020 requires a single simulation, but ten simulations were run for illustrative purposes to investigate stability.

Figure 2 shows the average waiting time results for a total passenger demand of 11.5%, 12.0%, 12.5%, and 13.0%, corresponding to average car loadings by area of 71%, 79%, 86%, and 88% on departure from the ground floor.

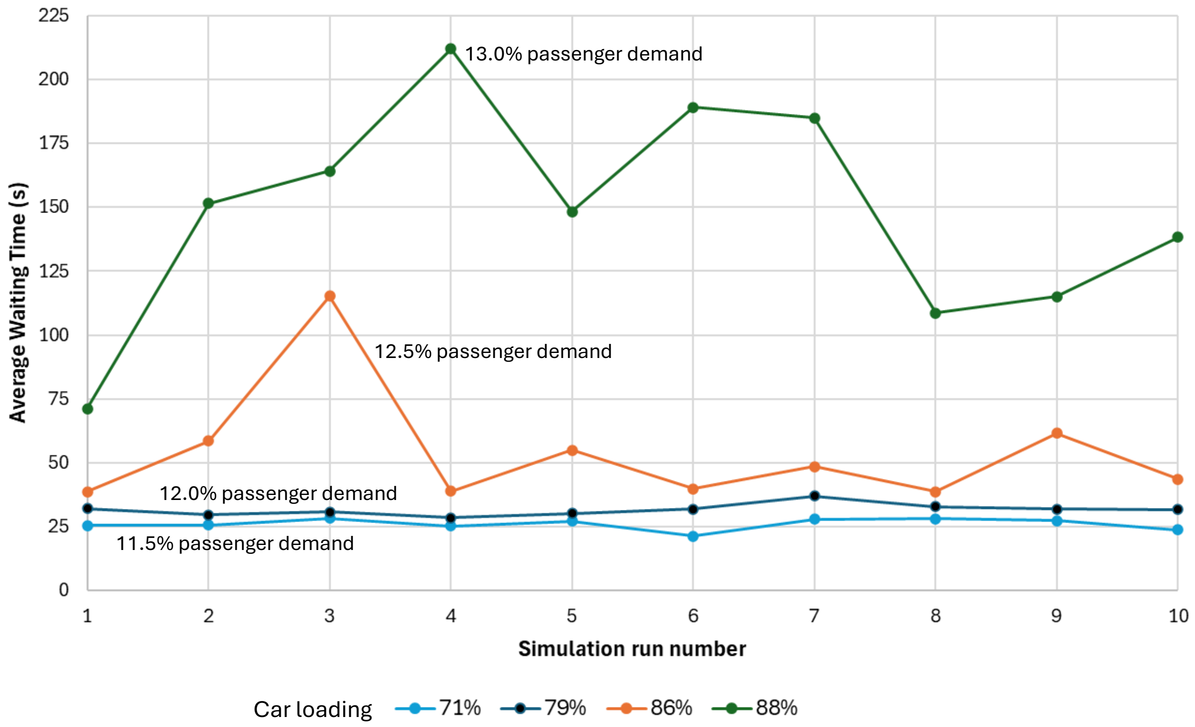


**Figure 2 Average Waiting Time results for simulations at four increasing levels of demand, resulting in increasing car loading and decreasing stability**

While the car loading is under 80% (light and dark blue plots), the results of the different runs are consistent. For the results above 80% (orange and green plots), the results of the various runs vary significantly.

A useful mathematical tool in this context is Standard deviation. Standard deviation is a statistical measure that quantifies the amount of variation or dispersion in a set of values. In the context of lift simulation, it provides a numerical indication of how much the results, such as average waiting time, fluctuate across multiple simulation runs. A low standard deviation suggests that the system behaves consistently under repeated conditions, whereas a high standard deviation indicates instability and unpredictability.

**Table 2 Standard deviation results for increasing passenger demand and car loading**

| Passenger demand (% population per 5 minutes) | Car loading by area (%) | Waiting time standard deviation over 10 runs |
|---|---|---|
| 11.5 | 71 | 2.2 |
| 12.0 | 79 | 2.3 |
| 12.5 | 86 | 23.3 |
| 13.0 | 88 | 42.2 |

The results in the table illustrate a clear relationship between car loading and the stability of simulation outcomes. At passenger demand levels of 11.5% and 12.0%, where average car loadings are below 80%, the standard deviation is low (2.2 and 2.3, respectively), indicating consistent and predictable system performance across multiple simulation runs. However, once car loading exceeds 80%, variability increases dramatically. At 12.5% demand (86% loading), the standard deviation jumps to 23.3, and at 13.0% demand (88% loading), it rises further to 42.2. This sharp increase demonstrates that the simulation results become increasingly unstable as the system operates closer to saturation. These findings reinforce the importance of maintaining average car loading below 80% as a practical threshold for reliable system behaviour and meaningful simulation analysis.

A standard deviation under 5% (ideally closer to 2–3%) would be a reasonable and practical definition of a stable result for average car loading across multiple simulation runs. This numerical guideline reflects established practice in engineering simulation rather than a formal statistical theorem. It follows the general principle of Monte Carlo simulation, where repeated runs are used to assess stability and convergence, and results are considered adequate once variation between runs is sufficiently small.

## 7 SUMMARY AND RECOMMENDATIONS

The 80% figure is a cornerstone of lift traffic analysis, but its purpose and correct application are often misunderstood. This paper has explored the basis of 80% car loading, its use in both calculation and simulation, and the importance of distinguishing it from other concepts related to car loading.

In calculation methods, 80% is applied directly to the available platform area. Combined with an assumed area per person (e.g. 0.21 $m^2$ in office buildings), it defines the number of passengers per trip used in round-trip time analysis.

In iterative calculation methods, where the passenger demand is an input, the 80% capacity factor by area becomes a result threshold.

In simulation, cars are allowed to fill to 100% of their rated area. The 80% rule is then applied as a validation threshold to ensure that the average car loading remains within a stable and realistic range.

Confusing or conflating the 80% rule with allowances for large passengers, pushchairs, or beds is a common mistake. These cases should instead be addressed by increasing the assumed area per person, not by reducing the 80% benchmark.

The assumption that 80% compensates for discrepancies between rated mass and actual occupancy is incorrect. Passenger capacity is constrained by floor area, rather than rated loading, and this distinction becomes particularly critical in safety-related applications, such as evacuation modelling.

Simulation results become unstable when average car loading exceeds 80%, reinforcing the need to maintain this threshold in design validation.

By applying these principles consistently, designers can produce lift traffic models that are realistic, resilient, and defendable, helping to avoid the costly consequences of underperforming vertical transportation systems.

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# Enabling Innovation Through an Internet of Things (IoT) Platform that Operates Alongside the Lift Controller Without Modifying the Safety Chain

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**Keywords:** Internet-of-Things (IoT), Platform Technology, Dispatching, Innovation

**Abstract.** The vertical transportation industry is dominated by a small number of global players who have introduced many significant innovations. However, these have typically been deployed as proprietary systems, limiting wider adoption and preventing others in the industry from building upon them.

Various efforts have been made to increase accessibility and interoperability across manufacturers, particularly for self-contained subsystems where innovation is permitted within the bounds of applicable codes. More intelligent applications, however, often require interaction with the lift controller.

To improve interoperability, multiple initiatives have sought to standardise communication protocols between lift controllers and subsystem devices. Despite some of these efforts dating back decades, widespread adoption remains limited. In the absence of regulatory requirements, uptake depends on individual manufacturer strategy—many of whom favour fully integrated systems for reasons including product standardisation, subsystem coordination, and legacy compatibility.

This paper explores an alternative approach: enabling innovation through an Internet of Things (IoT) platform that operates alongside the lift controller without modifying the safety chain. The system architecture uses retrofittable edge devices that are compatible across different lift manufacturers and models to monitor door activity and passenger movement.

Designed for compatibility across manufacturers, models, and equipment generations, this approach creates new opportunities for integrating functions such as intelligent dispatching and people-flow analytics without relying on proprietary system access. By decoupling innovation from the core controller, it offers a scalable path towards greater openness and faster adoption of new technologies across the industry.

## 1 INTRODUCTION

Innovation can be open or closed depending on the extent to which an organisation needs or chooses to interact with a wider ecosystem. Historically, innovations were mainly closed, involving little communication or collaboration outside the organisation. In today's highly connected, networked, knowledge-based economy, open innovation is increasingly becoming a necessity to remain competitive as innovation cycles become increasingly shorter. Open innovation, by its very nature, requires knowledge exchange outside the organisation and in particular across the organisation's supply chain [1]. Essentially, open innovation leverages external relationships and collaboration to enhance systemic knowledge-sharing and drive innovation outcomes. Table 1 on the next page outlines the high-level differences between closed versus open innovation according to Chesbrough [1].

**Table 1 Closed vs. Open innovation**

| Innovation Type | Intra-Organisation | Supply Chain | Wider Ecosystem |
|---|---|---|---|
| Closed | In-house research and development. | Joint research and development activities between two supply chain partners | Not Applicable |
| Open | Not Applicable | Co-development, IP-licensing, joint venture activities | Strategic partnerships, informal network, wider knowledge sharing |

The global lift industry is traditionally characterised by its closed innovation, for which various reasons exist. Section 2 explores the current innovation dynamics in the lift industry. Nevertheless, the introduction of IoT-based technologies has and continues to have a profound impact on the innovation dynamics of the lift industry. Section 3 explores how the adoption of IoT is nudging the lift industry towards more open innovation. Subsequently, given the long lifespans and modernisation intervals of lifts, retrofit solutions are needed to make innovation accessible to the wider lift installed base. Section 4 explores how new innovations could be retrofitted on existing equipment if the safety chain is not impacted. Section 5 builds on the previous section by exploring possible practical applications from a technology viewpoint. Section 6 concludes this paper, summarising the key points.

## 2 CURRENT INNOVATION DYNAMICS IN THE LIFT INDUSTRY

The global lift industry is traditionally characterised by its closed innovation, for which there are various causes. This section will explore some of the common characteristics that drive the lift industry's tendency towards closed forms of innovations.

### 2.1 Limited need for innovation

Although records on the practical application of lifts can be traced back to the ancient Greek mathematician Archimedes of Syracuse in 236BCE [2] (recent studies trace it even further back to the construction of the Saqqara pyramid approximately 2500BCE [3]), lifts were not considered safe for use by people and therefore restricted in use for lifting materials. It was not until the invention of the lift safety brakes, which prevent lifts from falling down the shaft if the suspension cables fail, by Elisha Graves Otis in 1853 [4], that lifts became safe for use by humans. With the successive inclusion of electric motors since 1880 by Werner von Siemens [4] and automatically operated lift doors since 1887 by Alexander Miles [5], the public's confidence in the safe and convenient use of lifts increased, and the lift industry took off.

Lift design consolidated early on into a well-defined set of common elements: the cabin, counterweight, suspension cables connecting the two, rails to guide the cabin and counterweight, a motor hoist for the actual lifting, and, of course, the safety brake to prevent a free-fall from happening. Respectively, hydraulically powered lifts use a mechanism whereby a pump motor pumps hydraulic fluid into or out of a piston-cylinder, pushing a cabin up or facilitating a controlled descent from below, eliminating the need for suspension cables and a counterweight.

The consistency of the base design over time meant that there was little necessity for major innovations. Mostly, development was focused on gradually improving existing lift and subsystem designs. Wider cross-industry technology trends such as automation through electrification and later computerisation typically follow a gradual adoption curve in the lift industry. Although publicly available statistics are lacking, the development time for a new model lift is generally accepted to be between 5-7 years by industry professionals. Within this context, there was no need for the complexities typically associated with open innovation [6].

## 2.2 Few market leaders with a globally dominant position

A significant share of the global lift industry is dominated by a small number of players [7]. These dominant players are each characterised by a high degree of vertical integration, a business strategy where a company takes ownership of various stages of its production process to streamline operations and reduce reliance on external suppliers. This business strategy fostered the creation of highly integrated and manufacturer-specific systems and models.

Subsequently, innovation in the lift industry has been characterised by its closed nature. Research and development are mostly intra-organisational. Collaboration within the supply chain is typically limited towards how innovations from supply chain partners can be integrated into the lift manufacturer's next-generation lift model and certified accordingly. As a consequence, innovations by individual lift part manufacturers are not always compatible as a standalone innovation that is interchangeable between different lift manufacturers. Figure 2 below illustrates a simplified view of the lift industry value chain.

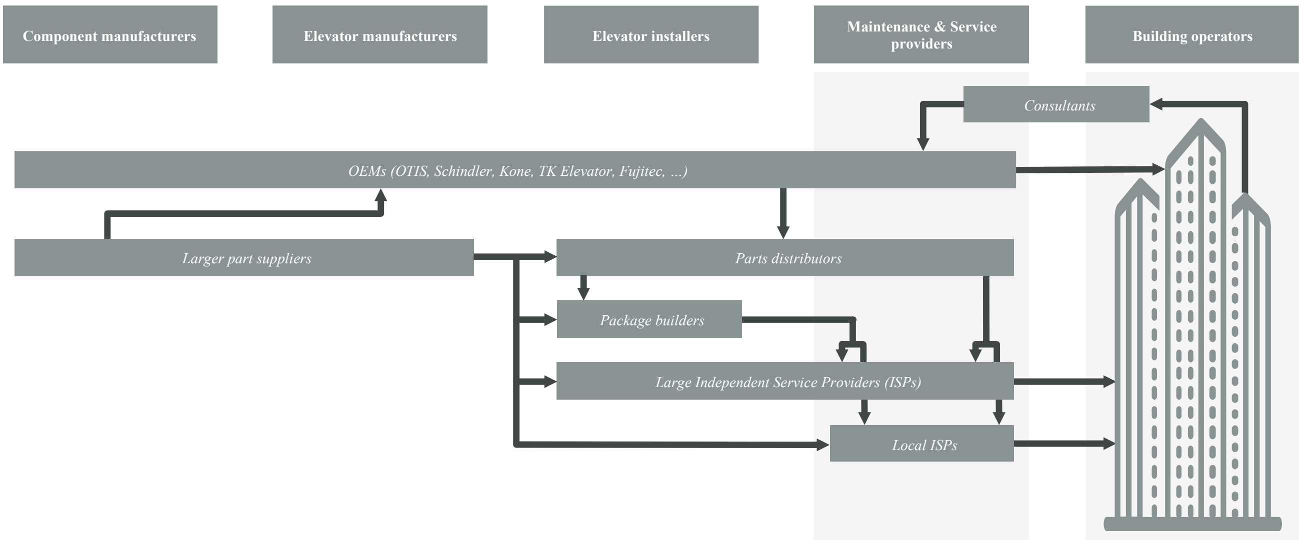


**Figure 1 Simplified view of the lift industry value chain (illustration by the author)**

## 2.3 Exclusivity and uniqueness as competitive advantages

Closed innovation of highly integrated certified systems arguably leads towards proprietary solutions by default (unless intervened by regulators or industry associations). As fewer companies became increasingly global dominant players within the lift industry, it is widely accepted that the make-up of the lift installed base evolved accordingly. Subsequently, it can be argued that the dominance of market leaders has now extended into the in-life phase of lift equipment; spare parts as well as more advanced troubleshooting capabilities are perceived as being dominated by the leading lift manufacturers. Therefore, no matter how minimised the effect, there will always exist a degree of dependency by independent players on the market leaders. Arguably, this dependency causes innovation barriers outside the control of independent players. Instead, incremental improvements of existing products catering to lift manufacturers is the typical path for smaller players across the supply chain.

Notwithstanding these dynamics, attempts are being made to mitigate the proprietary nature of the majority of lift systems. The conventional approach is to focus on the communication protocol. The lift control system is typically regarded as the proverbial "brain" of the overall system, meaning that for the lift to operate as an automated system, all subsystems need to be compatible with the respective lift control's communication protocol. To date, there is not a globally harmonised lift communication protocol, though various cross-industry communication protocols have found wider adoption in the lift industry (e.g. RS232, RS485, CAN, Ethernet, …). To improve this situation, the non-profit CAN in Automation (CiA) association (established in 1992 and based in Nuremberg, Germany) developed the CiA 417 profile – more commonly referred to as "CANopen Lift" communication protocol – for lift control systems and released it in 2002. The goal was to agree on a common specification which enables suppliers to design interoperable CAN-connected devices for lifts [8].

### 2.4 Notable exceptions exist where science is applied through technology

Science refers to the systematic study of the natural world, while technology refers to the application of scientific knowledge for practical purposes. The relationship between science and technology can be seen as a two-way street; scientific discoveries lead to technological advancements, and vice versa, technological innovations drive scientific research.

The science behind lift dispatching is widely regarded as a field of study supportive of open innovation. The global lift community, as well as academia, has already collaborated closely for decades to further advance this field of study as well as its practical application through technology. However, in coherence with the lift industry's characteristic closed innovation, solutions remained proprietary.

Fortunately, the introduction of IoT has opened up the lift industry to modes of cooperation more supportive of open innovation. Essentially, access to digital technologies was needed by the lift industry; however, these were not core to its typical area of domain expertise. Also, innovation cycles were much shorter, meaning that gradual incorporation of these technologies over time – as was the approach until then – was not a viable option. Cross-industry collaboration was therefore inevitable.

The next chapter will explore how the adoption of IoT is nudging the lift industry towards more open innovation. Subsequently, section 4 explores how IoT is crossing over into the domain of lift dispatching, enabling retrofit-based solutions for the existing lift installed base.

## 3 HOW THE ADOPTION OF IOT IS NUDGING THE LIFT INDUSTRY TOWARDS MORE OPEN INNOVATION

The introduction of Internet-of-Things (IoT) based technologies provided an opening towards more open innovation within the lift industry. IoT is a technology domain characterised by collaborative efforts and fast innovation cycles. The practical application of IoT continues to have a profound impact on our everyday lives and has subsequently found widespread adoption across industries. Like other internet-based technologies, its development is in a constant state of flux with limited standardisation and regulation. Due to these characteristics, the introduction of IoT technologies into the lift industry necessitated the market leaders to extensively collaborate outside their organisation.

Initially, the introduction of IoT into the lift industry was mostly regarded as an evolutionary step in remote lift monitoring – a technology that was well established since the early 1990s [9]. However, the open innovation ecosystem soon presented opportunities for IoT technology to be leveraged further. One such use case is the robot-lift interaction for autonomous robotic multi-floor operation [10]. Another use case is touchless lift access through a voice command using a cloud-based virtual assistant (e.g. Amazon Alexa) [11]. As the number of use cases keeps expanding, multiple market leaders have meanwhile introduced new, digitally native lift models such as EOX (TKE), DX-class (KONE), and the Gen3 (OTIS). With IoT first introduced at scale since 2015 [12], the lift industry has advanced significantly over the past 10 years.

As open innovation provided accelerated access to new technologies, scaling these necessitated another key enabler: finding a solution to retrofit the existing lift installed base. Although coherent statistics on the global lift installed base do not exist, Statista puts the number at 20 million lifts globally as of 2023 [13]. According to a related statistic by Statista, 1 million new lifts were added to the global installed base in 2023 [14]. At first glance, it could be argued that with an installation rate of new equipment being 1 in 20 against the existing installed base, the need for retrofittable solutions is less urgent. However, when taking a deeper look, this would be an incorrect assumption.

Firstly, installed base developments differ significantly on a regional level. According to the National Elevator Industry, Inc. (NEII), the US had an installed base of 1.03 million lifts as of 2020, and 40,000 new installations in 2016 [15]. According to the European Lift Association (ELA), Europe had an installed base of 6.22 million lifts and 145,397 new installations as of 2022 [16]. According to the China Elevator Association, China had an installed base of 10.63 million lifts and 1.03 million new installations as of 2023 [17]. Notwithstanding the coherency concerns of these statistics, what is clear is that China's emerging market accounts for the overwhelming majority of newly installed lifts globally.

Secondly, the lifecycle of existing lift equipment is generally tied to the lifecycle of the building it is installed in. Total replacements occur predominantly when a building is emptied and renovated in its entirety, as dependency on the lifts by the building's tenants does not allow prolonged unavailability of the lifts due to capacity handling concerns. A lift, like any electromechanical equipment, is susceptible to wear and tear over time; modernisation intervals of existing lifts are typically between 20-25 years [8]. For example, the ELA states that over half of Europe's lift installed base is currently over 25 years of age [18].

It is therefore clear that to scale digital technologies fast in developed economies such as the US and Europe, the new installation channel is not a feasible main option. Hence, market leaders in the lift industry first focused on retrofittable IoT solutions before developing completely integrated systems. What remains, however, is that both solution types – despite the open innovation models that enabled their creation– are still largely proprietary, causing compatibility and interoperability issues between different manufacturers, models, and ages of lift equipment.

The next section explores opportunities that enable retrofitting of new technologies across the wider lift installed base, provided that the safety chain is not impacted. Earlier references regarding lift dispatching will be further elaborated upon as a practical example of how this could work.

## 4 RETROFITTING NEW TECHNOLOGY ON EXISTING EQUIPMENT MEANS RESPECTING THE SAFETY CHAIN

As elaborated in section 2.1 "Limited need for innovation", the invention of the safety brake by Elisha Graves Otis in 1853 made lifts safe for use by people for the first time in history. However, in modern lifts, the safety brake is part of a larger system of safety measures whereby the safety gear contact is part of the safety chain. Essentially, one break in the chain and the lift stops until the issue is resolved. For instance, if a sensor detects that a door lock has not engaged, the lift control system prevents motion of the lift, as riding with open doors is extremely dangerous with potentially lethal consequences.

Modern lifts have two basic sets of safety components: electrical and mechanical. The electrical components include the lift control system, sensors, and automation software. As elaborated in section 2.3 "Exclusivity and uniqueness as competitive advantages", the lift's control system serves as the proverbial brain of the lift. Subsequently, the sensors monitor the operation and safety-related functions and send such data back to the lift control system. The automation software provides an independent assessment to validate redundant sensor systems and operate the lift in a safe manner. The mechanical components include the lift's motor, hoist and its brake, overspeed governor, safety brakes, suspension cables, and the buffers at the bottom of the hoistway [19].

The overall system of safety measures is certified by independent authorities or notified bodies and may not be modified without recertification. To avoid potential scalability complications, the design of retrofit-based solutions for existing lifts should be preconditioned to not impact the overall safety system. This can be achieved through operating a separate intelligent platform alongside the lift control system, such as an IoT-gateway device.

Before IoT was introduced as the next generation technology for Remote Monitoring Systems (RMS) for lifts, RMS based on analogue technologies had been around since the late 1980s and had become mainstream in the 1990s [9]. Similarly, these earlier RMS were not part of the overall system of safeties – though in certain cases were designed to interface with them through means of a read-only mode – and essentially operated alongside the lift control system through a wired interface between the two systems. To function as a parallel platform, computer hardware and a communication modem were needed. These devices are typically referred to as "gateways". As IoT-based use cases advanced, so did the IoT gateways needed to enable them.

Around the turn of the current decade, the first IoT solutions using data directly from the sensor edge (typically referred to as sensor fusion) started to emerge in the lift industry. Unlike previous generations, which take pre-processed diagnostic data from the lift's control system, sensor fusion takes its data directly at the source from multiple different sensors working in parallel. This richer, more versatile data enabled a more physics-based data science approach towards analysing the health state of the lift. This not only changes the nature of lift monitoring – i.e. by removing the dependency on the lift's control system, sensor-fusion based IoT platforms are compatible and interoperable across different lift manufacturers, models, and ages – but also the possibilities of what additional insights can be derived from the sensors. For example, the optical sensors of the lift's light curtains lend themselves to object recognition, i.e. the counting of people and goods going in and out of the lift at every floor. This is where IoT crosses over with lift dispatching.

A modern lift traffic control system – often known as a dispatcher – can collect passenger calls in several ways. Conventional dispatching uses up-and-down buttons on the landing with additional buttons for each floor in the car. Destination control dispatching uses destination input devices on the landings so that passengers can select their required floor when the lift is first called. Hybrid dispatching systems use a combination of landing call buttons, car call buttons and destination input devices [20]. However, all of these methods are limited by inadequate access to information on the actual traffic of lift passengers entering and exiting the lift on each floor.

As the use of buildings evolves, the lifts are expected to accommodate this. In buildings with comparatively low lift utilisation, this is typically also the case. However, those buildings that operate with increased dependency on the lifts can be negatively impacted by evolving needs. For reference, IBM in 2010 surveyed 6,486 office workers in 16 U.S. cities for its Smarter Buildings study and asked them about 10 building-related issues, including waiting times for lifts. IBM tallied the cumulative time that office workers spent waiting for lifts during the past 12 months. Table 3 below shows the complete results [21].

**Table 2 Time spent stuck in or waiting for lifts**

| City | Labour Force -1/10 bls.gov | Adj Elevator Pop | Years Stuck in Lifts | Years Waiting for Lifts |
|---|---|---|---|---|
| Atlanta, GA | 2.664.311 | 683.800 | 1,9 | 4,3 |
| Boston, MA | 2.529.949 | 693.000 | 1,8 | 5,4 |
| Chicago, IL | 4.832.372 | 1.213.400 | 3,2 | 9,0 |
| Dallas–Fort Worth, TX | 3.211.548 | 743.220 | 2,4 | 5,5 |
| Denver, CO | 1.347.934 | 348.300 | 1,0 | 2,3 |
| Detroit, MI | 2.076.045 | 387.140 | 1,1 | 2,7 |
| Houston, TX | 2.881.612 | 878.460 | 2,9 | 6,8 |
| Los Angeles, CA | 6.412.821 | 1.230.240 | 4,3 | 8,7 |
| Minneapolis–St. Paul, MN | 1.842.087 | 539.768 | 0,5 | 3,1 |
| New York, NY | 9.436.392 | 2.053.548 | 5,9 | 16,6 |
| Philadelphia, PN | 2.990.914 | 663.625 | 1,7 | 6,0 |
| Phoenix–Prescott, AZ | 3.137.804 | 666.000 | 0,8 | 4,1 |
| San Francisco–Oakland–San Jose, CA | 2.229.581 | 691.730 | 1,4 | 4,5 |
| Seattle–Tacoma, WA | 1.889.840 | 506.400 | 1,0 | 3,2 |
| Tampa–St. Petersburg, FL | 1.309.090 | 263.800 | 0,6 | 1,6 |
| Washington. DC–Hagerstown, MD | 3.133.022 | 1.137.570 | 2,2 | 7,7 |
| | | **Totals** | **32,7** | **91,5** |

Without insights into how the building operates, the typical approach would be to upgrade the equipment such that round-trip times are optimised within the given limitations of the existing building. However, lift modernisations are both invasive to the lift system, disruptive to the riding public while in progress, and costly for the building owner (and ultimately the tenants). The next section will explore the possible practical application of dynamic dispatching on the basis of IoT infrastructure.

## 5 EXPLORING PRACTICAL APPLICATIONS FROM A TECHNOLOGY VIEWPOINT

An alternative approach to comprehensive lift modernisations that would arguably be less invasive, disruptive, and costly would be to leverage passenger traffic and lift health status data from sensor-fusion-based IoT solutions within the dispatcher, making it more dynamic.

The concept of Sensor Fusion essentially leverages sensory inputs from multiple sensors, which are then processed simultaneously and interpreted wholistically. When properly synthesised, Sensor Fusion helps to reduce uncertainty in machine perception as each sensor comes with its unique pros and cons. Using just one sensor to identify the surrounding environment is not sufficiently reliable, which translates to errors in the produced outcome. Conversely, Sensor Fusion algorithms process all inputs and subsequently produce outcomes with higher accuracy and reliability, even when individual measurements are not always sufficiently reliable [22].

Given the advancements of IoT gateway devices, such dispatching software is no longer dependent on compatibility with the lift's control system hardware. Rather, the dispatching software could run on a platform operating alongside the lift's control system either [A] locally on the IoT-gateway device or [B] centrally on the cloud:

[A] Dispatcher running locally on the IoT-gateway device: this setup envisages both the IoT signal processing and analytics software as well as the dispatcher software to be running on the same IoT-gateway device. By integrating or synchronising both software on the same device, IoT analytics are fed directly into the dispatcher algorithms without external processing layers in between. This way, there is minimal latency and no data transmission costs. Subsequently, the IoT-gateway device should interface directly with the lift's control system as an input device, giving the lift's control system dispatching instructions. However, to run both software on a single IoT-gateway device, hardware with increased performance specifications may be required, which could increase the initial investment in hardware.

[B] Dispatcher running centrally in the cloud: this setup envisages the dispatching interface to run inside a central cloud. For this setup to work, a data feed from the sensors through the IoT-gateway device needs to be transmitted to the dispatcher running in the cloud. Post processing of the data in the cloud, the dispatcher then sends back dispatching instructions to the lift's control system via the IoT-gateway device. In the author's view, there are several downsides to this approach. Firstly, the lift can no longer operate as a self-contained system, as the dispatching logic sits physically removed from the lift system. Second, there are latency considerations concerning the time it takes to communicate between the lift and the cloud. Thirdly, the recurring operational costs of the lift could arguably increase, considering the data transmission and cloud software licence fees.

The following applies to both cases [A] and [B]:

- Based on the solution being retrofittable to existing lift installations, the physical input signal to the lift's control system must be provided by the IoT-gateway device using a common/compatible communication protocol. A wide variety of such protocols is being used across the global lift portfolio; hence, possible cases of incompatibility cannot be ruled out at this point.

- The sensor data gathered can be transmitted to the cloud for data science purposes. For option [A], this capability is not mutually exclusive. For statistical relevance purposes, having access to a larger pool of traffic and dispatching data helps the continued data science development efforts.

- Future improvements to the respective software and algorithms can be installed remotely on the IoT-gateway devices through Over-The-Air (OTA) updates using the IoT backbone infrastructure.

## 6 CONCLUSION

Innovation can be open or closed depending on the extent to which an organisation needs or chooses to interact with a wider ecosystem. The lift industry is typically characterised by its closed innovation. With every aspect of innovation being conducted in-house, from research and development to implementation, only limited resources and perspectives are available for innovation. Although this hinders an organisation's ability to pursue major innovations and shorten innovation cycles, the base design for lifts remained stable over time; hence, there was no perceived need.

The introduction and comparatively fast-paced development and adoption of IoT started to change this paradigm. The domain of IoT has, since its inception, been thriving on open innovation. Collaboration across wider ecosystems and fast innovation cycles are hallmark characteristics. Subsequently, this necessitated market leaders in the lift industry to accept open innovation in pursuit of their digitalisation strategies.

To open up the lift to retrofitting new technologies, the safety chain must not be compromised. This is achieved by running a platform in parallel alongside the lift's control system, typically an IoT-gateway. As use cases expanded, IoT-gateway technologies needed to advance in tandem to accommodate. With the introduction of sensor fusion, IoT gateways needed to support extensive signal processing. This gave rise to new opportunities with existing sensor data, as these were no longer pre-processed by the lift control system. For instance, the optical sensors of the lift's light curtains enabled object recognition of what passes through the doors.

By incorporating passenger traffic data, the dispatcher becomes dynamic and arguably much more precise, as this data is not available through prior conventional means. By leveraging the IoT-gateway device, the dynamic dispatcher becomes accessible to a wider lift installed base with minimal invasive impact to the system, disruption to the riding public, and cost for tenants.

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## BIOGRAPHICAL DETAILS

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# Electromagnetic Compatibility (EMC) and Why it is Often Ineffective

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**Keywords**: Electromagnetic Interference, Emissions, Immunity

**Abstract.** In theory, meeting the global standards for Electromagnetic Compatibility (EMC) protects a lift or escalator from electromagnetic interference (EMI) caused by outside sources. It protects other equipment in a building by limiting the emissions generated by the vertical transportation equipment.

Installation methods and ageing often render EMC measures ineffective.

EMI and its sources are identified, both proper and improper installation methods are detailed, and the degradation of EMC equipment over time is explained.

## 1 INTRODUCTION

BS EN 81-20: Safety rules for the construction and installation of lifts – Lifts for the transport of persons and goods – Part 20: Passenger and goods passenger lifts [1], and BS EN 115-1, a similar standard for escalators and moving walks [2], include two normative references that address Electromagnetic Compatibility for lifts and escalators. The normative references are BS EN 12015 [3] and BS EN 12016 [4].

## 2 BACKGROUND

Electromagnetic compatibility, or EMC, involves the methods that permit electronic devices, such as lifts and escalators, to operate safely without interfering with other equipment through electromagnetic signals [5].

Electromagnetic interference (EMI) is the unwanted noise or signals emitted by electronic devices such as radio and television stations, mobile communication devices, variable frequency drives, switching power supplies and any circuit board with a clock or oscillator chip [6].

EMC ensures that a device does not emit too much EMI and that it is immune to a reasonable amount of interference from other sources.

### 2.1 BS EN 12015 Emissions

This standard establishes permissible levels of emissions over a wide frequency range. Levels for both radiated and conducted emissions are specified [3].

### 2.2 BS EN 12016 Immunity

This standard establishes minimum levels of electromagnetic interference that a lift or escalator must withstand for the following types of interference [4]:

1. Radio Frequency common mode from 80 MHz to 2,655 MHz.
2. Electrostatic discharge.
3. Fast transients, common mode.
4. Voltage surges.
5. Voltage dips (sags).
6. Voltage interruptions.

## 3 COMPLIANCE TESTING OF BS EN 12015 AND 12016

The verification of the ability of vertical transportation equipment to meet these standards is performed in a controlled laboratory environment. Typically, the electrical and electronic components of the lift or escalator system are connected electrically in an anechoic chamber. The chamber is a Faraday cage lined with Radio Frequency (RF) absorbing materials. The chamber creates a space where Radio Frequency Interference (RFI) from outside the chamber does not interfere with the testing process. Additionally, signals from the chamber do not interfere with electronic equipment outside the chamber. See Figure 1.

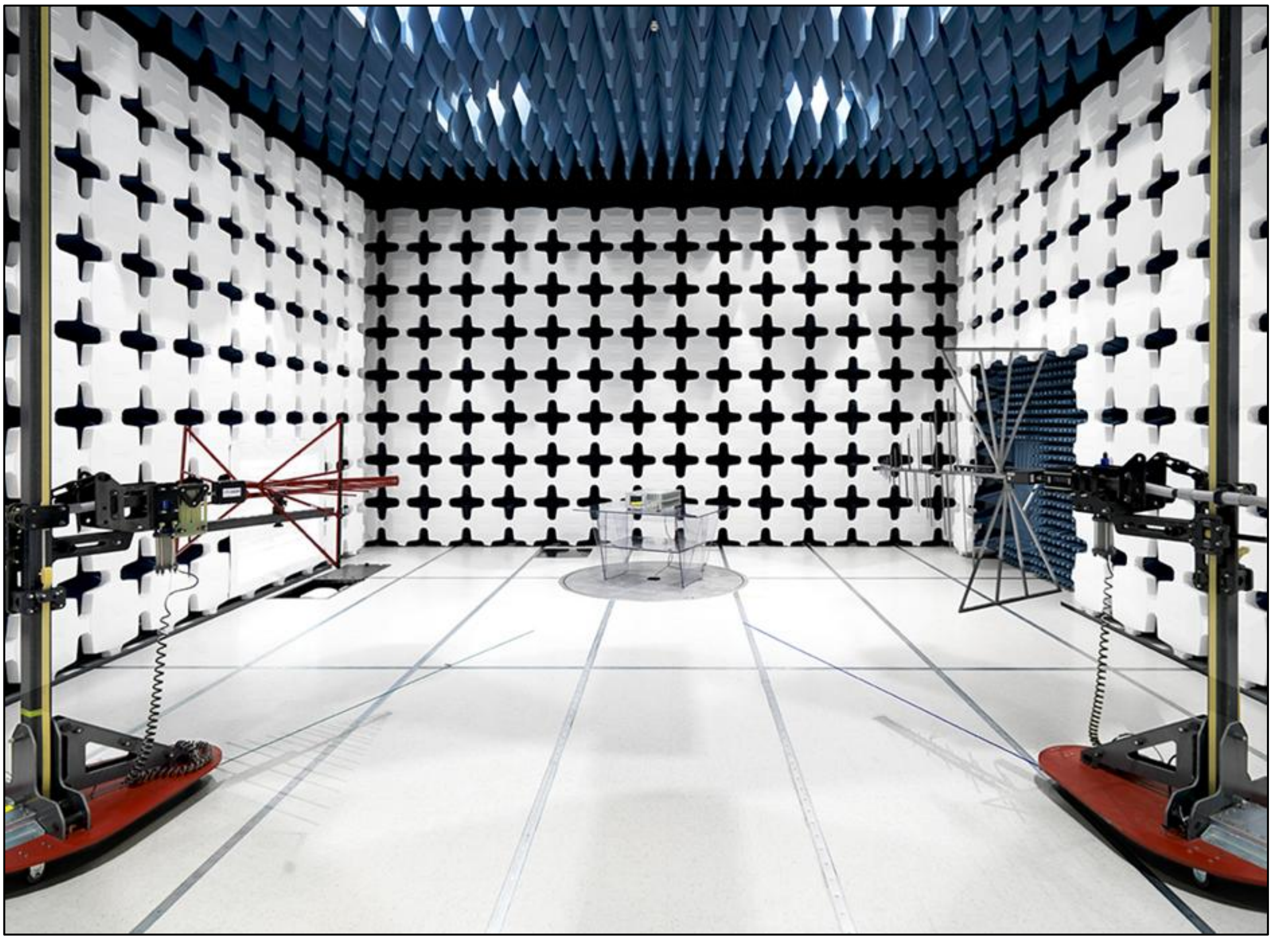
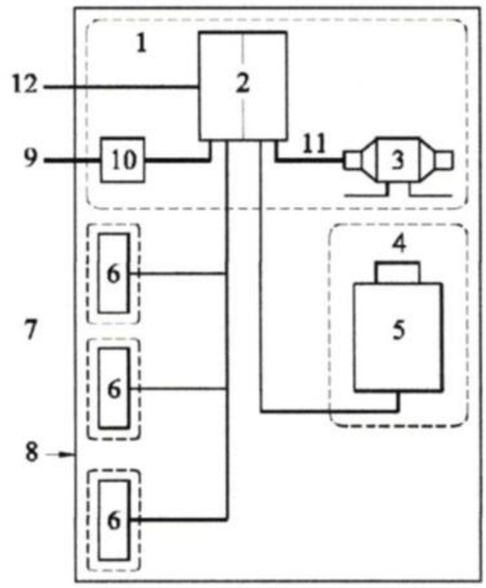


**Figure 1**

Figures 2 and 3 are excerpts from BS EN 12015 and BS EN 12016 that represent the components of lifts and escalators that are evaluated together in an anechoic chamber.

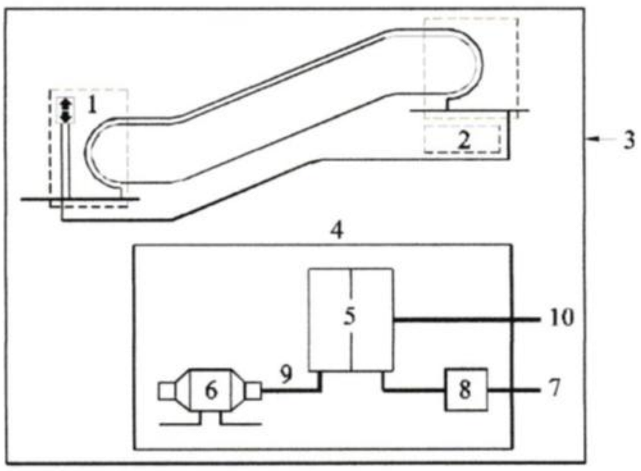



**Key**

[ ] assembly of apparatus

| | | | |
|---|---|---|---|
| 1 | machinery space | 7 | landings |
| 2 | main control/control cabinet | 8 | system boundary |
| 3 | machine | 9 | AC – and/or DC power ports |
| 4 | door control | 10 | main switch |
| 5 | lift car | 11 | output power port |
| 6 | apparatus installed at the landing (e.g. pushbuttons, indicators) | 12 | ports for monitoring and remote alarm systems |

**Figure 2**




**Key**

[ ] assembly of apparatus

| | | | |
|---|---|---|---|
| 1 | control panels | 6 | machine |
| 2 | machinery space (see 4 to 10) | 7 | AC – and/or DC power ports |
| 3 | system boundary | 8 | main switch |
| 4 | machinery space | 9 | output power port |
| 5 | main control/control cabinet | 10 | ports for monitoring |

NOTE The machinery space can also be an external room.

**Figure 3**

In lift and escalator installations, it is common to have long cables between components. Travelling cables, hoistway wiring, and wiring between upper and lower pits on escalators are examples of such long cables. When the cable length is anticipated to be longer than five meters in length, then a 5-meter length of cable is evaluated in the chamber.

### 3.1 Emissions testing

The components are placed in the anechoic chamber, connected, and powered from an external source.

#### 3.1.1 Radiated Emissions

Antennas are also placed in the chamber and connected to a receiver such as a spectrum analyser that is located external to the chamber.

The emission levels are recorded over a wide range of frequencies, and all the levels must be at or below the maximum levels required by the standard.

Examples of emitters are variable frequency drives, switching power supplies and any circuit board with a clock or oscillator chip.

#### 3.1.2 Conducted Emissions

The antennas are replaced by a coupling transformer connected to the power supply cables and the spectrum analyser. Note, the coupling transformer is located externally to the chamber. Emission levels are recorded over a wide range of frequencies, and all the levels must be at or below the maximum levels required by the standard.

### 3.2 Immunity testing

#### 3.2.1 Radiated interference

The antennas are reconnected to RF transmitters, and the transmitters bombard the systems with elevated levels of RF energy over the same frequency ranges. The RF radiation should not cause the system to malfunction.

#### 3.2.2 Conducted interference

A coupling transformer is connected to the power supply cable, and several types of interference are induced into the external power supply cable. The interference should not cause the system to malfunction.

#### 3.2.3 Electrostatic Discharge

An electrostatic discharge gun is used to subject the system to discharges of between 8 kV and 15 kV, depending on circuit type and whether the discharge is by contact or through the air.

### 3.3 Installation Instructions

Both standards contain a section titled *Documentation for the installer of the apparatus/assembly of apparatus.* This documentation must include the following:

1. Instructions for assembly and physical arrangement with other apparatus.
2. Instructions and precautions for interconnection to other apparatus.
3. Specifications of interconnection cables and devices.
4. Instructions for commissioning and testing.
5. Guidance on avoiding incorrect actions and assembly of apparatus which are known to cause noncompliance with the standard.

### 3.4 Efficacy of the standards

These standards have been in use for over 25 years. They have been upgraded periodically to keep up with changes in technology. The author has been involved with lift and escalator installations on six continents, where the equipment was built in compliance with these two standards. The only EMC issues encountered have been either units installed incorrectly or units that have been in operation for more than 10 years.

These two issues, which are quite common, will be explored in the next sections of this paper.

## 4 EMC INSTALLATION PROBLEMS

Most installation issues are related to the following:

1. Earthing
2. Coupling

### 4.1 Earthing

Earthing has two functions [7]:

1. Safety
2. EMI control

**Safety:** Most lift installers are familiar with how earthing prevents shock. If a controller cabinet were not earthed and a high-voltage power supply wire were to contact the cabinet, then a person contacting the cabinet and earth would be shocked. With an earthed cabinet, when the wire contacted the cabinet, a short circuit would occur, and the circuit would be interrupted by a fuse or circuit breaker.

**EMI Control:** High-frequency EMI tends to follow the path of least impedance (resistance). The grounding system offers that path, directing interference to earth and away from sensitive components [8].

Earthing for safety only requires that there be continuity between the object and earth. However, for alternating currents, particularly high-frequency alternating currents such as EMI, the currents are only conducted in the skin of the conductor. This is known as the **skin effect** [9].

### 4.2 Coupling

In addition to direct conduction, EMI can enter a system through coupling [10] [11]. The following are the three types of coupling:

1. Inductive
2. Capacitive
3. Radiative

These three types of coupling can be created by improper installation.

Inductive coupling occurs when wiring is placed close enough to create a transformer. When one thinks of a transformer, one usually thinks of coils of wire. However, electricity can be induced from one wire to another even if both wires are straight.

Capacitive coupling occurs when wires are placed close enough to behave like plates of a capacitor.

Radiative coupling occurs when wires function as a receiving antenna and interference is transmitted to the antennas of a system.

Coupling can be reduced through separation, shielding, and by a combination of both separation and shielding [12]. See Figure 4.

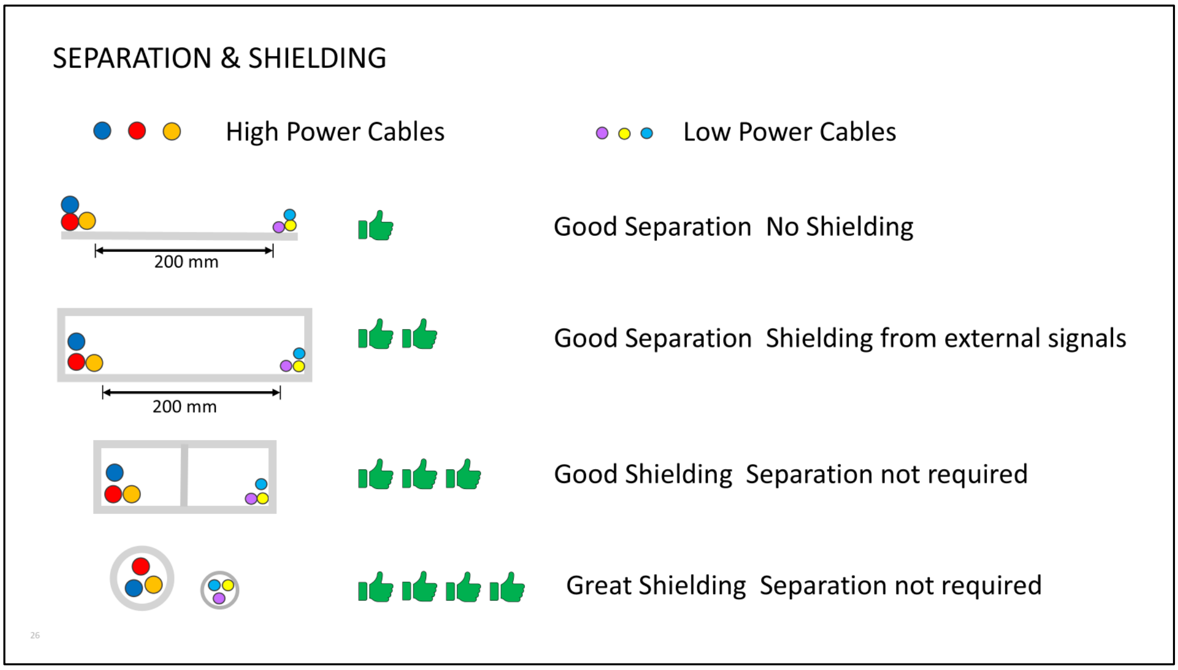



**Figure 4**

Figure 5 shows power and data cables laced together as they enter a Variable Voltage Variable Frequency (VVVF) drive.

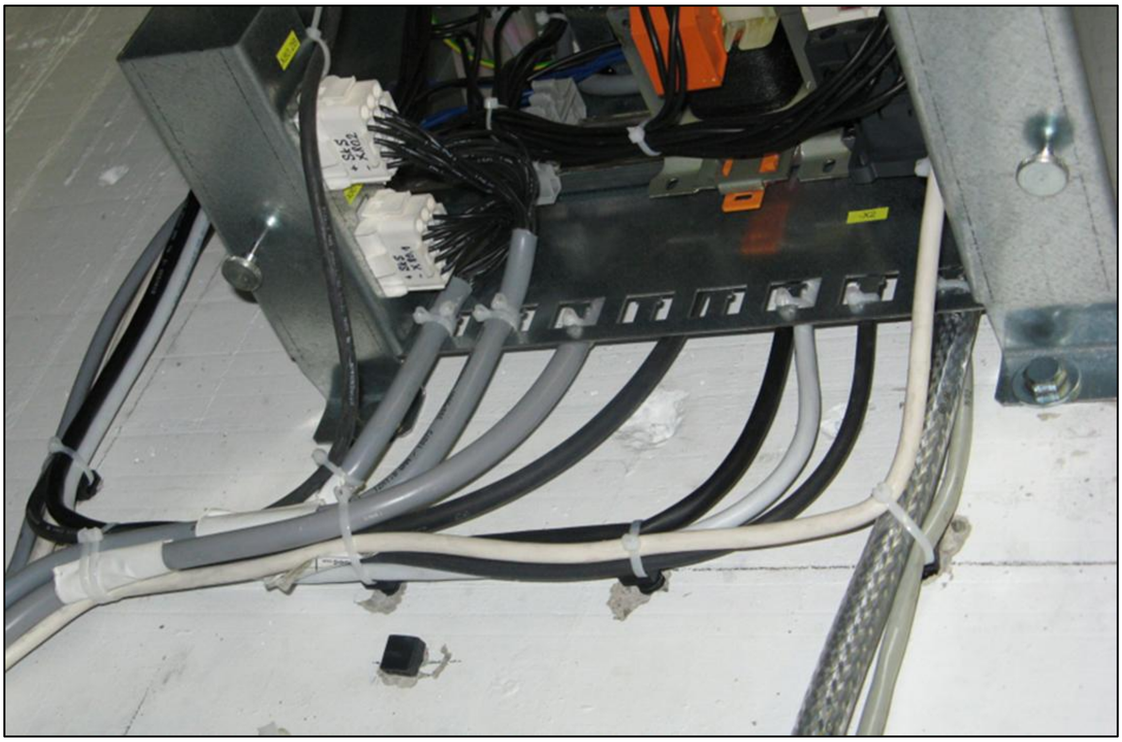


**Figure 5**

Figure 6 also shows power wires laced to data wires. However, in this case, the wires are looped to improve induction.

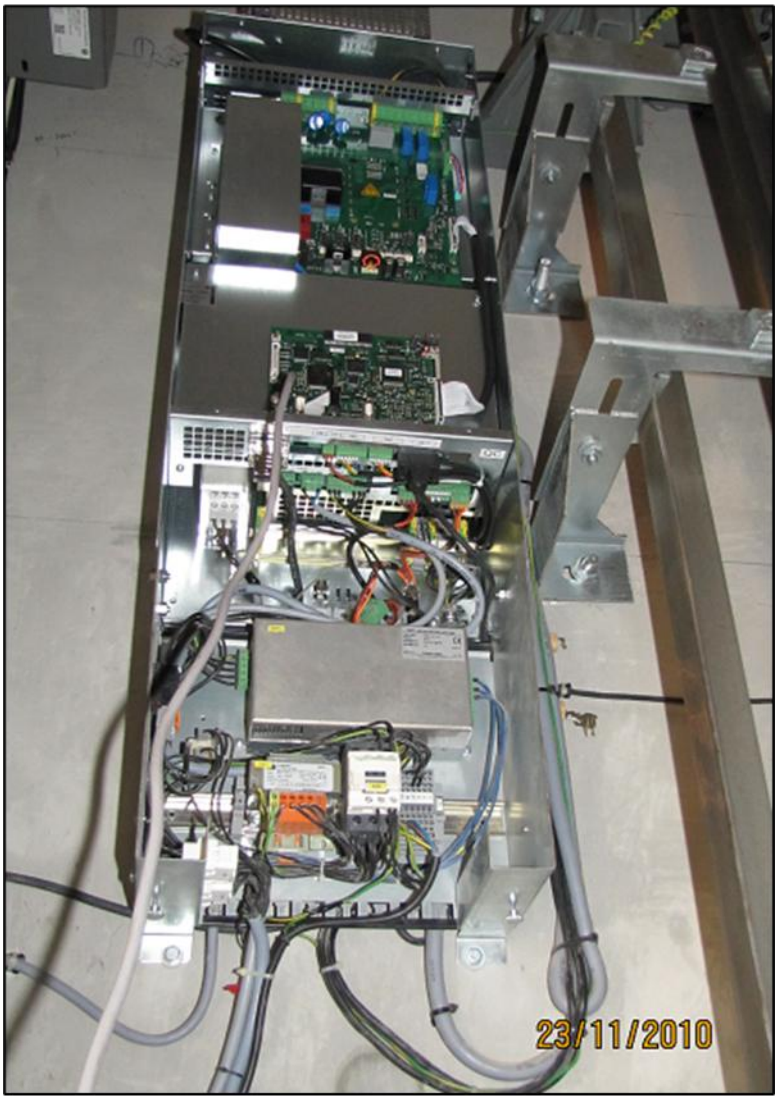



**Figure 6**

Figure 7 shows shielded cables correctly installed. Note how the entire circumference of the shields is connected to the control panel. This connection technique takes advantage of the skin effect to conduct the interference to earth.

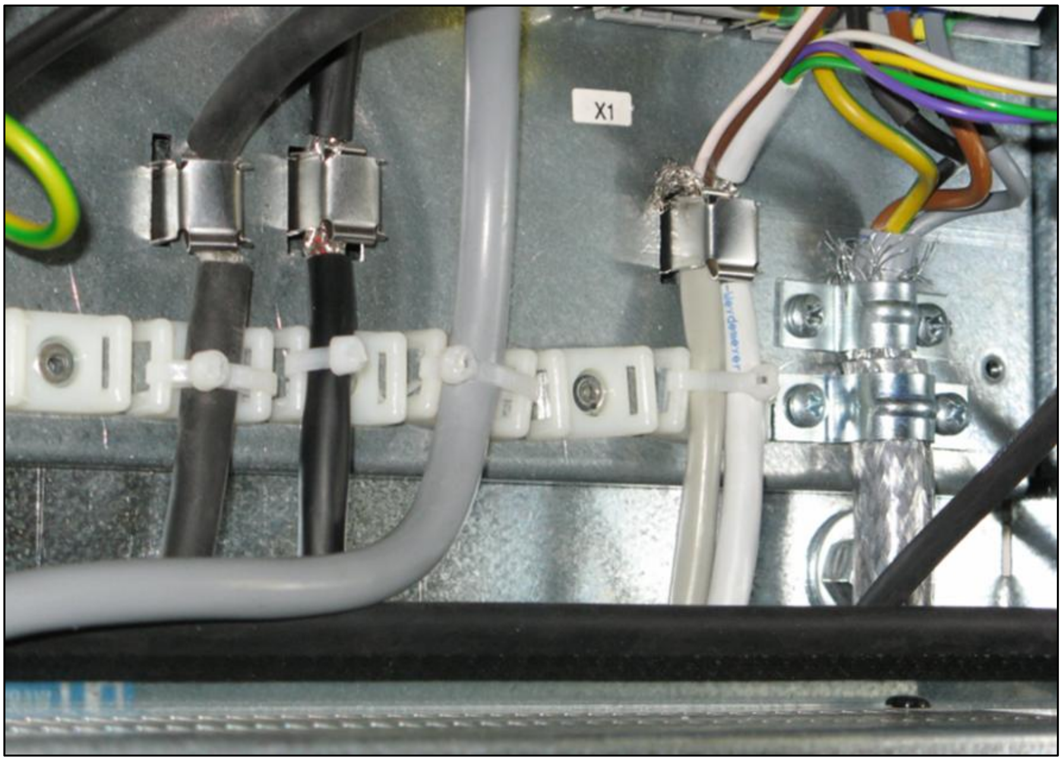



**Figure 7**

Figure 8 shows shielded cables improperly installed. The braided shield has been formed into a wire pig tail, and the pig tail is then earthed.

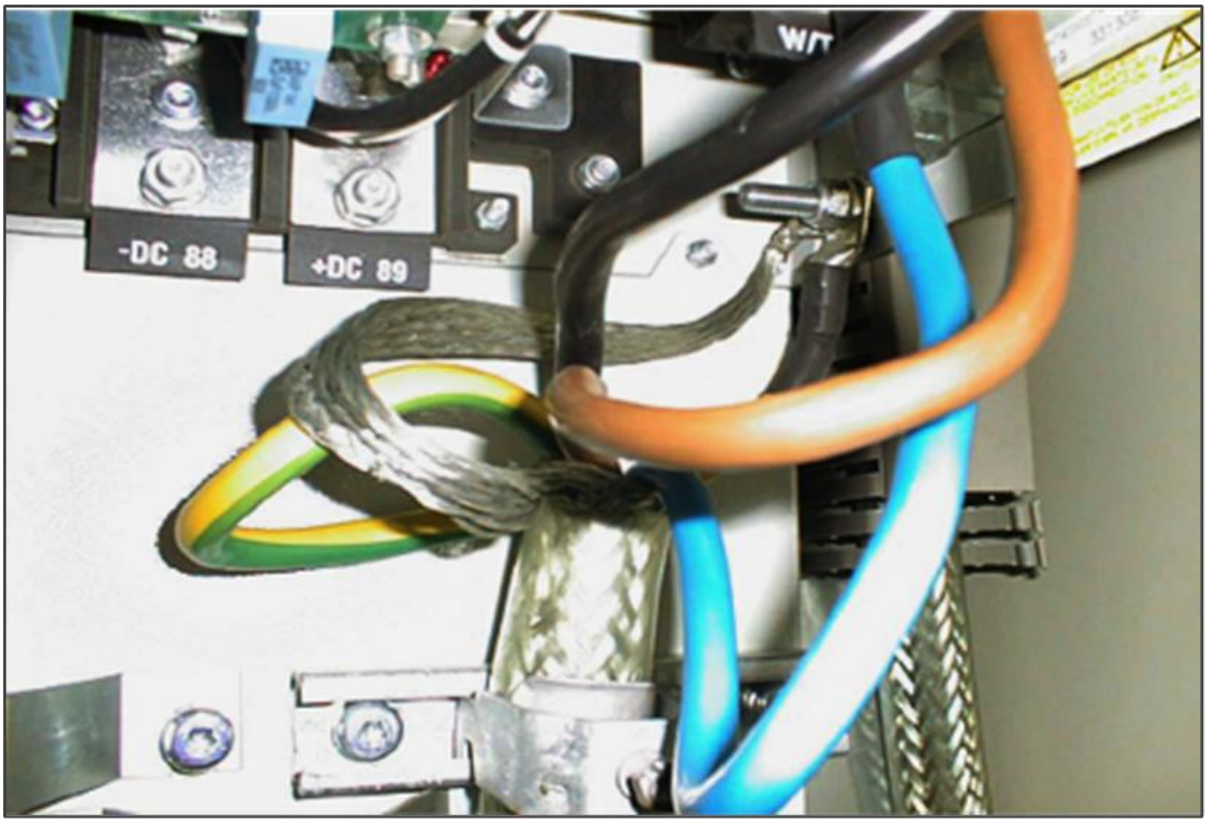



**Figure 8**

## 5 EQUIPMENT AGEING

Most lifts and escalators with VVVF drives are fitted with an EMC Filter to comply with the conducted emissions standard. See Figure 9.


**Figure 9**

These filters are located on the Line side of a VVVF drive. These devices contain Inductors, Capacitors, and Resistors that impede the EMI emitted by the drive from entering the power mains and provide an easy path for EMI to travel to earth.

Whilst these filters are provided to control conducted emissions, they also prevent EMI from external sources from entering the lift or escalator system.

EMI filters and transient protection devices such as Metal Oxide Varistors (MOV) have a limited life.

Capacitors, which are an integral part of EMI filters, have a life span of about 10 years [13].

MOVs degrade slightly each time they absorb a voltage surge. Their life span is a function of both the quantity and intensity of the surges they absorb. Ten years is a typical life span [14].

It is therefore logical to assume that lifts and escalators with VVVF drives and/or MOVs are operating with EMC devices that are no longer functioning because they are over 10 years old. If these units were retested after 10 years in service, they would most likely fail the EMC tests.

## 6 SYMPTOMS OF EMI PROBLEMS

EMI problems usually result in lift and escalator shutdowns for which no cause can easily be determined. For example, an escalator intermittently shuts down, but none of the safety switches have been actuated. The escalator can be returned to service simply by cycling the isolator switch.

Another symptom of EMC problems is the appearance of error codes that seem either illogical or impossible.

EMC problems often come to light when a customer calls the service manager to complain about constant breakdowns, and the technician had informed the customer that either he could find nothing wrong, or the unit was running on arrival (ROA).

## 7 CONCLUSION

Electromagnetic Compatibility is dependent upon not only proper design and fabrication, but also proper installation. Whilst installation instructions are required by the EMC standards, the author has never encountered such instructions at installation sites.

Successful EMC installations are possible if the installation and commissioning teams are trained.

To ensure that EMC measures continue to function over time, a filter replacement program should be implemented.

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## BIOGRAPHICAL DETAILS

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# Lift Buffer Forces Under Unfavourable Collision Conditions

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**Keywords**: Hydraulic buffer, load case, full load, partial load, unfavourable load, limit acceleration, limit jerk, DIN EN 81-20.

**Abstract.** Energy dissipation buffers are standard equipment for lift installations, especially at lifting speeds greater than or equal to $v$ = 1m/s. They are used for the limitation of car accelerations and the reduction of impact loads on structures during processes of kinetic energy reduction. This is realised by a certain buffer force acting along the stroke of the buffer. The product of buffer force and stroke results in the energy dissipated during a buffering process.

The intentionally restricted buffer force is a result of the load mass, the load speed and the buffer stroke chosen. The buffer stroke is subject to the requirements of the standard. In order to gain suitable buffer capacity values of mass and speed rated to applicable standards are considered during design. Nevertheless, more unfavourable conditions may occur. This all results from the standard applied, e.g., DIN (Deutsches Institut Für Normung) EN 81-20.

The contribution discusses the relevant definitions of DIN EN 81-20 and the resulting unfavourable operating conditions. For certain examples [2], suitable buffer designs are evaluated. For these designs, the buffer force outcomes are revealed for the most unfavourable operational condition. The most unfavourable condition is assumed to be a buffer shock at a lift speed equal to the tripping speed of the speed limiter. The resulting jerks are evaluated with regard to the jerk requirements of DIN EN 81-20. Design measures to keep the jerk within the requirements of DIN EN 81-20 are analysed and discussed.

## 1 INTRODUCTION

Lifts are machinery that move people and goods. The movement process comprises decelerations, negative accelerations, with restricted amounts of acceleration.

In extraordinary cases, higher amounts of acceleration occur, introduced by the safety equipment involved. An example is the collision of the car with the limit buffer. For this collision, the standard defines the car speeds for buffer rating and restricts the accelerations and jerks allowed at certain operating conditions [1, 2].

At failure of the load-bearing support, DIN EN 81-20 allows maximum car speeds exceeding the limits drawn in clause 5.8.2.2 on energy dissipation buffers. In extraordinary cases, these maximum speeds may be applied to the buffer. This paper reveals the accelerations occurring at such unfavourable buffer shock situations. It shows the path to meet the standard requirements in the buffer clause and the consequences of this approach.

## 2 REQUIREMENTS ACCORDING TO EN 81-20

Lifts have to meet safety requirements. This includes requirements on buffers in lifts. A main standard on requirements on lifts is EN 81-20: “Safety rules for the construction and installation of lifts - Lifts for the transport of persons and goods, Part 20: Passenger and goods passenger lifts”; German version

EN 81-20:2020. The requirements on buffers listed in clause 5.8 of this standard were shown and discussed in [2].

For lifts with speed limiters, braking safety gear and speeds above v = 1 m/s, DIN EN 81-20, 5.6.2.2.1.1 “General regulations” requires a tripping speed $v_{tripping}$ of the lift car for the speed limiter at a maximum of

$$v_{tripping} = 1.25 \cdot v + 0.25/v \quad (1)$$

The standard recommends adjusting the speed limiter close to this limit rather than at a lower limit. At first view, the characteristics of tripping speed $v_{tripping}$ look linearly dependent on the lift speed v (Fig. 1, red). A detailed view reveals a linear part, $v_{t1} = 1.25 \cdot v$ (Fig. 1, blue) and an additional non-linear part, $v_{t2} = 0.25/v$ (Fig. 1, green). For “higher” lift speeds of about v > 4m/s, the tripping speed $v_{tripping}$ is about 25% above the nominal speed v. At “lower” speeds, the surcharge S is higher. The maximum surcharge of 50% appears at a nominal lift speed of v = 1m/s (Fig. 2).

$$S = 0.25\left(1 + \frac{1}{v^2}\frac{m^2}{s^2}\right) \quad (2)$$

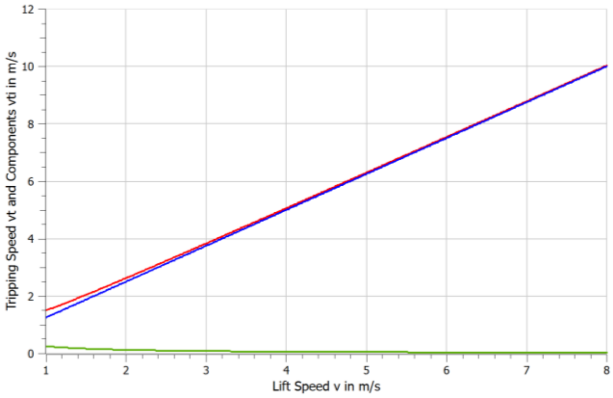


**Figure 1 Speed limiter tripping speed depending on nominal speed**

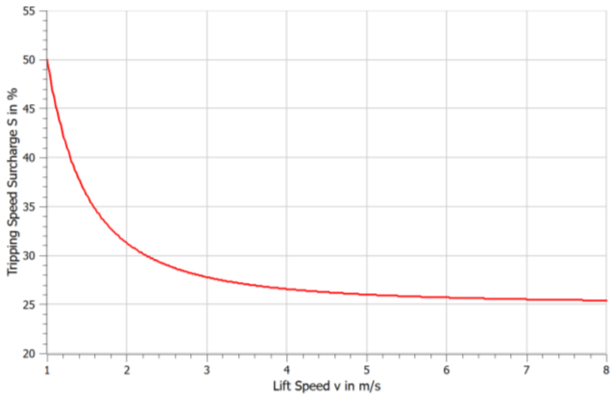


**Figure 2 Increase of speed limiter tripping speed against nominal speed**

**Table 1 Speed limiter tripping speed depending on nominal speed**

| **Lift speed v in m/s** | **1** | **2** | **4** | **8** | **16** |
|---|---|---|---|---|---|
| **Tripping speed $v_{tripping}$ in m/s** | 1.5 | 2.63 | 5.06 | 10.03 | 20.02 |

For the lifts considered [2] with a nominal speed of v = 1.0m/s and v = 4.06m/s, respectively, the maximum tripping speed of the speed limiter according to (1) equals $v_{tripping}$ = 1.50m/s and $v_{tripping}$ = 5.14m/s, respectively. Neglecting the very short reaction time of the safety brake, the maximum tripping speed of the speed limiter equals the absolute maximum lift speed. This absolute maximum lift speed is the most unfavourable speed at impact to the buffer. The acceleration from nominal speed to maximum tripping speed takes a time span of Δt = 0.051s and Δt = 0.110s, respectively. During this time span, the lift travels a further distance of Δs = 64mm and Δs = 505mm, respectively.

$$\Delta t = \frac{0.25}{g} v \tag{3}$$

$$\Delta s = v \cdot \Delta t + 0.5 \cdot g \cdot \Delta t^2 \tag{4}$$

Following the unfavourable scenario of a buffer shock at maximum tripping speed is assumed. If considering the reaction time of the safety brake was not equal to zero, an even more unfavourable scenario can be imagined.

## 3 EXAMPLE OF A BUFFER AT LOWER CAR SPEED

The first example considered is the first example from [2]. The car, including maximum load with mass $m_{max}$ = 3,250kg, travels at a nominal speed of $v_{nom}$ = 1.0 m/s. Due to gravitation, this leads to a driving force of about $F_d$ = 31,883N acting onto the car. According to the standard, the impact speed to be considered equals $v_{115\%}$ = 1.15m/s. Further data are piston diameter d = 50mm and stroke $s_{stroke}$ = 73mm. This stroke fulfils the requirement on the available stroke, $s_{avl} = 0.5 \cdot v^2/g$ = 67.4mm. $s_{stroke} > s_{avl}$. The data assumed is comparable to typical lift buffers available on the market for nominal speeds of $v_{nom}$ = 1.0 m/s. Case 1.

Simulation of a buffer shock with this data results in an average deceleration of $a_{avrg}$ = 9.7m/s$^2$ and a maximum deceleration of $a_{max}$ = 10.9m/s$^2$ (Fig. 3). The requirements are met as the average deceleration $a_{avrg}$ = 9.7m/s$^2$ < 1.0·g and the maximum deceleration $a_{max}$ = 10.9m/s$^2$ < 2.5·g. The jerk requirement Δt (a > 2.5·g) < 0.040s is already met, as no higher decelerations occur.

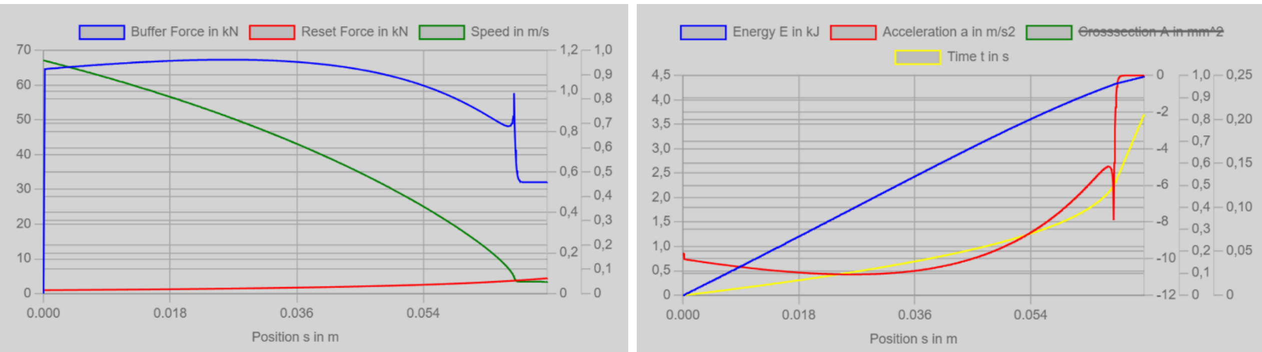


**Figure 3 Maximum mass at rated speed**

Now the car, including minimum load with mass $m_{min}$ = 380kg, travels at the same nominal speed of $v_{nom}$ = 1.0m/s. This leads to a driving force of about $F_d$ = 3,728N and, acc. to the standard, an impact speed of $v_{115\%}$ = 1.15m/s. Case 2.

Fig. 4 shows the resulting data for the simulation of this case. The initial buffer force $F_b$ just depends on the buffer design itself and the impact speed v. These data are the same as in the maximum load case considered. The initial buffer force $F_b$ is the same for maximum load $m_{max}$ and for minimum load $m_{min}$. No effect of deceleration has occurred so far. At maximum load $m_{max}$, the buffer force $F_b$ stays more or less constant along stroke; at minimum load $m_{min}$, the buffer force $F_b$ decreases immediately after the first impact. This happens acc. to the high deceleration a of the small load $m_{min}$.

At smaller loads, the whole buffering process will take more time. At the minimum load $m_{min,}$ the initial buffer force $F_b$ equals the maximum buffer force $F_{b,max}$. At maximum load $m_{max,}$ the maximum buffer force $F_{b,max}$ is somewhat higher than the initial buffer force $F_b$. This is a result of the specific buffer characteristics. In a first approach, the maximum buffer force $F_{b,max}$ may be considered of the same height as the initial buffer force anyway. At minimum load $m_{min,}$ the initial buffer force $F_b$ equals the maximum buffer force $F_{b,max}$ exactly. The total kinetic energy dissipated, $E_{kin,}$ and the total potential energy dissipated, $E_{pot,}$ have about the same amount. But now the main amount of the kinetic energy $E_{kin}$ is dissipated at the beginning of the stroke. Hence, the energy dissipated, $E_{diss,}$ shows a fast growth at the beginning of the stroke and a moderate increase along the stroke (Fig. 4).

This data results in an average deceleration of $a_{avrg} = 9.7m/s^2$ and a maximum deceleration of $a_{max} = 159.5m/s^2 = 16.3 \cdot g$ (Fig. 4). As the impact speed v and the throttle cross-sectional area are the same as at high mass $m_{max}$, the lower mass experiences a quite high deceleration a at the beginning of the buffering process. The requirements are met with regard to the average deceleration, $a_{avrg} = 9.7m/s^2 < 1.0 \cdot g$. The average deceleration $a_{avrg}$ is at a low level, as after a short phase of high deceleration, a long phase of low deceleration occurs. As decelerations $a > 2.5 \cdot g$ occur, the condition $\Delta t\ (a > 2.5 \cdot g) < 0.040s$ has to be proven. Analysis of the data gained by simulation delivers $\Delta t\ (a > 2.5 \cdot g) = 0.010s$, the requirement is met.

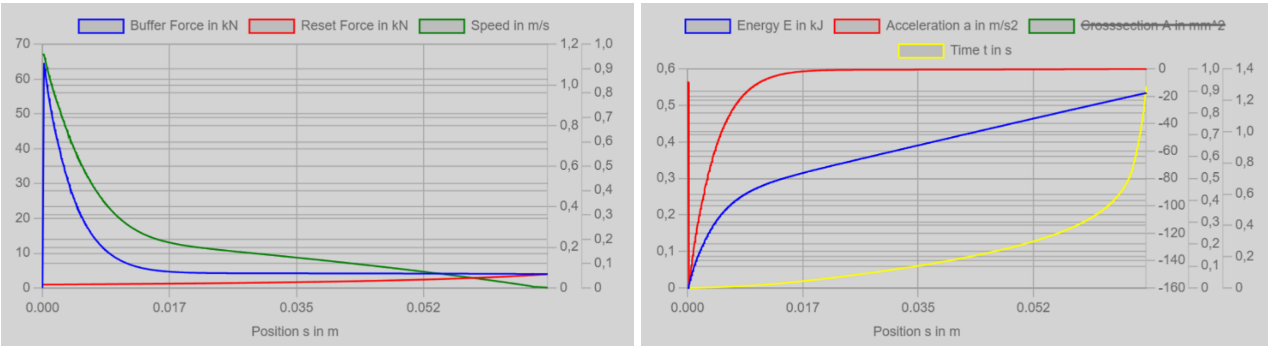


**Figure 4 Minimum mass at rated speed**

Now the car, including minimum load with mass $m_{min} = 380kg$, travels at the same nominal speed of $v_{nom} = 1.0m/s$. This leads to a driving force of about $F_d = 3{,}728N$ and, acc. to the standard, an unfavourable impact speed of $v_{tripping} = 1.50m/s$. Case 3.

This data results in an average deceleration of about $a_{avrg} = 16.5m/s^2$ and a maximum deceleration of about $a_{max} = 277.0m/s^2 = 28.2 \cdot g$ (Fig. 5). As the impact speed v and the throttle cross-sectional area are the same as at high mass $m_{max}$, the lower mass experiences a quite high deceleration a at the beginning of the buffering process. The requirements are not met with regard to the average deceleration, $a_{avrg} = 16.5m/s^2 > 1.0 \cdot g$. This results because the stroke requirement of the standard is not met for the higher impact speed. The average deceleration $a_{avrg}$ is at a low level, as after a short phase of high deceleration, a long phase of low deceleration occurs. As decelerations $a > 2.5 \cdot g$ occur, the condition $\Delta t\ (a > 2.5 \cdot g) < 0.040s$ has to be proven. Analysis of the data gained by simulation delivers $\Delta t\ (a > 2.5 \cdot g) = 0.012s$, the requirement is met.

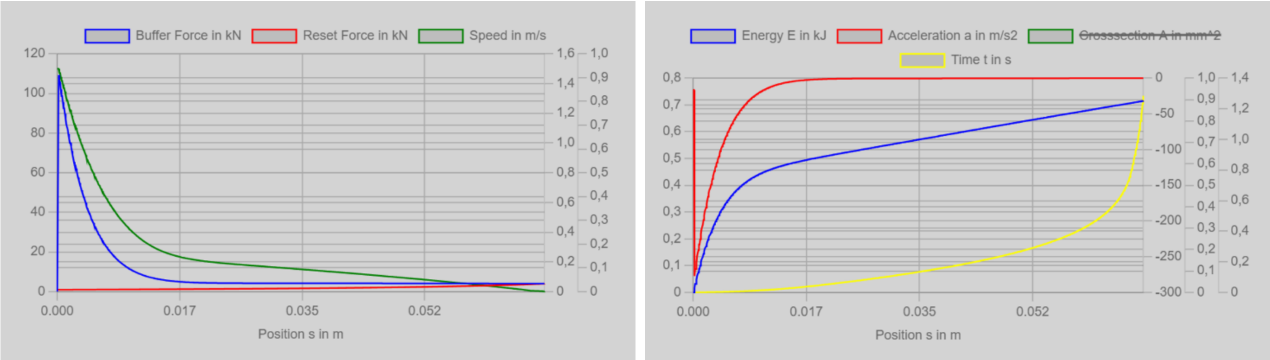


**Figure 5 Minimum mass at maximum speed**

## 4 EXAMPLE OF A BUFFER AT A HIGHER CAR SPEED

The second example considered is the second example from [2]. The car, including maximum load with mass $m_{max}$ = 8,330kg, travels at a nominal speed of $v_{nom}$ = 4.06 m/s. Due to gravitation, this leads to a driving force of about $F_d$ = 81,717N acting onto the car. According to the standard, the impact speed equals $v_{115\%}$ = 4.67m/s. Further data are piston diameter d = 120mm and stroke $s_{troke}$ = 1,200mm. This stroke fulfils the requirement on the available stroke, $s_{avl} = 0.5 \cdot v^2/g$ = 1,111.6mm. The assumed data is comparable to typical lift buffers available on the market for nominal speeds of about $v_{nom}$ = 4.0 m/s. Case 4.

Simulation of a buffer shock with this data results in an average deceleration of $a_{avrg} = 9.2m/s^2$ and a maximum deceleration of $a_{max} = 10.3m/s^2$ (Fig. 6). The requirements are met as the average deceleration $a_{avrg} = 9.2m/s^2 < 1.0 \cdot g$ and the maximum deceleration $a_{max} = 10.59m/s^2 < 2.5 \cdot g$. The jerk requirement $\Delta t$ ($a > 2.5 \cdot g$) < 0.040s is met, as no higher decelerations occur.

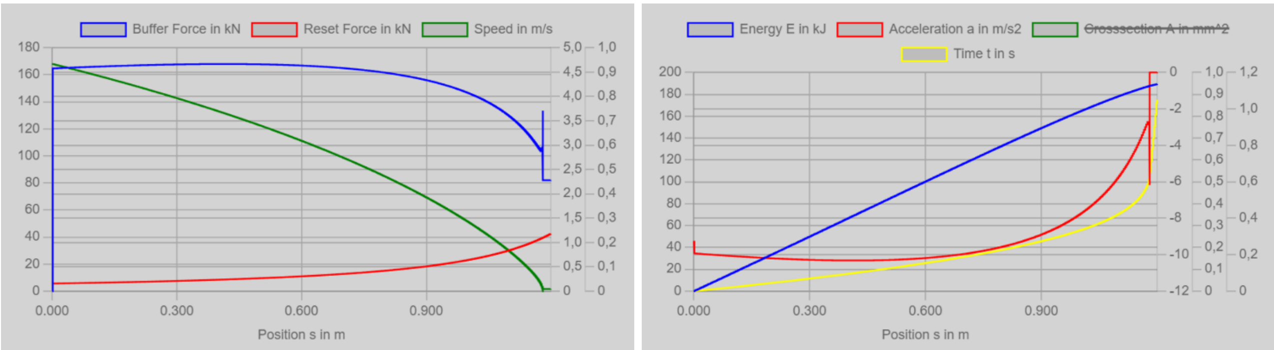


**Figure 6 Maximum mass at rated speed**

Now the car, including minimum load with mass $m_{min}$ = 1,000kg, travels at the same nominal speed of $v_{nom}$ = 4.06m/s. This leads to a driving force of $F_d$ = 9,810N and, acc. to the standard, an impact speed of $v_{115\%}$ = 4.67m/s. Case 5.

This data results in an average deceleration of $a_{avrg} = 9.2m/s^2$ and a maximum deceleration of $a_{max} = 154.6m/s^2 = 15.8 \cdot g$ (Fig. 7). The requirements are met with regard to the average deceleration $a_{avrg} = 9.2m/s^2 < 1.0 \cdot g$. As decelerations $a > 2.5 \cdot g$ occur, the condition $\Delta t$ ($a > 2.5 \cdot g$) < 0.040s has to be proved. Analysis of the data gained by simulation delivers $\Delta t$ ($a > 2.5 \cdot g$) = 0.045s, the requirement is not met.

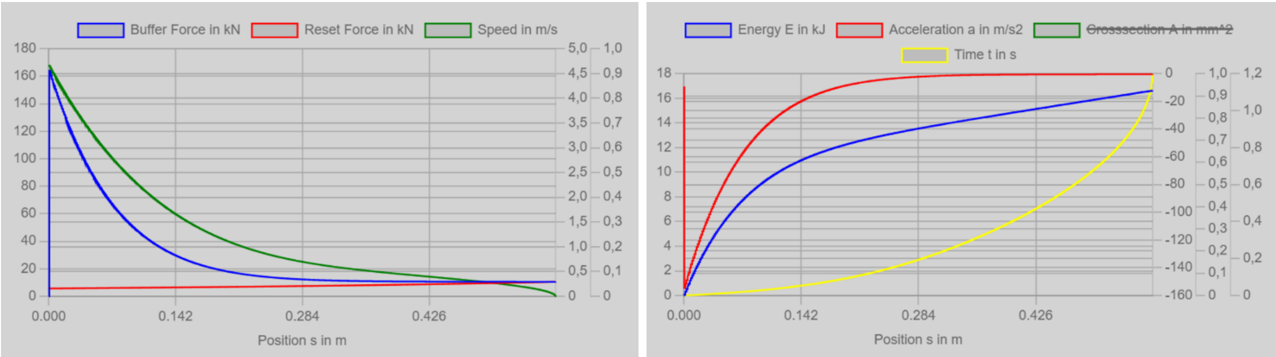


**Figure 7 Minimum mass at rated speed**

Now the car, including minimum load with mass $m_{min}$ = 1,000kg, travels at the same nominal speed of $v_{nom}$ = 4.06m/s. This leads to a driving force of $F_d$ = 9,810N and, acc. to the standard, an unfavourable impact speed of $v_{tripping}$ = 5.14m/s. Case 6.

This data results in an average deceleration of about $a_{avrg}$ = 11.2m/s$^2$ and a maximum deceleration of about $a_{max}$ = 188.3m/s$^2$ = 19.2·g (Fig. 8). The requirements are not met with regard to the average deceleration $a_{avrg}$ = 11.2m/s$^2$ > 1.0·g. As decelerations a > 2.5·g occur, the condition Δt (a > 2.5·g) < 0.040s has to be proved. Analysis of the data gained by simulation delivers Δt (a > 2.5·g) = 0.048s, the requirement is not met. The situation, considering the jerk, is even more unfavourable than at $v_{115\%}$.

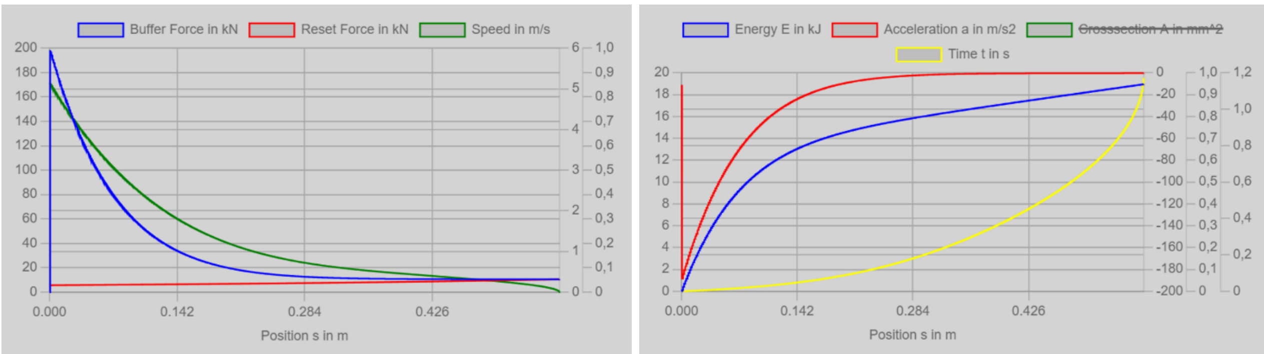


**Figure 8 Minimum mass at maximum speed**

To reduce the time span of high accelerations to a level Δt (a > 2.5·g) < 0.040s, the throttle cross-sectional area is increased now to 110% of the initial cross-sectional area.

The car, including maximum load with mass $m_{max}$ = 8,330kg, travels at a nominal speed of $v_{nom}$ = 4.06 m/s. Due to gravitation, this leads to a driving force of about $F_d$ = 81,717N acting onto the car. According to the standard, the impact speed equals $v_{115\%}$ = 4.67m/s. Further data are piston diameter d = 120mm and stroke $s_{troke}$ = 1,200mm. This stroke fulfils the requirement on the available stroke, $s_{avl} = 0.5 \cdot v^2/g$ = 1,111.6mm. Case 7.

Simulation of a buffer shock with this data results in an average deceleration of about $a_{avrg}$ = 9.2m/s$^2$ and a maximum deceleration of about $a_{max}$ = 11.1m/s$^2$ (Fig. 9). The requirements are met as the average deceleration $a_{avrg}$ = 9.2m/s$^2$ < 1.0·g and the maximum deceleration $a_{max}$ = 11.1m/s$^2$ < 2.5·g. The impulse requirement is met, as no higher decelerations occur.

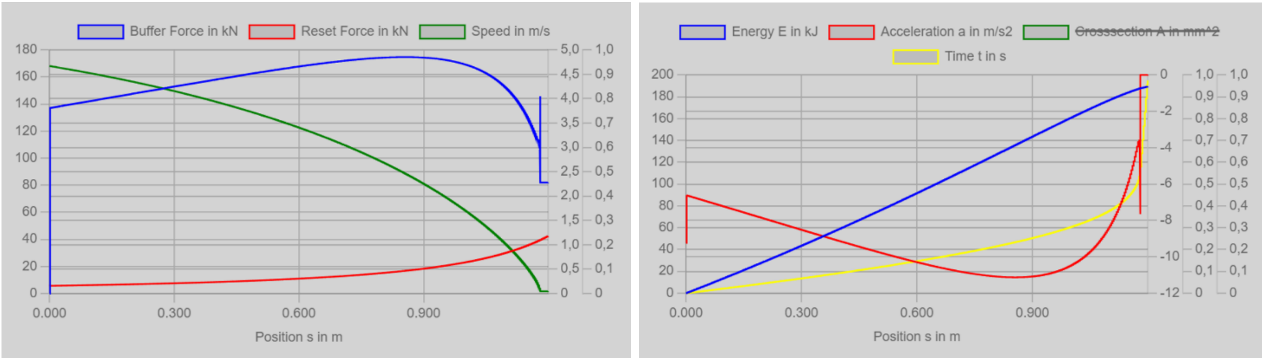


Figure 9 Maximum mass at rated speed (larger throttle)

Now the car, including minimum load with mass $m_{min}$ = 1,000kg, travels at the same nominal speed of $v_{nom}$ = 4.06m/s. This leads to a driving force of $F_d$ = 9,810N and, acc. to the standard, an unfavourable impact speed of $v_{tripping}$ = 5.14m/s. Case 8.

This data results in an average deceleration of about $a_{avrg} = 11.2 m/s^2$ and a maximum deceleration of about $a_{max} = 154.8 m/s^2 = 15.8 \cdot g$ (Fig. 10). The requirements are not met with regard to the average deceleration $a_{avrg} = 11.2 m/s^2 > 1.0 \cdot g$. As decelerations $a > 2.5 \cdot g$ occur, the condition $\Delta t\ (a > 2.5 \cdot g) < 0.040s$ has to be proved. Analysis of the data gained by simulation delivers $\Delta t\ (a > 2.5 \cdot g) = 0.049s$, the requirement is not met. Considering the jerk requirement, a larger throttle does not deliver the intended modification.

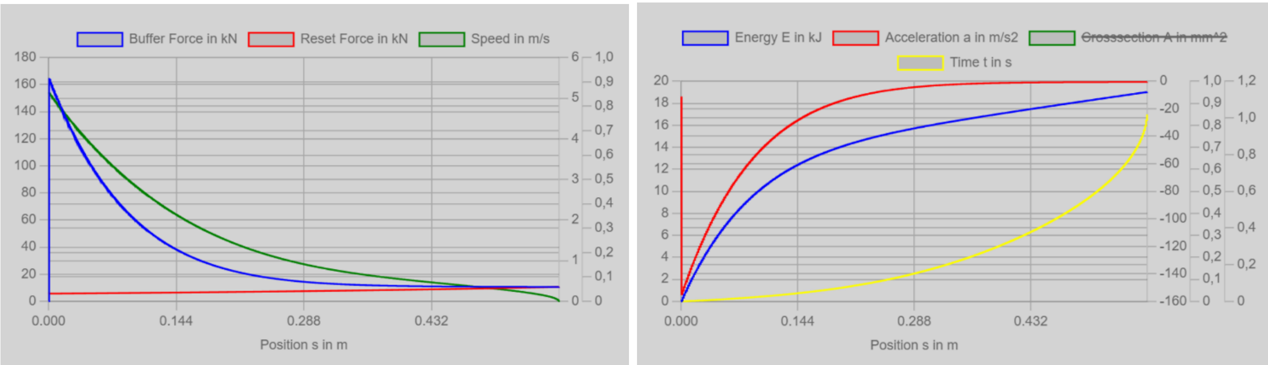


**Figure 10 Minimum mass at maximum speed (larger throttle)**

To reduce the time span of high accelerations to a level $\Delta t\ (a > 2.5 \cdot g) < 0.040s$, the throttle cross-sectional area is reduced now to 90% of the initial cross-sectional area.

The car, including maximum load with mass $m_{max}$ = 8,330kg, travels at a nominal speed of $v_{nom}$ = 4.06 m/s. Due to gravitation, this leads to a driving force of about $F_d$ = 81,717N acting onto the car. According to the standard, the impact speed equals $v_{115\%}$ = 4.67m/s. Further data are piston diameter d = 120mm and stroke $s_{troke}$ = 1,200mm. This stroke fulfils the requirement on the available stroke, $s_{avl} = 0.5 \cdot v^2/g$ = 1,111.6mm. Case 9.

Simulation of a buffer shock with this data results in an average deceleration of about $a_{avrg} = 9.2 m/s^2$ and a maximum deceleration of about $a_{max} = 14.4 m/s^2$ (Fig. 11). The requirements are met as the average deceleration $a_{avrg} = 9.2 m/s^2 < 1.0 \cdot g$ and the maximum deceleration $a_{max} = 14.4 m/s^2 < 2.5 \cdot g$. The impulse requirement is met, as no higher decelerations occur.

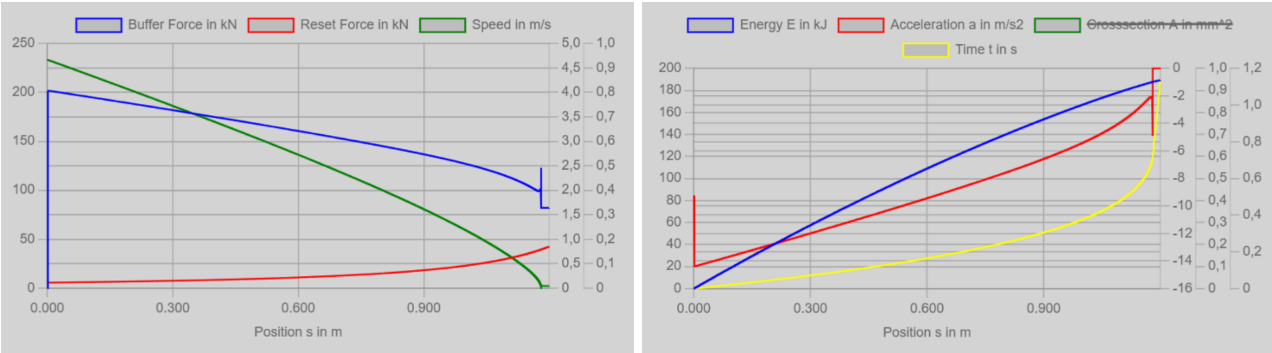


**Figure 11 Maximum mass at rated speed (smaller throttle)**

Now the car, including minimum load with mass $m_{min}$ = 1,000kg, travels at the same nominal speed of $v_{nom}$ = 4.06m/s. This leads to a driving force of $F_d$ = 9,810N and, acc. to the standard, an unfavourable impact speed of $v_{tripping}$ = 5.14m/s. Case 10.

This data results in an average deceleration of about $a_{avrg} = 11.2m/s^2$ and a maximum deceleration of about $a_{max} = 233.4m/s^2 = 23.8 \cdot g$ (Fig. 12). The requirements are not met with regard to the average deceleration $a_{avrg} = 11.2m/s^2 > 1.0 \cdot g$. As decelerations $a > 2.5 \cdot g$ occur, the condition $\Delta t\ (a > 2.5 \cdot g) < 0.040s$ has to be proved. Analysis of the data gained by simulation delivers $\Delta t\ (a > 2.5 \cdot g) = 0.044s$, the requirement is not met. Considering the jerk requirement, a smaller throttle delivers the intended modification.

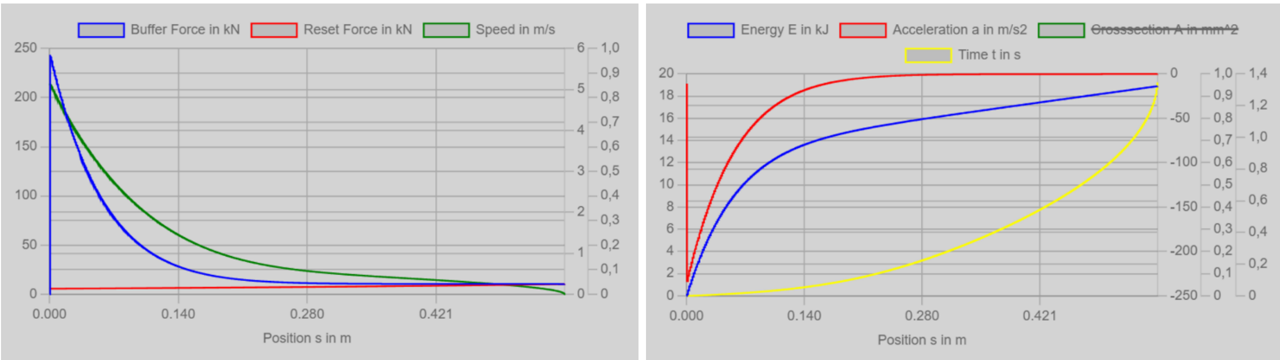


**Figure 12 Minimum mass at maximum speed (smaller throttle)**

To reduce the time span of high accelerations to a level $\Delta t\ (a > 2.5 \cdot g) < 0.040s$, the throttle cross-sectional area is reduced now to an even smaller level at 70% of the initial cross-sectional area.

The car, including maximum load with mass $m_{max}$ = 8,330kg, travels at a nominal speed of $v_{nom}$ = 4.06 m/s. Due to gravitation, this leads to a driving force of about $F_d$ = 81,717N acting onto the car. According to the standard, the impact speed equals $v_{115\%}$ = 4.67m/s. Further data are piston diameter d = 120mm and stroke $s_{troke}$ = 1,200mm. This stroke fulfils the requirement on the available stroke, $s_{avl} = 0.5 \cdot v^2/g$ = 1,111.6mm. Case 11.

Simulation of a buffer shock with this data results in an average deceleration of about $a_{avrg} = 9.2m/s^2$ and a maximum deceleration of about $a_{max} = 29.8m/s^2$ (Fig. 11). The requirements are met as the average deceleration $a_{avrg} = 9.2m/s^2 < 1.0 \cdot g$ and the maximum deceleration $a_{max} = 29.8m/s^2 > 2.5 \cdot g$. The impulse requirement may be met, as no very high decelerations occur.

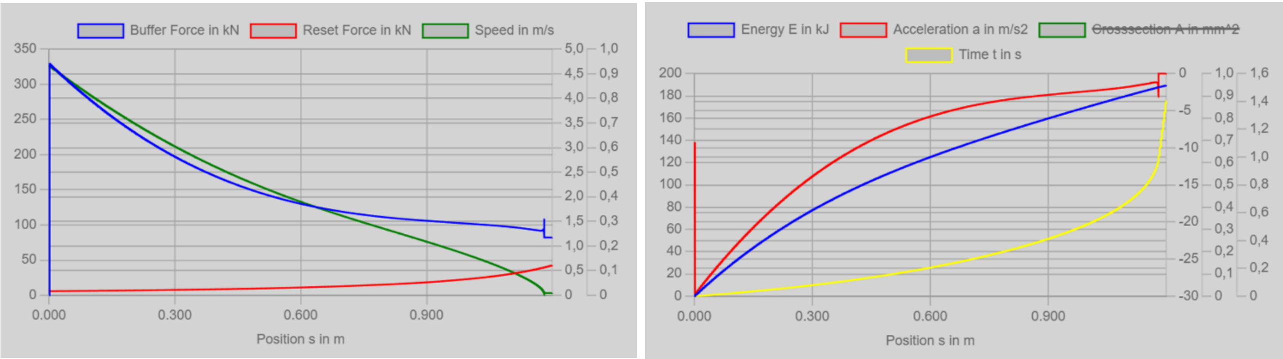


**Figure 13 Maximum mass at rated speed (smallest throttle)**

Now the car, including minimum load with mass $m_{min}$ = 1,000kg, travels at the same nominal speed of $v_{nom}$ = 4.06m/s. This leads to a driving force of $F_d$ = 9,810N and, acc. to the standard, an unfavourable impact speed of $v_{tripping}$ = 5.14m/s. Case 12.

This data results in an average deceleration of about $a_{avrg}$ = 11.2m/s$^2$ and a maximum deceleration of about $a_{max}$ = 388.7m/s$^2$ = 39.6·g (Fig. 14). The requirements are not met with regard to the average deceleration $a_{avrg}$ = 11.2m/s$^2$ > 1.0·g. As decelerations a > 2.5·g occur, the condition Δt (a > 2.5·g) < 0.040s has to be proved. Analysis of the data gained by simulation delivers Δt (a > 2.5·g) = 0.038s, the requirement is met. Considering the jerk requirement, the smallest throttle delivers the intended modification and is able to meet the jerk requirement.

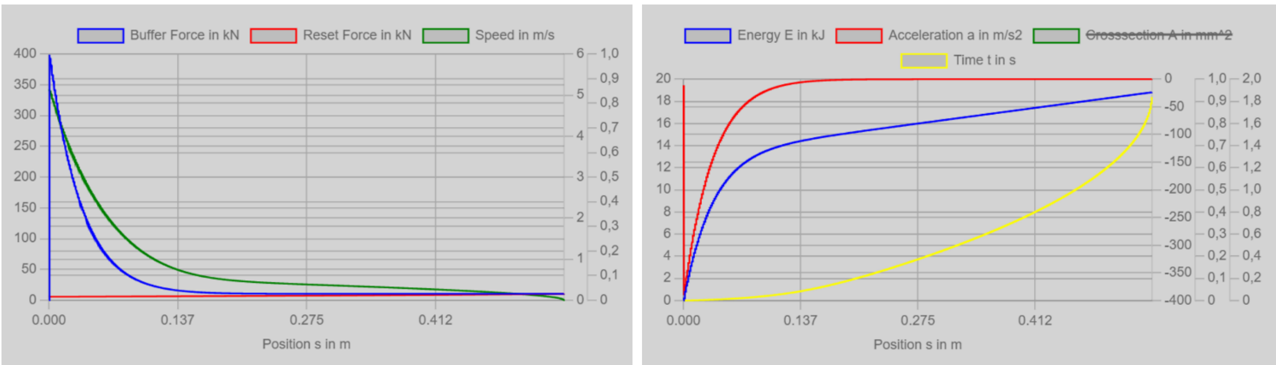


**Figure 14 Minimum mass at maximum speed (smallest throttle)**

## 5 SUMMARY AND CONCLUSION

Table 2 summarises the results gained for cases 1 to 12. Green: Requirement met. Yellow: Requirement on average acceleration not met. Red: Requirement on jerk not met.

Hydraulic buffers are designed to cover the load at maximum mass combined with maximum speed. In hydraulic buffer design, the maximum speed equals the nominal lift speed plus a speed surcharge of 15%.

The resulting initial buffer force also acts in situations of lower load, especially lower mass of the car, including passengers. This induces high decelerations, which might lead to or even beyond the jerk limit defined in EN 81-20. Meeting the average deceleration requirement does not imply meeting the impulse requirement automatically.

**Table 2 Summary of cases considered**

| Case # | $m_{min}$, $m_{max}$ in kg | $v_{115\%}$, $v_{tripping}$ in m/s | $A_{throttle}$ | $a_{avrg}$ in m/s² | $a_{max}$ in m/s² | $\Delta t$ (a > 2.5·g) in ms |
|---|---|---|---|---|---|---|
| Lift1 | | | | | | |
| 1 | 3250 | 1.15 | 100% | 9.7 | 10.9 | 0 |
| 2 | 380 | 1.15 | 100% | 9.7 | 159.5 | 10 |
| 3 | 380 | 1.50 | 100% | 16,5 | 277,0 | 12 |
| Lift 2 | | | | | | |
| 4 | 8330 | 4.67 | 100% | 9.2 | 10.3 | 0 |
| 5 | 1000 | 4.67 | 100% | 9.2 | 154.6 | 45 |
| 6 | 1000 | 5.14 | 100% | 11.2 | 188.3 | 48 |
| 7 | 8330 | 4.67 | 110% | 9.2 | 11.1 | 0 |
| 8 | 1000 | 5.14 | 110% | 11.2 | 154.8 | 49 |
| 9 | 8330 | 4.67 | 90% | 9.2 | 14.4 | 0 |
| 10 | 1000 | 5.14 | 90% | 11.2 | 233.4 | 44 |
| 11 | 8330 | 4.67 | 70% | 9.2 | 29.8 | 18 |
| 12 | 1000 | 5.14 | 70% | 11.2 | 388.7 | 38 |

The standard allows even higher impact speeds in unfavourable situations. This occurs, as the tripping point of the speed limiter is recommended to be close to a speed surcharge of 50% to 25%. This condition induces even higher accelerations and jerks, which are even more difficult to meet.

An approach comprising the modification of the throttle cross-sectional area to meet the jerk requirement of DIN EN 81-20 was shown. Meeting the jerk requirement leads to quite high maximum accelerations. This is not relevant in proving against the standard, as it sets no limit to maximum accelerations at all.

Meeting the medium acceleration requirement seems more difficult, surprisingly. It is not possible to find a proof by modification of the throttle. It is probably not possible to meet this requirement at all if the buffer does not fulfil the minimum stroke requirement for the lift speed, including 50% to 25% surcharge.

The definitions of the standard do not consider a concept of increased buffer utilisation as presented in [3]. Maybe this is an approach to meet the requirements without an adaptation of the jump height to the 50% to 25% speed surcharge. This might be in focus for future activities.

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[3] Vöth, Stefan: Exploiting the Capacity of Industrial Hydraulic Buffers, 14th Lift and Escalator Symposium, (2023)

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MAN GHH Logistics GmbH, Heilbronn
Head of Engineering Design and Development Tower Cranes

Mannesmann Demag Fördertechnik AG, Wetter
Head of Engineering Design Bridge Cranes

Technische Hochschule Georg Agricola, Bochum
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