2nd Symposium on Lift and Escalator Technologies

September 2012

THE UNIVERSITY OF NORTHAMPTON
School of Science and Technology

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FOREWORD

It is with great pleasure that we present the proceedings of a Symposium on Lift and Escalator Technologies, September 2012, organised jointly by The Lift Engineering Section of the School of Science and Technology and The CIBSE Lift Group.

The Lift Engineering programme offered at The University of Northampton includes postgraduate courses at MSc/ MPhil/ PhD levels that involve a 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.

The Symposium brings together experts from the field of vertical transportation, offering an opportunity for speakers to present peer reviewed papers on the subject of their research. Speakers include industry experts, academics and post graduate students. There will also be keynote addresses by international industry experts invited by the CIBSE Lifts Group.

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

We are grateful to everyone who has submitted papers and in particular our invited speakers: Dr B Powell, Mr A Shiner, Mr D Smith and Dr A So. We are also grateful to organisations that have supported this venture, as highlighted by their logos below.

Professor Stefan Kaczmarczyk, The University of Northampton and
Dr Richard Peters, The CIBSE Lifts Group

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The HARint plane: A Graphical Method for Visualising the Optimality of an Elevator System Design Option

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ABSTRACT

This paper presents a graphical methodology of visualizing the optimality of an elevator design solution. It introduces a new plane called the HARint plane, each point on which represents a solution to the elevator design problem.

By visually inspecting the plane and examining the intersection of various curves on the plane, the designer can understand how far the offered solution is from the optimal solution and also whether the offered design is wasteful.

The HARint plane comprises the quality of service, represented by the actual interval and the quantity of service, represented by the handling capacity. These are compared with the client/site requirements in terms of the target interval and the arrival rate. A number of curves can then be plotted on the plane based on the possible number of elevators and the car loading in passengers.

In drawing the curves on the plane, the round trip time has to be known. The round trip time can either be calculated analytically or by the use of Monte Carlo simulation. However, the calculation of the round trip time is only part of the design methodology. This paper does not discuss the round trip time calculation methodology as this has been addressed in detail elsewhere. The optimality of the design is assessed by a clear step by step methodology that uses the user requirements to select an optimal design.

Keywords: Elevator, lift, round trip time, interval, up peak traffic, rule base, Monte Carlo simulation, average travel time, HARint plane.

1. INTRODUCTION

The round trip time is the time needed by the elevator to complete a full journey in the building, taking passengers from the main entrance(s) and delivering them to their destinations and then expressing back to the main entrance, under up peak (incoming) traffic conditions.

This paper presents a step-by-step automated method for elevator design under specific arrival conditions, assuming that a method exists for calculating the round trip time. It uses a combination of rules and graphical methods to arrive at an optimal solution. A graphical tool, called the HARint plane, is presented as a means to visualise the solution.

The fact that the methodology is fully automated makes it very attractive for implementation as a software package. It has also been used for teaching elevator traffic analysis to final year undergraduate mechatronics engineering students.

Full details on the use of the method in optimising the number of elevators as well as the speed and capacity can be found in [1].

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2. THE PROBLEM WITH CONVENTIONAL DESIGN METHODS

It will be assumed that the designer starts with the knowledge of the following parameters that are given either by the architect or the building owner or that can be inferred from the type of occupancy (e.g., office, residential…etc.). These represent the *user requirements*.

a) The total building population, U. If this is not given directly, it can be calculated from either net floor area of the gross floor area.
b) The expected arrival rate, $AR\%$. This is the percentage of the building population arriving in the building during the busiest five minutes. This value depends on the type of building occupancy.
c) The target interval int_{tar}.

A sufficient design meets the following two conditions:

$$HC\% \geq AR\% \tag{1}$$

$$int_{act} \leq int_{tar} \tag{2}$$

…where:
$AR\%$ is the arrival rate expressed as a percentage of the building population in five minutes
$HC\%$ is the handling capacity expressed as a percentage of the building population in five minutes
int_{tar}.is the target interval in seconds
int_{act}.is the actual interval in seconds

A design that meets equations (1) and (2) is an acceptable design, but might not be an optimum design (i.e., it could be a wasteful design). The optimum design is one that meets the two equations shown below (3) and (4).

$$HC\% = AR\% \tag{3}$$

$$int_{act} = int_{tar} \tag{4}$$

In practice however, it is nearly impossible to find a design that meets both of equations (3) and (4) above. This is due the fact that the number of cars in the group, L, cannot be a fraction (it has to be a whole number). Hence, in practice, an optimum solution will satisfy the two equations (5) and (6) shown below:

$$HC\% = AR\% \tag{5}$$

$$int_{act} < int_{tar} \tag{6}$$

This section illustrates the main problem with the conventional design method. It relies on the user picking a suitable speed, v, and a suitable car capacity, CC. The user then assumes that the cars will fill up to the 80% of the car capacity.

The round trip time is then calculated based on the selected speed and the selected car capacity. This provides a value for the round trip time, τ. Dividing the round trip time by the target interval and rounding up the answer provides the required number elevators.

The user has now two values that represent the qualitative and quantitative performance of the systems: The handling capacity and the actual value of the interval, respectively. Comparing these values to the desired values, results in four possible cases, discussed in detail below.

Quantitative Design Criterion	Qualitative Design Criterion	
	$int_{act} > int_{tar}$	$int_{act} < int_{tar}$
$HC\% < AR\%$	**Case I** Unacceptable design. Cannot be addressed by reducing the car loading. The designer will have to increase the number of elevators and repeat the analysis.	**Case II** Unacceptable design. Might be addressed by increasing the car loading and using a larger car capacity if needed.
$HC\% > AR\%$	**Case III** Unacceptable design. But it might be addressed by reducing the car loading.	**Case IV** Acceptable design, but might not be an optimum one. There may be further scope in reducing the number of elevators, reducing the rated speed or both.

Specifically, there are two problems with this method:

1. In the three cases where the design is unacceptable, the designer does not have a clear set of rules of how to move to an acceptable design (as defined in Case IV). It is a mixture of judgement, experience and trial and error.
2. Even where the user manages to get to an acceptable design by arriving at Case IV, he/she cannot be sure that he/she has an optimum solution, despite the fact that the design meets both qualitative and quantitative criteria. The designer will have to do further trial and error iterations to check that the design is optimum (e.g., further reduce the number of elevators, L and then repeat the calculation of the round trip time). The main reason for this is that the designer starts from an arbitrary car size and assumes it fills up to 80% of its capacity rather than calculating the actual passenger arrival expected.

The next section attempts to address the drawback with this traditional methodology.

3. ANALYSIS AND DEVELOPMENT OF THE FORMULAE

The design methodology developed in this section allows the designer to arrive directly at a design that is optimum and in a fixed number of steps without the need for trial and error searches or iterations. This section develops the method and the associated formulae.

Developing a clearly defined methodology for design with concrete steps, offers the following advantages:

1. It allows designers to carry out the design regardless of their level of expertise, through a clearly defined set of rules.
2. It offers the opportunity to automate the design process in software.

The methodology presented here uses the following rule:

The following parameters should be minimised in an optimal design in the following order of importance (that reflects the cost of the whole installation):

a) Number of elevators.
b) Elevator speed.
c) Elevator capacity.

So where two solutions have different number of elevators, the one with fewer elevators is selected; for solutions with the same number of elevators, the one with lower speed is selected; for solutions with same number of elevators and the same speed, the one with the smaller car capacity is selected.

Nevertheless, it is accepted that there are situations where the order of priority above is not correct (e.g., the restricted headroom in the building might restrict the rated elevator speed and force the designer to use a larger number of elevators in order to force a lower rated speed). In such conditions the designer can alter the rule for the priorities and select the answers accordingly.

The design process starts by finding the actual number of passengers that will board the elevator in any round trip journey. In effect, this is the number of passengers that will board the elevator from the main entrance (in the case of a single entrance arrangement) or the number of passengers boarding the car from all entrances (in the case of multiple contiguous entrances). This depends on three parameters that are all known at the start of the design process and are usually provided by the client, the developer or the architect. These are the target interval, int_{tar}, the arrival rate, *AR%*, and the total building population, *U*. This is shown in equation (7) below.

The number of passengers arriving in the peak five minutes can be found by multiplying the arrival rate by the total population, as shown below (the five minute period has traditionally been used as the design basis in elevator systems):

$$P_{5\min} = AR\% \cdot U \tag{7}$$

The arrival rate can then be expressed in units of persons per second by dividing by 300 seconds per minute as shown in (8) below.

$$\lambda = \left(\frac{AR\% \cdot U}{300} \right) \tag{8}$$

Thus an initial estimate of the actual number of passengers that will arrive in a single interval can be found by multiplying the target interval by the arrival rate of passengers as shown (9) below.

$$P_{act\ i} = \left(int_{tar} \cdot \lambda \right) \tag{9}$$

The subscript *i* denotes the fact that is an initial estimate. It is worth noting that (9) is used in reference [4] as a tool to assess the actual interval at partial car loading, but not as a sizing tool.

There is no need at this stage to consider the car capacity. This can be done later when the final number of the passengers in the car has been determined.

Having arrived at an estimate for the actual number of passengers in the car, the next step is to find the corresponding round trip time. Using a classical method of calculating the round trip time [2] and [3] or using Monte Carlo Simulation [5], the value of the round trip time can be found. The round trip time is in effect a function of the actual number of passengers if all other parameters are kept constant (such as the kinematics, number of floors, total building population, door timings, floor heights). This provides an initial value for the round trip time as shown in (10).

$$\tau_i = f\left(P_{act} \right) \tag{10}$$

From the calculated value of the round trip time, the required number of elevators can be calculated as shown in (11):

$$L = ROUNDUP\left(\frac{\tau_i}{int_{tar}} \right) \tag{11}$$

It is worth noting that this act of rounding up is unavoidable as a whole number of elevators can only be selected. The resultant number of elevators, *L*, is the nearest to the optimum as practically as possible.

Due to the process of rounding up to find the actual value of the interval will be slightly lower than the target interval, and the actual value of the handling capacity, *HC%*, will be slightly higher than the arrival rate, *AR%*.

The actual value of the interval can be found by dividing the round trip time by the number of elevators, as shown below in equation (12):

$$int_{act\,i} = \frac{\tau_i}{L} \tag{12}$$

The actual handling capacity can also be found by using equation (13) below:

$$HC\%_i = \frac{300 \cdot P_{act\,i}}{U \cdot int_{act\,i}} \tag{13}$$

This provides an acceptable solution that satisfies Case IV discussed in the previous section. This is the optimum number of elevators required to meet the design criterion. However, it is not an optimum design regarding the required speed and car capacity. These two variables are discussed in detail in [1].

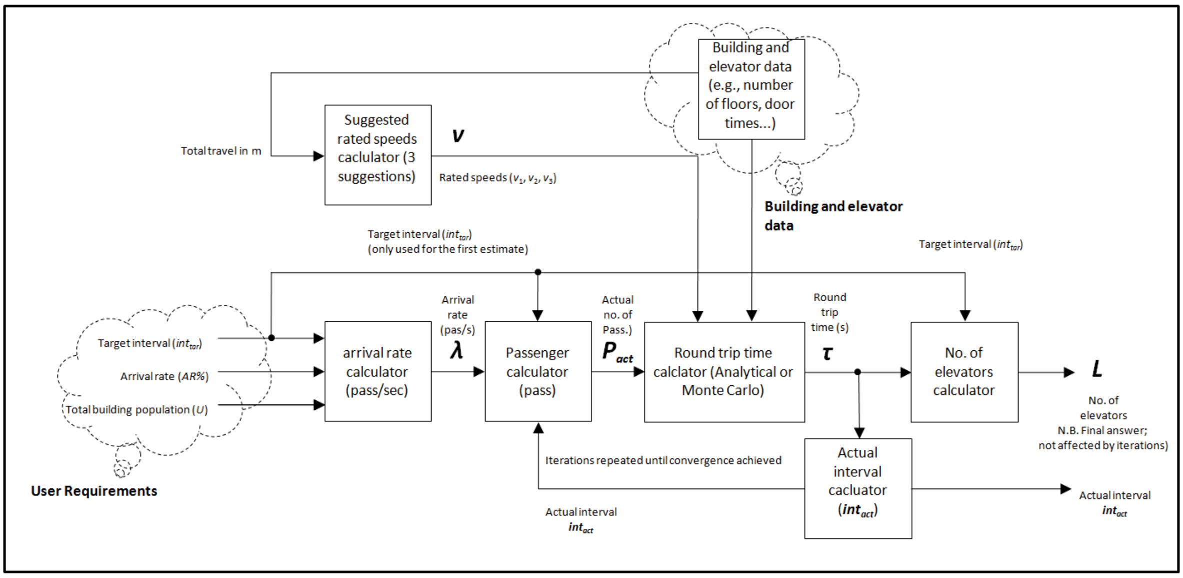

Figure 1: Block diagram showing the automated optimal design methodology.

Figure 1 shows an overview of the whole process of finding the optimum number of elevators, speed and capacity.

4. GRAPHICAL REPRESENTATION: THE HARINT PLANE

The methodology described in the last section can be represented in a graphical format. The aim of the graphical representation in this case is to allow the designer to understand the effect of changes on the resulting solution, and be able to assess how far it is from the optimum solution.

In order to develop the graphical representation, a plane is presented. This plane has two axes; the *x*-axis represents the interval in seconds and the *y*-axis represents the handing capacity. Each point on the plane represents a possible solution (not necessarily an acceptable or correct one). The point representing the optimum solution, can be located by the intersection of the vertical line representing int_{tar} and the horizontal line representing *AR%*, as shown in Figure 2. The plane is referred to as the HARint plane, as it contains the *HC%* and the *AR%* on the y-axis and the *int* on the x-axis (HCARint abbreviated to HARint).

Plotting lines of equal *L* (number of elevators) values and plotting lines of equal *P* (number of passengers) produces the HARint plane shown in Figure 2. The HARint plane can be very useful in visualising a specific solution and appreciating the optimality or otherwise of suggested solutions.

Figure 2 shows the position of the hypothetical optimum solution on the HARint plane which is the intersection point of the *AR%* horizontal line and the int_{tar} vertical line. It is hypothetical because it is not achievable in practice as it requires a fractional number of elevators, *L*. Applying the rounding up equation (11) and then applying the iterations (as shown in reference [1]) moves the solution to the practical optimum solution (that lies on the *AR%* line and uses a whole number of elevators, *L*.

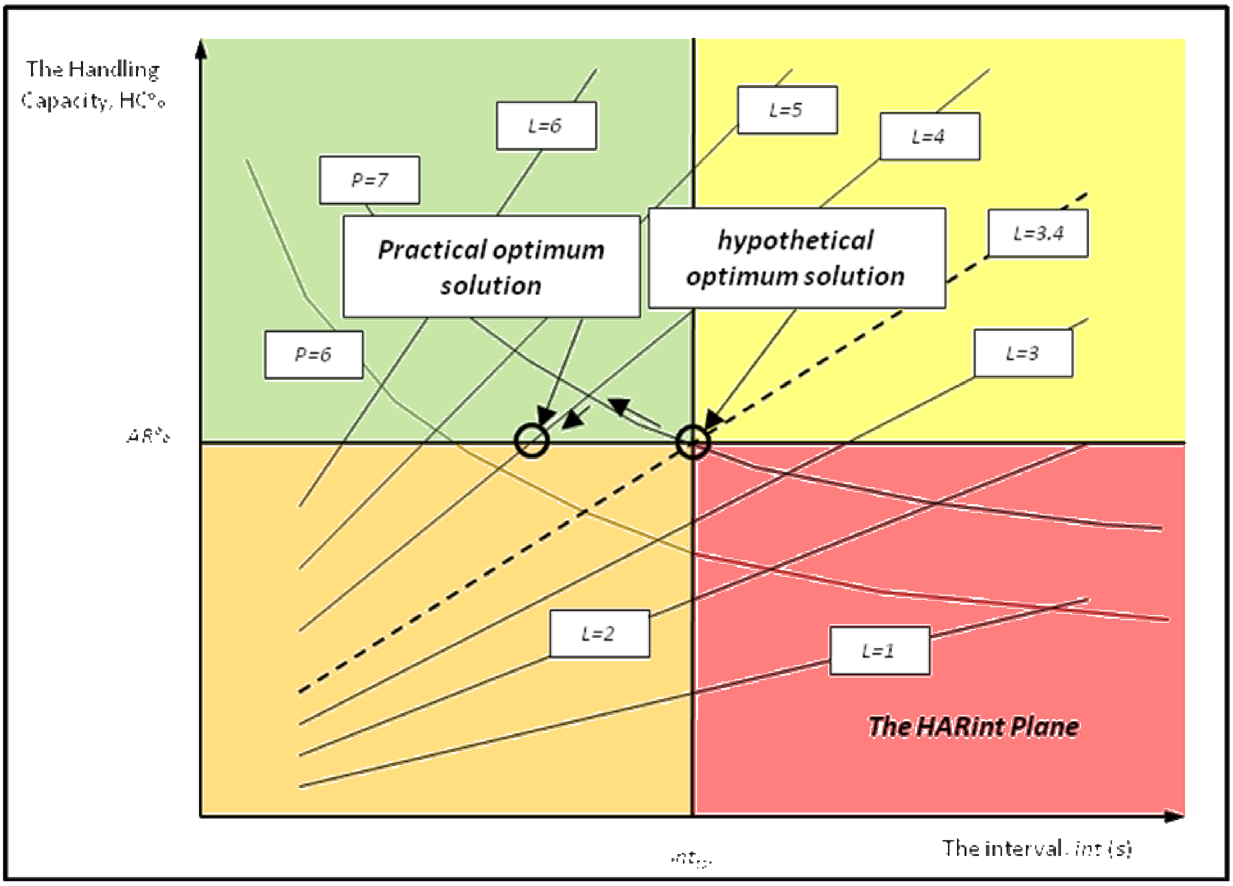

Figure 2: Hypothetical optimum solution and practical optimum solution on the HARint plane.

The use of the HARint plane shown in Figure 2 has been useful for visualising the solution, but has not been used to actually find a solution by the use of graphical methods. It might be possible to find a graphical method of finding a solution for a problem by the using the HARint plane as a solution chart (e.g., as the Smith chart is used in radio engineering and the Nichols chart is used in control systems). However, before this can be achieved, a method of normalisation needs to be introduced in order to make the HARint plane a universal tool.

5. CONCLUSIONS

A new methodology has been introduced that provides a set of rules and graphical methods that can be used to design elevator systems in buildings. The method optimises the number of elevators in the group of elevators for a building based on the user requirements of arrival rate (*AR%*), target interval (int_{tar}) and the total building population (*U*). The methodology then optimizes the speed of the elevators and then the elevator car capacity. The method allows the user to work backwards from the actual arrival rate in the building in order to find the optimum number of elevators, instead of the trial and error method.

The methodology assumes that a method exists for accurately calculating the round trip time. Both analytical and Monte Carlo simulation methods can be used to calculate these parameters.

Due the automated and rule based nature of the methodology, it is very attractive for implementation in a software tool for the design of elevator systems.

The method has also been successfully used in teaching the principles of elevator traffic analysis to final undergraduate mechatronic engineering students at the University of Jordan. One of the main reasons for its success is that students do not possess any past experience in elevator traffic design and hence rely on the rule base and graphical methods in reaching an optimal and convergent design.

It is worth noting the analysis in this methodology has assumed a constant uniform passenger arrival process. Further work is currently being done in understanding the effect of a random arrival process on the results and the final answers.

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The modelling, simulation and experimental testing of vertical vibrations in an elevator system with 1:1 roping configuration

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ABSTRACT

Vertical vibrations affect passenger comfort during an elevator travel. In this work the results of a study to investigate the vertical vibrations caused by torque ripple generated at the drive system and transmitted through the suspension ropes to the car is presented. The acceleration response at the suspended masses and at the drive machine end in a laboratory rig are measured during the system travel. The machine torque ripple and the radial forces generated at the machine air-gap between the stator and the rotor are computed using the Finite Element Method simulation with the software FLUX. The torque ripple excitation is then accounted for in a non-stationary lumped-parameter model of an elevator system with 1:1 roping configuration. The model accommodates the dynamics and control of the drive system. The model is implemented in the MATLAB/Simulink computational environment and the dynamic response of the system during travel is determined through numerical simulation. Both computer simulation and experimental results demonstrate that the vibration generated at the machine is transmitted to the elevator car becoming magnified if the excitation frequency is close to the natural frequencies of the system.

INTRODUCTION

One of the main problems in elevator installations is to achieve and to maintain adequate ride quality standards. Car ride quality can be compromised by excessive vibrations. Hoist ropes due to their flexibility and loading conditions are particularly affected. The drive machine is the source of energy supplied to the system but it is as well a source of vibration, caused by imbalance of the machine, eccentricity of the traction sheave or the torque electromagnetic ripple.

Vertical vibration in elevator systems has been studied in a number of papers. Regarding the mechanical part, the elevator system is usually modelled as a translating assembly of inertia elements coupled and constrained by one-dimensional slender continua. The inertial elements are the rotating components of the machine, the car assembly and the counterweight. The one-dimensional slender continua are the suspension ropes. They are usually divided into sections, lumping the mass of each section at corresponding discrete points and joining the mass points by springs and dampers with the corresponding stiffness and damping properties. Those models are described by a set of ordinary differential equations. The number of discrete mass points determines the number of degrees of freedom (DOF) of the system and the number of natural frequencies and mode shapes that need to be considered [1]. This approach enables one to simulate the vertical vibration during a travel by updating the models at every time step. Various strategies to suppress vertical vibration have been tested with time-varying models of this sort [2].

In this work investigation is carried out to identify the torque ripple excitation that is generated in a synchronous motor used in a laboratory model of an elevator system with a 1:1 roping configuration. The Finite Element Method (FEM) simulation tests with FLUX are conducted to determine the magnitude and frequency of the corresponding harmonics. Then, the vibration response at the main components of the laboratory rig is measured during travel. Furthermore, a mathematical model of an elevator is developed in order to analyze the response of the system. This model includes a comprehensive representation of the drive system. The mechanical part of the system is represented by a model with 3 DOF: the vertical displacement of the car, the vertical displacement of the counterweight and the angle of rotation of the traction sheave, measured relative to the equilibrium configuration of the system. The model comprising a set of ordinary differential equations is solved numerically to predict the response of the elevator components to the torque ripple excitation generated at the drive system. Experimental and simulation results are then compared and discussed.

THE LABORATORY SETUP

The schematic of the laboratory model and the experimental setup are shown in Fig. 1.

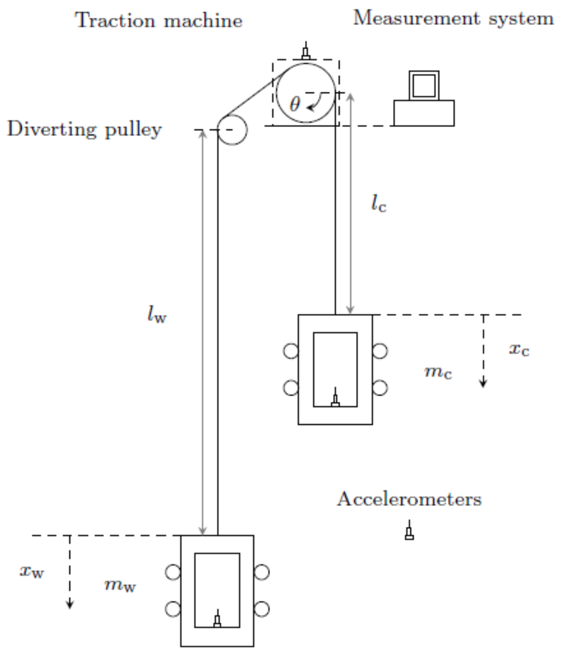

Fig. 1. Schematic diagram of the laboratory setup

Two equal rigid rigs, whose masses are $m_c = m_w = 33$ kg, are suspended at each side of the traction sheave and guided vertically, together with the machine assembly with the traction sheave and the diverting pulley. The suspended rig at the diverting pulley side will be referred to as the counterweight, and that one suspended directly from the traction sheave as the car.

The lengths from the counterweight to the diverting pulley and from the car to the traction sheave are l_w and l_c respectively. The sum $l_\mathrm{w} + l_\mathrm{c}$ equals 8 m. Other approximate values of the system parameters are $I = 0.3385$ kg·m^2, $R = 0.065$ m, $m =$ 0.095 kg/m and the product EA between the Young's modulus and the cross-section area of the rope is 10^6 N.

ELEVATOR SYSTEM MODEL

In order to describe and determine the dynamic response of the elevator system to any vertical excitation originated from the drive system, an elevator model has been developed. The model is composed of two main parts (see Fig. 2): the first part represents the drive system and the second is the model of the vertical dynamics of the car-sheave-counterweight-suspension rope system.

Drive System Model

The input to the drive system (see Fig. 2) is a desired velocity profile and the output is the machine torque. It comprises a permanent magnet synchronous motor powered via an inverter that supplies a pulse width modulated (PWM) voltage. The motor shaft speed is controlled in order for the car to follow a prescribed velocity profile ω_m^* to achieve good ride quality.

In order to simplify the analysis of three-phase synchronous machine of the setup, a mathematical transformation known as the direct quadrature zero (dqo) transformation [3] is used. In the case of balanced three-phase circuits, application of the dqo transform reduces the three AC quantities to two DC quantities. Simplified calculations can then be carried out on these imaginary DC quantities before performing the inverse transform to recover the actual three-phase AC results.

According to the reference frame transformation theory, the three phase variables, currents and voltages, are transformed to the d-q reference frame, which is rotating at the stator current frequency ω_s, representing the fundamental frequency. In this setup, the d-q components of the currents and the voltages are constant.

A well known vector control strategy oriented to the magnets flux has been implemented in the computer simulation [4]. Such control scheme consists of two control loops: outer and inner loops. In the outer control loop the speed of the motor is regulated by a conventional Proportional Integral (PI) controller, which sets the torque reference τ^* with the aim of minimizing the speed error $\omega_\mathrm{m}^* - \omega_\mathrm{m}$. In the inner control loop two PI controllers are implemented in order to regulate the d-q axes currents i_d and i_q. These two controllers set the d-q axes voltage references v_d and v_q in order to minimize the current errors.

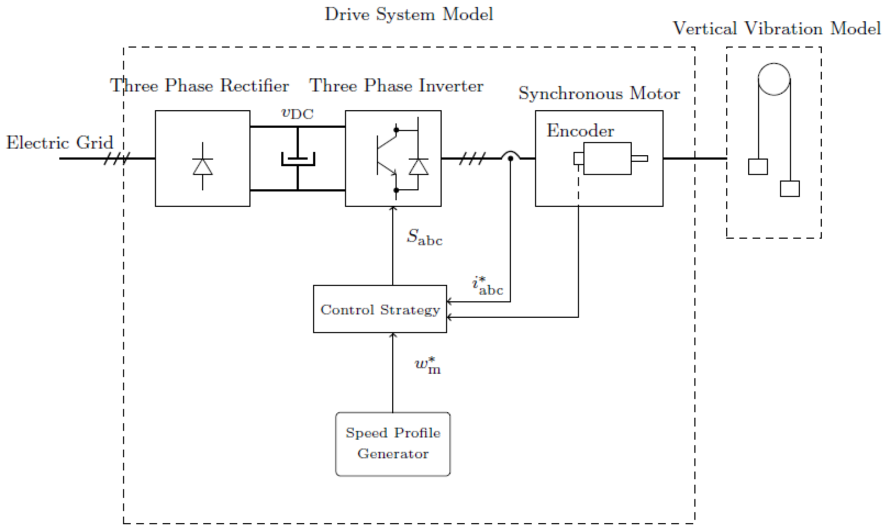

Fig. 2. The drive system, including the control diagram, the power converter and the electric motor

The q axis current reference i_q is obtained directly from the torque reference τ^*, because in permanent magnet synchronous motors the relationship between the torque and the q axis current is practically constant and known as the torque constant (see Eqn. (8)). The field weakening strategy is not implemented so that the d axis current reference i_d is set to zero [5].

Therefore, the PI controllers try to regulate the d-q currents to constant reference values so that the stationary error in the currents can be compensated by the integral action of the controllers.

Electric motor model

The machine is a 12 pole permanent magnet synchronous motor comprising a stator with 72 slots. The electric model of the motor is described by two differential equations

$$v_d = R_s i_d + \frac{d\Psi_d}{dt} - p\omega_m L_q i_q \quad (1)$$

$$v_q = R_s i_q + \frac{d\Psi_q}{dt} - p\omega_m \left(L_d i_d + \Psi_{pm}\right) \quad (2)$$

where v_d, v_q are the d-q axes voltages, i_d, i_q are the d-q axes currents, Ψ_d, Ψ_q are the d-q axes flux linkages, Ψ_{pm} is the magnet flux linkage, that is constant, R_s is the stator resistance, L_d, L_q are the d-q axes inductances, ω_m is the mechanical speed and p is the number of pole pairs. From [3] it can be deduced that the d-q axes flux linkages are defined as,

$$\Psi_d = L_d i_d + \Psi_{pm} \quad (3)$$

$$\Psi_q = L_q i_q \quad (4)$$

Consequently,

$$v_d = R_s i_d + L_d \frac{di_d}{dt} - p\omega_m L_q i_q \quad (5)$$

$$v_q = R_s i_q + L_q \frac{di_q}{dt} - p\omega_m \left(L_d i_d + \Psi_{pm}\right) \quad (6)$$

The torque τ generated by a motor is composed of two components: the average torque τ_0 and the torque ripple τ_r. In addition, the torque ripple is composed of another two components: the electromagnetic torque ripple and the cogging torque. The electromagnetic torque ripple is mainly due to the spatial distribution of stator windings and the magnets shape, while the cogging torque depends mainly on the number of stator slots and pole pairs [6].
The average value of the torque produced by the motor can be modelled by the next equation.

$$\tau_0 = \frac{3}{2} p\left(\Psi_d i_q - \Psi_q i_d\right) \quad (7)$$

If the d axis current i_d is set to 0 the following results

$$\tau_0 = \frac{3}{2} p\Psi_{pm} i_q \quad (8)$$

Eqn. (8) shows that the average torque generated by the motor τ_0 is proportional to the q axis current i_q. The magnitude of the electromagnetic torque ripple τ_r is also proportional to the q axis current i_q as it is demonstrated in [7]. Nevertheless, the magnitude of the cogging torque does not depend on the current magnitude and it is constant, even when the motor is not supplied.
Then, the overall torque τ is computed as follows

$$\tau = \tau_0 + \tau_r = \frac{3}{2} p\Psi_{pm} i_q + K_{\tau k} i_q \sin(kp\omega_m t) + \Delta\tau_c \sin(np\omega_m t) \quad (9)$$

where $K_{\tau k}$ is the torque constant for the main component of the electromagnetic torque ripple, of order k, and $\Delta\tau_c$ is the magnitude of the main cogging torque component, whose order is n. The main electromagnetic torque ripple and the cogging torque frequency values are respectively $k = 6$ and $n = 12$ times the fundamental frequency, given by $\omega_s = \omega_m p$, for the particular motor of the laboratory setup. Those components of the torque ripple have been computed by the finite element analysis (FEA).
In addition to the components of the torque ripple described, radial forces are generated at the air gap between the stator and the rotor of the machine [8] that causes vibration of the stator core and yoke. Those forces are decomposed in Fourier series, so that the inner surface of the stator is subjected to several sinusoidally distributed loads. The main components in the series contribute as well to the torque ripple, especially when the spatial order and frequency of the excitation force are close to a stator mode shape and corresponding natural frequency respectively. The torque ripple components are added to the machine torque generated at the drive system as a perturbation in the MATLAB-Simulink model.

Vertical Vibration Model

The input to the vertical vibration model (see Fig. 2) is the machine torque and the output is the machine shaft velocity. The assembly composed of the car, the counterweight, the sheave and the ropes is represented by a 3 DOF model where the variable are the counterweight and car displacements and the sheave rotation angle, $x_{\mathrm{w}}, x_{\mathrm{c}}, \theta$ respectively. The ropes are divided into two sections: the car-ropes subsystem and the counterweight-ropes subsystem. Both subsystems are represented by a mass-less spring whose stiffness is calculated by Eqn. (10)

$$k = \frac{EA}{l} \tag{10}$$

where l is the length of the corresponding rope subsystem.
The ordinary differential equation set defining the dynamics is given by Eqn. (11).

$$\mathbf{M}\ddot{\mathbf{x}} + \mathbf{C}\dot{\mathbf{x}} + \mathbf{K}\mathbf{x} = \mathrm{T} \tag{11}$$

The inertia, damping and stiffness matrixes are given by Eqns. (12); the machine torque τ is included in the vector T that together with vector $\mathbf{x}$ are given by Eqn. (13). The parameters $k_{\mathrm{w}}, k_{\mathrm{c}}$ correspond to the counterweight- and car-ropes subsystems respectively and are calculated according to Eqn. (10) and updated every time instant during an elevator travel. The damping matrix accounts for the friction at the guides-rails contact. The values of the coefficients $c_{\mathrm{w}}, c_{\mathrm{c}}$ have been calculated from the vibration decay observed when impacting the rig with a hammer. The coefficient c_{s} has been neglected.

$$\mathrm{M} = \begin{bmatrix} m_{\mathrm{w}} & 0 & 0 \\ 0 & m_{\mathrm{c}} & 0 \\ 0 & 0 & I \end{bmatrix}; \mathrm{C} = \begin{bmatrix} c_{\mathrm{w}} & 0 & 0 \\ 0 & c_{\mathrm{c}} & 0 \\ 0 & 0 & c_{\mathrm{s}} \end{bmatrix}; \mathrm{K} = \begin{bmatrix} k_{\mathrm{w}} & 0 & k_{\mathrm{w}}R \\ 0 & k_{\mathrm{c}} & -k_{\mathrm{c}}R \\ k_{\mathrm{w}}R & -k_{\mathrm{c}}R & (k_{\mathrm{c}} + k_{\mathrm{w}})R^2 \end{bmatrix} \tag{12}$$

$$\mathrm{T} = \begin{bmatrix} 0 & 0 & \tau \end{bmatrix}^{\mathrm{T}}; \quad \mathbf{x} = \begin{bmatrix} x_{\mathrm{w}} & x_{\mathrm{c}} & \theta \end{bmatrix}^{\mathrm{T}} \tag{13}$$

The three natural frequencies calculated by solving the eigenvalue problem for the case of the laboratory setup as a function of the counterweight-rope subsystem length l_w are shown in Fig. 3 (natural frequency is 0 Hz and corresponds to the overall transport motion of the system).

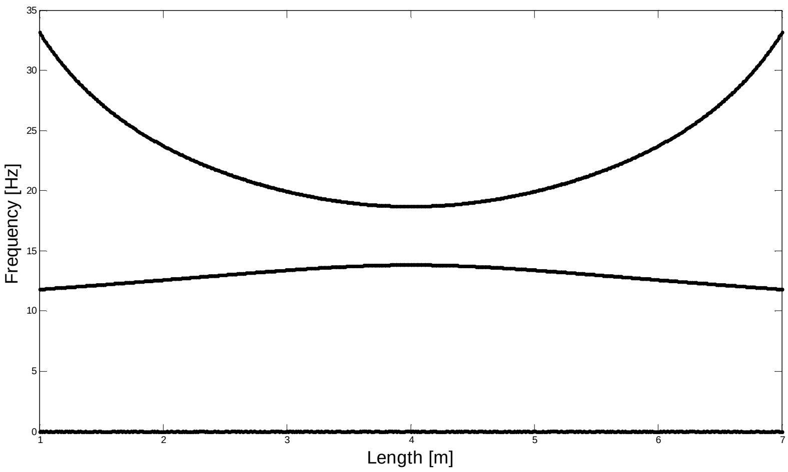

Fig. 3. The natural frequencies of the setup

COMPUTER SIMULATION AND EXPERIMENTAL TESTS

The dynamic behaviour of the elevator system will be simulated by employing the model developed above and the results will be compared to those obtained from the experimental tests.

Computation of the motor parameters by Finite Element Analysis

The electric motor model uses some characteristic parameters such as inductances, resistance, magnet flux linkage and torque constants. All those parameters of the motor have been computed by Finite Element Analysis (FEA) with the software FLUX. In Fig. 4 1) the simulated motor geometry along with the mesh distribution are shown. As the motor consist of $p=6$ pole pairs, the simulation geometry can be simplified to one pole pair domain. In Fig. 4 2) the magnetic field induced by the magnets around the geometry of the motor is shown. Table 1 summarises the main motor parameters computed by FEA simulations.

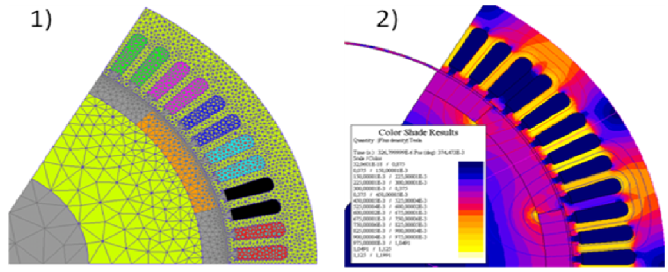

Fig. 4. 1) Mesh distribution, 2) Spatial distribution of the magnetic field induced by the magnets

Coil resistance	R_s	0.33 Ω
d-axis inductance	L_d	8.5 mH
q-axis inductance	L_q	11.7 mH
Magnet flux linkage	Ψ_{pm} (rms)	0.83 Wb
Average torque constant	K_τ	10.44 N·m/A
Torque ripple constant	$K_{\tau 12}$	0.1354 N·m/A
Cogging torque magnitude	$\Delta\tau_c$	1.25 N·m/A

Table 1. Parameters computed by FEA simulations

Apart from those components of the torque ripple considered, additional harmonics appear due to the radial magnetic forces between the stator and the rotor generated at the air-gap. The radial magnetic force per unit area or magnetic pressure waveform at any point of the air gap is obtained by means of the Maxwell's stress tensor theorem [8] given by Eqn. (14).

$$p_r(\theta,t)=\frac{1}{2\mu_0}\left(B_n^2(\theta,t)-B_t^2(\theta,t)\right) \quad (14)$$

where θ is the rotation angle with respect to the axis of symmetry of the machine, μ_0 is the magnetic permeability, t is the time, and B_n and B_t respectively the normal and the tangential components of the magnetic field around the air-gap. Fig. 5 a) shows the waveform of the magnetic radial pressure at a certain point of the stator core as a function of the rotor position. The spatial period of this signal is pi/6 for symmetry reasons. Fig. 5 b) shows the components (spatial orders) in the corresponding Fourier series. The highest component corresponds to the spatial order 0 and it is a constant pressure; the spatial order 2 is a sinusoidal pressure distribution of spatial period pi/6 and corresponding excitation frequency twice the fundamental one $2\omega_s$ and it is the main harmonic of the radial force.

Simulations and tests

Three accelerometers, each with its corresponding charge amplifier (see Table 2) have been placed on both masses and on the machine, as it is shown in Fig. 1.

Acquisition system	B&K Pulse
Accelerometers	B & K 4371, s.n. 1573419
Charge amplifiers	B & K 2635, s.n. 1602883

Table 2. Details of the data acquisition and measurement system

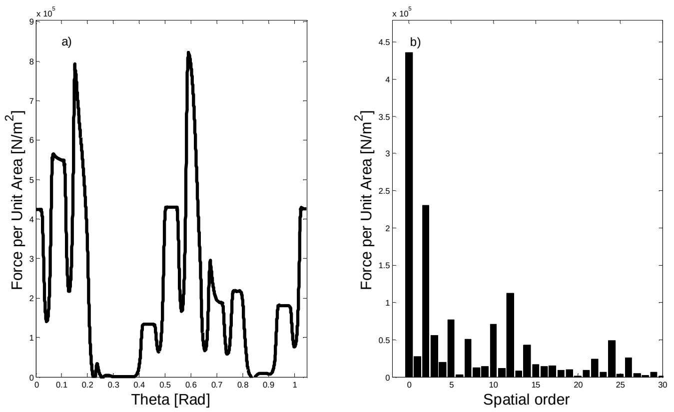

Fig. 5. a) Magnetic radial pressure at a certain point of the stator core as a function of the rotor position and b) components (spatial orders) of the radial pressure in the Fourier series

Fig. 6 a) and b) show the variation of the car-side rope length l_c and the velocity profile of the elevator model during a travel. The model has been implemented in MATLAB-Simulink and the vibration during a travel simulated. The ripple components expressed in Eqn. (9) with values given by Table 1 have been included. According to Fig. 5 b), excitation harmonic force due to 2^{nd} order component in the radial force has been added as well, as it could arise due to any eccentricity in the motor. The magnitude of this component is uncertain and has been given an arbitrary value similar to the amplitude of the cogging torque (see Eqn. (9)). At the setup rated speed of roughly 0.4 m/s the fundamental frequency ω_s is around 6 Hz.

Fig. 7 a) and b) show the measured (red) and the simulation (blue) accelerations of the car and the counterweight respectively during the travel. The recorded signals have been sampled at 512 Hz.

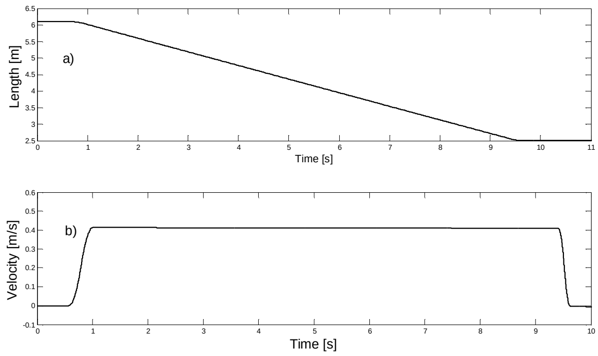

Fig. 6. Evolution of the a) car-side rope length and b) the velocity

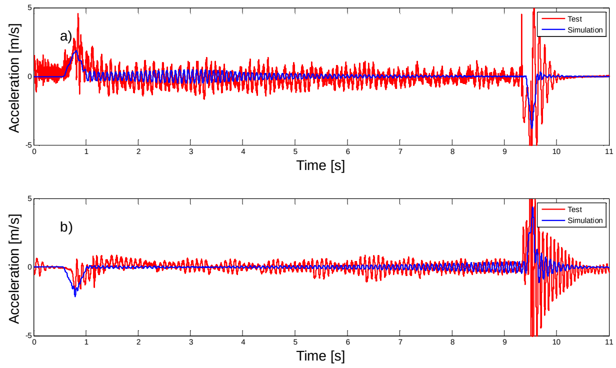

Fig. 7. Measured and simulated acceleration of the a) car and the b) counterweight

Figs. 8, 9 and 10 show spectrograms of the accelerations measured by the sensors placed on the machine, the car and the counterweight respectively, during the constant velocity stage. The spectrograms, in dB/Hz (dB relative to the reference value of 1 m/s^2), have been calculated by the Burg algorithm [9].

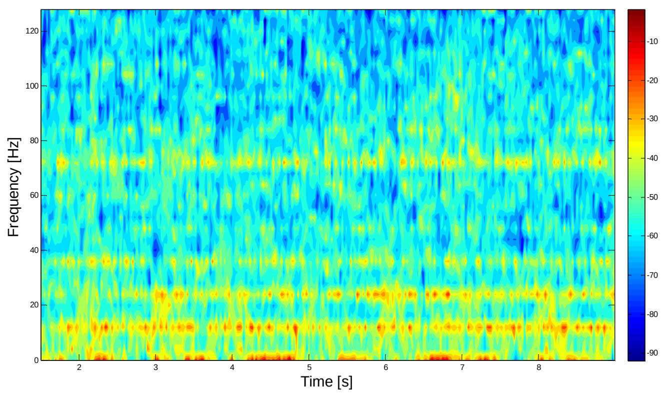

Fig. 8. Evolution of the PSD of the acceleration measured on the machine

Figs. 11 and 12 show the evolution of the PSDs of the simulated accelerations of the car and the counterweight respectively.

Discussion on experimental and simulation results

The results shown in Fig.7 demonstrate that the acceleration response predicted by the simulation model does not capture all measured vibration components and the vibration levels predicted by the model are much smaller than the actual levels. This would indicate that the actual excitation has been underestimated in the model. Furthermore, more mechanical degrees of freedom would have to be applied to obtain a more accurate simulation model.

As described before, the main electromagnetic torque ripple and the cogging torque frequency values are respectively $k = 6$ and $n = 12$ times the fundamental frequency, that is around 6 Hz at the setup rated speed. Those frequencies are 36 Hz and 72 Hz respectively. Furthermore, the 2^{nd} order component of the radial force is around 12 Hz. All these frequencies appear in the spectrograms presented in Figs. 8-11.

As expected, the resonance regions are evident in the spectrograms. This is manifested by the presence of the frequency components corresponding to the excitation frequencies that are near the natural frequencies of the system (see Fig. 3). At the frequency of 12 Hz, de amplitude of vibration of the car decreases and that one of the counterweight increases during the travel (see Figs. 7, 9-12). This is because in the 1^{st} modal shape the amplitude of vibration of the rig suspended from the longest rope part is higher than that one suspended from the shortest. The experimental results (see Figs. 8-10) show as well that there is an excitation frequency at 24 Hz; it could correspond to the component of spatial order 4 in the radial force (see Fig. 5 b)). Although its amplitude is not so high in the FEM calculation, it could be amplified because it is close to the 2^{nd} natural frequency (see Fig. 3). The simulation results show another excitation around 108 Hz (18 times ω_s) that is not clear enough in the experimental spectrograms (see Figs. 8-10).

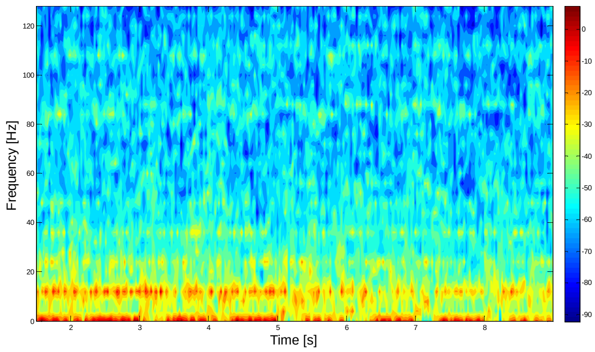

Fig. 9. Evolution of the PSD of the acceleration measured on the car

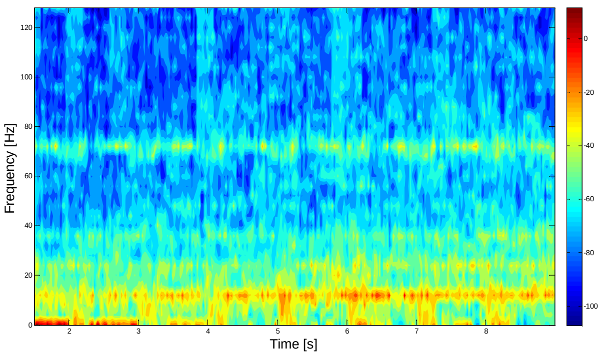

Fig. 10. Spectrogram of the acceleration measured on the counterweight

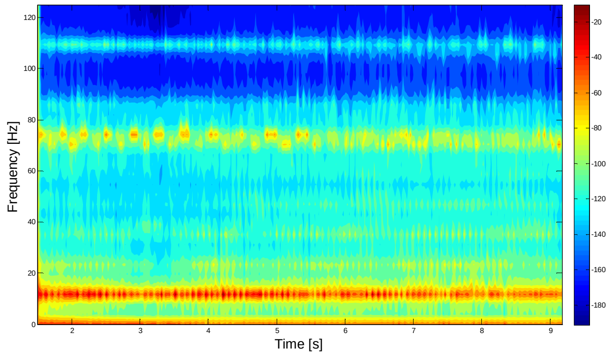

Fig. 11. Spectrogram of the acceleration of the car predicted by the model

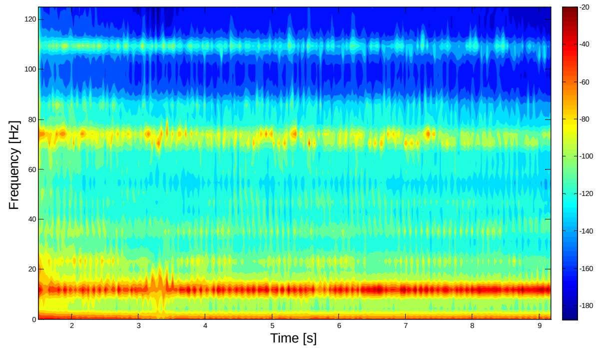

Fig. 12. Spectrogram of the acceleration of the counterweight predicted by the model

CONCLUSIONS

Experimental tests confirm that the hoist ropes, due to their elasticity, are a key component of an elevator system, as they transmit to the car, and even amplify, the excitation forces that originate at the drive system. This leads to excessive vibrations at the car end that compromise ride quality of an elevator system. The FEM model employed in the simulations provides an estimate of the machine torque ripple and the radial forces generated at the machine air-gap between the stator and the rotor. Those estimates can be introduced in a comprehensive drive system model of an elevator, where the car-counterweight-sheave-ropes assembly is represented by a 3 DOF lumped parameter model. The simulation results are compared to those obtained from the experimental tests performed using a laboratory model. The comparison shows that the simulation model underestimates the excitation forces and the dynamic response of the actual setup. Nevertheless, the simulation results help to identify which the main frequency components of the excitation forces are. The dynamic model can then be employed to predict the resonance regions and the dynamic behaviour of the system.

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2nd Symposium on Lift and Escalator Technologies

Origin Destination matrix estimation and prediction in vertical transportation

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ABSTRACT

The dispatching algorithm serving in a building with more than one lift can use passenger flow detailed information based on the requests made by the passengers to go up and down in order to improve the performance of the system. The requests can be analysed in order to extract detailed information about passenger arrival and destination floors and that information used to improve lift assignments. The control strategy can be optimised to look for ways to react to changes in traffic flow. In this paper the traffic flow is described as detailed origin-destination matrixes for 5 minute time intervals. The passenger flow analysis process is divided in two steps, first passenger detailed counting and then, a forecasting process applied to the data coming from the first step. For the first step, the passenger counting process, data obtained from a typical multi-storey office building is used and the results compared with actual manual counts from the same building. After this validation process, the next step uses the data as time series where prediction methods can be applied. Prediction methods can forecast the next time interval traffic flow. Neural networks are able to approximate different time series and are used in this paper with two different data resolution entries, 5 minute interval data and 2.5 minute interval data. The results of both forecasts are compared at a resolution of 5 minutes, and the results show that a methodology of working at a higher resolution to later aggregate the result at a lower resolution can be useful in this context.

INTRODUCTION

A LGCS (Lift Group Control System) serving in a building with more than one lift can use passenger flow detailed information in order to improve its performance. This information can be used to improve assignments of passenger requests to the cabs. Using detailed information about passenger arrival and destination, the optimal route selection process will be dynamically improved. With this information, the service that the system is giving to the lift passengers can be improved. It can also be helpful to understand the building needs and to improve the management of the resources it has. As an example, some lifts can be temporarily out of order or travel at different velocities according to the passenger requests and minimum service levels. It is also expected that improving the planning will move more people per time unit. This paper shows some empirical results obtained across the passenger origin destination counting process. Passengers moving through a building are manually counted and the passenger profile of the building created using Elevate™ simulation software. After this, the profile has been used to generate a log data file and this data used as an entry for an algorithm that performs the passenger counting as suggested in [1]. The validation process compares these two different passenger flows, the first coming from manual counting and the next extracted from the log data generated by Elevate™. These two different counts are used for comparison purposes and as a validation process in order to assess the accuracy of the log based passenger counting algorithm that we have implemented.

The information extracted from this first process is very detailed and can be useful for the next step, the prediction step. Although neural networks have been widely used for predicting incoming passengers and the next stopping floor, in this case, some different neural network topologies are going to be used to predict each origin and each destination of the passenger flow. We will try two different information entries to the neural network, with data at different resolutions. The output from both of the entries will be used later to validate the prediction step using data from the real count.

PASSENGER FLOW AND DETAILED COUNTING

When the passengers travel in multi-storey building using lifts, they use the up and down call buttons of a lift system to register landing calls. These landing calls are assigned to one lift by a control unit called a lift group control system (LCGS). The information about the requests and the number of passengers boarding and alighting for each stop can be recorded and this data used to extract passenger flow patterns specific for the building. The passenger flow can be converted into origin destination matrices. These matrices show the number of passengers moving from one origin of the transportation network to a destination for a period of time.

We will demonstrate an example of the information extracted for one 5 minute time interval, presented in an origin destination (OD) matrix for an 11 floor building. Each row in this matrix shows the number of passengers moving from the origin floor corresponding to the row number, to the destination floor corresponding to the column number. The matrix is first filled with 0s; the diagonal of the matrix, 0-0, 1-1, 2-2, etc. is always 0 because in a journey there is no passenger going to and from the same floor. Consider that there is a passenger on the floor 2nd who wants to travel to the 10th floor, 3 passengers travelling from floor 3rd to 9th, and 2 passengers travelling from floor 5th to 11th. If the building has 11 floors the OD matrix will be as shown in Figure 1.

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
1	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	**1**	0
3	0	0	0	0	0	0	0	0	**3**	0	0
4	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	**2**
6	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0

Figure 1: An origin destination matrix (OD) of a up journey with 6 stops, people board on 2th, 3th, 5th floors and alight at 9th, 10th and 11th.

In order to fill the OD matrices, the principle of the conservation flow is applied and linear equations are solved for each lift journey. A journey can be understood as a trip of one lift, where people travelling in the same direction use the cab, boarding and alighting but all in the same direction.

A journey finishes when the direction changes or the lift has no requests to attend to for a period of time. The information about how many people are moving from floor to floor in each journey is then aggregated for all the cabs and processed for each time interval, 5 minutes or 2.5 minutes.

A system that wants to perform this counting has to complete the next steps:

1. Divide the log data, for the time period needed, in our case it was 5 minutes (also 2.5 minutes for forecasting purposes).
2. For a given period, separate the lift movements into journeys.
3. From those journeys, the following information is collected every time the lift stops:
   - Number of passengers leaving and entering the lift at each floor. To obtain this number it is necessary to have three weight measures, just before the lift arrives at the floor where it is going to stop, after the passengers leave the lift and after the lift has left the floor. The information about the number of passengers boarding and alighting can be extracted from weight sensor data or maybe the processing of camera information.
   - Time stamp associated with the landing calls coming from this floor.
   - Car calls that have been registered after leaving that floor.
4. The principle of passenger flow conservation equation, says that the number of passengers entering and leaving a lift during a journey is equal. Using that principle, it is possible to estimate the missing information about the real passenger movements in the journey. This calculation has been done using the symbolic calculation module of MATLAB. In some cases, some rules, extra rules, are needed to be applied in order to solve the equations. These calculations are completed for all the journeys across all the lifts.
5. Information about the timestamp corresponding to the first request of the journey has to be collected to later aggregate the passenger movements across all the lifts for the five minutes time intervals. The final value is obtained by aggregating from the same time interval the different journey data in one OD matrix and then, aggregating the OD matrices of the different lifts.

Data collected manually in a London office building with 12 floors and 8 cars has been used to generate an Elevate™ profile. From that profile, a log file has been obtained after processing the passenger requests and this information given as an entry to the passenger counting estimation process. The data processed was from 10:30 to 12:50 in the morning, and the Figure 2 shows the manually counted number of passengers entering the building and the results of the estimation process. The results of the 5 minutes passenger origin destination flow are aggregated to extract the incoming passenger flow for comparison with the manual count.

The X axis runs from 1 to 29, the number of 5 minute intervals between 10:30 and 12:50, have both been included. There were a total of 1015 passengers manually counted as incoming flow and we were able to detect 960, corresponding to an accuracy of 95%. We lost some journey data because the movement complexity of some journeys was impossible to solve. They were so complex that the symbolic equations could not be solved. It is possible that some additional rules could be added to achieve a better fit.

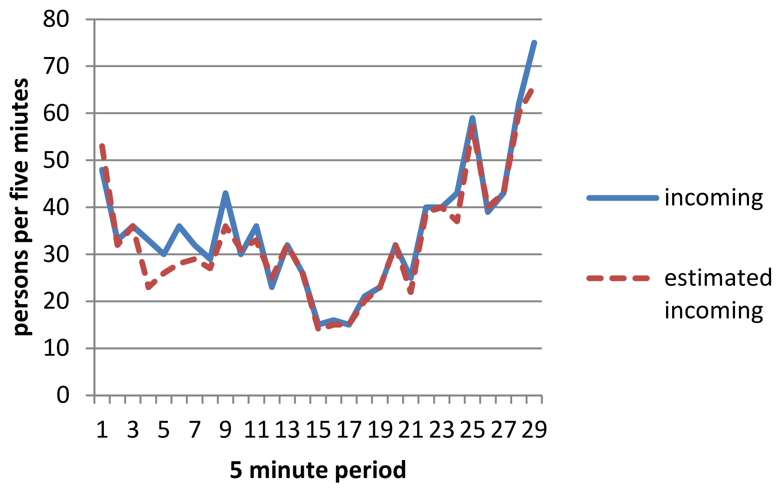

Figure 2: The number of real passengers entering the building and the estimated number of passenger incoming.

Regarding the outgoing traffic, Figure 3 shows the comparison between the real counting of the number of passengers that are leaving the building, and the estimated ones. In this case, the total number of passengers leaving the building was 1152 and we were able to detect 1087 of them, with an accuracy of 94%.

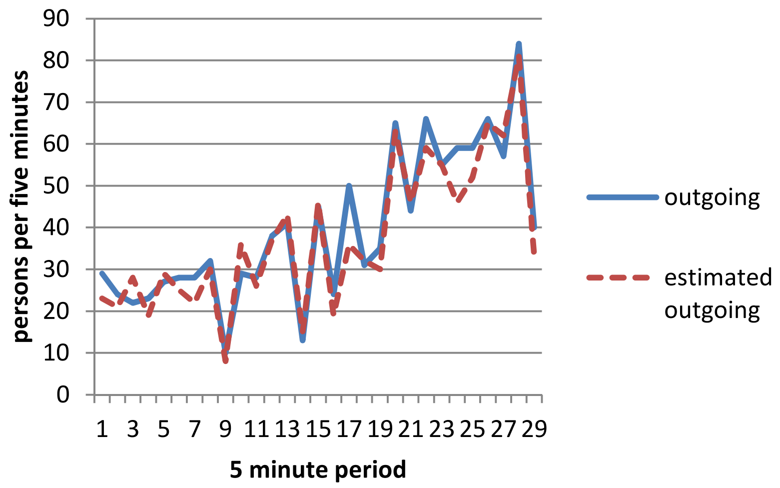

Figure 3: The number of real passenger leaving the building and the estimated number of passenger outgoing.

In order to complete the next step, the forecasting, the data has to be disposed as measures at regular intervals of time. The number of passengers moving from one floor to another (132 combination, excluding the ones that are not possible to and from the same floor), measured along the 29 intervals of 5 minutes and ordered over time are shown in Figure 4.

We have 132 different time series and 29 measures, at consecutive time intervals, for each one. The objective of this step will be to use a number *h* of previous time intervals for each time series to forecast the next value. As an example, one time series that represents the number of passengers moving from floor 2 to floor 6, have the next values: 6, 5, 4, 3, 0, 1. It has to be understood that 6 passengers has gone from 2nd to 6th in the first time interval, t_1, 5 passengers in the next time interval, t_2 and so on. Generalizing we can talk about the X time series as a sequence of values registered at regular time intervals.

$$X = x_1, x_2, x_3, x_4, \ldots, x_n$$

FORECASTING

Traffic flow forecasting is the core of the transport planning and traffic control. There are a lot of forecasting methods but it is important to know the nature of the data and try to select a method that can be appropriate for the task in hand. Traffic flow data features are nonlinearity and strong interferences.

The forecasting task can be tackled in different ways. Some of the methods [3] only try to train the system to identify a possible congestion with algorithmic methods. Others understand the data as a time series and use some signal processing methods [4] or box-jenkins methods [5] to do the forecasting. Support vector machines has been used also [6] for this task. A brief table, with the advantages and disadvantages of some methods can be seen in the table 1.

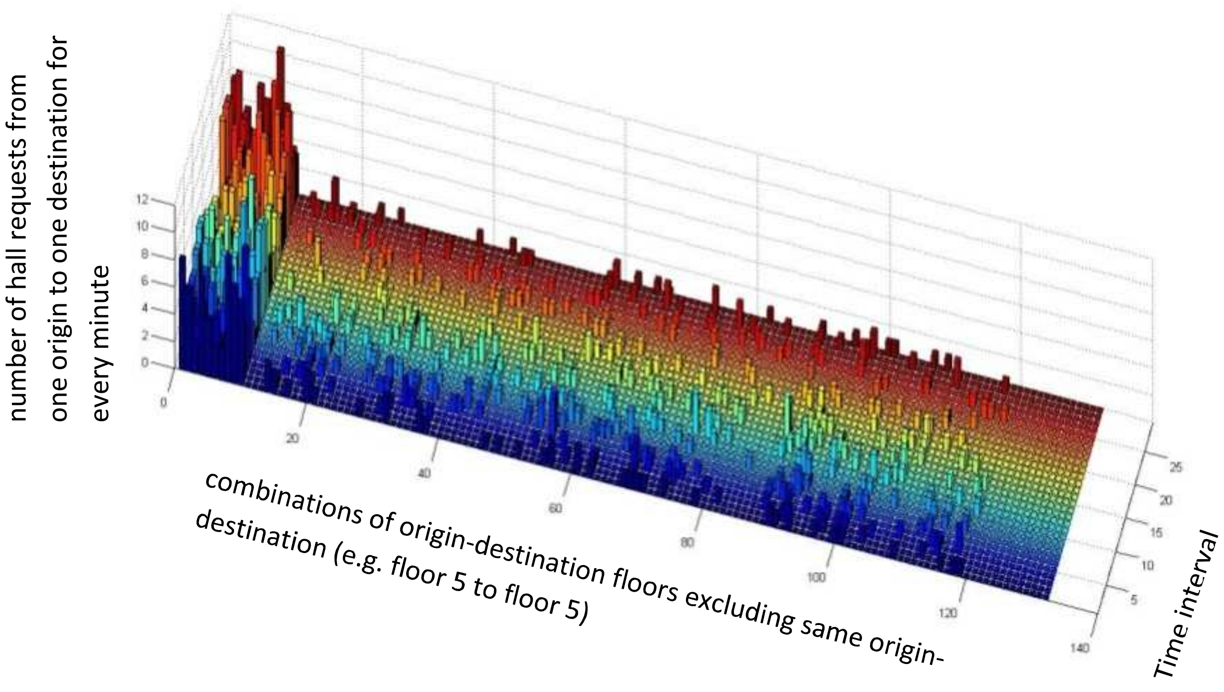

Figure 4: A bar plot of the requests for the 132 combinations (12*12 floors excluding the requests from one floor to the same) across the 29 five minute intervals.

Table 1 : Advantages and disadvantages of some forecasting methods

Methods	Advantages	Disadvantages
Moving Average	Simple	Not Good Fit
Arima	Good Fit	Tedious Programming
Kalman Filters	Good Fit	Tedious Programming
Bayesian Networks	Good Fit	Tedious Programming
Artificial Intelligence & Neural Networks	Well known	Fall In Local Minima
Support Vector Machines	Forecasting Of Small Samples	Sensitive To The Selected Kernel Function
Wavelets & ARIMA	Wavelets Have Good Decomposition Power And ARIMA Good Linear Fitting	Tedious Programming

Using soft computing methods, like Neural Networks, it is possible to train a network with information about how many passengers have requested a lift trip from one floor to another and then expect the network to predict the number of passengers that are going to make the same request for the next time interval.

The topology of the neural network is a question that can be discussed. In this work we are going to use quite a simple topology, where the input layer is going to have $h=4$ neurons and the hidden layer is going to have 10 neurons. The output layer will have only 1 neuron. The neural network will be trained with the previous 4 values, x_{t-4} $x_{t-3},$ $x_{t-2,}x_{t-1},$, and the result of the neural network will be x_t. Figure 5, shows this structure and the relationship with the OD matrices. 132 different neural networks were created and trained with requests data specific to each origin and destination and the previous 30 intervals time data used for the neural network training. After that, 14 consecutive time intervals data are given to the neural network as an entry and the prediction results used to evaluate the forecasting step.

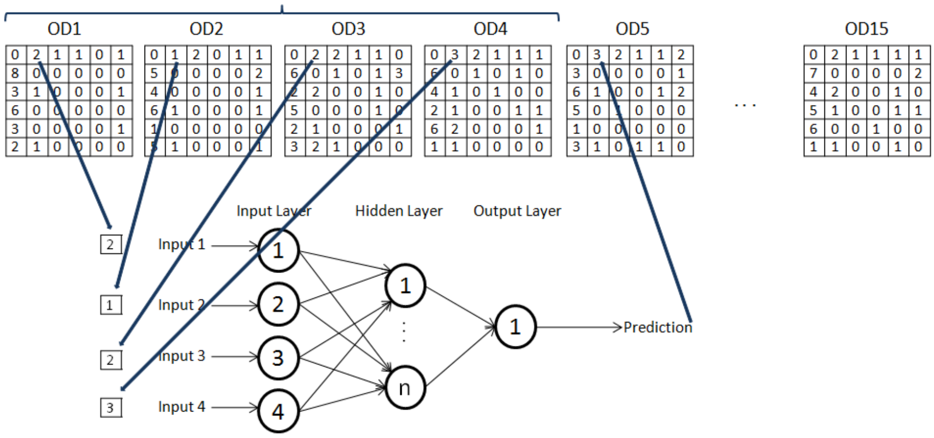

Figure 5: Structure of the Neural Network

Figure 6 shows an example of real requests coming from one origin and going to one destination, in blue, and the predicted requests for the same origin and the same destination, in red.

The methodology used for the forecasting approach was to work at two different resolution levels and to compare both sets of results. Working with detailed passenger flow data facilitates this approach because detailed data about each journey is available. Five minute interval forecasting is understood well enough to feed the dispatching algorithm. However having detailed passenger requests data for each journey, working at a low level (2.5 minutes interval or lower) and then, processing the results to obtain the desired five minutes forecasted data can be a useful approach.

The combination of more than one method has also been applied as a powerful approach, combining the better of the two methods to improve prediction accuracy.

The forecasting process must be evaluated in order to select the appropriate method. For this task, some indicators are needed to measure the quality of the method. In time series theory, three measures of the error are commonly used; MSE (mean square error), MRE (mean relative error) and MAE (mean absolute error). All of them calculate a discrepancy between the real data and the forecasted data. The equations 1, 2 and 3 show how these discrepancies are calculated. In all the equations, predictions are converted to OD matrixes, where OD_{ij}, represents the real OD matrix data for the origin-destination pairs, represented by (i, j). In the same way, ODe_{ij} is the estimated data matrix and f represents the number of floors.

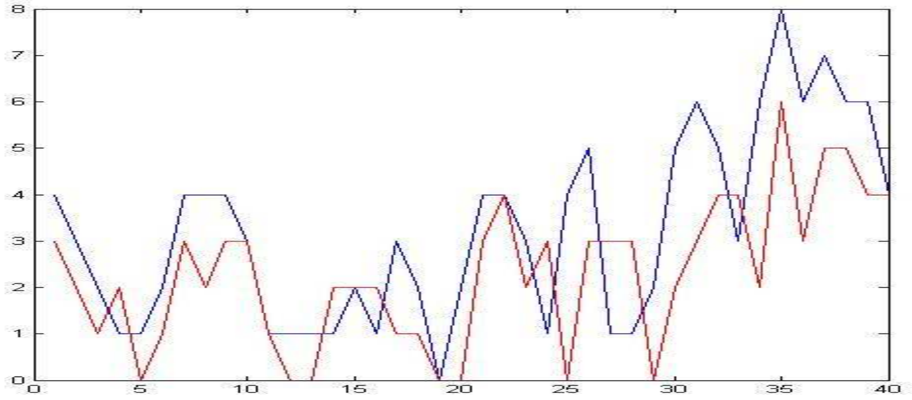

Figure 6: Passenger requests from one origin to one destination floor and the predicted requests

The first measurement is the mean square error (MSE) that describes the concentration and degree of dispersion about the error dispersion:

$$MSE = \frac{1}{2*f}\sum_{i=1,j=1}^{f,f}(OD_{ij} - ODe_{ij})^2 \qquad (1)$$

The second measurement is the mean relative error (MRE), an indicator to evaluate the whole forecasting process:

$$MRE = \frac{1}{2*f}\sum_{i=1,j=1}^{f,f}\left|\frac{OD_{ij}-ODe_{ij}}{OD_{ij}}\right| \qquad (2)$$

And the third measurement is the mean absolute error (MAE), the absolute average error between the predicted and actual values:

$$MAE = \frac{1}{2*f}\sum_{i=1,j=1}^{f,f}\left|OD_{ij} - ODe_{ij}\right| \qquad (3)$$

Table 2 shows the results of the three error measurements for 14 intervals. They correspond to the time period between 11:40 and 12:45. The table shows the time period, the total number of real calls for this period and the total number of predicted calls. It shows also MSE, MRE and MAE. The table also contains prediction measurements, when data about the journey for each 2.5 minutes is used to feed the neural network. The results obtained are later used to calculate the mean for the number of requests coming for each origin destination. The results are really good with this second approach. We understand that the mean calculation process can reduce the impact coming from the great variability of this data.

Table 2 : Results for the prediction step for 5 minutes interval data.

		5 minutes time interval OD matrix based prediction				2.5 minutes time interval Od matrix based prediction			
Periods	Real calls	Estimated calls	MSE	MRE	MAE	Estimated calls	MSE	MRE	MAE
11:40-11:45	35	58	3,0682	67,42%	0,0523	34	0,5019	34,47%	0,0374
11:45-11:50	31	49	1,6970	54,55%	0,0302	32	0,3655	28,41%	0,0163
11:50-11:55	32	71	2,5076	73,48%	0,0500	43	0,4754	30,68%	0,0208
11:55-12:00	33	59	2,2424	65,15%	0,0560	44	0,4318	28,79%	0,0278
12:00-12:05	28	52	2,2727	62,12%	0,0501	50	0,6155	26,14%	0,0316
12:05-12:10	47	55	3,0606	68,18%	0,0710	47	0,6023	35,61%	0,0420
12:10-12:15	32	38	0,9242	34,85%	0,0217	40	0,3902	23,48%	0,0222
12:15-12:20	52	79	1,9167	53,79%	0,0490	52	0,5095	26,14%	0,0272
12:20-12:25	48	62	1,4848	53,03%	0,0469	40	0,9811	31,82%	0,0383
12:25-12:30	50	35	2,1894	67,42%	0,0489	48	0,6117	32,2%	0,0309
12:30-12:35	72	84	2,7576	72,73%	0,0510	64	1,1420	39,02%	0,0252
12:35-12:40	50	48	1,5303	57,58%	0,0624	54	0,4242	28,03%	0,0300
12:40-12:45	58	50	2,8485	69,7%	0,0883	49	0,4337	26,89%	0,0335
12:45-12:50	79	42	3,1288	79,55%	0,0586	57	0,9905	40,53%	0,0243
Total	647	782	31,6288	8,7955	0,7364	654	8,4753	4,3221	0,4075

CONCLUSIONS

In the vertical transportation the information provided by the log of the requests and trips of the cabs, provides the possibility to perform a comprehensive movement counting between floors. This valuable information can also be used to forecast demand in the minutes after. This will allow for better planning in dispatching and also support building applications that can take advantage of it. As for the prediction, neural networks offer good fitting to variable data. The methodology for analysis at high resolution and subsequent average at lower resolution has proven effective for this type of data but subsequent tests need to confirm it. Further development will consider origin-destination matrices estimation [2] and hybrid methods [7].

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2nd Symposium The Lift and Escalator Technologies

Economically Efficient Green Hydraulic Lifts

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ABSTRACT

The general trend in the lift industry is towards lifts with lower energy requirement. Hydraulic power units with inverters were introduced to decrease energy consumption for heavily used lifts. Since existing solutions are generally more demanding and rather costly these systems have not found enough appeal yet. A compact, simpler and cost-effective solution to compete with advantages of the conventional hydraulic elevator system is necessary to make energy-efficient solutions more attractive.

With the use of an inverter the pump outputs just enough flow for the momentarily targeted speed. When pump leakage increases due to higher load and/or oil temperature, the car speed decreases which results in longer travel time and uncomfortable ride. Therefore, pump flow should be regulated according to the load and oil temperature to assure targeted speeds and good ride-quality.

In this paper, a sensor-less load compensation solution that basically consists of a control valve and an inverter with sophisticated hydraulic software module is introduced to assure targeted speeds under all load conditions. The solution has no sensoric interface between the control valve and the inverter, works with open loop control and also provides an extra energy saving mode. All these advantages not only make the solution an energy efficient one but also an economically-efficient one as well. The paper gives the details of the solution and features implemented in the development of the control valve and the advanced inverter software.

INTRODUCTION

Use of an inverter with the Permanent Magnet Synchronization machine (PMS) has been the most accepted development in the lift industry. This is called as “the new or the latest drive technology”, which reduced operational energy consumption considerably and also enabled engineers to construct Machine Room-Less lifts (MRL). Focusing on the energy consumption issue and using it as a marketing tool, MRL installations have managed to obtain an increasing trend in the market. As a result of that hydraulic lift installations are said to be reduced up to 40% globally.

“The new technology“ has been reflected like it provides always the most energy efficient solution, perfectly suits every installation and energy can be always regenerated and dumped into the grid. However, the mentioned benefits of the existing “new technology” are not remarkable and mostly leads to higher energy consumption when it is used for low-usage lifts [1] where, the investment for the new technology may never be gained back during the life-time of the lift [2]. This is because of the fact that the inverter and its peripheral devices are costly and require energy to be active even when the lift is at stand-by [3].

On the other hand, future developments in drive technology and competition in the market is expected to reduce or eliminate stand-by energy consumption (matrix converters) and lower inverter prices considerably. In this respect, suitable vvvf solutions that are simple, inexpensive, easy to maintain and offer high compatibility will be used widely in low-rise buildings in coming years.

APPLICATION OF INVERTER DRIVE ON HYDRAULIC LIFTS

Hydraulic lifts had been largely utilized in low-rise buildings because of their superior properties such as high reliability, low initial cost, easy and cost effective installation, high ride quality and low servicing cost. In addition, they have the best records in safety and robustness against natural disasters like earthquakes.

Having a more challenging market, hydraulic lift manufacturers have also given the first priority to energy saving factors in their designs. Energy-efficient power units that employ an inverter drive, so called the new-generation power units, have been introduced to the market long ago. However, utilization of the new generation power units has not found sufficient appeal yet. This is because while concentrating on the marketing issue to have the state of the art solutions, advantageous properties of hydraulic lifts have been ignored in many cases. By doing so practical, reliable and low-cost ingredients of hydraulic lift have been left instead, more demanding, impractical and expensive solutions have been introduced.

Having failed to address the main objectives of new-generation power units properly, solutions either became so primitive or rather complicated and costly. In many cases a conventional power unit with the addition of the inverter drive is presented as the state of the art. In fact, simply adding an inverter does not necessarily lead to energy savings [4]. Moreover, employing the inverter without justifying its 95% efficiency would only increase energy bills.

Alternatively there exist more demanding and costly solutions [5], which besides the inverter, need additional components like pressure and temperature sensors, flow meter, encoder, electronic control card etc. In these solutions, the inverter is used mostly both in up and down directions with the help of exclusive inverter software. Application of such systems, no matter how good ride quality they give and how little they vary the oil temperature, are in general away from meeting real market needs; unnecessarily extended pay-off time (beyond the renovation period), difficulty in finding competent technicians and increased servicing needs are some to pronounce.

REQUIREMENTS FROM NEW GENERATION CONTROL VALVES

High usage or low stand-by power: to reduce stand-by energy consumption and obtain maximum benefit.

Low cost: to have reasonably short pay-off period and to meet market expectations. At present, inverter, control valve and sensoric systems keep the price of the new-generation hydraulic solution high. Particularly inverters are having 2 to 4 times higher prices than the conventional control valves. Therefore, a suitable solution should justify the use of an inverter with an inexpensive control valve and a simplified system design.

Minimum number of interfaces/components: to assure simplicity, reliability, easy maintenance, low cost and also to eliminate the need for highly-qualified technical personnel.

High compatibility: to be fitted easily on existing lift controllers and power packs in order to respond renovation needs.

Exclusive software: to assure ease of use, safety, good ride-quality and low energy consumption.

EV4 NEW GENERATION CONTROL VALVE

There can be many ways to engage a control valve with an inverter to obtain a new-generation valve. The most important question is how to satisfy inexpensive and simple solution with good ride quality. Fig. 1(a) shows some new-generation applications. Here, the closed-loop control solution (requires a submersible encoder and interface electronics) with the electronic (requires a flow meter and an electronic card) or mechanical valve increases the cost of the system considerably. Simplicity of the system may be further disturbed with the existence of pressure, proximity or/and temperature sensors. In terms of energy-efficiency and initial investment, application of such systems can only be justified for very high-usage lifts (over 700 cycles/day).

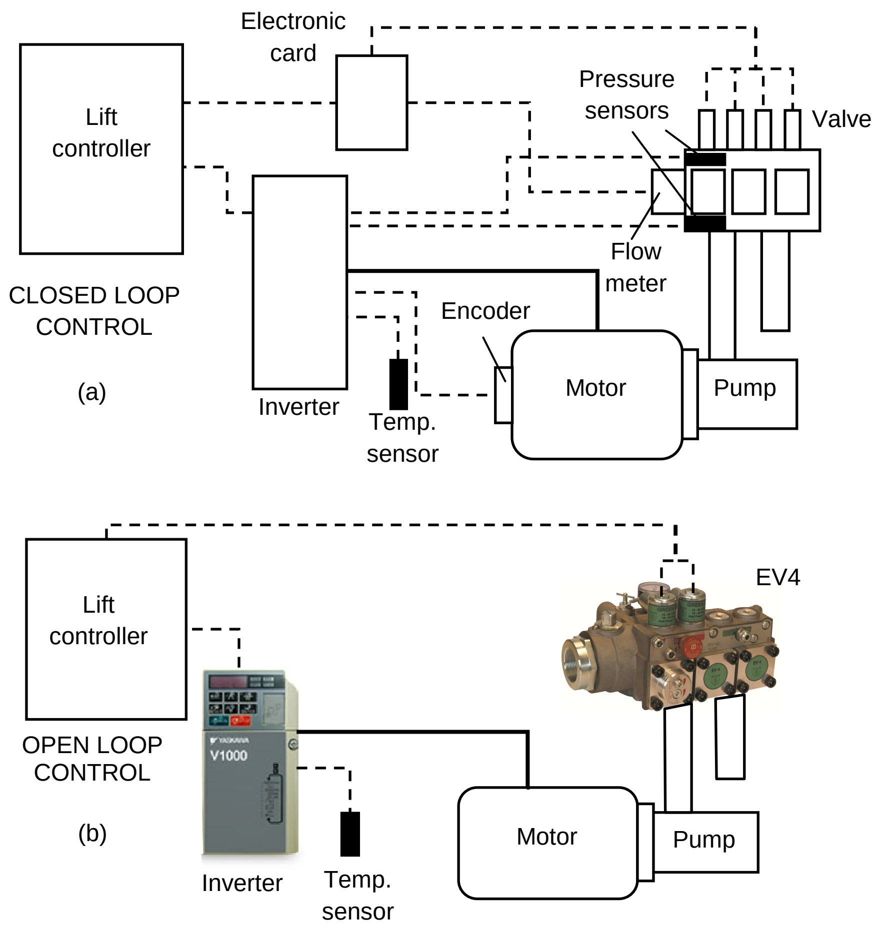

Figure 1. (a) Standard closed loop control solutions (b) EV4 open-loop control solution.

Knowing the market needs and evaluating truly necessary requirements from the new generation power unit, the new-generation control valve, EV4 has been developed, as shown in Fig. 1(b). EV4, which inherently offers the same advantageous properties of electro-mechanical valves, is a simplified version of an electro-mechanical valve. It was designed to employ a V1000 inverter for up travel whereas down travel is managed by the electro-mechanical means. EV4 has no interfaces with its peripheral devices and does not require sensoric for load compensation. Since up travel is controlled by the inverter, up solenoids and adjustments were removed from the valve and by-pass transition stage was cancelled, which simplified both the valve and the system set-up considerably. To lower the initial cost and simplify the system requirements further, open-loop control has been implemented. Thus, the need for a costly submersible encoder was eliminated. The real supremacy of the system comes from the exclusive inverter software, which eases the use of the system and provides excellent travel characteristics. The software was designed to sense the load condition to allow necessary compensation for the motor output. The software is also intelligent enough to modify transition times, when necessary, to assure good ride quality. Moreover, the inverter can be optionally used for the down travel to control down speed and to improve ride-quality without needing any modification on the valve. An inexpensive temperature sensor was also included in the system to account for the effects of oil temperature variation. Optionally, the car may be run either at a constant speed mode, where the lift speed is kept constant, or at an energy saving mode (Maximum speed mode), where the speed of the car is lowered according to the load in the car [6].

APPLICATION OF THE METHOD

The EV4 valve is an electro-mechanical type and it was designed to allow inverter to take control of the complete speed regulation of the up travel. In this way only necessary flow rate is supplied to the valve and no oil is by-passed. As a result, less energy is consumed during up travel, which increases the efficiency of the system and also reduces oil heating. Using the inverter also reduces motor starting current and the size of the electric energy meter.

On the other hand car load and oil temperature influence the leakage of screw pump drastically, which may cause speed and the total travel time of the lift to vary considerably (Fig.2). In some cases, when oil temperature or/and car load is extremely high, speed of the pump during levelling phase may not provide positive flow and lift stands still (zero speed) which is illustrated by the dashed-dotted line in Fig. 2. Therefore, a suitable solution should allow for the compensation of pump leakage by adjusting the speed of the pump.

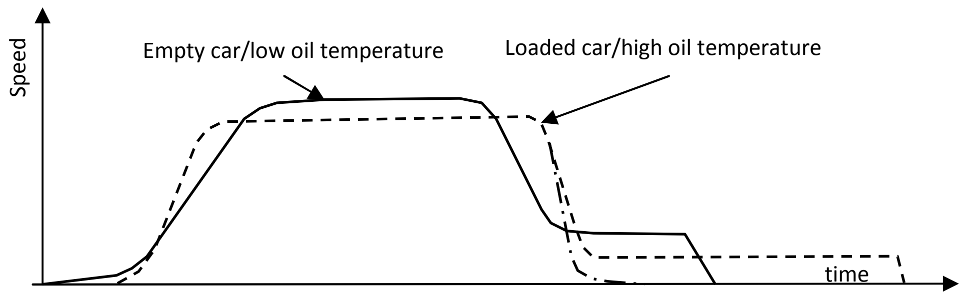

Figure 2. Ride-quality and travel duration variations with car load/oil temperature.

Initial Settings

In order propose a simplified and cost-effective solution V1000 inverter, which also contains computing, memory and monitoring modules, was utilized. At a very initial stage of the set-up process, the user selects the oil type from a menu. As the selection is performed, necessary viscosity and temperature parameters are assigned to the registers.

In the second stage, the user inputs lift data and pump performance data (obtainable from pump manufacturers) according to the working pressure range of the lift. Inverter then reads the current temperature ($Temp_2$) and processes oil and pump performance data to obtain motor speeds (speed frequencies) in Hz for the full, levelling, inspection and secondary full speeds. Additionally, temperature control gain ($Gain_{temp}$) and leakage speed frequencies for empty and loaded car pressures are also calculated. For simplicity these are given parametrically below:-

$$f_k \text{ [Hz]} = f(a_i, Temp_2) \quad (1)$$

$$Gain_{temp} = f(a_i) \quad (2)$$

where, f_k : calculated speed frequencies [Hz], a_i input data (pump performance and oil-type).

The software also allows the user to input these variables manually in case the data is not available or the pump is old and worn.

Car Load and Oil Temperature Compensations

V1000 inverter software was re-designed to include some compensation procedures to sense the car load and regulate the motor speed. The inverter can monitor at least one of the internal inverter parameters such as, output current, torque producing current or internal torque reference, which is mostly used, and also measures constantly the oil temperature by means of a temperature sensor. The monitored parameter is then compared with a pre-set reference value to determine the load condition at recent oil temperature.

To obtain the pre-set reference values and the necessary control gains precisely the inverter software has been armed with a teaching mode option. At "Teaching Mode" a probe (teaching) run is performed with the empty car to capture the reference parameters. This is shown in Fig. 3 where, capturing locations of full and levelling speed torque references, T_{2full} and $T_{2leveling}$ are shown. Knowing T_{2full} , $T_{2leveling}$ and their corresponding speeds, other torque references for secondary full speed ($T_{2second}$) and inspection speed (T_{2ins}) are calculated with interpolation.

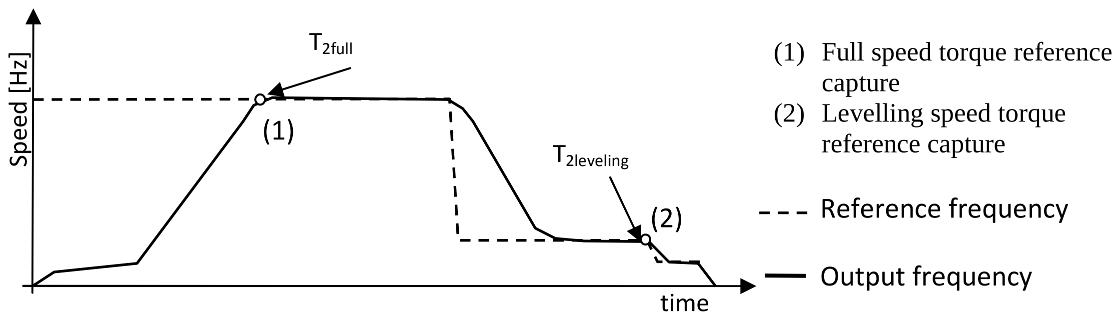

Figure 3. Capturing torque references, T_{2full} and $T_{2leveling}$ during a teach run

In Fig. 4 derivation of lift speed with respect to empty and loaded car speeds is shown. Here, T_1 and T_2 are torque references that are captured at loaded and empty car probe runs respectively. From Fig. 4, speed n_x for a captured torque of T_x may be written as:-

$$n_x = n_2 - \frac{\Delta n_i}{\Delta T_i} * (T_x - T_2)^{\gamma} \quad (3)$$

where, γ : constant, T_x : captured torque, T_2 : torque reference captured at empty car probe run at a reference temperature $Temp_2$, Δn_i : difference in measured speeds, ΔT_i : difference in captured torque references. Thus, $\frac{x}{n_2}$, which is the amount of speed loss in %, can be simplified as:-

$$\frac{x}{n_2} = Gain_{torque} * (T_x - T_2)^{\gamma} \quad (4)$$

Knowing T_2, the lift and pump performance data $Gain_{torque}$ can be calculated.

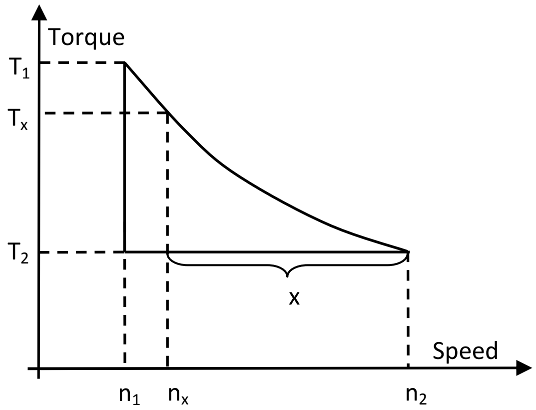

Figure 4. Derivation of lift speed from the reference parameters obtained through the probe runs.

$$\mathrm{Gain}_{\mathrm{torque}} = \mathrm{f}(\Delta \mathrm{n_i}, \Delta \mathrm{T_i}^{\gamma}) \tag{5}$$

Thus, new speed frequency can be calculated as:-

$$\mathrm{f_{new}} = \mathrm{f_{old}} * \left(1 + \mathrm{Gain}_{\mathrm{torque}} * (\mathrm{T_x} - \mathrm{T_2} * \mathrm{I})^{\gamma}\right) \tag{6}$$

$$\mathrm{I} = \mathrm{Gain3} * \mathrm{f}(\mathrm{Temp_2}, \mathrm{Temp_x}) \tag{7}$$

"I" is a special function that accounts for the variation of system resistance to flow as oil temperature varies. Similarly temperature calculation can be derived as below;

$$\mathrm{f_{new}} = \mathrm{f_{old}} * \left(1 + \mathrm{Gain}_{\mathrm{temp}} * (\mathrm{Temp_x} - \mathrm{Temp_2})^{\theta}\right) \tag{8}$$

where, θ : a constant, $Temp_x$: measured oil temperature, $Temp_2$: oil temperature reference.
The resulting equation for both load and oil temperature compensations may be given by:

$$\mathrm{f_{j_{new}}} = \mathrm{f_j} + \mathrm{f_{level}} * \left(\mathrm{Gain}_{\mathrm{torque}} * (\mathrm{T_{xj}} - \mathrm{T_{2j}} * \mathrm{I})^{\gamma} + \mathrm{Gain}_{\mathrm{temp}} * (\mathrm{Temp_x} - \mathrm{Temp_2})^{\theta}\right) \tag{9}$$

where, j indicates speed frequencies of full, secondary full, inspection or levelling speeds, f_{level} is the speed frequency of levelling speed, T_{2j} and $Temp_2$ are reference frequencies for load and oil temperature. In operation mode, T_2 and $Temp_2$ remain unchanged but T_x and $Temp_x$ are measured for each run by the inverter to calculate the speed frequencies under the actual load and oil temperature condition. Speed compensation due to oil temperature variation is applied throughout the travel whereas, that due to car load variation is applied after reading the torque at point 1 in Fig. 3.

Down Speed Compensation

When electro-mechanical valves are used for down travel, speed of the car increases with increasing oil temperature and system pressure (car load). This may result in jerky starts, rapid accelerations and hard decelerations, and jerky stops when working pressure range is large. The total travel time also changes due to varying speed and levelling duration. This is depicted in Fig.5.

Some of the new-generation valves can also be used for down travel. In that, while the pump/motor shaft is rotated in reverse direction by the hydraulic force of the oil column, the inverter controls the shaft rotation to regulate the speed of down travel. Here, the energy generated by the system is burned into a resistor, which prevents hydraulic oil getting heated further. However, such a solution complicates the valve design, increases the system cost and can only be justified with high-usage.

An inexpensive, simpler and easier way of controlling down travel ride-quality is introduced by the V1000 inverter software for low- and mid-usage lifts. In that, to control downward speed variations, controlled upward flow is produced when car load and oil temperature are excessive. During down acceleration, the motor torque (T_{x_down}) is measured and a up-flow ramp is determined to provide smooth acceleration and constant speed. This is shown in Fig. 5 where, the dashed-dotted line shows uncontrolled down travel under loaded car or/and high oil temperature. The compensations optionally can only be applied during acceleration and deceleration stages, which is shown with the dashed line (Energy saving mode), or during the complete travel, which is shown with the solid line (Constant speed mode).

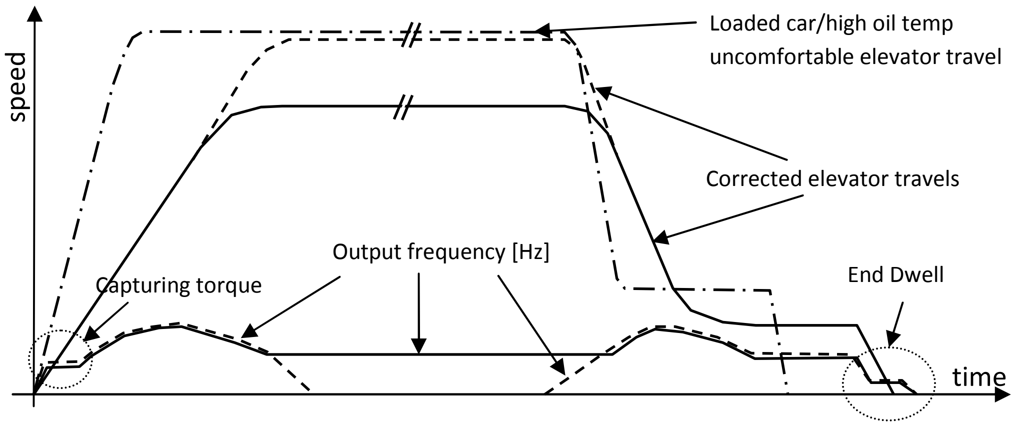

Figure 5. Application of load &oil temperature compensations in down direction.

Travel Modes. At constant speed mode, lift speed is kept constant whereas, at energy saving mode (also called maximum speed mode), speed of the lift is modified with respect to the car load. In that, car load and oil temperature compensations are applied normally for the levelling speed however, the full speed is limited by a pre-set limiting torque value, T_{x_limit}. This is shown in Fig. 6. When the measured torque during the run exceeds the limiting torque, T_{x_limit} (eg. point 1 in Fig.6) then the speed frequency takes the value of output frequency until the end of the full-speed run. This is indicated with point 2 in Fig. 6. In this way maximum allowable motor torque will not be exceeded when the car load is excessive. Conversely, the lift could travel at close to the maximum speed when the car load is low. In energy saving mode the deceleration path/time is also recalculated for each run to assure fix levelling duration. The energy saving mode may allow lower motor sizes to be employed and may lead to lower energy consumption.

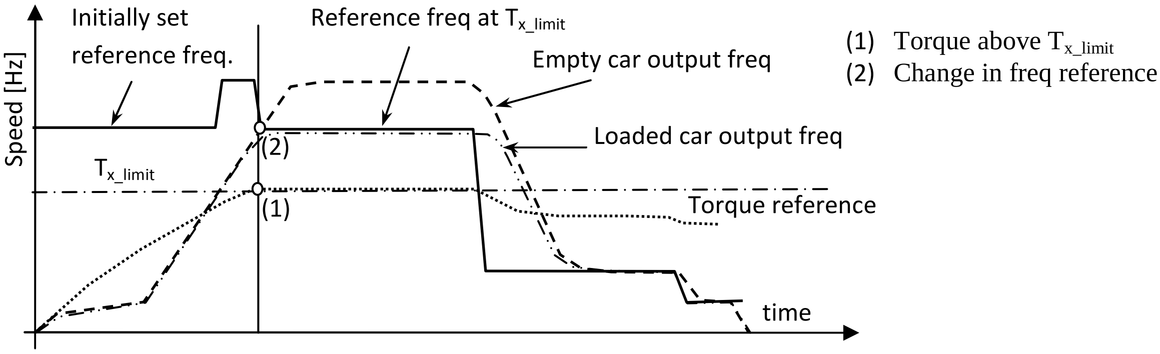

Figure 6. Load and temperature compensations.

Deceleration Time Compensation

When the full speed is modified to a lower speed then levelling travel time, L may become considerably long and create uncomfortable ride. This may happen for example, at *energy saving mode*, as lift speed changes with varying car load. In Fig. 7, L and L' show levelling durations of normal and modified travels that are illustrated with solid and dashed lines respectively. Here, levelling duration of L' becomes rather long. In order to have a fixed levelling time, L levelling duration and/or deceleration path of the modified travel is altered.

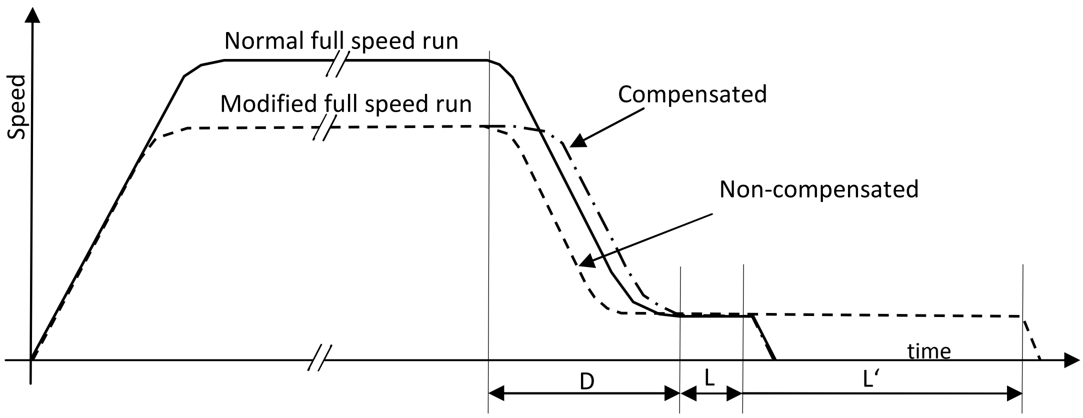

Figure 7. Deceleration path/time compensation.

Additional Procedures for Better Ride Quality

In Fig. 8 some of the additional properties of the inverter software are shown. These were introduced basically to assure high ride-quality. Some of these are:-

Start dwell: A special soft start procedure that is defined with the leakage frequency Q1 and ramp frequency Q2, and ramp times Q3 and Q4, which allows smooth and quick take-off.

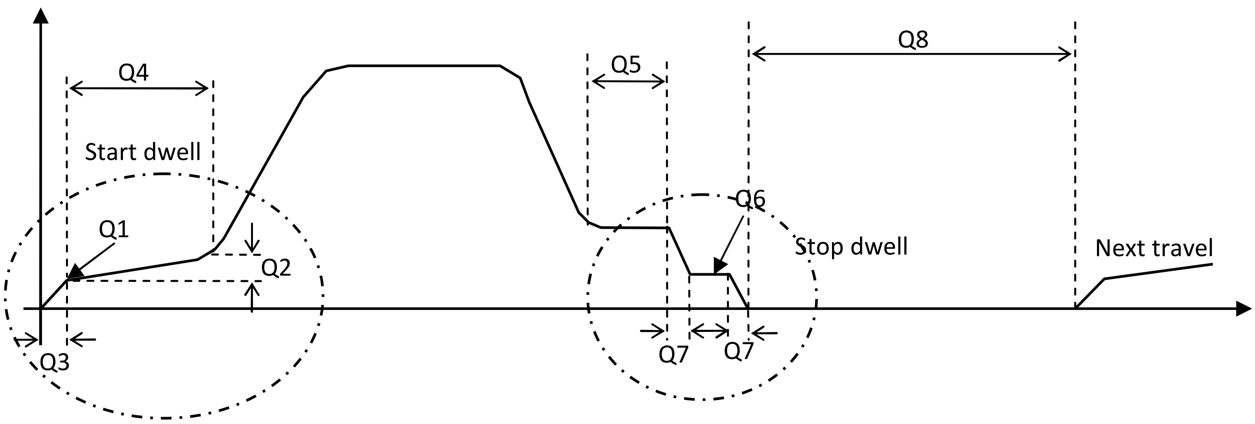

Figure 8. Some of the additional procedures used by the inverter software.

Stop dwell: To assure short levelling duration, smooth and accurate stop, fully compensated Q6 dwell (leakage) frequency was implemented.
Levelling duration check: to provide better ride-quality levelling run duration is checked and when necessary, corrective actions are taken.
Long waiting durations: The time between two consecutive runs is measured to assure smooth take-off after long waiting durations.

SUMMARY

Most of the new generation hydraulic power units are only suitable for high-usage lifts while they put up with high stand-by energy consumption, high initial cost, impractical and complicated set-up. With the present inverter technology, solutions that are simple, cost-effective, service-free and easy to install seem to meet market requirements and could acceptably be utilized on low-usage lifts.

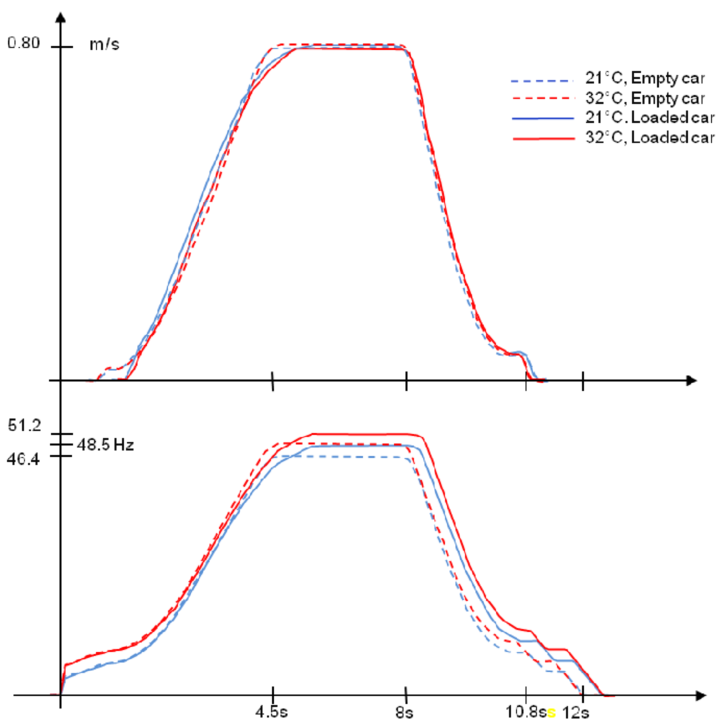

Figure 9. Speed and travel duration control by EV4

EV4 valve and V1000 inverter, using open-loop control and sensor-less load compensation with the use of special inverter software introduces a cost-effective and simplified solution for the new generation power units. The solution employs open-loop control routine together with specially designed procedures to assure good ride-quality. It can easily be applied to both up and down travels without increasing the complexity of the system by using either the constant speed mode or energy saving mode. In addition, the solution can be integrated with existing power units easily for renovation needs. In Figure 9, an example for the speed and total travel duration control of the EV4 valve is shown under varying oil temperature and car load.

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BIOGRAPHICAL DETAILS

Dr. Ferhat Celik received his BSC degree from Istanbul Technical University and later obtained his MSc and PhD degrees from University of Manchester. He worked for Istanbul University as an Assistant Professor for 6 years before joining Blain Hydraulics, where he acts as the International Coordinator and is also in charge of R & D of Electronic valves. Dr. Celik is a member of the committees in ELA and AYSAD, and a member of Consulting Committee of Asansor Dunyasi.

2nd Symposium on Lift and Escalator Technologies

Energy Models for Lifts

Determination of average car load, average travel distance and standby/running time ratios

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Abstract: Lifts are essential for the operation of a building and contribute to its energy burden. They use energy in one of three main modes: standby (when the lift is dormant), running (when the lift is moving) and idle (when the lift is between standby and running modes). The proportion of time taken in each mode, and hence the energy consumed, depends on many factors including: type of building, traffic patterns and technology used. This paper gives data for these time proportions for a specific installation by means of simulation tools, based on a set of buildings. In addition, other important parameters are presented to enable accurate estimations of energy usage to be determined.

Keywords: Lifts, standby time, traffic pattern, Energy classification of lifts.

1 INTRODUCTION

The demand for energy-efficient lifts has increased in recent years fostered, for example, by the European Directive on the Energy Performance of Buildings. There are also several international initiatives for buildings classification, such as BREEAM, LEED, CASBEE, etc. as well as an international standard ISO 25745-1: 2012 [1] and some national guidelines such as VDI 4707 [2]

Any method of assessment/classification requires reliable methods for calculating the total energy consumption of a lift during a given period, according to which the overall energy efficiency can be assessed. Some of these methods incorporate formulas for estimation, whereas others leave the choice to the manufacturer. Different methods have been proposed and most calculate the energy consumption of the lift in two main operating conditions: running (when the lift is moving) and standing (when the lift is stationary). The second mode can be further split into: standby mode (when the lift is dormant) and idle mode (when the lift is between standby and running modes). The energy efficiency of a lift is intimately associated with the building in which it is installed and how the building population uses it. This usage can be used to develop a classification labels for lift installations.

Whilst the energy consumed in each operating condition can be easily measured, for example, using the methodology described in the ISO 25745-1: 2012, or estimated from the mechanical and electrical components of the lift, there are no clear rules on how to estimate the other relevant parameters. This paper shows how to obtain the parameters by means of simulation tools and provides data for general usage.

In the following sections, the chronological order of this research work is described. In Section 2 the objectives of the work are laid out, Section 3 describes the simulation protocol design, Section 4 deals with the simulation execution, data treatment and definition of templates for collecting the data and the final sections (5 to 9) with the first and the advanced analysis of results, summary tables, further work proposed and conclusions.

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2 DEFINITION OF THE OBJECTIVES

The ISO/TC178/WG10 (working group) committee was tasked to provide a means to classify the energy efficiency of lifts in use. To achieve this it is necessary to carry out an accurate calculation of the estimated energy usage. The research described here supported the work of WG10.

For a certain installation, where the characteristics of the building (number of floors, total height of the building, interfloor height, population and level of demand, etc.) and of the lift/s installed in it are known, the daily operation of the lift can be emulated using simulation software.

One of the results that can be obtained from a simulation is the spatial plots of each car's movement. Using this spatial plot it is possible to calculate the occurrences in each possible trip, characterized by distance travelled, direction of movement and load carried in a specified period. Then knowing the number of trips it is possible to easily estimate the energy consumption. To assist WG10 it was necessary to obtain values for the following parameters:

average distance travelled;
average load carried;
average time spent in running and standing conditions (idle and standby).

These parameters ideally should be obtained for many building types: residential, office, hotel, hospital, airport, transport stations, schools, universities, etc.) and for different intensities of use (low, medium, high, etc.) represented by the number of starts per day.

The objectives of this work are therefore to analyse the factors that influence the usage of a building and to issue application tables that can allow the estimation the energy consumption of lifts. A set of standard benchmark buildings has been selected and the main parameters: type of building, level of demand, traffic patterns, lifts mechanical parameters, etc. has been defined.

A publicly available traffic simulation software, *Elevate*, has been used (with some customisation for this research) to simulate different scenarios considering the population movement from floor to floor. The results, obtained in the form of spatial plots or list of trips, have been processed, and the values of average distance travelled, average load carried, the proportion of time spent in each energy mode: running and standing (standby, idle) have been calculated. This information allows the calculation of the total energy consumed in a period, depending on different building or lift configurations.

3 SIMULATION PROTOCOL DESIGN

3.1 Analysis type

Elevate performs simulations using statistical procedures to digitally model specified lift installations. A large quantity of data is collected and presented in different ways. [1]

3.2 Traffic control algorithm

The traffic control system (dispatcher algorithm) determines how the lifts will serve the calls placed on the system by the passengers. The ISO 25745 series of standards does not consider the effects of the traffic control system and only considers a single lift. To obtain plausible results, the research reported here considers two car (duplex) installations operating under two simple traffic control algorithms: the basic group collective (COL) and the estimated time of arrival (ETA) control algorithms only. The modern hall call allocation (aka: destination control, see CIBSE Guide D: 2010 -Ch 9 [3]) is not considered.

[1] Visit http://peters-research.com/index.php?option=com_content&view=article&id=96&Itemid=91

3.3 Building data

Initially it was decided to consider office buildings with 5, 10 and 16 floors [2] above the main terminal. Later some simulations were carried out with 2, 3 and 4 floors above the main terminal to accommodate residential buildings at the request of WG10. Buildings with express zones or parking zones were not considered as they are not part of the ISO 25745 standards. Two rated speeds have been selected to meet the criteria in CIBSE Guide D: 2010-3.5.7 [3]. All interfloor distances were assumed equal and 3.75 m high.

The other important variable is the population of each floor. For the purpose of this research, the maximum handling capacity of the building was set at 12.5% of the total population[3]. From the value of population that can be served by a specified lift installation a population per floor was obtained. All floor populations were assumed equal. The formula for the calculation is shown in equation 4.9 of the Elevator Traffic Handbook [4]

3.4 Lift data

As already stated, the simulations considered simple duplex installations. Initially rated loads of 630 kg, 1000 kg, 1600 kg and 2500 kg were selected to span the common range of lifts installed in offices. Later lifts with rated loads of 450 kg were added to accommodate residential buildings. Other typical lift data such as door operating times, start delays, single floor flight times, acceleration values, jerk values, etc. were selected [4].

3.5 Passenger data

The passenger parameters that influence the behaviour of the installation are passenger transfer times, passenger mass and car capacity factor (%)

3.6 Traffic patterns/templates

Traffic patterns are defined by passenger arrival rates at specific floors and passenger destinations. This activity is set to occur in five minute periods. *Elevate* can customize the passenger traffic flow by defining a number of periods, each with its own set of arrival rates (in persons per 5 min.) and destination probabilities for passengers travelling from each floor to create benchmarking templates. Many of these are described in CIBSE Guide D: 2010 -Ch 4 [3].

For this research, three different templates have been used. The latter two were at the request of WG10.

Siikonen full day template [5]

This is based on a sample multi-tenant office building in Paris.

Strakosch residential all day traffic template [6]

The profile is based on the requirements of a residential building,

CIBSE Guide D: 2010,

A third traffic profile based on CIBSE Guide D: 2010 was provided by Dr. Richard Peters.

The resulting Total Passenger Activity graphs can be found in the *Elevate* manuals and CIBSE Guide respectively.

[2] 16 floors is considered the maximum practical number of floors in a building zone.
[3] This is considered by CIBSE GUIDE D and BCO as a starting point for most traffic designs for offices.
[4] Data available on request.

4 SIMULATION EXECUTION, DATA TREATMENT AND DEFINITION OF TEMPLATES FOR COLLECTING THE RESULTS.

Initially, the simulations were performed on 24 systems, that had three different number of floors (5, 10 and 16), each with four rated loads (630, 1000, 1600 and 2500) and two rated speeds (0.63, 1.0, 1.6 and 2.5m/s combined in pairs) and a collective (COL) traffic control system.

The simulations used the Siikonen all day (12 h) template, which was considered the most representative one, as it has up/down/inter-floor traffic and includes a lunch break (CIBSE Guide D: 2010-4.6 [3]). Although it corresponds to an office building, it can emulate other building types.

In order to consider the four different levels of intensity of use, four runs are carried out in the 24 different buildings with floor populations at 100%, and reduced by 1/2, 1/4, 1/8 representing intense, heavy, medium and low use respectively. In this way, there were 96 sample systems.

The simulation is run only once, but as there are two lifts in each installation, the results obtained for each simulation corresponded to two cases. This gave 96 x 2 = 192 cases.

From the reports automatically provided by *Elevate*, it was necessary to obtain the following information: average travel distance, average car load, idle/standby time in different time slots (1 min, 2 min, 5 min, 15 min and 30 min.) and the number of starts.

The standard version of the *Elevate* software provides spatial plots and a corresponding table of data.

The processing of the full table provided:

Total running time
Total standing time
Times the lift is stationary by time bands (<1 min, <2 min, <5 min, <15 min, <30 min, >30 min)
Total number of starts per day
Average distance travelled

The details of the car load transported can be extracted from the graph named "Car loading on arrival at home floor" provided by *Elevate*, which shows the average and maximum values (in % of rated load) in 5 minute time slots.

Depending on the purpose of a study, this average information can be sufficient, as it allows the calculation of the average load transported by a lift in a certain period. However, it is not precise enough for an accurate calculation, where it is necessary to know the number of occurrences of each possible trip (defined by direction of movement, distance travelled and load carried), which are the parameters necessary to calculate the actual energy consumption.

For this reason, an *Excel* macro was created to analyse the detailed information related to the passenger trips. A later processing of this database, made it possible to create the matrix of occurrences, from which the average distance travelled and average mass transported in loaded trips can be easily calculated. The number of empty trips could be calculated as the difference between the total number of starts provided by *Elevate* automatically in the *Excel* sheet and the final number of standard trips. In this way, they could be accounted for with view to the calculation of the average load, but not for the calculation of the average distance travelled, as the origin and destination of these empty trips was unknown. To obtain this information, the software was customized.

The 96 sample buildings (192 cases) where simulated again at the end of these improvements and the deviation in the average travel distance showed an error of approximately 5% compared with the first estimation, which had supported the first drafts of the work for the ISO standard. Later improvements to the analysis software further improved the results.

5 FIRST ANALYSIS OF RESULTS.

From the first set of simulations carried out, it was concluded that, as expected, the number of starts increases with intensity of use. This caused the predictable effect of extending the running time at the expense of the standing time and modifies the distribution of the trips in the different idle/standby time slots depending on the number of starts. The trends also showed that lower traffic levels would produce even lower average car loads and longer travel distances.

The presentation of the results to the WG10 group of lift experts developing the draft of ISO/DIS 25745-2 [7] raised questions.

1 For example, how good is the traffic template? Besides the very good office template used (Siikonen), *Elevate* also provided a reasonably representative residential pattern (Strakosch) and the new one based on the CIBSE Guide D: 2010 -Figure 4.1 [3]. The simulations were repeated with additional traffic patterns to assess their influence.

2 The need to add systems with lower capacity cars (450 kg) and lower rise 3/4 storeys, in order to accommodate residential buildings. Although the addition of such low rise buildings would lead to significant errors in the simulation model (owing to the poor statistics) these were simulated for completeness.

3 The desire to have higher usages above 2000 starts per day. It has often been stated that the number of starts in Asian countries is considerably higher than those in Europe, so higher usage categories with the number of starts above 2000 starts per day were requested. Although this might indicate an incorrect traffic system design, it was included.

4 A wider range of traffic intensities to six.

5 More statistical data were needed to produce regression graphs.

In order to give response to all these questions, the range of simulations was increased.

6 ANALYSIS OF RESULTS.

In this section, the final plots obtained after the software and templates were updated are presented and the results and tendencies observed are explained. They contain the results of the final set of sample installations, which were increased to achieve the six usage categories requested by WG10.

6.1 Effect of the traffic pattern on number of starts

The number of starts in the simulated period increases with the population served per lift, Figure 1.

The results are almost identical for the collective (COL) and estimated time of arrival (ETA) traffic control algorithms. The values obtained for residential buildings using the Residential (Strakosch) template are higher, followed by the Office (Siikonen) template and the Modern Office (CIBSE) template. However, it has to be noted that the simulated period differs (slightly), but should have a minor effect, depending on the traffic template used:

(RS)	Strakosch	Residential	14 00 h
(OS)	Siikonen	Office	12.25 h
(OC)	CIBSE	Office	12 00 h

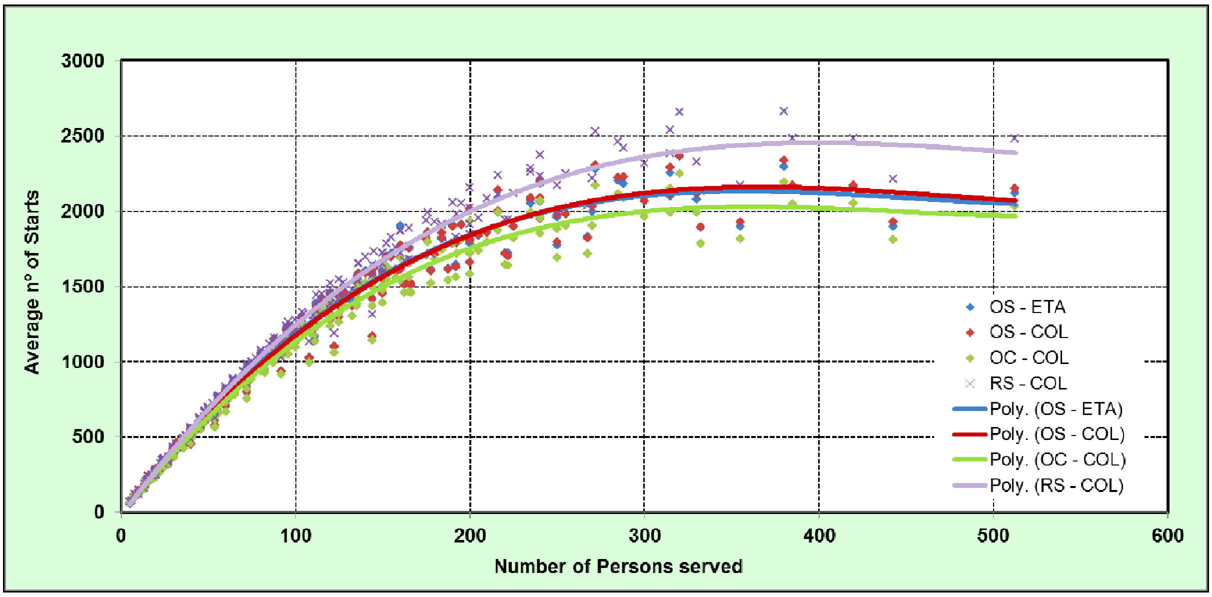

Figure 1: Average number of starts -v- number of persons served (all patterns)

If a plot of average number of starts per hour instead of the absolute value was presented (Figure 2), then the different lines would become closer together with the Modern Office template producing the highest number of starts per hour and the Residential one the lowest.

CIBSE: 1.04 starts per hour/person
Siikonen: 0.96 starts per hour/person
Strakosch: 0.88 starts per hour/person

The first part of the graph shows a linear dependence, which becomes a nonlinear (polynomial of degree 3) at the maximum values with around the 2,200 starts. After reaching this maximum value, note the curve begins to fall, which indicates the lift installation has reached saturation.

Although logically it might be thought that an increasing population demand (persons served) would result in the number of stops limiting to a maximum, the real effect is that they fall. The reason seems to be that at higher demand levels the lift installation has reached the limit of its traffic handling capabilities. The result is a traffic build up in the lobbies, passenger boarding/exit times increase and the transportation becomes inefficient. These inefficiencies can be also observed in the plots showing the distribution of the time spent in the different operating conditions. However, further research might be carried out with additional samples to confirm the validity of this reasoning.

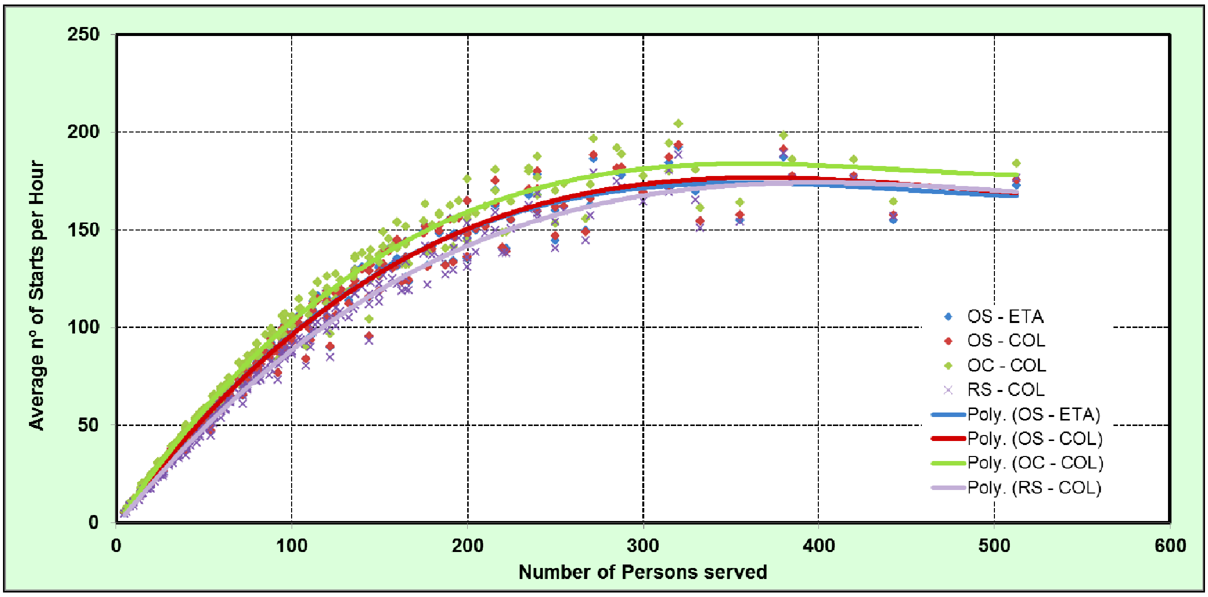

Figure 2: Average number of starts per hour -v- number of persons served (all patterns)

The graphs confirm that the traffic template (traffic pattern) does not make a large difference and show that the values are similar for Residential and Office buildings.

A further important conclusion is that the higher number of starts reported from Asian countries can only be achieved if the operational time is increased from 12-14 hours to include night time activity at high levels.

6.2 Average distance travelled -v- average number of starts

The average distance travelled decreases with the number of starts, Figure 3. It ranges from a maximum average of around 50%, except for very low rise buildings (see rectangle in the figure), and a minimum of 20% for very intense use. If the results were represented as average distance vs. number of starts per hour, the difference between traffic templates would be small.

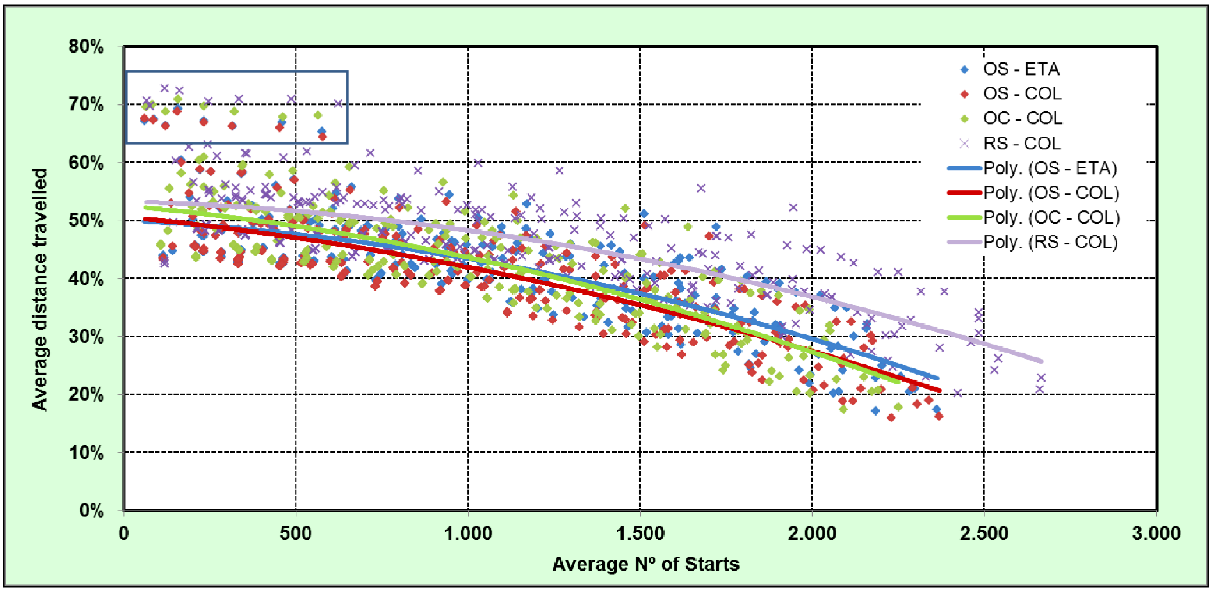

Figure 3: Average distance travelled (all patterns)

Lift professionals frequently state that intuitively (from their own experience) the average distance travelled should be larger. A further analysis was carried out to check this impression. Could it be caused by the fact that the observers only see this effect when they are travelling in loaded cars?

The graph obtained (Figure 4) confirms that the average of distance is heavily influenced by the intensity of use, which drastically reduces this average.

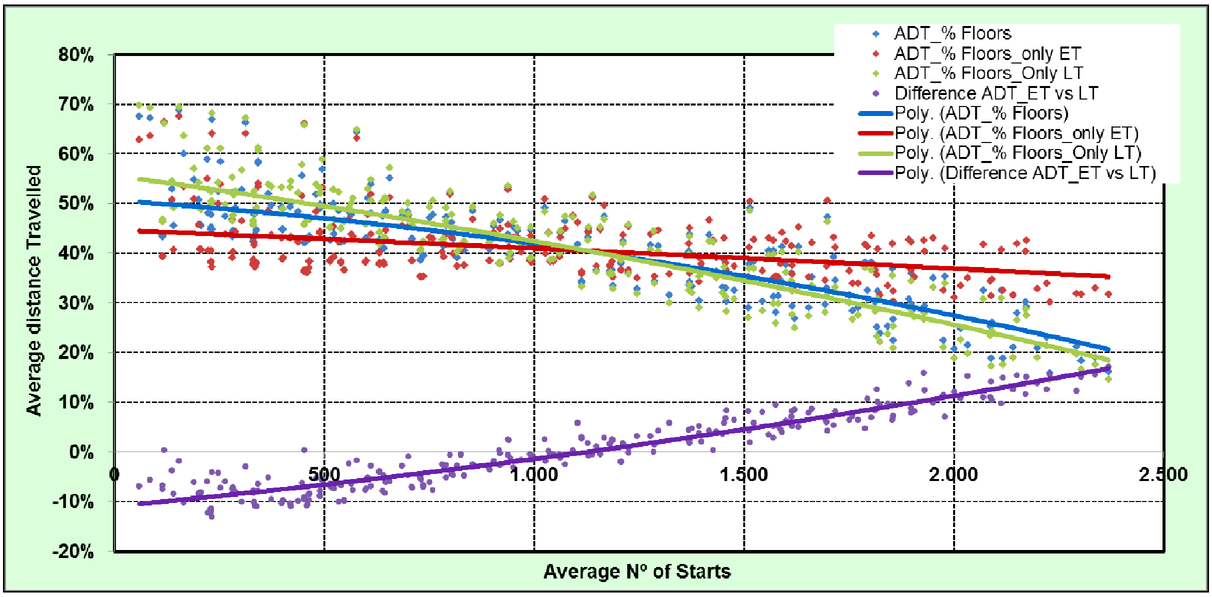

Figure 4: Average distance travelled (% of Building Height) [ADT] – Average, empty trips [ET], loaded trips [LT], difference

6.3 Average load transported -v- average number of starts

A plot of average load transported vs average number of starts shows an intense "swarm" of points, which strongly indicates that the average load transported depends on another factor and not only on the intensity of use. Looking at the results for lower intensities, where the points are more concentrated, five groups of points can be seen, which coincide with the different rated capacities analyzed. Another finding is that, as expected, the load increases with the population handled. The range of variation is large (from 5% to 25%). However, by taking the median values, the results do not change very much with the traffic template used (a maximum of 3% for high numbers of persons served) or the traffic control algorithm. This can be more clearly observed in Figure 6 where the results for 1000 kg capacity cars only are shown

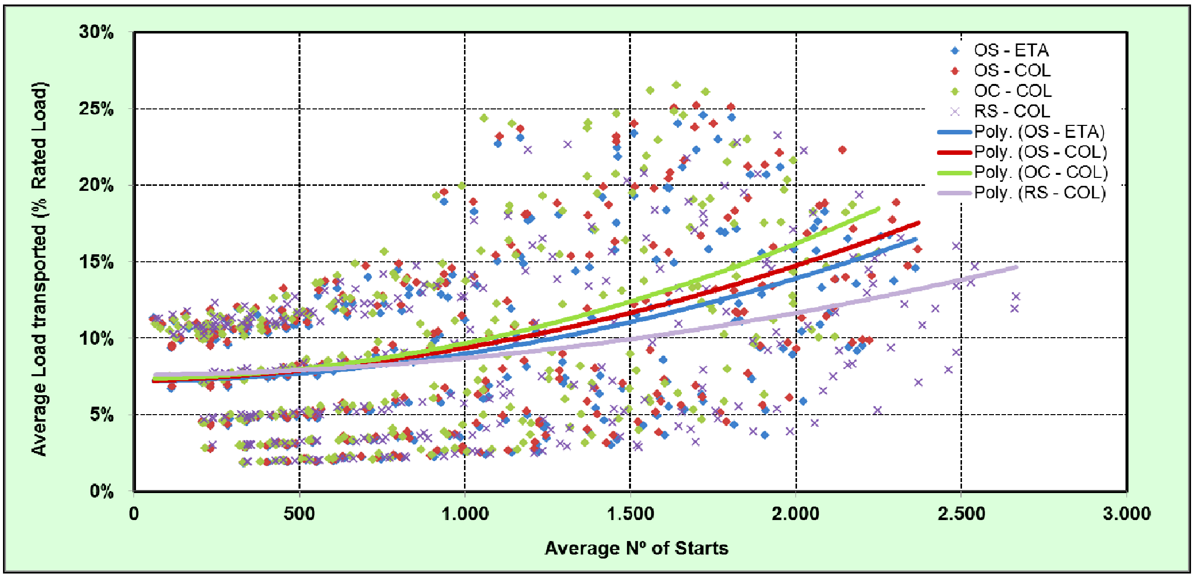

Figure 5: Average load transported (% rated load) (all patterns)

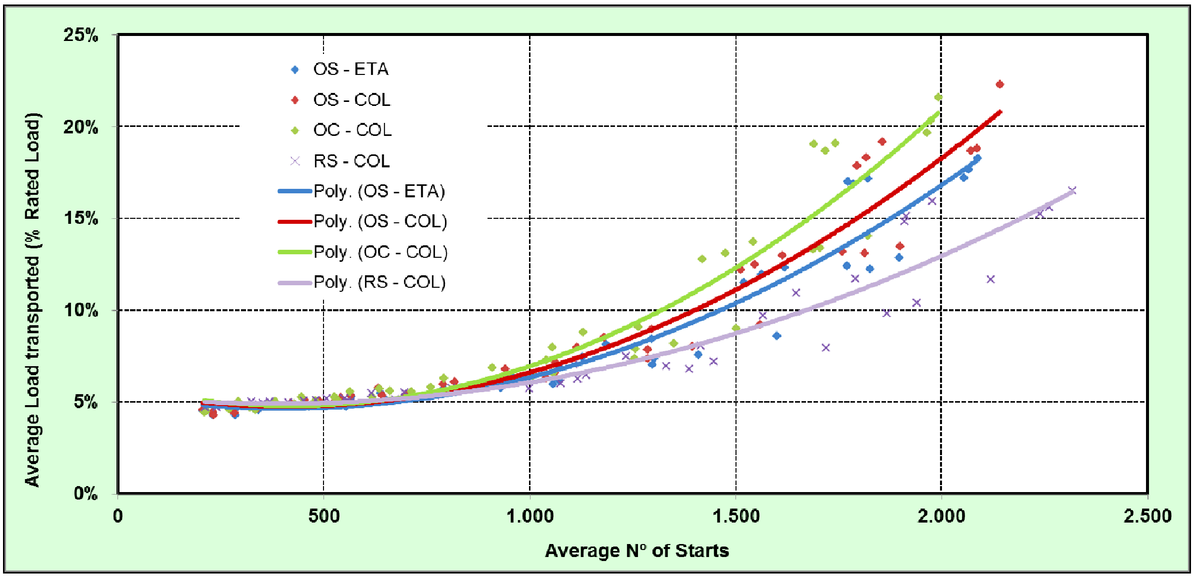

Figure 6: Average load transported (% rated load) for 1000 kg rated load lifts

If the data is plotted for one single template and the results grouped by car capacity, a much clearer tendency can be seen of the load increasing with the use with delimited range bands, according to the car capacity Figure 7.

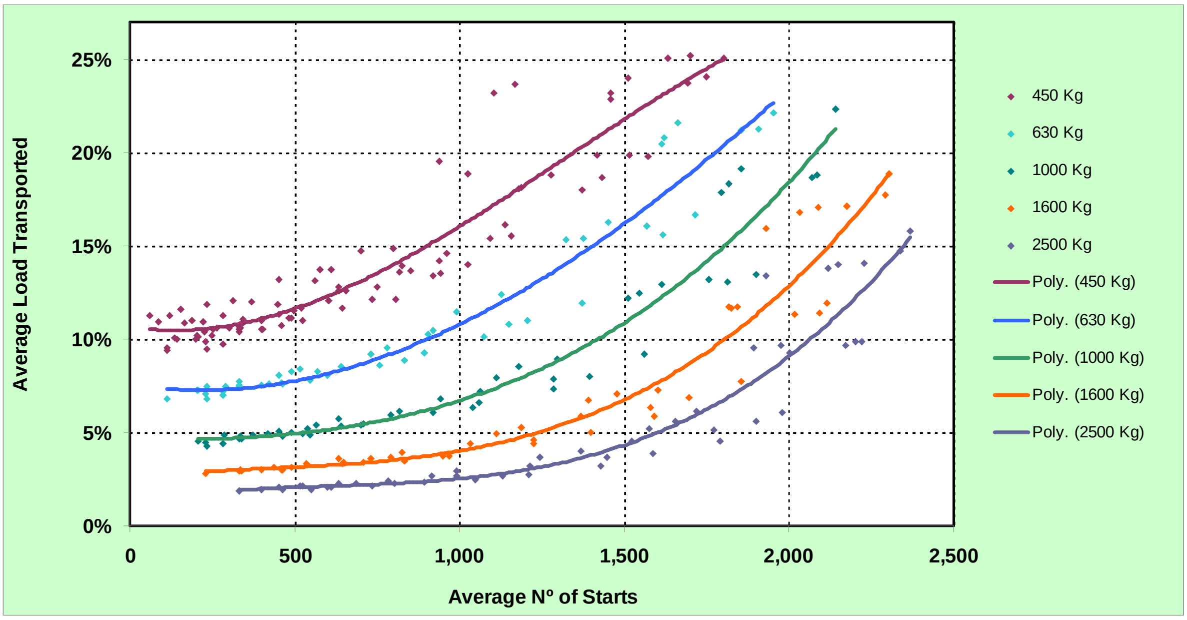

Figure 7: Average load transported -v- number of starts (grouped by car capacity)

6.4 Distribution of running, idle and standby times -v- average number of starts

The average time between trips shows a very clear exponential tendency, with its maximum at a very low building occupancy. It can be observed, that only for a very low number of starts, does the lift spend more than five minutes stationary between consecutive trips This is a result of great importance, as currently most lifts switch into a lower energy consumption mode after this time[5]. This leads to the supposition that the standby status may not be reached during the daily operation time and just during the non-operating hours.

If for any specific number of starts the running, idle and standby times are summed, the results will always be 100%, see Figure 8.

[5] ISO25745-1 defines standby as commencing after five minutes of inactivity.

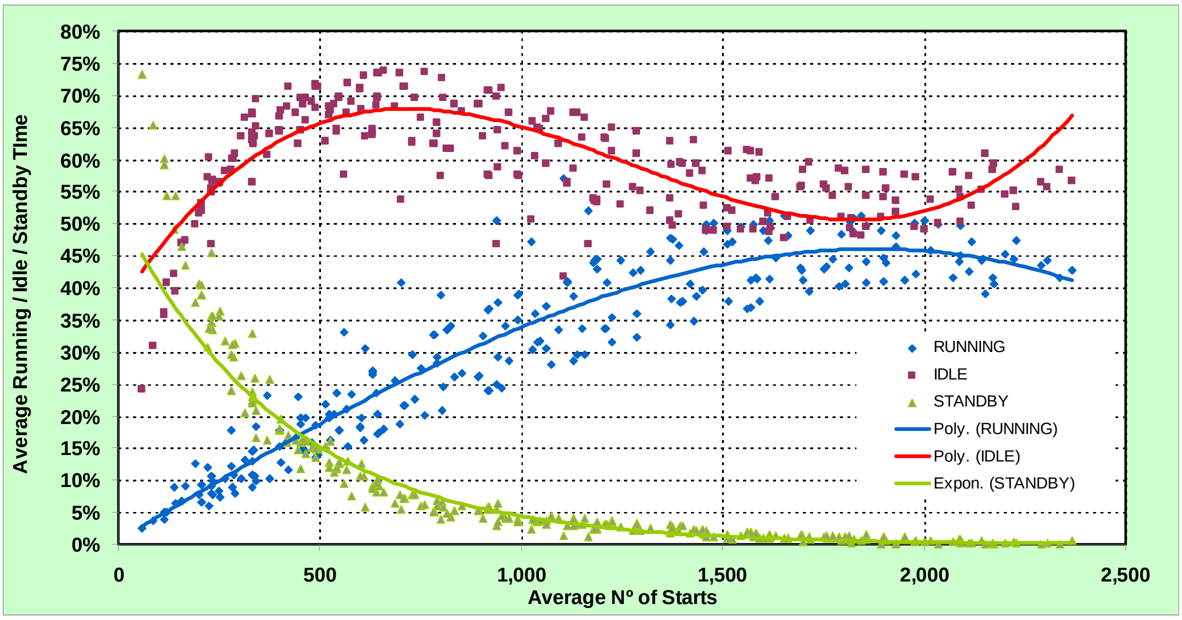

Figure 8: Distribution of time in different operational modes -v- number of starts

In the following graphs, it can be observed that the time spent by the lift in running conditions increases with usage, reaching a maximum of 50% for a high activity (2000 starts). When the number of starts increases above this quantity, the lift loses efficiency as already stated before.

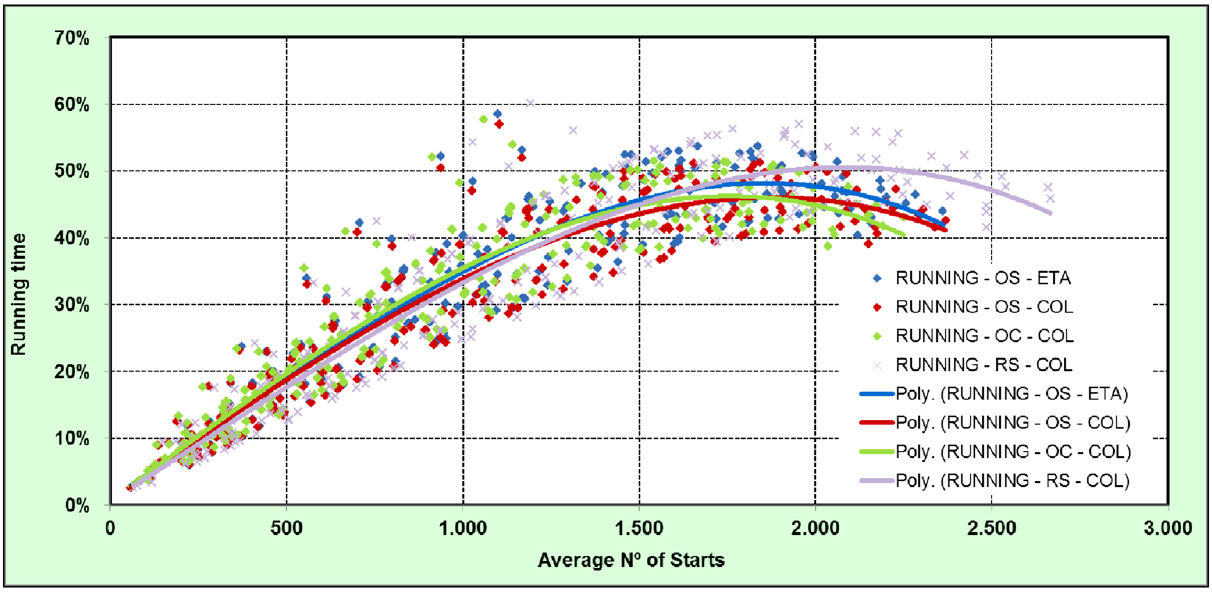

Figure 9: Distribution of running time during normal operation

The time in non-running conditions is split into Idle (Figure 10) and Standby (Figure 11).

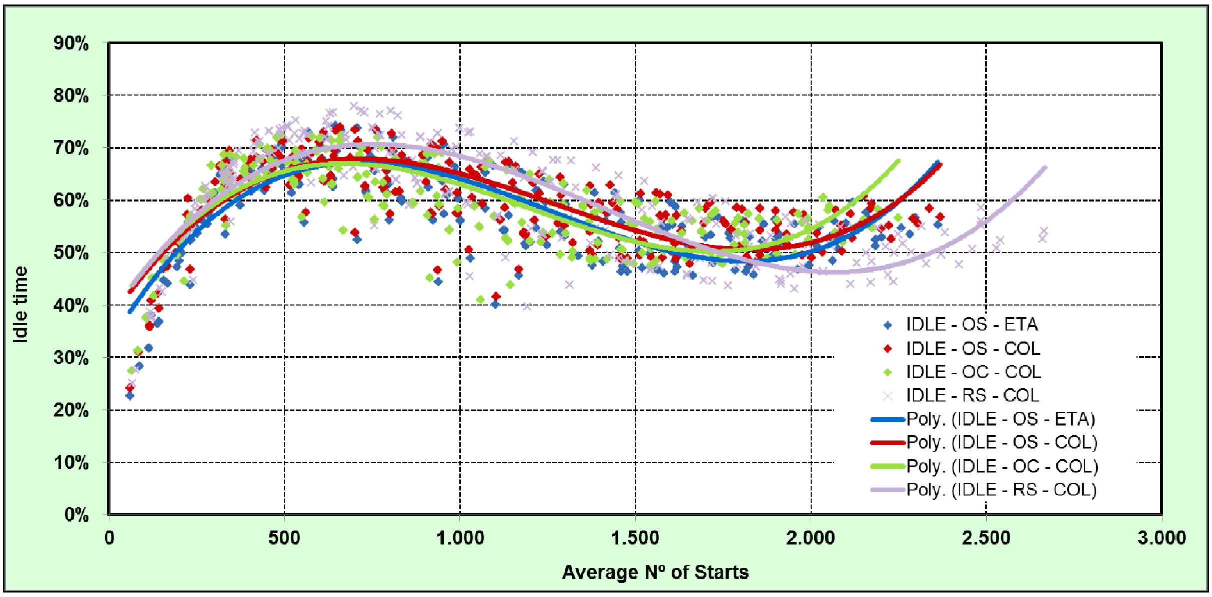

Figure 10: Distribution of idle time during normal operation

The plot of the idle time (Figure 10) also shows the inefficiency of the passengers handling when increasing the number of starts above 2000, as the time that it is stationary increases again.

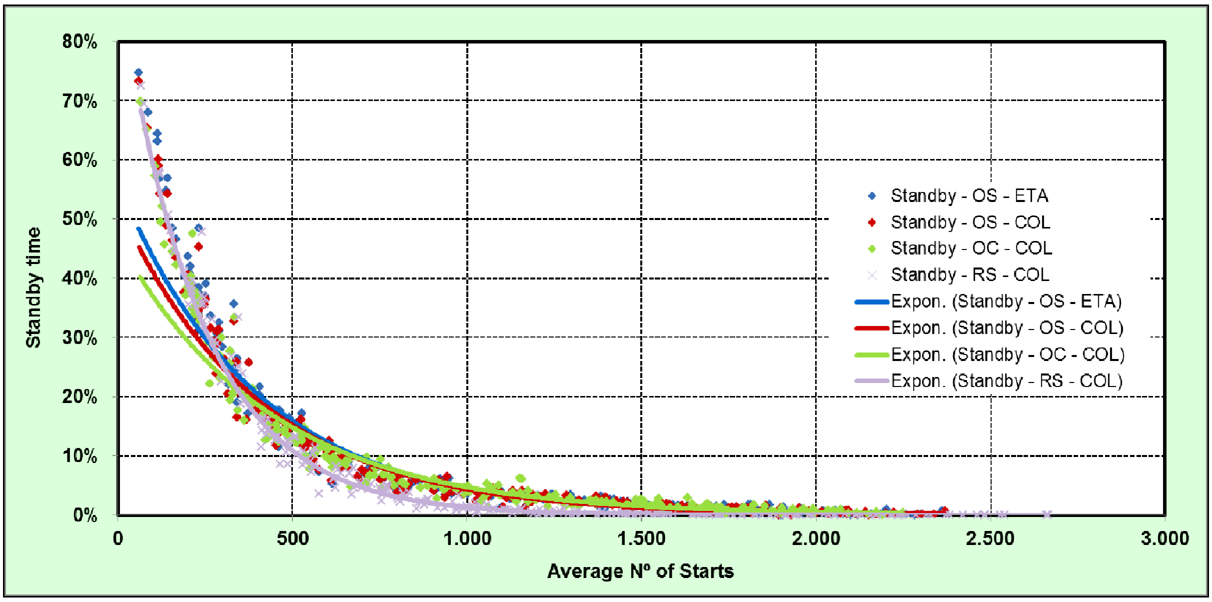

Figure 11: Distribution of standby time during normal operation

The standby mode (lower energy consumption) will be activated after the lift has been inactive for five minutes.

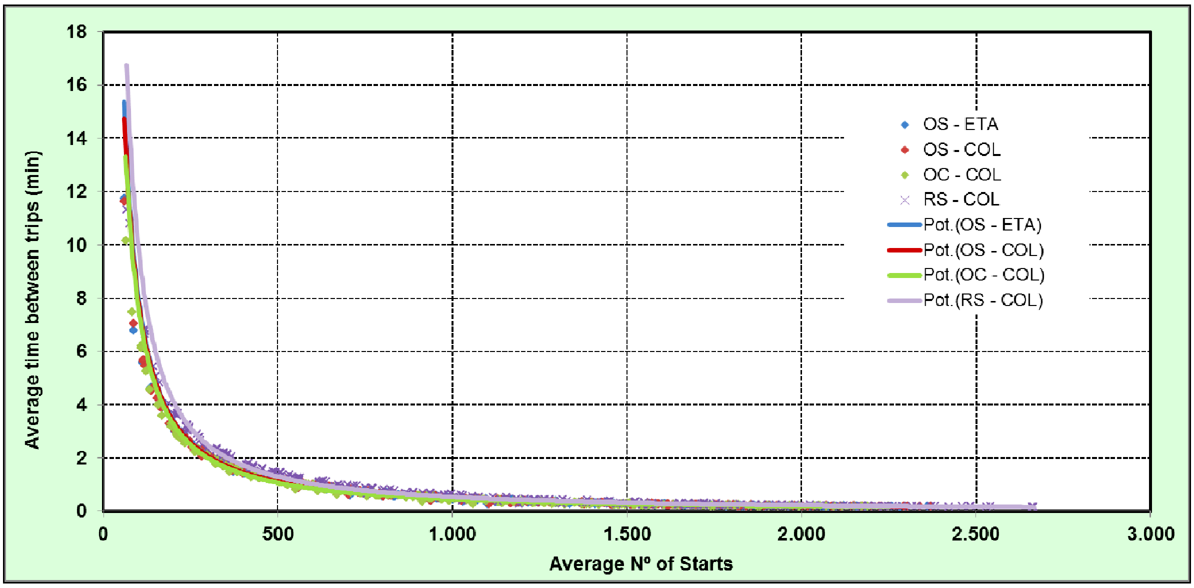

Figure 12: Average time between trips (min)

Distribution of the time spent by the lift running or in stationary conditions, during the daily operation time is shown in Figure 12. The graphs clearly show (in accordance with the tendency of the average time between consecutive trips) that for high traffic demands, the lift does not have time to switch into standby very often, the time being spent in this low energy state is less than 10% for more than 500 starts.

7 SUMMARY

Table 1: Summary of results

Usage category		1	2	3	4	5	6
Usage		very low	low	medium	high	very high	intensive
Trips per day		50	125	300	750	1500	2500
Average travel	**2 storeys**	100%					
	3 storeys	67%					
	>3 storeys	44%				33%	18%
Average car load -v- Rated load	**≤ 800 kg**	7.5%			9.0%	16.0%	23.0%
	801 – ≤1275 kg	4.5%			6.0%	11.0%	18.5%
	1276 – ≤ 2000 kg	3.0%			3.5%	7.0%	13.0%
	>2000 kg	2.0%			2.2%	4.5%	9.0%
Time ratios (%)	**Idle**	13	23	36	45	42	
	Standby	87	77	64	55	48	

Table 1 summarises the results of the research, much of which have been adopted by WG10. Note there are six usage levels. Surprising the rule of thumb assumed in ISO 45745-1 of an empty car that travels about half the distance between terminal floors is close to reality in many circumstances.

8 FURTHER WORK

The ISO 25745 series of standards only considers a single unit. From the results obtained, the two simple traffic control algorithm do not seem to have influenced the results for the type of buildings analysed However to be more scientifically rigorous, work on other traffic control systems will be undertaken, in particular, the hall call allocation traffic algorithm. This algorithm differs significantly to with other dispatchers. The simulations should also be run for groups of at least four lifts rather than two lifts. The effect of unequal distribution of floor population/demand should also be researched.

The effect of an express zone should be analyzed in more detail to allow the method to be used for zones located high in the building.

It is hoped to validate these results by collaboration with industry as most real life measurements are carried out by lift companies.

9 CONCLUSIONS

The research study detailed in this paper is based on the results of thousands of simulations, which are considered as if they were experimental data.

However, simulation is notorious for delivering answers, which do not occur in real systems, but these answers will be as good as the traffic pattern used in their production. The use of simulation tools for predicting the value of parameters with view to the calculation of the energy consumption of lifts seems to be the most accurate method currently available.

Although average tables (calculated for standardized buildings to cover the scope defined in ISO 25745) are precise enough for standardization purposes, for a better prediction in any commercial offers, it is recommended that every specific case is calculated taking into account the real characteristics of a building and the lift and the most suitable traffic pattern.

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2nd Symposium on Lift and Escalator Technologies

Lift Performance Time

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ABSTRACT

Performance time is a measure of how long it takes for a lift to travel between two floors, including opening and closing of the doors. Performance time has a major effect on handling capacity and passenger waiting times. Performance time can be modelled in traffic analysis and simulation through the application of lift kinematics. Formulae can be used to calculate travel times and to plot the distance travelled, velocity, acceleration and jerk against time. Measurements of these parameters can be derived from accelerometer readings. Measurements of start and levelling delays are more difficult to make, but are necessary to model a lift trip completely. Site measurements and ideal lift kinematics are plotted together for comparison. Performance time assumptions typically made in lift traffic analysis and simulation are compared with site measurements. The difference between assumed performance times and measurement are considered in the context of their impact on handling capacity and waiting times. Proposals are made which help designers to avoid discrepancies compromising the traffic design.

LIST OF SYMBOLS

a	Acceleration (m/s²)
d	Lift trip distance (d)
j	Jerk (m/s^3)
T	Performance time (s)
$T(d)$	Performance time for flight distance d (s)
t_a	Advanced door opening time (s)
t_c	Door closing time (s)
$t_f(1)$	Single floor flight time (s)
$t_f(d)$	Flight time for travel distance d (s)
t_o	Door opening time (s)
t_{sd}	Start delay time (s)
v	Rated speed (m/s)

INTRODUCTION

For traffic analysis and simulation results to be realistic, we need to base our calculations on achievable performance times, specify the required performance in tender documents, and measure the installation to ensure that the necessary performance is being delivered.

In the 1960's and 70's a major lift company had a definition for performance time, “start of doors close to doors three quarters open on the next floor”. For a floor to floor height of 3.5 to 4m, a time of less than 9 seconds was expected for a high performance lift. *CIBSE Guide D Transportation Systems in Buildings* Section 3 (1) breaks performance time into five components:

$$T = t_f(1) + t_{sd} + t_c + t_o - t_a \qquad (1)$$

In the Elevator Traffic Handbook (2), Barney defines the door opening time as "a period of time measured from the instant that the car doors start to open until they are open 800 mm". Like Otis, Barney recognises that in traffic analysis, from the passenger's prospective, the passengers can start loading and alighting lifts before the doors are fully open.

The performance time as described above gives a good overall picture of lift performance and can be measured simply with a stop watch. However, its limitations are:

1. The performance time of the same equipment will be different according to floor height.
2. The performance time cannot be applied in simulation as the travel time for two floors is not twice the travel time for a single floor.

To overcome these limitations, we need to make accelerometer measurements and to apply an understanding of lift kinematics.

LIFT KINEMATICS

Lift kinematics is "the study of the motion of a lift car in a shaft without reference to mass or force". We are studying how the lift moves and not, for example the implications of the car size on the lift motor.

The time it takes for a lift to travel between two floors is limited by the rated speed, acceleration and jerk. The jerk is rate of change of acceleration, i.e. when a lift accelerates is does not accelerate at the same rate all the time, it takes time to build up and down to the rated acceleration.

Humans are sensitive to acceleration and jerk and can feel discomfort if either is too high. We are not sensitive to lift speed, except in very high speed lifts where the change in atmospheric pressure, particularly during descent, can cause discomfort.

Formulae can be derived (3) to plot distance, velocity, acceleration and jerk against time. Microprocessor controlled variable speed drives can be programmed to match these profiles very closely. The plots look different depending on the trip; options A, B and C as shown in Figure 1.

For option A, the lift reaches full speed, travels at this speed for some time and then slows down again. The plots are typical for a lift which is travelling several floors.

For option B, the lift does not actually reach full speed. The plots are typical for a high speed lift travelling one floor; there is insufficient time to reach the rated speed before the car needs to start slowing down again.

For option C, the lift does not even have time to reach full acceleration. This is representative of a re-levelling operation, so would not normally be seen in lift performance measurements.

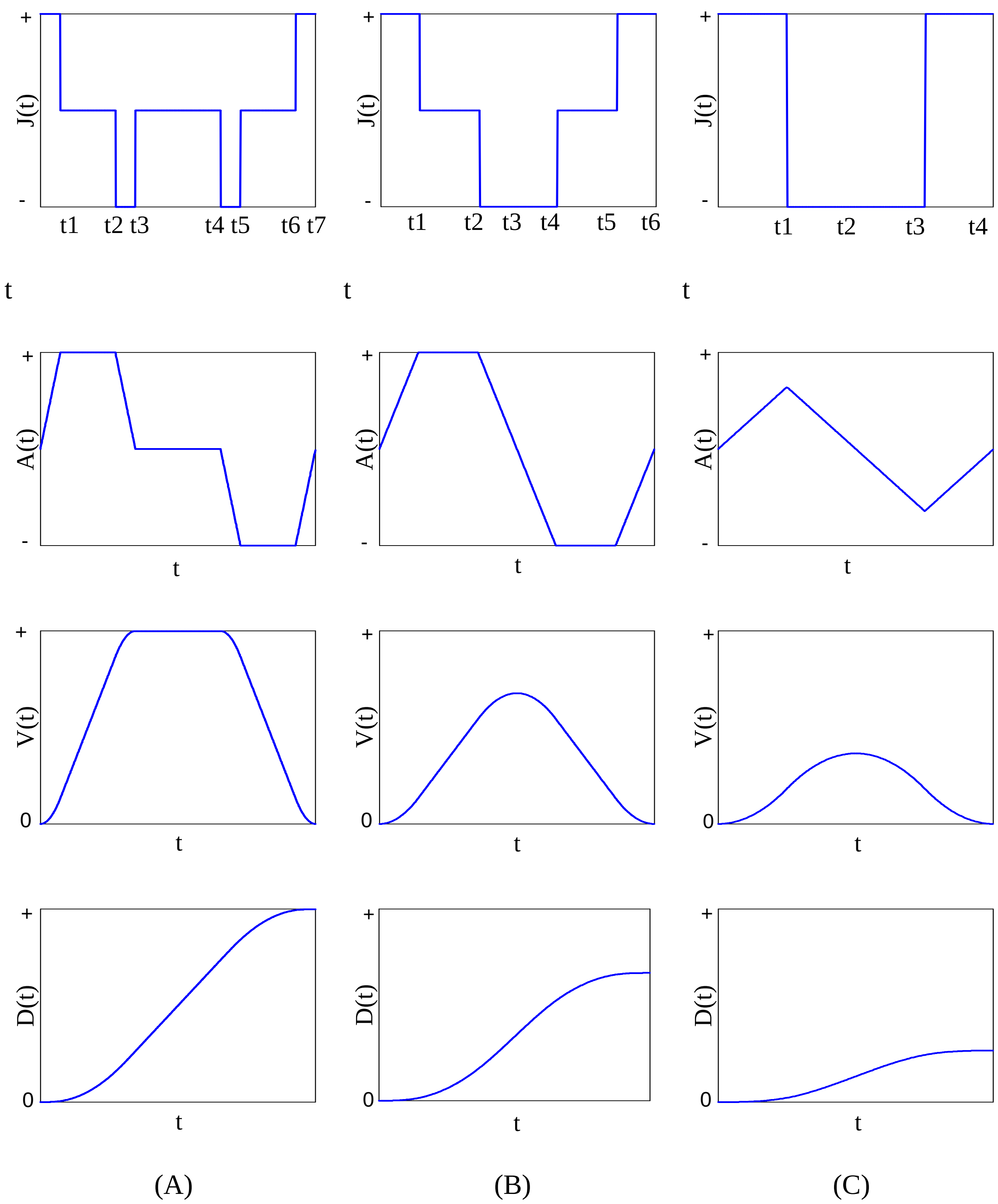

Figure 1 Ideal lift kinematics for: (A) lift reaches full speed; (B) lift reaches full acceleration, but not full speed; (C) lift does not reach full speed or acceleration

MEASURING LIFT PERFORMANCE

Equipment

There are a number of lift performance tools which will help measure lift velocity, acceleration and jerk (4) (5). Measuring start delay and advanced door opening is more difficult, so we have developed our own performance tool (6) which integrates accelerometer and time measurements, then uses software algorithms to interpret these measurements directly.

Measuring procedure
With the accelerometer placed on the lift car floor the measurement points are triggered when the:

(i) doors start closing at floor
(ii) doors are fully closed
(iii) doors start opening at destination floor
(iv) doors fully open at destination floor.

The accelerometer is taking measurements continuously for the whole period so, for example, we can calculate the start delay as the software knows both when the doors have closed, and when the car starts moving.

General observations
Note that we have chosen to measure door time until the doors are fully open rather than three quarters or 800 mm open. This gives us enhanced, although more complex options to improve our modelling of door dwell times and passenger transfer times. Currently where passenger transfer occurs while the doors are still opening we would reflect this in passenger transfer time assumptions and calculations.

In some installations the car doors finish closing shortly after the landing doors. Our measurement for door close time ends when the car doors are fully closed. At the instant the car doors are fully closed we start our measurement of start delay. A valid observation is that if the car doors finish closing after the landing doors, it is easier to get a low start delay as the landing door interlocks are made before the end of the door close time. This delayed car door closing has been observed in the installations where we have observed zero motor start delay. To minimise start delay, some equipment pre-torques the motor and lifts the break before the doors are fully closed.

Ride comfort has become more important in recent years. This has resulted in the use of lower accelerations in some high rise buildings with high speed lifts; requirements are subjective and sensitive to culture. At the economy end of the market, some very low values of acceleration have been measured. This is probably because lower accelerations require less torque, so smaller lift motors can be used.

Processing measurements
As all accelerometer measurements have signal noise, the acceleration reported will depend on how you filter the signal. However, for performance (rather than comfort) analysis, we want to model the trip as accurately as we can with lift kinematic formulae. So, our approach is to best fit the idealised measurement to the idealised kinematic plots, see Figure 2. In this example the maximum acceleration is 0.95 m/s, but the acceleration using best fit is 0.81 m/s^2. This second value gives us the most accurate input for modelling the lift in simulation.

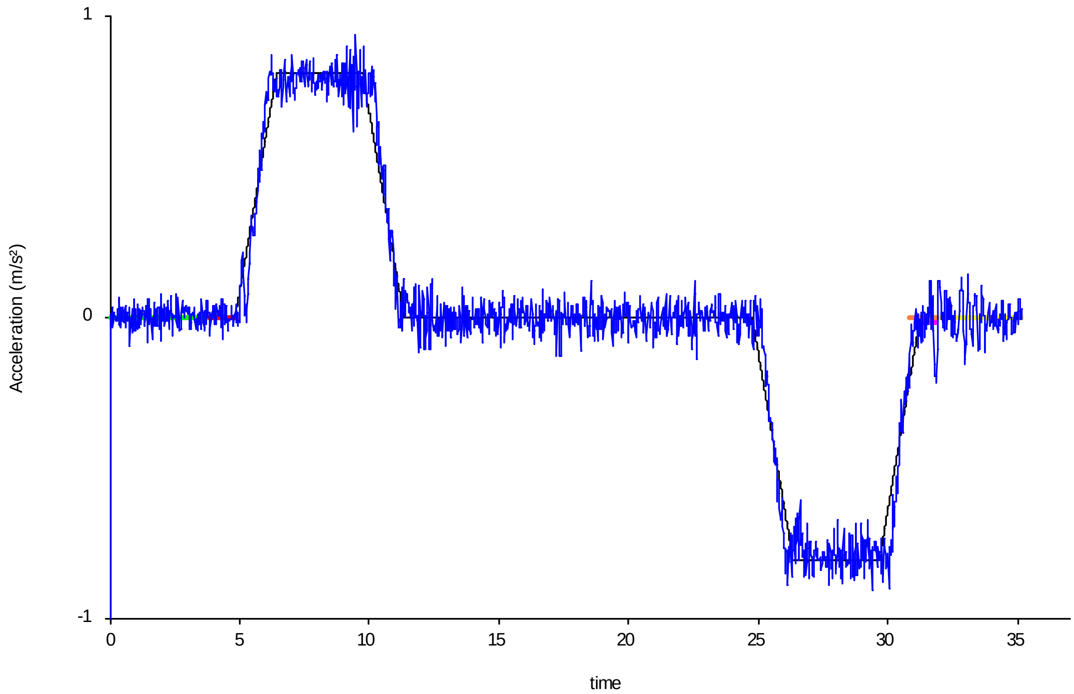

Figure 2 Measured and ideal acceleration

By differentiating the acceleration measurements we can determine jerk, see Figure 3.

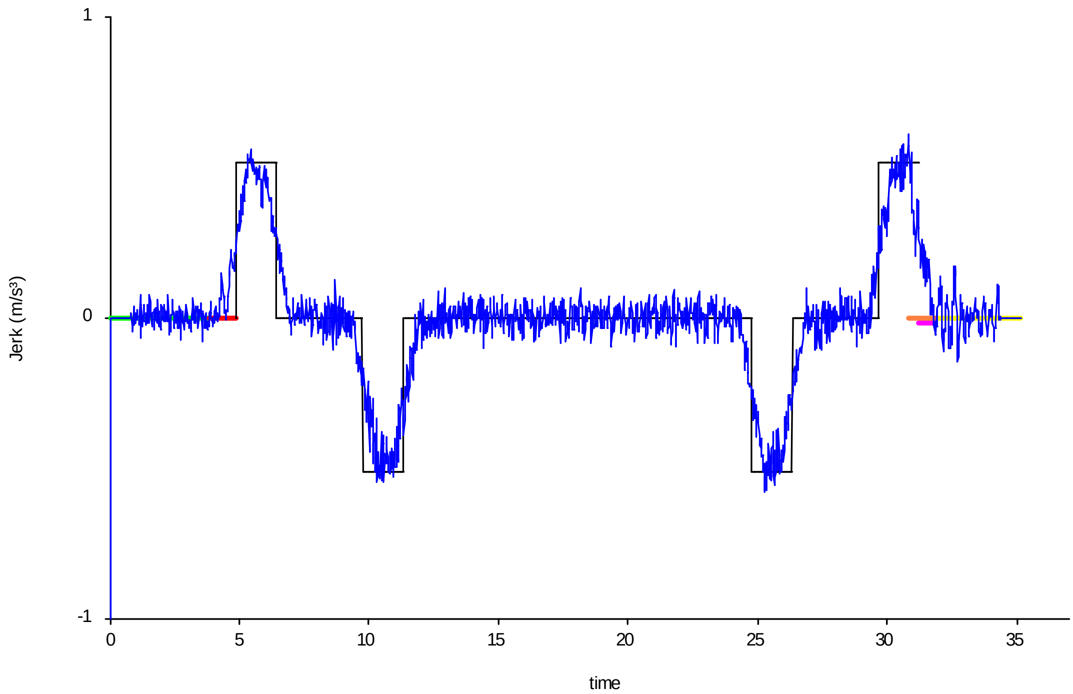

Figure 3 Measured and ideal jerk

Integrating the acceleration gives us the velocity, see Figure 4.

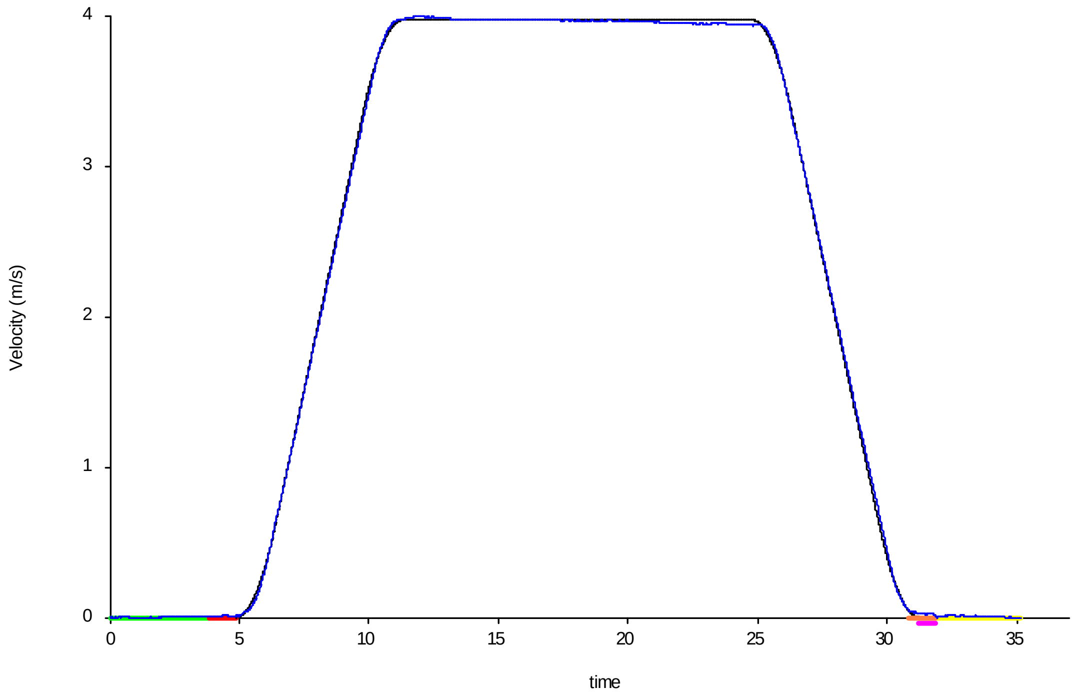

Figure 4 Measured and ideal velocity

Finally, integrating the velocity provides the distance travelled, see Figure 5.

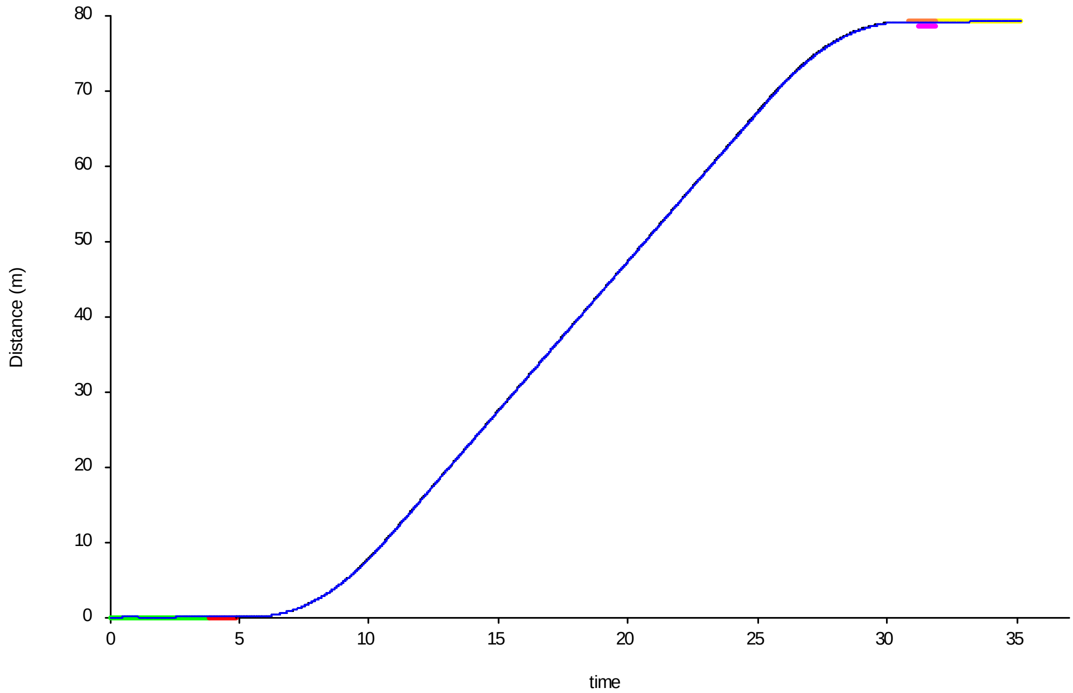

Figure 5 Measured and ideal distance travelled

Calibration of the accelerometer can be confirmed by comparing the measured and actual distance travelled.

Door closing time and start delay are overprinted on the start of the plots, see Figure 6.

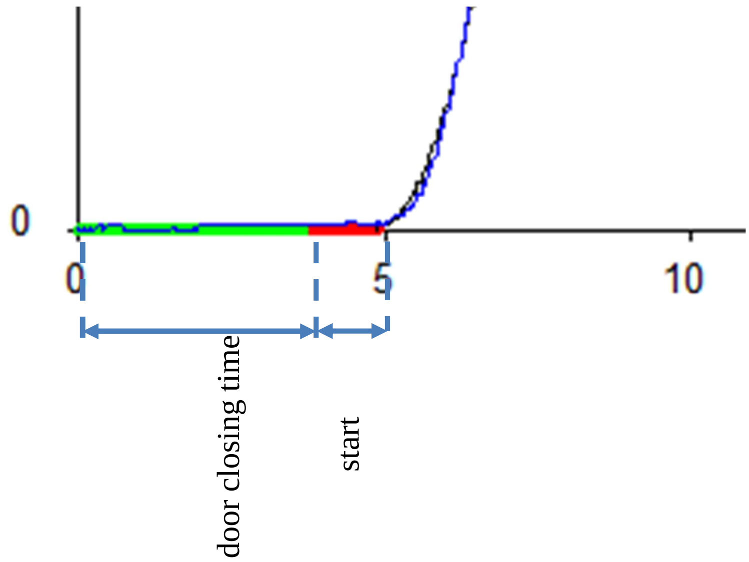

Figure 6 Close up of start of velocity plot showing door closing time and start delay

Although modern drives normally allow lifts to travel directly into the floor, we have measured a number of installations where there is a significant levelling time. The combination of acceleration and time measurements allow the software to determine when the doors start opening relative to when the car stops. Figure 7 provides a close up on the end of the velocity plot. Note the levelling delay and door opening time overlap; in this installation part of the levelling delay is compensated for by advance door opening.

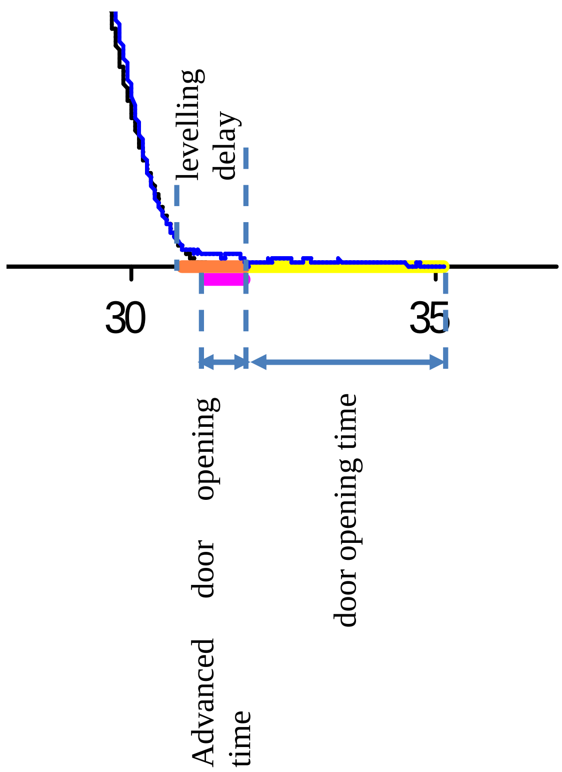

Figure 7 Close up of end of velocity plot showing levelling delay, advanced door opening time and door opening time

The software summarises results which correspond directly to the inputs of our traffic analysis and simulation software (7), see Table 1.

Table 1 Sample performance measurements

Distance (m)	79.12
Velocity (m/s)	3.97
Acceleration (m/s^2)	0.81
Jerk (m/s^3)	0.51
Door opening time (s)	4.31
Door closing time (s)	3.84
Start delay time (s)	1.00
Levelling delay time (s)	0.61
Advanced door opening time (s)	1.00

ENHANCED PERFORMANCE TIME FORMULAE

As all the performance parameters have been determined, performance time can be now calculated including levelling delay, and for a trip of any distance. Equation (1) is revised to:

$$T(d) = t_f(d) + t_{sd} + t_l + t_c + t_o - t_a \qquad (2)$$

The travel time function $t_f(d)$ is know from kinematics research (3):

If $d \geq \dfrac{a^2 \cdot v + v^2 \cdot j}{j \cdot a}$ then $\mathrm{t}_f(d) = \dfrac{d}{v} + \dfrac{a}{j} + \dfrac{v}{a}$ (3)

If $\dfrac{2 \cdot a^3}{j^2} \leq d < \dfrac{a^2 \cdot v + v^2 \cdot j}{j \cdot a}$ then $\mathrm{t}_f(d) = \dfrac{a}{j} + \dfrac{\sqrt{a^3 + 4 \cdot d \cdot j^2}}{\sqrt{a.j}}$ (4)

If $d < 2 \cdot \dfrac{a^3}{j^2}$ then $\mathrm{t}_f(d) = \left(32 \cdot \dfrac{d}{j}\right)^{\frac{1}{3}}$ (5)

PERFORMANCE MEASUREMENTS

We are building a database of performance measurements to:

(i) improve industry design guidance for people planning lift installations

(ii) help owners and consultants assess the relative performance of their lift installations, particularly in the context of modernisation projects.

Some initial results are given in this section; we have different amounts of data for each plot as early measurement techniques yielded just some of the parameters. These results include measurements by consulting engineering firm Arup; we welcome others to contribute their measurements. For more information, and the latest results please see our lift performance web pages (6). Currently some results are “peak” rather than “best fit” values; in due course all results will be presented as “best fit” as this allows for more accurate simulation modelling.

Figure 8 shows acceleration measurements; each point represents a separate lift group. Guidance from CIBSE Guide D 2010 (1) Table 3.4 is plotted on the same graph; where CIBSE suggests a range the minimum and maximum is plotted.

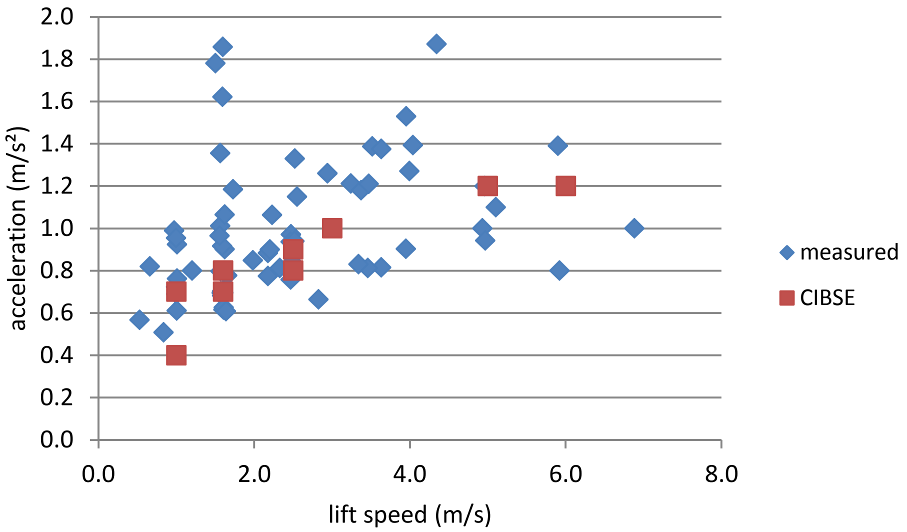

Figure 8 Site measurements of acceleration plotted with CIBSE guidelines

Figure 9 shows jerk measurements. CIBSE Guide D Table 3.4 recommendations are also plotted.

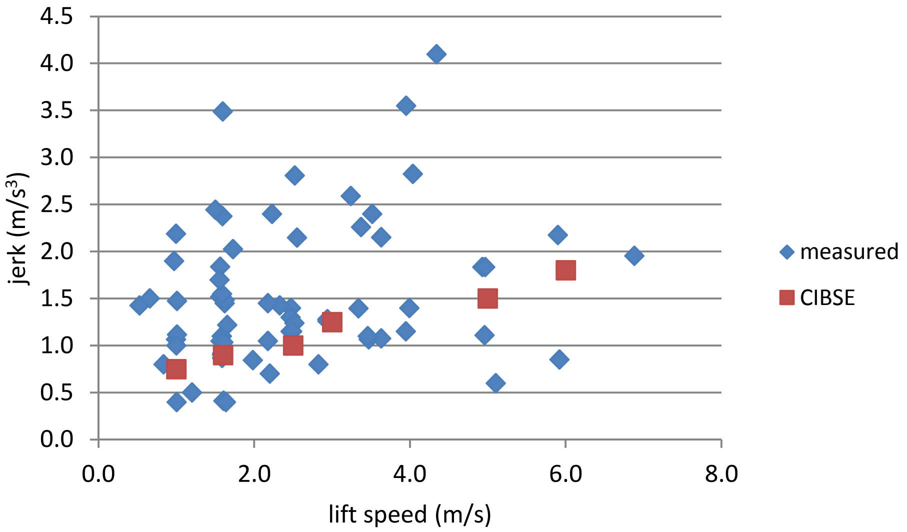

Figure 9 Site measurements of jerk plotted together with CIBSE guidelines

Figure 10 shows motor start delay measurements. CIBSE guidance is to refer to the lift installer, otherwise to assume 0.5 s.

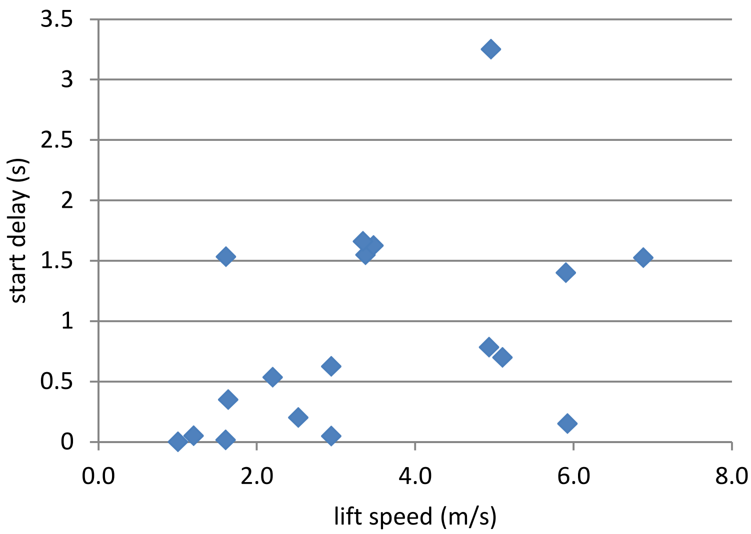

Figure 10 Site measurements of start delay

Figure 11 shows site measurements of levelling delay. This is a new variable not discussed in the current edition of CIBSE Guide D.

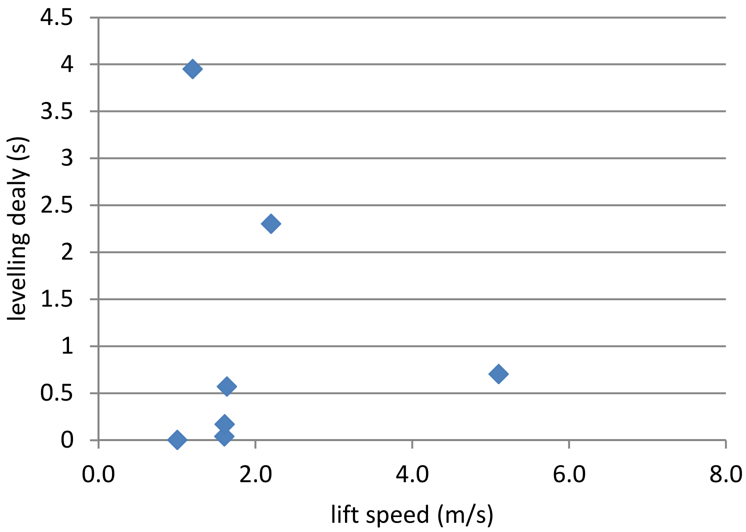

Figure 11 Site measurements of levelling delay

SENSITIVITY ANALYSIS

To investigate the impact of a single parameter, consider a simulation of a building with lunch time traffic, based on Example 4.3 in CIBSE Guide D 2010 (1). This simulation is repeated for increasing start delay. The average waiting time and transit time to destination is plotted in a stacked area graph, Figure 12 .

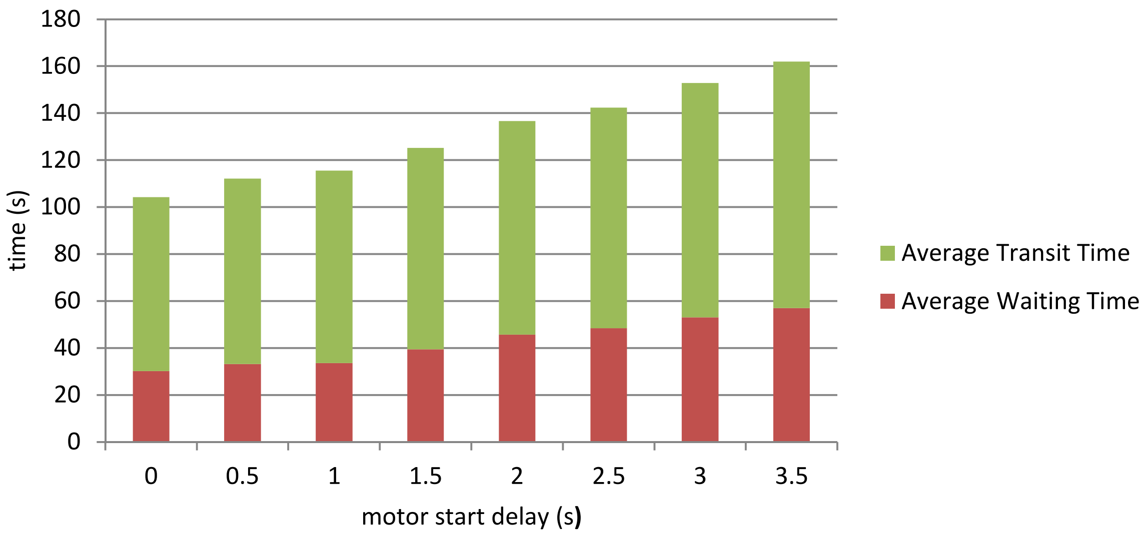

Figure 12 Sensitivity analysis showing impact of motor start delay on simulation results

To investigate the impact on handling capacity, use an up peak round trip time calculation for the same building, again with increasing motor start delay, see Figure 13.

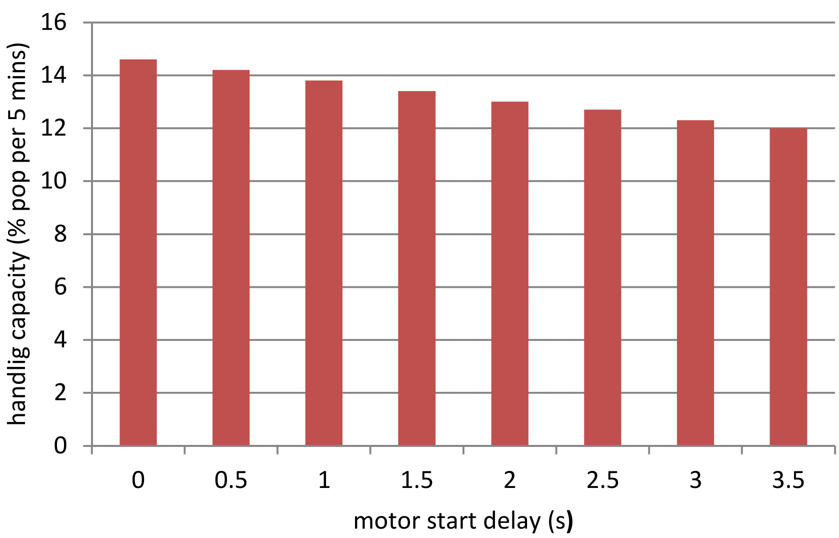

Figure 13 Sensitivity analysis showing impact of motor start delay on handling capacity

Measured variances in a performance time parameter have a major impact on passenger waiting time and handling capacity; variances in other parameters can have an equally dramatic impact. These differences can compromise the traffic design.

CONCLUSIONS

Performance measurements demonstrate that CIBSE performance guidelines are achievable, and in some instances are surpassed. However, they also show that sometimes performance is compromised, for example by a long motor start delay. The impact on waiting time, transit time and handling capacity can be significant; this is demonstrated with a sensitivity analysis.

In planning and specification of a lift installation is it important to specify the required performance parameters. Although specifying performance time for a single floor flight time is a valid approach, our recommendation is to specify all the performance parameters individually, as listed in Table 1. In variations provided with tenders, recognise that it is the combination of all the parameters which is ultimately is the most important; for example a 0.5s start delay may be offset by doors which close 0.5s faster. All parameters should be checked as part of the commissioning process, and monitored during the lifetime of the installation to ensure the best possible performance is maintained.

As we can now measure all the performance parameters, if the performance is poor, we have a clear indication of what is going wrong.

Measuring performance is especially important when considering modernisation. In some instances we find clients have been recommended control system upgrades (e.g. to destination control) where adjusting or upgrading equipment to achieve better performance times would represent better value.

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2nd Symposium on The Lift and Escalator Technologies

Analysis of the frequency behaviour for vertical motions in elevator systems

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INTRODUCTION

Knowledge about the transfer function and the frequency behaviour for elevator systems is of interest for several aspects. For example, to analyse the sensitivity of the cabin to specific frequencies, which may causes mechanical and acoustical vibrations and thus results in discomfort. In addition the frequency behaviour is of high interest while applying control algorithms for active vibration suppression or cabin position control [1]. Due to the different suspension rope length, depending on the cabin's position, the transfer function is time-varying during the travel on one hand. On the other hand it depends on the cabin's payload. Existing literature concentrates on the frequency response analysis lower than 20 Hz [2], while this paper concentrates on methods and measurement signals which are precise enough to determine the frequency behaviour up to 100 Hz.
In addition a wide range of elevator constructions exists, which differs for example in roping, number of rope pulleys or the location of isolation elements. For the model validation of numerous elevator constructions a method is needed, which may be easily applied to many elevators and preferably does not need additional measurement sensors.

At first, this paper describes different measurement possibilities and input shapes for the identification process. It is analysed which input and output signal produce meaningful transfer functions and how they can be compared to each other. Afterwards the different identification methods are described, which is followed by the description how the experiments have been conducted at a real elevator. Finally, the frequency behaviours are discussed, which are obtained at a low-rise elevator for different cabin positions and payloads.

METHODS FOR SPECTRAL ANALYSIS IN ELEVATORS

Determining the frequency behaviour it is of specific interest to know the resonance frequencies of the system. While the resonance frequencies apply for the whole system, the peaks of the transfer function depend on the chosen input and output signals. Thus meaningful signals have to be chosen to ensure that all system resonances are represented in the transfer function. It is advantageous to use excitation and measurement signals which are already available in the system and thus determining the frequency behaviour may be conducted in many elevators, easily. This is especially important, as elevators are constructed in many different ways concerning the roping, rope pulleys and the position of spring elements, which results in different frequency behaviour.

In state of the art elevators, often permanent magnet machines with a frequency converter and a position encoder with sine/cosine traces are used. Thus, the currents, voltages and traction sheave position/velocity are available in a high precision and in a high frequency. In this paper the set current i^{*}_{q} is used for excitation, while actual current $i_{q,act}$ and actual rotational velocity ω_{act} are evaluated to determine the frequency behaviour of the elevator. This dependence is shown in the block diagram of figure 1 and for the modelling of the mechanical system the reader may refer to

[1]. If other measurement signals are used, e.g. cabin or counterweight acceleration [2], additional sensors are needed as they are usually not installed in elevators. The data of different sensors also have to be accurately synchronized as otherwise the calculation yields a wrong transfer function. This is with less effort ensured for the current and traction sheave velocity measurements, as both are captured by the frequency converter.

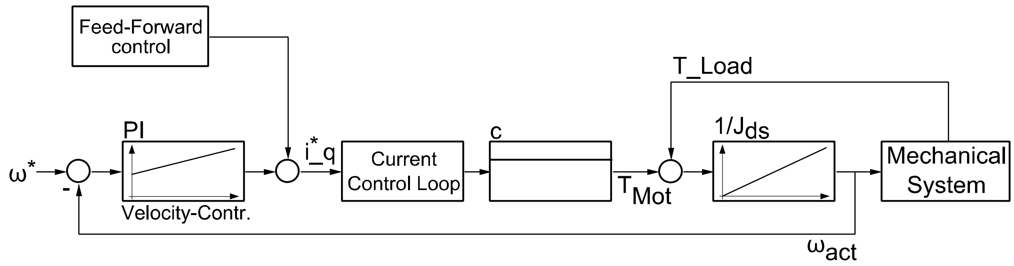


Figure 1: Overview cascaded control structure

Several Methods for the identification of the transfer functions in the frequency or time domain exits [3]. In the following the frequency response analysis (FRA) with a pseudo random binary signal (PRBS) as excitation is described. In addition the excitation with a single discrete frequency and the evaluation with the orthogonal correlation method are considered.

Transfer functions in elevators

In literature transfer functions with different input and output signals are analysed which makes it difficult to compare the results. In addition, if less meaningful input and output signals are chosen, the peaks in the transfer function do not represent the system resonances. In [1] the transfer function $G_{aC,Tmot}$ from motor torque T_{mot} to car acceleration a_C is used, which is, except for a constant factor, the same like $G_{FC,Fmot}$ from motor force F_{mot} to car force F_C [4]. In the following and in [5] the frequency behaviour $G_{\omega,Tmot}$ from motor torque T_{mot} to traction sheave angular velocity ω_{act} is regarded. Furthermore, in [2] the transfer function $G_{vC,vT}$ from traction sheave velocity v_T to car velocity v_C is used.

In this section the similarities and differences of the transfer function are showed up, while analysing the poles and zeros of a simplified 3-mass model. The equations are described in [1][4] and yield the following differential equations which are solved via the Laplace operator

$$F_C = m_C a_C = (v_T - v_C)D_C + (x_T - x_C)C_C \quad (1)$$

$$\rightarrow F_C = \frac{m_C(d_C s^2 + c_C s)}{(s^2 + d_C s + c_C)}(v_T) \quad (2)$$

$$\rightarrow F_{CW} = \frac{m_{CW}(d_{CW} s^2 + c_{CW} s)}{(s^2 + d_{CW} s + c_{CW})}(-v_T) \quad (3)$$

Here $d_C = D_C/m_C$, $C_C = C_C/m_C$, describes damping and spring constant of the rope on the cabin's side. Indices $_{CW}$ represent the variable on the counterweight side. Furthermore x_T and x_C are the displacements of traction sheave and cabin.

Via the relation $F_C = m_C \cdot v_C \cdot s$, equation (2) yields the transfer function listed in equation (4) from traction sheave velocity v_T to car velocity v_C.

$$G_{vC,vT}(s) = \frac{v_C}{v_T} = \frac{(d_C s + c_C)}{(s^2 + d_C s + c_C)} \quad (4)$$

This represents the differential equation with forced velocity excitation at the traction sheave. Then the parameters of the counterweight's side have no impact on the resonance frequencies. The behaviour is equivalent when the brake is closed and the cabin is excited. With the forced velocity excitation and elevators with compensation ropes the counterweight parameters influence the transfer function only via the compensation sheave, however not via the traction sheave.
Equation (5) results from equation (3), if the traction sheave is excited via the motor torque. Via transposition of equation (5) this yields the function $G_{\omega,Tmot}$, which is displayed in equation (6).
Here the static forces due to gravity are neglected and only the d'Alembert forces which influence the frequency behaviour are considered.

$$\omega_{act} = \frac{1}{sJ_T}\left(T_{mot} - \frac{m_{CW}(d_{CW}s^2+c_{CW}s)}{(s^2+d_{CW}s+c_{CW})}\omega_{act}r_T^2 - \frac{m_C(d_C s^2+c_C s)}{(s^2+d_C s+c_C)}\omega_{act}r_T^2\right) \quad (5)$$

$$G_{\omega,Tmot}(s) = \frac{\omega_{act}}{T_{mot}} = \frac{v_T}{r_T T_{mot}} = \frac{1}{sJ_T}\left(\frac{(s^2+d_{CW}s+c_{CW})(s^2+d_C s+c_C)}{(s^2+d_{CW}s+c_{CW})(s^2+d_C s+c_C)+m_{CW}r_T^2(d_{CW}s^2+c_{CW}s)(s^2+d_C s+c_C)+m_C r_T^2(d_C s^2+c_C s)(s^2+d_{CW}s+c_{CW})}\right) \quad (6)$$

Out of this also the transfer function between motor force F_{mot} to car force F_C is derived in the following equations.

$$G_{\omega,T}(s) = \frac{v_T}{r_T T_{mot}} \quad (7)$$

$$\rightarrow G_{\omega,T}(s)\frac{v_C}{v_T} = \frac{v_T}{r_T T_{mot}}\frac{v_C}{v_T} = \frac{v_T}{r_T^2 F_{mot}}\frac{F_C}{s\, m_C v_T} \quad \text{with} \quad v_C = \frac{F_C}{s\, m_C} \quad (8)$$

$$\rightarrow G_{Fc,Fmot}(s) = \frac{F_C}{F_{mot}} = G_{\omega,Tmot}(s) \cdot G_{vC,vT}(s) \cdot s\, m_C r_T^2 \quad (9)$$

As visible from above equations the transfer functions $G_{FC,Fmot}$ and $G_{\omega,Tmot}$ are dependent also on the suspended masses and the elasticity of the suspension ropes at the counterweight side. Looking at $G_{FC,Fmot}$ (eq. (9)) it results, that the poles from $G_{vC,vT}$ (eq. (4)) are cancelled via the zeros of $G_{\omega,Tmot}$. Thus $G_{FC,Fmot}$ has the same denominator and poles like $G_{\omega,Tmot}$, however slightly different zeros. Therefore the resonance frequencies are the same, while antiresonance frequencies differs. In comparison $G_{vC,vT}$ has different poles and respectively resonances. With the forced velocity excitation the counterweight's influence over the traction sheave to the cabin is not considered. Thus the function $G_{vC,vT}$ is only meaningful for a part of the elevator system.

Frequency Response Analysis

Most identification schemes are only valid for transfer functions which are time-invariant during the identification process [4]. This requires in elevators that the cabin stays at the same position, as otherwise the transfer function changes [1]. Thus identification cannot be performed during higher speeds and only small motions around a constant cabin position are allowed. Therefore the static and coulomb friction influences the transfer function [1].
For the frequency response analysis the elevator system is excited by the torque generating set current i^*_q with a pseudo random binary signal (PRBS), which beginning is shown in figure 2. In this paper the sample time T_s has been chosen to 1.008 ms, which results with the Shannon theorem in a frequency range up to 496 Hz. Additionally a 13bit PRBS is used, which results with equation (10) in a measurement time for each sequence of 8.26 s. During this time the PRBS is uncorrelated, which is a mandatory requirement for the frequency response analysis [3]. Afterwards the PRBS is reiterated several times, to obtain a less noisy result. This has a frequency resolution of the transfer function of 0.12 Hz as displayed in equation (11).

$$T_M = (2^{13}-1)\cdot 1.008e^{-3}\text{ s} = 8.26\text{ s} \quad (10)$$

$$f_{res} = 1/\ T_s = 0.12\ \text{Hz} \tag{11}$$

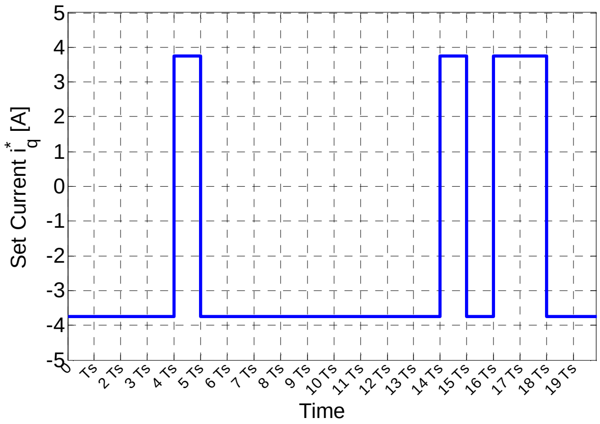


Figure 2: Pseudo Random Binary Signal

The spectral densities $S_{uy}(f)$, $S_{uu}(f)$ are determined while calculating the cross/auto spectral density between input signal u and output signal y. Then the transfer function is given by equation (12).

$$G(f) = S_{uy}(f)\ /\ S_{uu}(f) \tag{12}$$

For determination of the open loop transfer function from actual motor torque T_{mot} to actual speed ω_{act} the velocity controller is set to a low bandwidth to avoid influence from the feedback. In equation (12) the input signal u is represented by the actual current $i_{q,act}$, while the output y is ω_{act}. With this procedure the non-parametric transfer function $G(s)=\omega_{act}(s)/T_{mot}(s)$ is obtained, where motor torque is given for permanent magnet machines by $T_{mot} = c \cdot i\_q_{act}$. The transfer function in equation (12) has complex numbers, thus a common way to illustrate the frequency behaviour is via bode plots, which display the absolute value and phase.

For evaluation of the calculated transfer functions the coherence is chosen as assessment criterion and given in equation (13).

$$\gamma^2 = |S_{uy}(f)|^2\ /\ (S_{uu}(f) \cdot S_{yy}(f)) \tag{13}$$

If the system has strongly linear dependence, then the coherence equals one. Otherwise it is less than one, which occurs also at the location of resonance frequencies [4].

Orthogonal Correlation Method

The orthogonal correlation procedure may be used to determine the frequency behaviour and excites the system with single frequencies via a sine function [3][6]. In figure 3 the scheme of the method is displayed with the amplitude of the set current $\hat{u}$ which excites the single frequency f_0. The system is excited using a sine signal during the measurement time Tm. With this estimation method the real and imaginary parts are obtained for the transfer functions

$$G_1(s) = \omega_{act}(s)\ /\ i^*_q(s) \tag{14}$$
$$G_2(s) = i_{q,act}(s)/\ i^*_q(s) \ \text{ with } \ s=j2\pi f_0\ . \tag{15}$$

Out of these the complex transfer function between actual current to actual speed is given by $G(s)= G_1(s)/\ G_2(s)$ and the gain $|G|$ may be calculated via $|G_1(s)/\ G_2(s)|$. This is reiterated for several discrete frequencies and the data is added to the resulting bode plots of previous section. Also here, the velocity controller is set to a low bandwidth as described in the previous section.

Advantageous of the orthogonal correlation method is the concentration of the total energy of the excitation signal to one frequency. This yields more accurate results, especially if non-linearities like friction or quantization inaccuracies are present. In contrast the energy of the PRBS is distributed over the whole frequency range and thus each single frequency is less excited.

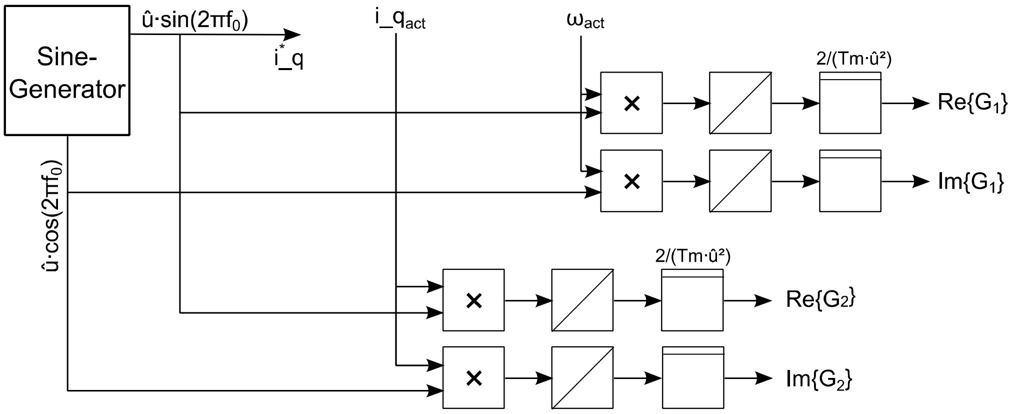


Figure 3: Scheme of orthogonal correlation

EXPERIMENTAL SETUP

To apply the tests to many elevator constructions, the experimental setup should be easily installed. In figure 4 the general setup is shown, where the elevator controller is unplugged and instead a dSPACE box is plugged to the CAN-buses. The box controls the frequency converter via the first CAN-bus for slow signals - e.g. initiating, open brakes, cabin position, load sensor signal or set speed. It also provides via the second CAN-bus the fast signals, like the set current excitation and also the captured sensor data from the frequency converter is exchanged. The captured data is offline processed and then the transfer function is calculated.

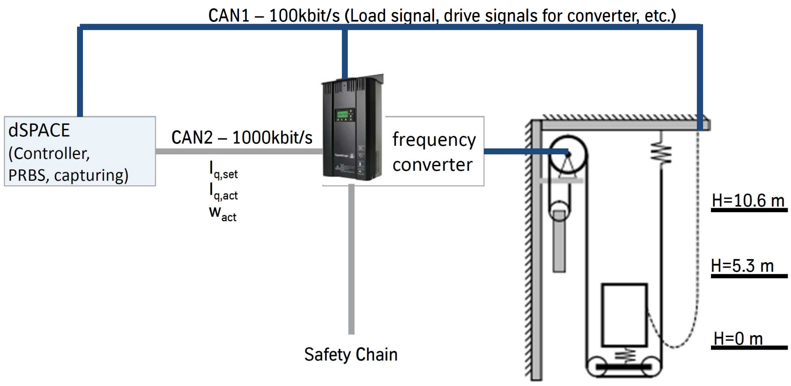


Figure 4: Experimental setup

The basic safety is ensured via the safety chain, which is coupled to the frequency converter. It would stop the drive, if e.g. the elevator would move to the end switches of the shaft.

The test elevator used in this paper has a travel height of 10.6 m, a 2:1 roping and a maximum payload of 450 kg. Further parameters are listed in table A.1.

EXPERIMENTAL RESULTS

The experiments have been performed for different cabin positions and loads. In figure 5 the results are shown for different cabin positions, while the payload is held constant at m_L=180 kg. The distance in meters has its origin in the bottom floor, referring to H=0 m. Therefore, the distance 9.6 m is shortly below the top floor, which is located at H=10.6 m. The first resonance frequency at 5 Hz stays constant for this elevator. The second resonance is also distinctive and increases with lower cabin position. The reason is found in the short suspension ropes between counterweight and traction sheave when the cabin is in bottom position. This results in a very stiff coupling between counterweight and traction sheave. This coupling is stiffer than the coupling when the cabin is in top position as the cabin is additionally isolated via the cabin springs. This behaviour is also confirmed by the theory of a simplified three mass model, while looking at the poles of the transfer function (eq. 6). If typical parameters are inserted it results in a higher second resonance frequency when the cabin is in bottom position and the counterweight is not isolated with additional springs applying to this test elevator.

Further resonances occur above 30 Hz and vary strongly with the cabin's position. Mainly the anti-resonances or the zeros of the transfer function change the location, which thus may eliminate or reduce the peak of a resonance. Especially, this is visible for the cabin in top position and the first resonance.

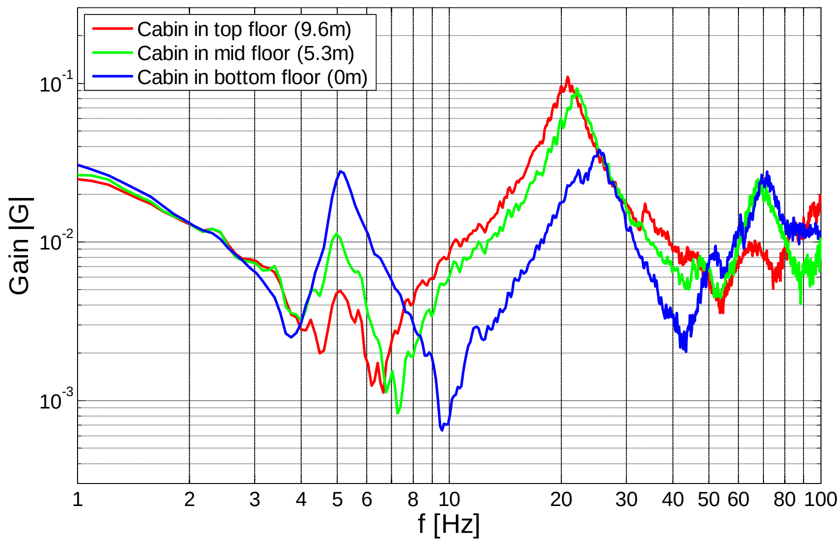
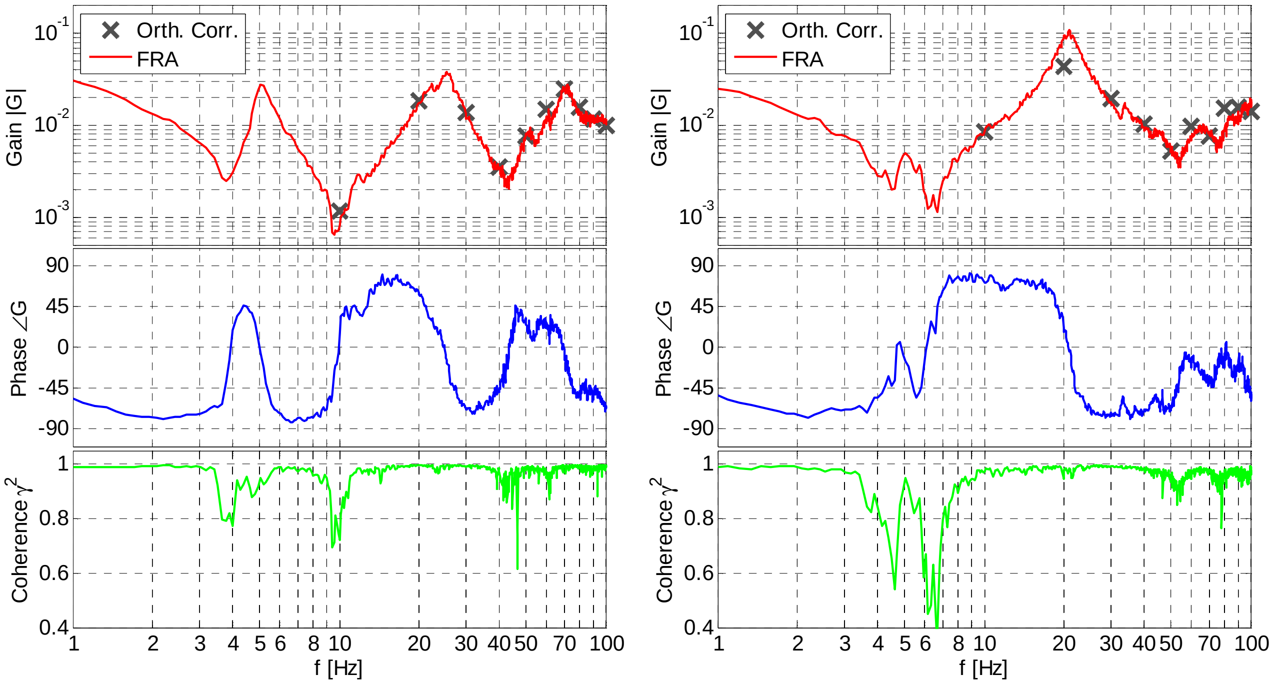


Figure 5: Bode plot for different positions: $|G(s)| = |\, \omega_{act}(s)/T_{mot}(s)|$; $s=j2\pi f$

Looking at the frequency range up to 10 Hz the transfer function of the elevator with cabin in top position is much noisier than in bottom position. Here, the reason is a higher friction of the cabin in top position, which is also visible in the coherence shown in figure 6 (b). It drops significantly in this range, indicating the non-linear relationship. The strongest friction is caused between guide rails and cabin as well as between the guide rails and counterweight. For this low-rise elevator this influence is stronger as guide shoes are used and would be smaller, if roller guides are installed. Additionally, friction occurs at the traction sheave shaft and also for the rope pulleys at the counterweight and cabin.

The main reasons for the influence of the friction are the identification schemes, which are valid for transfer functions which are time-invariant during the identification process [3]. Time-invariance in the elevator system requires that the cabin stays at the same position, as otherwise the rope length changes and thus the transfer function (see figure 5). Therefore the identification cannot perform during higher speeds and only small motions around a constant cabin position are allowed, which thus causes in static and sliding friction. During the travel, for non-zero speeds, the friction causes a constant force in opposite of the direction of travel, which results only in a different value for the constant frequency content at zero Hertz, however not for the other frequencies. Therefore the static and sliding friction influence the identification process.

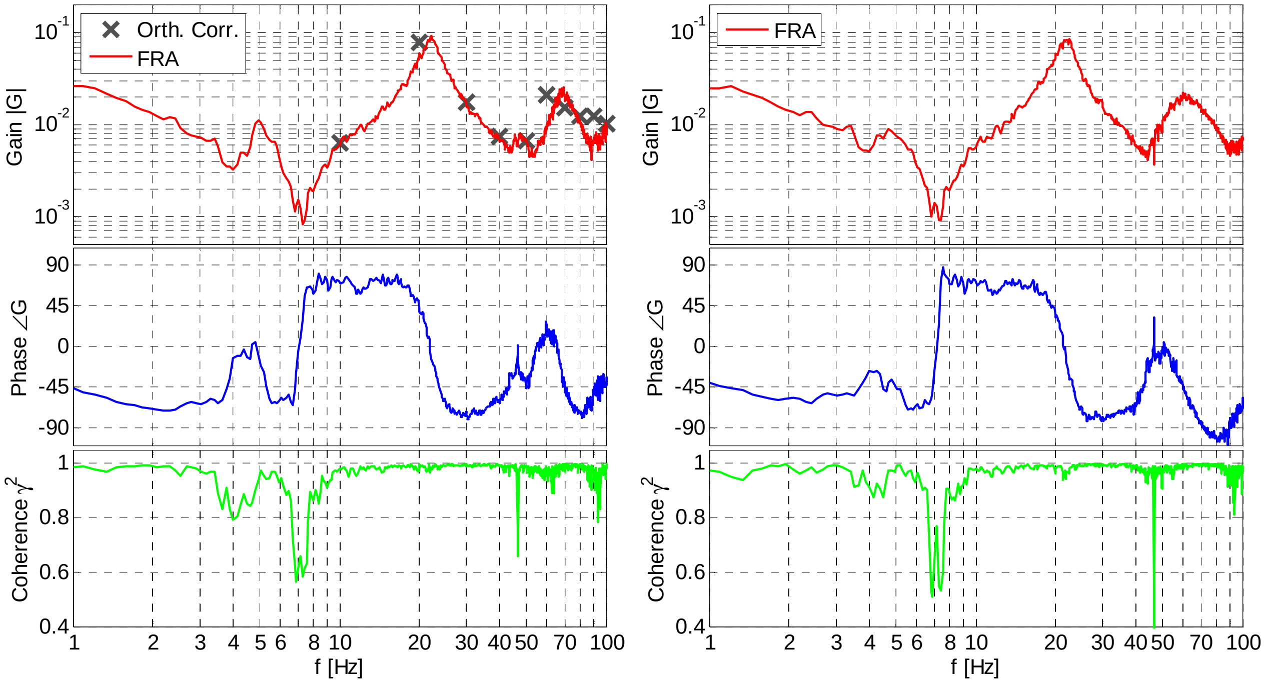


(a) m_L = 180 kg, H = 0 m (b) m_L = 180 kg, H = 9.6 m

Figure 6: Transfer functions $G(s) = \omega_{act}(s)/T_{mot}(s)$; $s=j2\pi f$

In figure 6 and figure 7 (a) also the results of the orthogonal correlation are marked with the grey crosses. In general the crosses fit very well on the transfer function estimated by the FRA. Small differences occur in figure 6 (b) at 20Hz, where the peak is directly located at a resonance and is the reason for the deviation. As expected, it is also visible, that the small deviations occur when the coherence drops.

While looking at the phase, it shows the same relationships like the gain and the effect of resonances is apparent. Especially, this is visible in figure 7 (b), when the payload is removed and thus the first antiresonance occurs at a higher frequency. This results almost in an elimination of the first resonance, which is visible at the gain. However, the phase indicates even more clearly this elimination and only a small rise and drop in phase occurs between 4 and 5 Hz.



(a) $m_L = 180$ kg, $X_K = 5.3$ m (b) $m_L = 0$ kg, $X_K = 5.3$ m

Figure 7: Transfer functions $G(s) = \omega_{act}(s)/T_{mot}(s)$; $s=j2\pi f$

SUMMARY

This paper describes two methods to obtain the frequency behaviour for the vertical motion of elevators. The sensor signals are chosen by means of availability in standard elevators and yield accurate results up to 100 Hz. The methods are applied at a test elevator and the frequency behaviour is obtained for several cabin positions and payloads. Both methods give meaningful and also very similar results.

Now, the results can be used to reduce vibrations while optimizing mechanical parameters like spring stiffness or rope pulley inertia. The results may be also used to validate simulation models and thus enable the optimization of elevators already in simulation.

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APPENDIX

m_c [kg]	585	Cabin mass
m_L [kg]	450	Maximum payload
m_{cw} [kg]	765	Counterweight mass
H [m]	10.6	Travel height
J_{ds} [kg m²]	0.18	Motor + traction sheave inertia
r_{ds} [m]	0.22	Radius traction sheave
c [Nm/A]	22.7	Motor constant
U	2:1	Roping
N	6	Number of ropes
D_{rope} [mm]	6	Rope diameter

Table A.1: Parameters of test elevator

2nd Symposium on Lift and Escalator Technologies

A Realistic Approach to "Interesting" Claims
- Lessons in Lift Traffic Analysis -

Dr. Bruce A. Powell
The Bruce Powell Company

INTRODUCTION

Over the past 10 years as a lift consultant, I have encountered a great deal of disorder and confusion with regard to traffic analysis. Elevator suppliers make unsubstantiated claims about performance of their elevators. Clients use the terminology Interval synonymously with Average Waiting Time. Consultants run simulation studies applied to high rise residential tower under the assumption of up peak traffic. If we in the lift consulting business are honest with ourselves, we would not have to look very far to find disorder and confusion. Although it is easy to contend that the confusion is due to "those other guys, not me," it is my contention that we lift professionals should do all we can to minimize the confusion. This paper will present four related lessons that I have learned as a specialist in elevator traffic analysis. The bottom line is something that I'm sure everyone would agree with … that clarity and the attention to technical detail are of the utmost importance.

We will present four examples where disorder might occur and recommend steps to minimize the confusion. These examples involve claims of lift performance, Destination Control, simulation, and modernization studies

LESSON 1

Over the past 10 years, the freight train called Destination Control has been picking up more and more momentum. For example, an overwhelming majority of the lift modernization projects in San Francisco have upgraded from conventional two-button ETA-based dispatch to a destination based system whereby a passenger enters his/her destination floor on an input device in the hallway.

But with this popular technology there often comes a bit of disorder and confusion. For example, I know a lift consultant who would have the building owner believe that if he would control his elevators with a destination-based system … commonly referred to as DD … he could save an elevator. In other words, for example, five elevators under DD control would perform as well as six elevators under conventional control. Also, I'm sure that we have all seen PowerPoint slides from one or more elevator suppliers who say categorically that "DD will improve performance by 25%." What's the customer to believe?

An example will be presented that will illustrate how these confusing and often unsubstantiated claims might be treated. We will show how it could be possible to use traffic analysis to fairly arrive at the conclusion that one fewer lift would "work" or that the performance would improve by some staggering percentage. The case will be made that full disclosure should be demanded. For example, if you claim to reduce the number of lifts based predominantly on Up Peak traffic, then you should also present analysis for other important traffic periods (e.g., lunch time) before forming your final recommendation. And if you claim a large improvement in performance, you should provide a precise definition of the metric that you are using for performance. Do you mean Passenger Waiting Time? Time to Destination? Hall Call Response Time? Lobby crowding?

LESSON 2

When a new office tower is in the proposal stage, it is common for the owner and his architect to spend a day interviewing several lift suppliers. Supplier X will say that "we have the best dispatch algorithm in the industry." Supplier Y will follow X's presentation with a slide that contains the following text: *We have the best dispatch algorithm in the industry.* The owner turns to his lift consultant and asks "Who really does have the best dispatch algorithm, and how do they know?"

We will present a discussion of this oft-unsubstantiated claim and what can be done to resolve the issue. One might think that we could propose a set of building and traffic conditions and ask each competitor (X and Y) to provide a traffic study in which values for important performance metrics are documented. However, we argue that this is not that easy. First, each competitor has its own software for traffic analysis which could have important differences in simulation modeling. Second, each competitor may well use slightly different values for important input parameters that would affect the results. Third, even such a fundamental concept as the definition of passenger waiting time can be different. So we contend that, for example, just because Supplier X claims an Average Passenger Waiting Time (AWT) of 18.7 seconds and Supplier Y claims 16.9 seconds … a 10% difference … we should not conclude that Supplier Y has a better dispatcher. We know that there are three very reasonable ways to determine waiting time, and there can be a substantial quantitative difference between them.

So how can we reduce the disorder and minimize the confusion? A good start would be to require each supplier to provide its analysis with the same software … e.g., Elevate … and use an identical set of input parameters. But in the end, it is entirely likely that neither Supplier X nor Supplier Y are very much interested in this solid, technical comparison. After all, if we could all agree as to who is the best, then all but one supplier has now lost the ability to claim superiority!

LESSON 3

As a consultant, I am often asked *"Why do you spend so much time and energy doing a wide range of simulations? I thought that all you needed are simple calculations for Interval and Handling Capacity."* The direct response to this question is that simulation software commonly available not only within each major lift manufacturer but also to the general public (e.g., Elevate) provides a much more realistic assessment of elevator performance than simple Interval and Handling Capacity calculations.

Until the 1960's, the traffic analysis for elevators in a new building was limited to what we now call Up Peak Calculations. Based on the general understanding at the time that the most critical time period for vertical transportation in an office building was the early morning when tenants arrived for work. An estimate was made for the time that an elevator required to make a round trip from the Lobby, delivering passengers along the way. Probability theory was used to determine the number of likely (i.e., probable) stops and the highest floor reached. It was then shown that if this Round Trip Time were, say, 120 seconds, and there would be, say, four lifts, an observer in the Lobby would see a lift departing with a load of passengers every 30 seconds. Then by inference, the all-important Average Passenger Waiting Time would be one half of the Interval, which is generally considered to be good service. This was easy. In fact, old timers will recall doing this by hand with a pencil and paper on something called the "long form." But this method had … and still has … several major shortcomings. First, the implicit assumption is that passengers would all load onto the lift at the main Lobby level. Second, the lift would return immediately to the lobby after the last passenger exited the car. Third, the method determines only an average and cannot provide information on the frequency of long waiting times. Finally and most important, the method is dispatch-logic independent; it cannot differentiate between performance of a conventional control system and performance of more up-to-date Destination Control. Furthermore, the calculations cannot adequately evaluate the elevator service during lunchtime which is now considered more difficult to handle than morning up peak.

Examples will be presented where Up Peak Calculations provide misleading information. In one case, the failure to consider multiple entry levels in an office building resulted in excessively long waits and vehement customer complaints. In another case, the surprise installation of a cafeteria on the top floor of an office building turned a well-elevatored building into a disappointment.

LESSON 4

An owner who is interested in modernizing the lifts in his office building has asked his lift consultant for a quick study to tell him how much the elevator service can be improved with a successful modernization and destination control. The consultant's traffic study showed that the Average Passenger Waiting Time can be reduced from 25 seconds to 18 seconds. After a moment's reflection, the owner recognizes some disorder and confusion. The AWT as reported by his traffic analyzer is only 15 seconds with his present conventional control system. Why is there such a major discrepancy?

It seems that the consultant has provided results based on industry standard requirements that the lifts must be able to handle a peak traffic volume of 12% or greater where all traffic is of the Entrance type. A job site survey at the building by a team from an elevator supplier quickly discovered a number of facts that may well have been overlooked in the quick study. The primary discovery was that the peak traffic volume was only 8% per 5-minutes, which is far lighter than the textbook recommendation. Another interesting finding was that fully 10% of the passengers counted during the morning up peak period were Exit passengers. In other words, not all passengers included in the count boarded the lifts in the Lobby to travel upward to their office. Far from it. Not only were there significant numbers of passengers getting off the lifts at the lobby but also there was a smattering of interfloor traffic. Other findings include the fact that the acceleration and floor-to-floor times were slower than the standard textbook values, and the door operation times were noticeably slower as well. Thus it was discovered that the source of the confusion and disorder was that the quick study was based on textbook parameters and requirements, which differ considerably from conditions in the building. The key issue in a modernization is to answer the following customer question: *"What performance improvement can I expect in my building?"* At this stage, the performance against textbook requirements is of only casual interest.

We will present a case study for a recent modernization project of the lifts in an 18-story office building which will highlight the difference in conclusions that one might draw using textbook requirements versus data gathered from the job site. The results will be surprising.

CONCLUSION

The four lessons that are presented are examples where attention to detail is of utmost importance. It doesn't have to be a jungle out there. Attention to technical detail, the proper use of simulation, and the understanding of key assumptions underlying the methodology will minimize disorder and confusion.

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Lift Design: Still room for improvement

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INTRODUCTION

Despite many advances in lift technology there are several areas of lift design that are still costly for lift owners and lift manufacturers. It is intended to briefly explore these areas with some historical examples as a spur to furthering research and improving the management of lifts during their life.

Two drivers of lift design advances are ride comfort requirements and reduction of energy consumption. Maintenance is driver of cost that can be better controlled.

Lift Ride Comfort. Lift ride comfort is easily specified but can be hard to achieve on site. For many buildings, the structural design, e.g. steel frame or wood provides a flexible springy support for the lift which also has similar characteristics. Often lift systems are designed assuming that they will be installed in a stiff concrete structure. When this is the case there is little dynamic interaction between the building structure and the lift. In the case of multiple lifts in the same lift well, there may be common load bearing suspension steel work having two or more lifts suspended from it. In this case the case common suspension can make a superb but unwanted coupling mechanism between the suspended lifts which act as complex pendulums. Unwanted interactions between the lifts (pendulums) can result in uncontrollable noise and vibration. As an example, two such suspended lifts were parked at the lowest floor of the building. One person with an EVA ride comfort meter was placed in one lift. A second person then did fast squats in the second lift to get the lift car oscillating vertically. The first car started moving in resonance with the second lift with an average vertical acceleration of $0.8 m/s^2$.

In the case of wooden and steel lift well structures, both are flexible in 3 planes. The stiffness of these structures is less than that of concrete and so the lift dynamics can interact more with the building structure. Undesirable effects as the distance between guide spacing and lift to landing running clearances varying with lift loading conditions can occur. External lifts in steel supporting structures have been affected by design of supporting structures that used flexible pinned joints. This has led to expensive reworks to the structures so that they support the lift and not vice versa.

Wooden structures need careful consideration of the lift to structure interfacing components such as load bearing fixings to the structure. A possibly hidden cost is the associated training needed for installation personnel to work with, what may be unfamiliar fixing methods.

The interaction between the building and the lift is seldom analysed in order to achieve the desired results in terms of dynamic performance. A similar situation pertains to the acoustic transmission of noise between the building and lift. The acoustic transmission performance of the building fabric is not a parameter in control of the lift manufacturer. Yet, in the case of excessive noise transmission (clicks and high frequency noise), it is often the lift manufacturer who is expected to solve the problem. Lift manufacturers should be able to provide a lift equipment noise power spectrum and kinematics to architects in order to allow a planned noise transmission design of the surrounding structure of the lift where low noise is important.

Modifications to existing lift installations by changing the mass of the car, rated speed, hoisting machine rated rpm can turn an originally quiet smooth running lift into a vibrating noisy box. One example created a 50 Hertz noise in the car due to the interaction of its dimensions with the new gearbox motor rpm at the rated speed of the lift. This was only economically solved by the addition of a Stockbridge damper to the crosshead of the sling of the car.

Reduction of Energy Consumption At first glance, energy consumption reduction is a simple matter of lowering acceleration values for the lift, switching off equipment when the lift is not required to run and reducing the mains supply voltage. The first helps with achieving specified ride comfort levels but decreases passenger handling performance. An increase of 1 second in a one floor travel time can reduce traffic handling capacity by approximately 5 %. There is more to lowering acceleration values than meets the eye.

Reduction of mains supply voltage can be an issue for lift component reliability in the control system. There have been several cases of voltage reduction schemes being applied to lifts in existing buildings with promises of big energy savings as a consequence. Typically the supply voltage at the incoming supply to the building has been reduced to 400 volts or lower. Almost without exception, the lift equipment has become unreliable with an increase in equipment breakdowns and failures of variable frequency drives, contactors and relays. What has been missed is:-

1. The lift hoisting power requirement is independent of the supply voltage. Reduction of the supply voltage increases the hoisting current.
2. Low supply voltage at the terminals of the lift controller is exacerbated by the increased voltage drop in the supply cables to the lift during acceleration of the lift.
3. Contactors and relays have a quite narrow operating voltage range for correct mechanical and thermal operation. Operating outside that range consistently causes contact welding and burning due to slow contact closure on low voltage and coil burnout on high voltage.

Lifts control systems for operation consistently on low supply voltages need subtle changes in design approach for economical manufacture of a system that will also work on high voltages. The use of switch mode power supplies to provide a suitable supply to contactors and relays is necessary for high reliability. Solid state drives such as variable frequency drives need to be rated for the higher input currents associated with lower voltage operation than the nominal mains supply voltage for the country of use. The mains supply cables from the incoming mains distribution board will need to be larger in the general case to provide acceptable voltage drop.

Lifts commonly use a lot of steel. Whole life energy use (including energy used to manufacture the lift) considerations may lead to other materials being preferred. Counterweight mass reduction is superficially attractive. However it can increase maximum current demand on the supply, will increase the required maximum hoisting motor torque and power output. Maintenance of traction may also need the use of compensation which is another increase in the use of materials.

Maintenance. The lift industry has a long way to go in order to provide reliability based maintenance that is an asset to both the lift owner and the maintenance provider. Many current approaches to maintenance are based on inadequate knowledge of the maintenance needs of individual equipment designs. Maintenance by many companies is based on a "One Size Fits All" module regime where specific tasks are carried out on a rolling fixed frequency basis. This may fit their own products where they know in detail what needs to be done in order to keep the lift running reliably. It is not at all true that the same approach can be taken with another product from another company or for older technologies. A classic error is to reduce the contact cleaning regime on older open relay equipment. This state of affairs is partly due to the maintenance documentation requirements laid out in [1]. This document requires that instructions are given for safety components but does not require information to be provided for rapid fault diagnosis, design life times of components, lubrication requirements in detail for the type of lift equipment. True reliability based maintenance requires such information so that correct and timely lubrication is carried out; wearing components are changed before they are life expired and causing (random) breakdowns. Most mechanical devices wear out due to time running, not the elapse of calendar time. As an example of unacceptable failures due to lack on design life knowledge take sealed bearings in lift components such as counterweight and diverter pulleys that are “sealed for life”. It is not a normal activity in maintenance at present to take the load off these bearings to allow a check for wear and excessive play or to take a sound signature that can be compared to a good bearing sound. Consequently there have been many bearing failures leading to free fall counterweights, rope damage. The incident described in [2] in 2008 is a classic example.

Two most important components to be added to a lift for effective management of this type of maintenance are an “Hours run meter” and a “Starts counter”. Lift components only wear when the lift is moving or required to move. Contactors and relays wear out on number of operations, dependant on contact loading as well. Without the meter and counter, all knowledge about the wear state of the lift is a “guestimate”. Who pays for that lack of knowledge and timely maintenance activity? It is the lift owner in the general case.

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Standards, who needs them, who creates them and how are they created

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1.0 INTRODUCTION

For the professional engineer, standards can be a blessing and bane all in one, sometimes being seen as a useful guide to what is expected whilst at others seen as a block to innovation.

1.1I have been in the lift industry since 1963 and spent half this time working in the field of stands development, firstly with Otis Ltd and then as Technical Director of the Lift and Escalator Industry Association. I was heavily involved with the development of many of the standards you will have heard of , such as, BSEN81 parts 1 , 2, 3, 28, 58, 70, 71, 72, 73, 76, BS7255, EN13015, BS5655, BS5656, BS5588, ISO4190 - 1, 2, 3, 7, ISO14798 and many others. The process for creating standards is well defined but varies slightly with the type of standard or document being created.

1.2 British Standards are under the control of the British Standards Institution (BSI) and they have their own set of complex rules that have to be followed. The creation of European standards has another set of rules as does the creation of ISO standards.
Before we worry about writing a standard someone must determine if a standard is required. What subject is to be addressed and who should create it?

2.0 BSI STANDARDS

2.1 Participation in lift/ escalator work

At BSI, standards relating to lifts and escalators are under the control of a committee named MHE 4. This is a large committee with representatives from ACE Association for Consultancy and Engineering, BIS department for Business innovation and Skills, Chartered Institution for Environmental Health, Chartered Institution of Building Services Engineers, Department for Communities and Local Affairs, Health and Safety Executive, Institution of Engineering and Technology, Institution of Mechanical Engineers, Lift and Escalator Industry Association, London Underground, Safety Assessment Federation Ltd, Society of Operations Engineers, Unite Union and University of Northampton.

2.2 There are currently some 1350 committees within BSI with approximately 10,000 members all giving their time and expertise on a voluntary basis usually with the support of their employer.
The amount of commitment varies depending on the work programme at any one time.

2.3 Frequency of meetings

Most committees only meet a couple of times each year but some members may also agree to represent BSI on other standards work in Europe or further afield.

BSI committees have to represent the interests of users, manufacturers, government departments and other bodies concerned with the work of the main committee MHE 4.

Some organisations will have representation almost automatically. As an example the government department of Business Innovation and Skill (BIS), The Health and Safety Executive (HSE) Lift and Escalator Association (LEIA) always have representation.

2.4 Where does work originate

Proposals for the creation of a standard can, in theory, come from almost any source but in practice, usually appear from one of the committee members such as LEIA, who through their work have realised some subject needs to be addressed or, it may be due to an accident or other reasons.

2.4.1 Is the work justified.

When a proposal is made it must first be determined if this is a subject that can be addressed by a British Standard (National standard) or if it will infringe on ISO or other standards such as those produced by the European Committee for Standardisation Committee (Comité Européan de Normalisation (CEN).

2.4.2 Avoiding duplication of work

If the work is of European Interest, the case for a standard is put to CEN and if they agree on the need, CEN will take on the work. If CEN have no interest BSI will look to see if the need for a National standard on the subject exists. They will look to ensure the proposed standard is not just an item of interest to a single manufacturer but will be of genuine interest to consumers, industry etc. If the proposal is accepted MHE4 will appoint a convener to manage the work. Is it to be a full British Standard, Publicly Available Specification (PAS), Draft for Development (DD), Method, Guide, Vocabulary, Code of Practice (CP) or Classification? This needs to be agreed by MHE4 before work starts.

2.5 Publication types

2.5.1 A Publicly Available Specification (PAS) a document developed by British Standards but commissioned by an external organization such as LEIA.

2.5.2 DD means Draft for Development and is used when it is thought the subject would benefit from an extended period of consultation. A DD is usually published for 2 years during which comments are invited. At the end of the period it is determined if the document should be made into a full standard or possibly withdrawn.

2.5.3 Method is a document that gives a complete account of the way a particular activity is performed and may include information on tools and the degree of precision appropriate for the purpose.

2.5.4 Guides provide general information about a subject.
Codes of Practice (CP) provide recommendations for accepted good practice as followed by conscientious and competent practitioners.

2.5.5 Amendments (AMD) as the name implies are used to amend existing published documents.

2.5.6 Classifications provide designations and descriptions of different grades of a product.

2..5.7 Vocabulary documents provide definitions of terms used by a particular sector of industry.

2.6 Forming a work group

Having agreed on the type of document to be produced a proposed convener will be given a scope for the work and should not step outside the scope without the agreement of MHE4. BSI may offer a secretary to support the organisation of the committee and a call for members will be sent out to MHE4 and other parties thought to have an interest. Who finally sits on the committee is usually a joint agreement between the WG convener and MHE4 with the MHE4 committee having the final say.

2.7 Work schedules and first meetings

BSI will set a schedule for the work and then the real work begins, usually starting with an initial meeting of members where they decide how often they need to meet, where to meet, who will provide the meeting room, if there is any research to be done and who will do it.

At meetings members are required to speak on behalf of those they are representing namely MHE4, SAFed, BIS or whoever, it's not always their employer, a point often forgotten.

2.8 Control of document format

As meetings progress draft text is produced in a BSI electronic template that assists committees in following format rules. Once the committee is satisfied with their work it is circulated to MHE4 members to gain their agreement to what has been produced.

2.9 Public enquiry stage.

When MHE4 agree, the document is sent out for a public enquiry, the period of which is normally 3 months. In theory anyone can purchase the enquiry document and comment, with comments being given on a BSI standardised comment template.

2.10 Handling comments from enquiry

At the end of the enquiry, all comments are gathered and the drafting committee that created the work must meet again and address the comments. This means they must consider each comment to determine if it's reasonable, editorial or of a technical nature. If a comment is accepted the committee has to revise the text of the draft document. If a comment is technical and sufficiently serious they will again revise the text extensively but this may drive the need for a second enquiry or they may reject the comment if justifiable. Whatever they do they must explain in the comment template so that interested parties can see why comments are accepted or rejected. Once this work has been completed the documents again returns to MHE4 to ensure they still agree with its content.

2.11 Final document

If MHE 4 do agree with the final proposed document it's then sent to BSI publishing that check formatting and text to ensure it follows the rule and then it's sent out for formal vote. Interested parties must either vote for the document to be published or explain why they are against its publication. Rejection must be supported by sound technical reasoning.

2.12 Use of risk assessments

The committee will often use a risk assessment based on ISO 14798 to determine if a particular requirements is essential. Some work will be based entirely on risk assessment especially where the proposed subject is very new to the industry and experience is limited. Members must also keep in mind the cost to society. We can all think of ways to make lifts safer but as serious accidents are few and far between, can the cost of some provisions be reasonably justified? The cost to industry must also be weighed against the improvement.

2.13 Official interpretation request

When complete, good standards should be unambiguous, easy to understand and not unnecessarily complex thus possibly impeding small businesses with limited resource. These things are not easy to achieve and as with many things the proof is in the eating. Good standards are used and bad ones ignored by all however, as modern standard are performance based and do not precisely define technical detail therefore misinterpretation can occur. Where this is the case standard users can write to MHE4 requesting an official interpretation. Any correspondence relating to interpretations should reference the standard number, give its title, date and the clause number in question as well as an explanation of the problem with the particular clause or sentence.

MHE 4 will reply with an official interpretation relating to any standard they created or maintain. If the question relates to a standard outside their control such as one of the EN standards they will pass the request on to those that manage EN standards or may provide an unofficial view of the their own to assist those asking the question, official answers to EN questions can take many months to obtain.

2.14 Once a standard is published it has to be maintained. MHE4 has some 106 standards at this time so plenty for MHE4 members to do with updates due to changes in other standards, legislation, technical improvements, etc. To assist with all the work MHE4 has a number of sub-committees under its control as follows.

MHE/4/-/1 Advisory panel
MHE/4/2 Domestic lifts and stair lifts
MHE/4/-/5 Fire tests of lift landing doors
MHE/4/4 National work coordination and drafting
MHE/4/1 Safe working on lifts
MHE/4/3 Safe working on escalators

3.0 EN STANDARDS

3.1 Main lift committee

The production of EN standards by CEN (Comité Européan de Normalisation) is similar but not identical to BSI. The main lift committee is named Technical Committee 10. TC10 as it's normally known. It's responsible for the maintenance and production of all Lift and Escalator standards for Europe. It's a large committee made up primarily of National committee members from 27 EU member states. Each member state nominates someone to speak on behalf of its National standards committee. This was my roles for many years. I would attend TC10 meetings and speak on behalf of BSI MHE4. So to be a member you have to be nominated by your National committee who will frequently provide a brief to be followed in relation to some aspect of standards work of UK Interest.

Other parties with a position at TC10 include inspection organizations such as TUV, Dutch Lift Institute as well as a CEN Consultant.

3. 2 **Proposed new work**

Proposals for new standards or the need for revision of a standard comes to CEN TC10 from many directions. It may be suggested by a National committee, may be mandated by the European Commission to support the introduction of a new directive related to lifts or, from CEN itself who inform the committee that some particular document is out of date and needs updating or withdrawal.

As with BSI work proposals they have to be justified by a business plan showing there is a real need and assuming there is a need and support within TC10 to do the work, TC 10 will look to find a convener from within its members.

3.3 TC10 structure

The current structure of CEN/TC10 is a shown below and new work may fit well into the existing structure where a convener already exists or a new work group may be formed.

<u>Table 1 CEN/TC 10 - Structure</u>

Secretariat	Chairperson	Secretary
AFNOR	Mr E.Gharibaan	Mrs E.Contival

SC/WG	Title
CEN/TC 10/WG 8	Stairlifts and vertical platforms for the disabled
CEN/TC 10/WG 6	Fire fighting lifts
CEN/TC 10/WG 10	Improvement of safety of existing lifts
CEN/TC 10/WG 9	Inclined lifts
CEN/TC 10/WG 1	Lifts and service lifts
CEN/TC 10/SC 1	Building hoists
CEN/TC 10/WG 4	Data logging and remote control
CEN/TC 10/WG 2	Escalators and moving walks

3.4 Work groups or Work teams

TC10 can decide if the work is to be performed by a working group (WG) ad-hoc group, work team (WT) etc but only a WG is in full control of its work. Depending on the subject, the decision related to WT or WG etc will depend amongst other thing on the type of document to be produced.

3.5 Publication options

As with BSI, CEN have various publication possibilities to pick from as follows.

3.5.1 European Norm (EN) a European standard that is not harmonized but must be adopted by member states who are obliged to withdraw conflicting National standards.

3.5.2 European Draft standard (pr EN) these are similar to BSI draft for development. When first sent to enquiry the enquiry document will carry the prEN title.

3.5.3 Ratified text is the official text sent by CEN to National bodies for publication.

3.5.4 European pre standard (ENV) Similar to a draft for development (DD) by BSI. Usually used where technology is still changing. It's not necessary for National conflicting standards to be withdrawn

3.5.5 Technical report (TR) document containing informative material but not suitable as a standard.

3.5.6 Guide usually contain material related to standardization principles and practice
Technical specification (TS) often used where a draft standard has failed to gain enough support to allow it to be ratified.

3.5.7 Harmonised EN standard. An EN standard drafted in support of one or more directive introduced to remove barriers to trade. Identifiable from other EN standards by its Z Annex at the rear of the document. The annex will explain the directive it supports. It must also be referenced in the Official Journal (OJ) of the European Union.

3.5.8 When required, National committees may ask for an official interpretation of a clause to TC10 for the standards under their control. Note, this is a request from a National committee so if you need an official interpretation of text, you should write to BSI MHE4 who will either answer your question or submit it to CENTC10 for reply. Official interpretations are published on a regular basis in BS CEN/TS 81-11.

3.6 Enquiry voting
Voting and format rules vary depending on what is to be published. A full standard must be precise in its wording and is subject to national voting where as some other documents need only TC10 approval before publication. The choice of publication type can also affect the availability of funding for participants.

3.7 Funding of participants. BSI participants to Work Groups are usually eligible for some financial support but this is not the case for Work Team delegate or ad-hoc delegates. TC10 will provide the convener with a scope of work and it's not for the convener to stray or change the scope without TC10 approval.

3.8 Mandated work
As previously stated, some work will be mandated by the European Commission in support of a European Directive. As an example when the Lift Directive was introduced the commission mandated CEN to produce a harmonised standard to support it and EN81 parts 1 and 2:1998 were created. In this situation the commission also appoints a CEN consultant who is responsible for keeping a watchful eye on the standard as it's developed. The consultant checks the document against the directive it supports to ensure that if it's followed compliant products will fully satisfy the legal requirements of the directive.

3.9 Avoiding duplication of work
CEN will notify National committees when new work is proposed to see if it will be of interest to them and remind them that if they are already working on the subject they will have to stop work.

3.10 Creating a work group or team
For work to start a call for delegates will be made to National committees and as the work is European, meetings will be conducted either in Paris at the head quarters of AFOR who publish the standards or, in another European country as agreed by the WG members at their first meeting. At the first meeting plans are usually agreed on the best way to proceed in order to meet the time table for work issued by the CEN secretary.

3.11 Standard templates
As with BSI, a CEN template for the document type will be provided for the committee to use so as to assist them in following the rules for CEN publications. The standard has to be written so that compliance can be ensured by manufacturers and other interested parties. As an example, you should not use phrase such as*, the access shall be safe* it's not acceptable as everyone will have an opinion on what make safe access. Instead you have to define what safe mean in terms of step height, lighting levels, hand holds etc or whatever is agreed makes an access safe.

3.12 Language of meetings
Meetings and drafting is normally conducted in English with publications of final text in English, French and German, the three official language of the EU.

3.13 Ratified text
Ratified text (agreed final text for publication) is always in English and if differences are discovered the correct wording can be ascertained from the ratified text Difference between the English, French and German version are not unusual to find.

3.14 First public enquiry
Once a draft document has been completed to the satisfaction of the WG and CEN consultant, it's circulated to TC10 members to see if they would agree with it and if accepted by TC10 it's sent to public enquiry at the level of National committees such at MHE4.

3.15 Length of enquiry
The length of the enquiry is typically 3 or 6 months with comments from National committees being made on a CEN comments template. National committees will be asked to indicate if they would support such a standard or not. If not they must explain the technical reason why not. A typical reply from a National committee could be, Yes, we would support such a standard subject to our official comments being addressed or No, we would not support this as its in directly conflict with National legislation and in our view could create a barrier to free trade etc. Comments are returned to the WG that performed the work and like BSI the comments must be addressed by the committee with a written explanation of why any particular comment is accepted or rejected.

316 Formal vote stage
The revised document is usually again returned to TC10 to ask if they are satisfied and agree to the document being sent for formal vote. If TC10 agree the document is sent out for formal vote again to National committees who can only vote No on technical grounds. The voting is weighted for each member state with Germany, France, Italy and UK holding the largest vote. Voting rules vary depending on document type and what is described here assumes an EN standards is being produced not a Technical Specification (TS where a vote is not essential.

4.0 ISO STANDARDS

4.1 ISO 178 structure
Once again the structure of ISO is not greatly different than CEN or BSI.

The main committee for lifts and Escalators being ISO178. This large committee has representative from many countries in the world such as China, Japan, Australia, France, German, Korea, Norway, Sweden, Russia, Denmark, Italy etc. Those attending represent mainly large manufacturers and lift examination bodies with occasional visits from government representatives.

4.2 Selection of delegates and funding

Delegates attend in their own right as experts in their field and normally carry the cost with the help of their company. They may receive some limited funding from their National committee who will also have a say in who attends. The costs involved for travel and accommodation can be considerable with no or a small donation from BSI so it's usually only large companies that can afford to participate.
ISO TC178 has a number of Work Groups , see Table 2.

Table 2. ISO 178 Work Groups

Subcommittee/Working Group	Title
TC 178/WG 2	Guide rails The convener can be reached through the secretariat
TC 178/WG 4	Safety requirements and risk assessment The convener can be reached through the secretariat
TC 178/WG 5	Escalators and passenger conveyors -- Safety standards comparison The convener can be reached through the secretariat
TC 178/WG 6	Lift installation fire related issues The convener can be reached through the secretariat
TC 178/WG 8	Electrical requirements The convener can be reached through the secretariat
TC 178/WG 9	Measurement of lift quality The convener can be reached through the secretariat
TC 178/WG 10	Energy efficiency The convener can be reached through the secretariat

4.3 Subject addressed by ISO/TC178

The ISO/TC178 documents published and maintained are mainly to do with Electromagnetic Compatibility, Energy Efficiency, Lift sizes load and speed, Global essential safety requirements for lift, provisions for accessible lift for disabled persons, requirements for disabled evacuation using lifts, fire testing for lift doors, Escalators and moving walks

4.4 Avoiding duplications of work

Whenever possible so as to avoid duplication of work, documents are drafted with the hope or sometimes agreement they will eventually be published as a European standard and not just an ISO standard. This requires considerable effort by participant and a considerable amount of compromise to make one document fit everyone's wishes and fit ISO and CEN rules.

4.5 Source of work
Work is normally generated by members (manufacturers) who see a need for some standardization. Proposed work is studied to try and ensure it is worthwhile and is likely to be supported by members. If ISO/TC178 agree to start new work they again select a convener from ISO/TC178 with the individual's prior agreements and then send out a call for delegates. Often the work will fit into other work underway in which case. it will be passed to the convener currently managing similar work.

4.6 Frequency of meetings
Work is performed by work groups and meetings usually take place twice each year with some intermediate video conferences to move things on.

Draft documents are produced in an ISO template that establishes the format of the document. AFNOR may provide a secretary to support work groups or a National standards maker may agree to provide the secretariat.

4.7 Controlling work progress
Rules will automatically set the time table for the work and meetings will be held anywhere in the world that the working group members agree to.

ISO/TC 178 will set the scope of work for the working group who will report progress to them through the secretariat. Once a draft document is completed it will be put to the ISO/TC 178 committee, to gain their agreement. If they agree the document is published in an ISO format for the document in question.

4.8 ISO document types

4.8.1 Internationally agreed standard.

4.8.2 Technical Specification (TS) often used where a draft standard has failed to gain enough support to allow it to be ratified.

4.8.3 Technical Report (TR) document containing informative material but not suitable as standard.

4.8.4 DIS a Draft International Standard during its comment stage.

4.8.5 FDIS Final document resulting from a DIS with comment included and distributed for final voting.

4.8.6 Technical Corrigenda document used to correct errors in a standard.

Appendix A
Example of ISO25743 development

A.1 After the disaster of 9/11 there was much debate across the globe regarding how such buildings should be designed and the role the lift could play, if any during an evacuation. Some people in the twin towers had escaped using lifts whilst other had died, trapped in lifts.

A.2 At the time, I was convener of ISO/TCWG6 a working group with responsibilities for lift fire related issues, see Table 2 and flow chart below Reading various publications, some by lift specialist and others by fire experts, it became clear to me that no one was really thinking through all the issues that the use of lifts would bring.

A.3 We discussed the idea of making a study into the use of lifts with my ISO working group, after lots of debate it was finally decided that as we would know more about lift capabilities than anyone else. We should study what lifts could contribute, if anything. We decided to suggest to ISO/TC178 that this was some work we should undertake that would be of use to many in year to come. After more debate with ISO/TC178 they finally agreed that we could and should at least make the study.

A.4 WG6 proposed a scope of work and with some modification the following was agree by ISO178 *Produce a Technical Report investigating and highlighting the main risks associated with using lifts for the evacuation of persons in various types of Emergencies in high rise building*

A.5. As the committee WG6 already existed we did not need to establish the convener and members, we commenced with the work. ISO set the time frame and work began. This posed a new problem, where to start?

A.6 We decided again after considerable debate that we should chart everything that could go on in a major building emergency. This resulted in a chart that identified where issues of some kind existed. Some of the issues were clearly lift issues whilst many of them related to how the building was designed and beyond the control of lift designers. As an example, if lifts were to be used in a fire we could make the lift do anything when a fire signal was sent to it. Nevertheless we don't design or provide the fire detection system for the building or determine where fire detectors will be, other do this tasks.

A.7 We decided that the report should point out the issue others must consider and give proposals with regards to what the lift could do if some provision was made by others.

A.8 The significance of some risks we identified was argued, with some WG6 members thinking they were serious risks whilst others considered them minor. We used the ISO14798 risk assessment methodology to settle many of these arguments, a great tool for this purpose.

A.9 As work progressed, we identified failings in our original scope and returned to ISO/TC178 to request change to the scope see flow chart 1 below, this happening more than once.

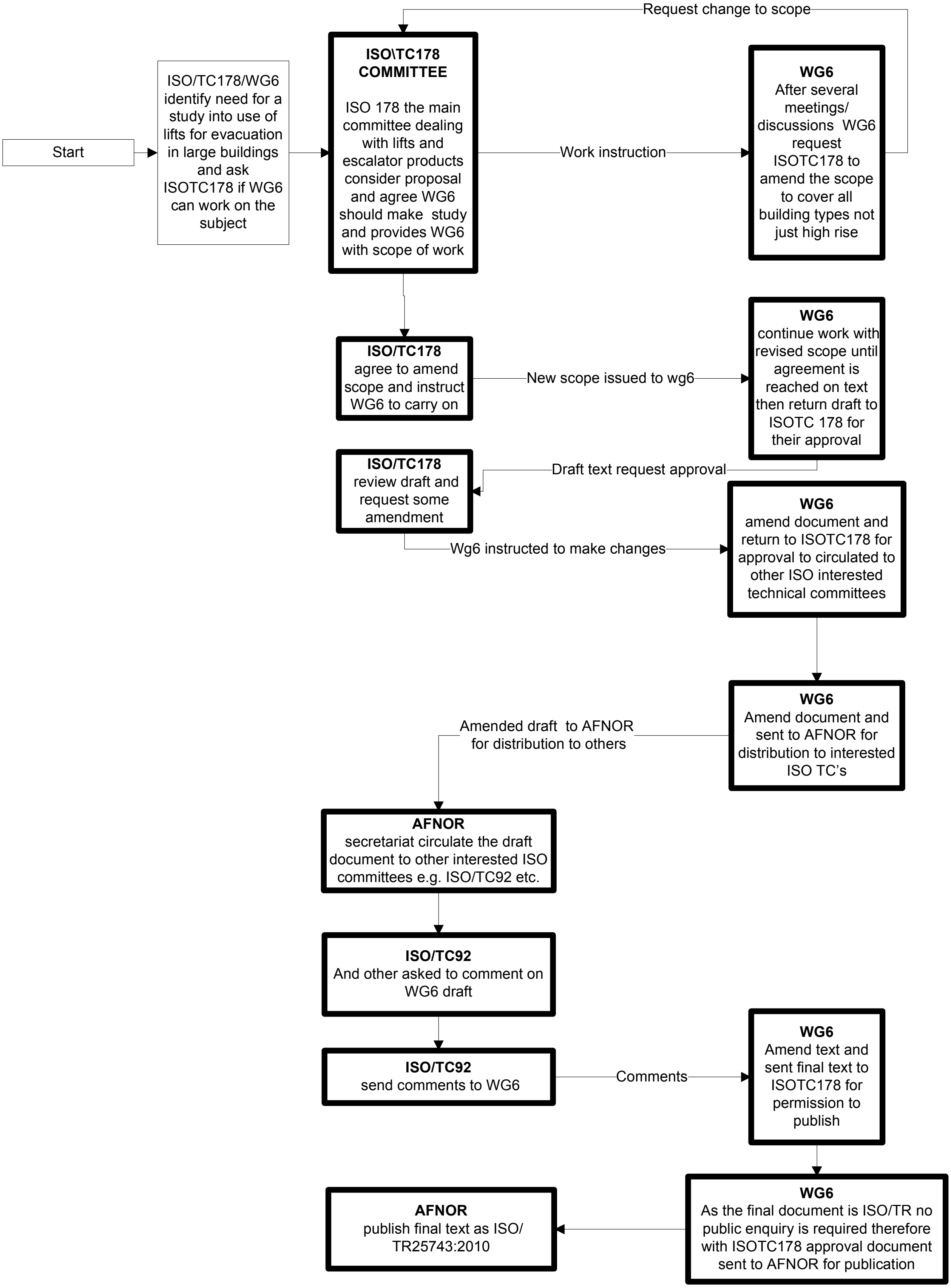
After much work and many meetings in places such as USA, Australia, Canada, France, UK etc, we had a draft document. The chart had gone through much iteration and identified over 40 issues resulting in 26 drafts of the TR.

A.10 The document was sent to ISO/TC178 who made a few comments and WG6 made corresponding amendments. With the amendments made the document was sent to other ISO/TCs who would have an interest. Again a few comments came back and amendments made before the document was sent out for official comment. 50 plus comments came back and these were addressed in following meetings before the document was finally agreed for publication as a Technical Report by ISO/TC178. Being a TR a final public vote was not required. It was finally published in 2010 having started in 2002.
So what has been done after all this, Is the report used?

A.11 Yes, USA has been using it in studies undertaken for high buildings and in addition other countries with similar building issues have been interested in the work.

WG6 is using it to try and develop a standard for lifts that could be used during a fire if the right building design provisions are made, so we wait to see what happens next.

Flow chart 1. Production of ISO/TR25743



2nd Symposium on Lift and Escalator Technologies

Traffic Analysis based on the Up Peak Round Trip Time method Why it works and how it can be improved

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INTRODUCTION

The Up Peak Round Trip Time (UPRTT) method is based upon a traffic pattern presented by Strakosch in the 1960's. This traffic pattern and the whole concept of how of how people use lifts has been called "a figment of the imagination" by Barney [1]. Barney goes on to state that "Countless buildings have been designed to its 'illusion' and the designs work".

The science behind the UPRTT method is examined and explained. The correctness of using a traffic estimate that does not initially appear to reflect reality is explored.

Elevatoring solutions for proposed buildings were developed using the UPRTT method. The same proposed buildings were also evaluated using simulation and applying modern estimates of traffic and the application of new technologies.

The solutions developed using the UPRTT method were shown to provide good traffic handling. The different solutions that were developed using simulation were found to provide equal or better traffic handling while being lower in cost and more sustainable.

BACKGROUND

The Up Peak Round Trip Time calculation is a method of determining the performance of a lift system during the morning up peak. The proper number of lifts, their capacity and their speed can determined using multiple iterations of this calculation to achieve the desired quantity and quality of service for a proposed building.

Barney states that Up-peak traffic sizing defines the underlying capability of a lift installation [1].

Since Up-peak sizing is believed to be an important way of determining the underlying capacity of a lift installation it is important to understand this process

Up-peak sizing is based upon calculating the round trip time of a lift during the Up-peak period and then using that round trip time to calculate Interval and Handling Capacity. This concept was first postulated by Basset Jones in 1923 and was later refined by Schroeder in 1980 to include a statistical determination of the probable high call reversal floor [1].

The Up-peak Round Trip can be simply described. A lift appears in the lobby and passengers fill the lift to capacity. The lift then deposits the passengers at multiple upper floors. When the lift is empty it returns to the lobby to pick up additional passengers. It should be noted that during this round trip there is neither inter-floor nor downward traffic.

An Up-peak traffic analysis requires the following:

1. A definition of the building's characteristics. This would include the building type (office, apartment, school, hospital, etc), class of building (Class A, Class B, luxury, government housing), tenant type (single, multiple), occupancy (area per person, area per floor), location (downtown, suburban, developing nation, developed nation), cultural expectations of users, floor to floor heights, and the relative desirability of floors [2].
2. Lift characteristics. These characteristics include the number of lifts, capacity, speed, door type, and door speed.
3. Traffic demand level or arrival rate.

Based upon the car size and the number of floors above the ground floor the number of probable stops that the car will make is calculated using the following equation [3]:

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

Where: S represents Probable Stops

N is the Number of floors above the main floor

p is the number of Passengers per trip

The highest floor that will be reached on a typical trip is a function of the number of floors in a building and the passengers per trip. The high call reversal floor is calculated as follows [1]:

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

Where: H is the High call reversal floor

N represents the Number of floors above the main floor

p represents the number of Passengers per trip

Using the calculated number of probable stops and the high call reversal floor, it is possible to calculate the time spent running at full speed, the time spent accelerating and decelerating, and the time spent making each of the probable stops. The sum of all these times is the round trip time.

Using the Round Trip Time (RTT) the Interval (INT) is calculated by dividing the RTT by the number of lifts in a group of lifts. For example, if the RTT for one car in a group of three cars is 90 seconds, then the Interval is 30 seconds. In theory, a lift should arrive at the lobby every 30 seconds if the lifts are perfectly spaced and the actual RTT is equal to the average RTT. The following is the equation for Interval [1]:

$$I = \frac{RTT}{NC} \tag{3}$$

Where: I is Interval

RTT represents Round Trip Time

NC is the Number of Cars

The average Waiting Time will be one half the average Interval. If the arrival of passengers was equally spaced in time, then the first passenger would arrive just as the lift doors closed and would wait for a length of time equal to the Interval. Likewise, the last passenger to arrive in the lobby would enter the lift just as the lift doors started to close and would have no waiting time. The simplified equation for Waiting Time (WT) is [3]:

$$WT = \frac{I}{2} \tag{4}$$

Where: WT represents Waiting Time

I represents Interval

Waiting time would be equal to the Interval divided by two if a passenger could enter the first lift that appears in the lobby. However, this is not always possible during the morning Up-peak. For this reason, Waiting Time is assumed to be about 60% of Interval [3].

As previously stated, an Up-peak traffic analysis requires the following:

1. A definition of the building's characteristics
2. Lift characteristics.
3. Traffic demand level or arrival rate.

The first two requirements involve known data, while the third requirement is an estimation. The Up Peak Round Trip Time method is a prediction of lift system performance based on prediction of traffic demand.

The traffic demand level is assumed to be 12% of the building's population in multi-tenant buildings and 18% of the building's population in single tenant buildings [3]. The origin of these values is from the traffic pattern shown in Figure 1. This traffic pattern is known as the Strakosch Traffic pattern. The demand level during the morning UP-peak can be seen to be 12%.

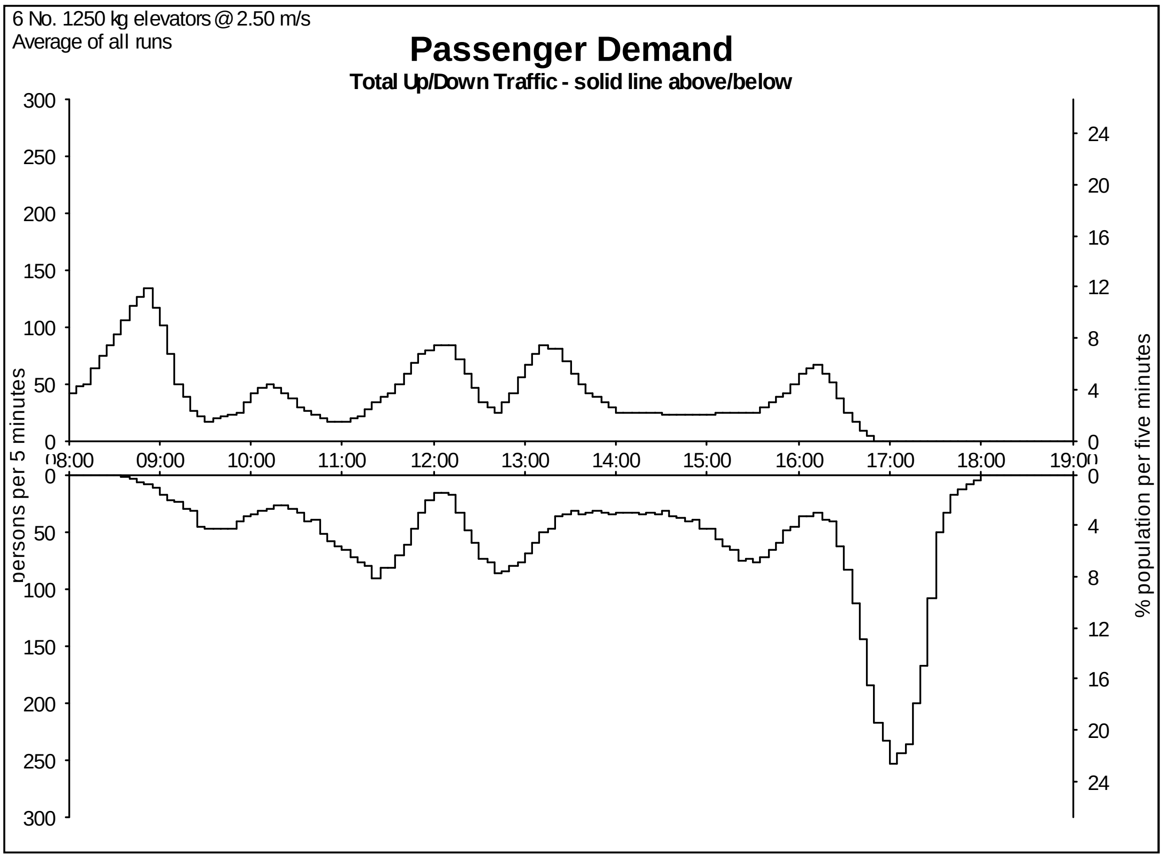

Figure 1

This traffic pattern and the whole concept of how of how people use lifts has been called "a figment of the imagination" by Barney. Barney goes on to state that "Countless buildings have been designed to its 'illusion' and the designs work" [1].

ANALYSIS EXAMPLE

To better understand the UPRTT method and to compare and contrast the results between simulation and the UPRTT method a hypothetical building is evaluated.

Hypothetical building:

Floors: 18 (Lobby +17)

Travel 66.8 meters

People per floor: 62

Proposed Lift System:

Cars: 6

Capacity: 1600 Kg.

Speed: 2.5 m/s

The UPRTT system performance was evaluated using a computer program. The results are as follows:

5 minute handling capacity: 12.6%

Interval: 31.2 seconds

Using the Enhanced UP Peak calculation with 12% demand gave the following results:

Interval 29.7 seconds

Based upon this result one would assume that the proposed lift system would be capable of handling 12.0% of the building' population during Up Peak conditions. However, when a simulation was run using a dispatching algorithm employed by an early microprocessor based control system with an arrival rate of 12%, the system saturated as can be seen in Figure 2. This dispatching algorithm most likely performed at a level similar to a good relay based system.

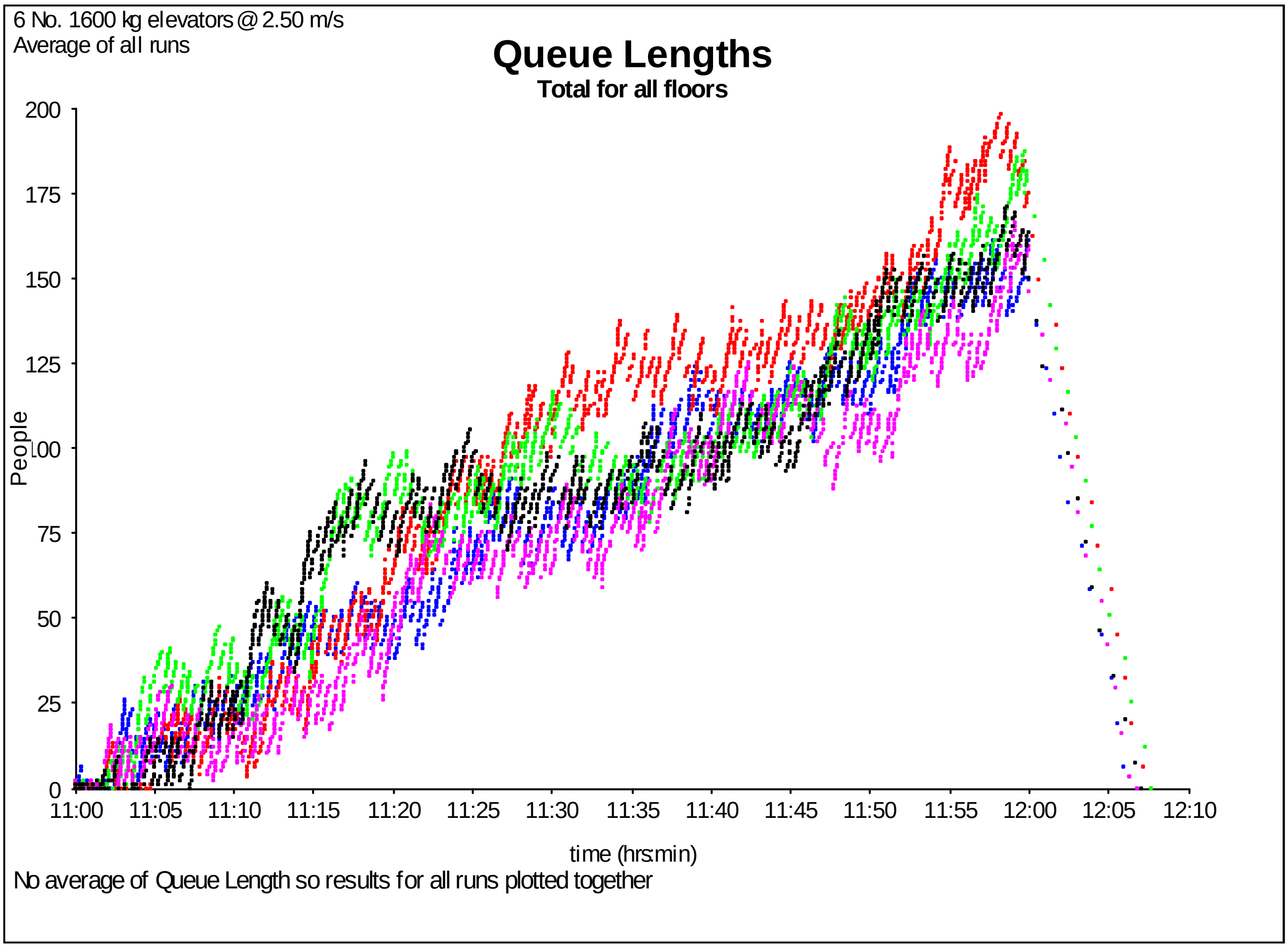

Figure 2

Figure 3 shows the results of a simulation of the up peak performance of the same lift system in the hypothetical building at a 10% demand level.

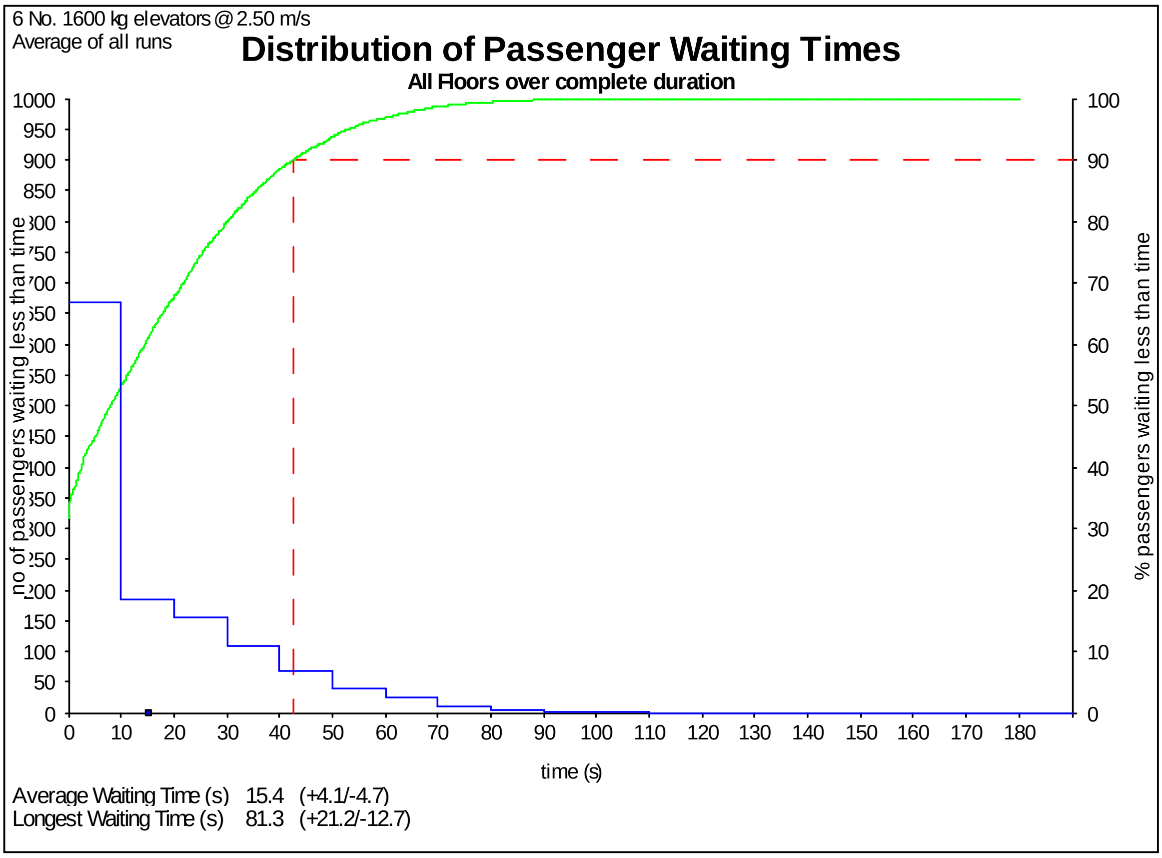

Figure 3

The UPRTT method predicted that the proposed system could handle 12% of the building system. The proposed system saturated at the 12% level but could handle a 10% demand level. As long as the real traffic level was 10% or less, the proposed system would deliver acceptable performance. One must conclude that actual traffic levels in real buildings were less than 12% because as Barney stated, "the designs worked" [1].

The difference between the demand level used in calculations and the real traffic levels can be viewed as a Safety Factor.

SAFETY FACTORS

Safety factors are commonly used in the design of almost any device where the consequences of failure of the device will result in substantial financial loss, serious injury or death [4]. An under lifted building can result in significant financial loss because it cannot command the same rents as a properly lifted building. There is, however, little risk of injury or death as a result of a poorly lifted building.

Safety factors in industrial design are selected based upon the risks involved, the variability of the component, wear estimates, and the accuracy of predictions used in the design. Wire ropes for lifts require a minimum safety factor of 12 [5]. However, some aircraft components have a safety factor of 1.2 [4].

Lower safety factors are possible if there is low product variability due to quality control processes such as Six Sigma. Improved calculation methods such as Finite Element Method make predictions of structural performance more accurate and therefore lower safety factors are possible [4].

The UPRRT method is based on the traffic pattern shown in Figure 1. The UPRTT method is a calculation tool. The designs developed by this tool work because the designs are based on a safety factor created by the 5 minute handling capacity selected. A design with a 5 minute handling capacity of 12% has a safety factor because the true traffic that the lift system will encounter will be less demanding than 12% of the building population, all traveling upward.

Better calculation methods permit the use of lower safety factors. Simulation has been shown to have a very high correlation between its predictions and actual system performance [6]. Simulation methods have the ability to better predict lift system performance.

The UPRTT method has been shown to require more lifts that would be required if simulation were used to calculate the required number of lifts for proposed building [7].

As an example of this, the hypothetical building that required 6 lifts based upon the UPRTT method was evaluated based upon applying 5 high performance lifts using simulation and the modern estimates of traffic presented by Peters in CIBSE Guide D [8]. Figures4 – 7 record the performance of the 5 lifts during the modern Up-peak and the modern Lunch.

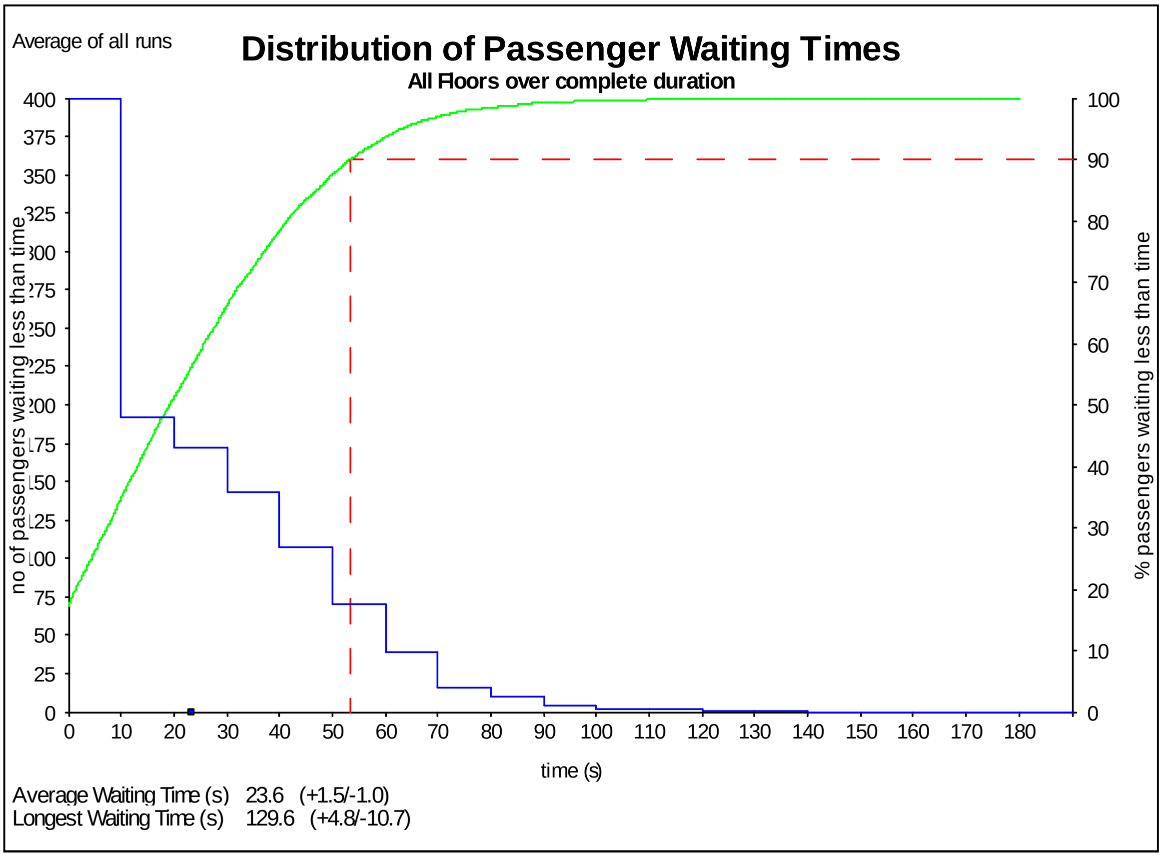

Figure 4. Up-peak Waiting Time

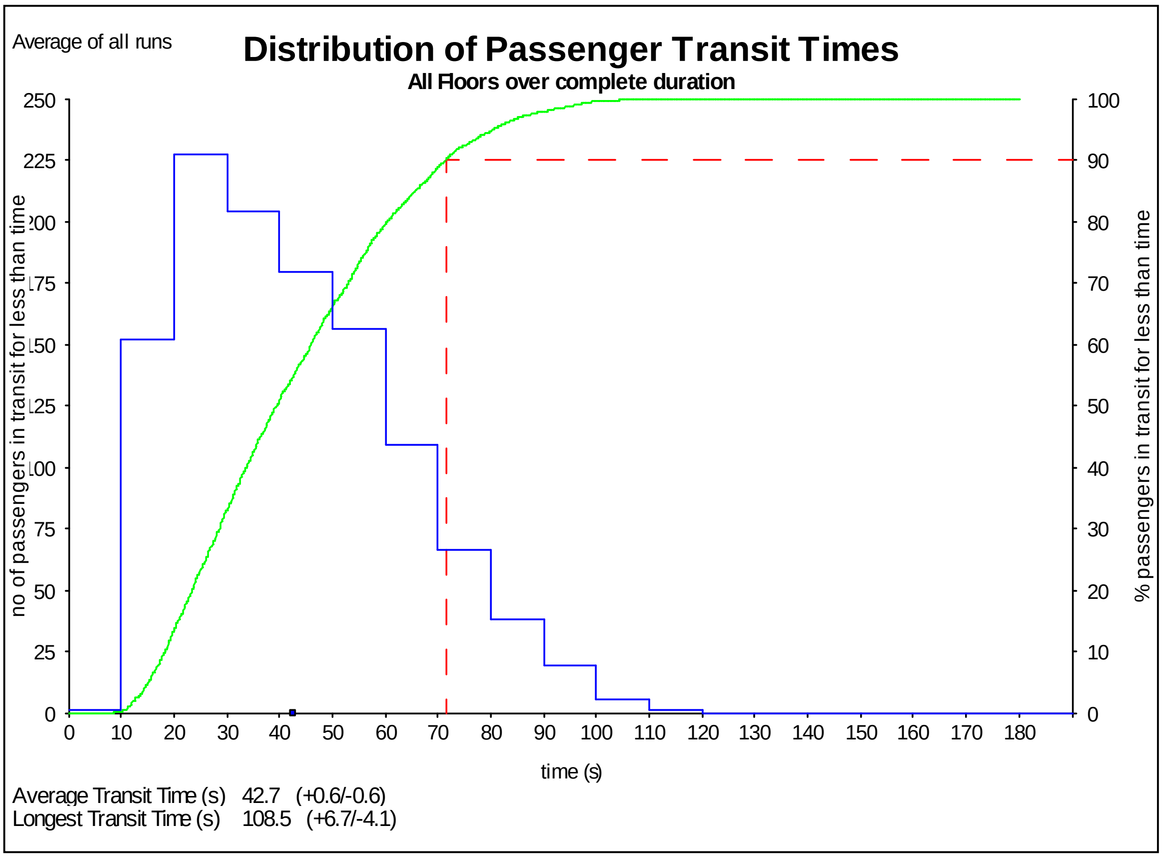

Figure 5. Up-peak Transit Times

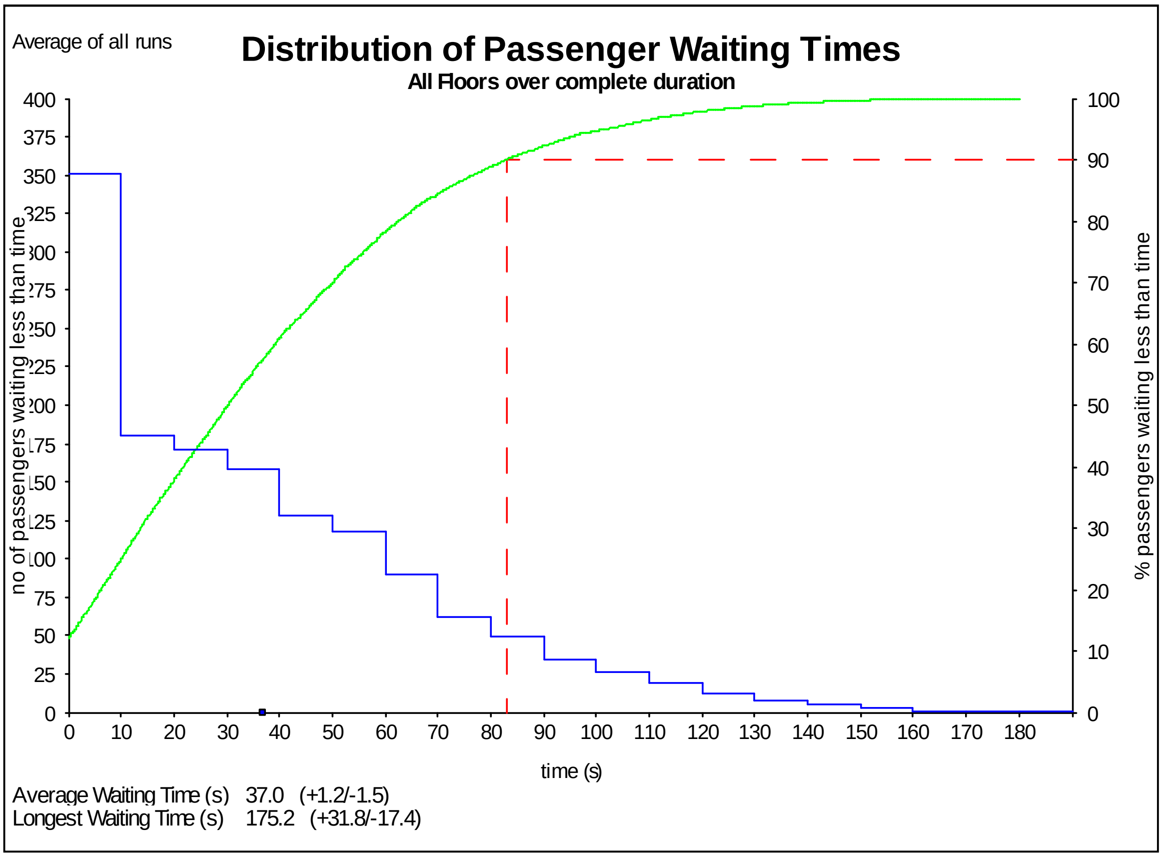

Figure 6. Lunch Waiting Time

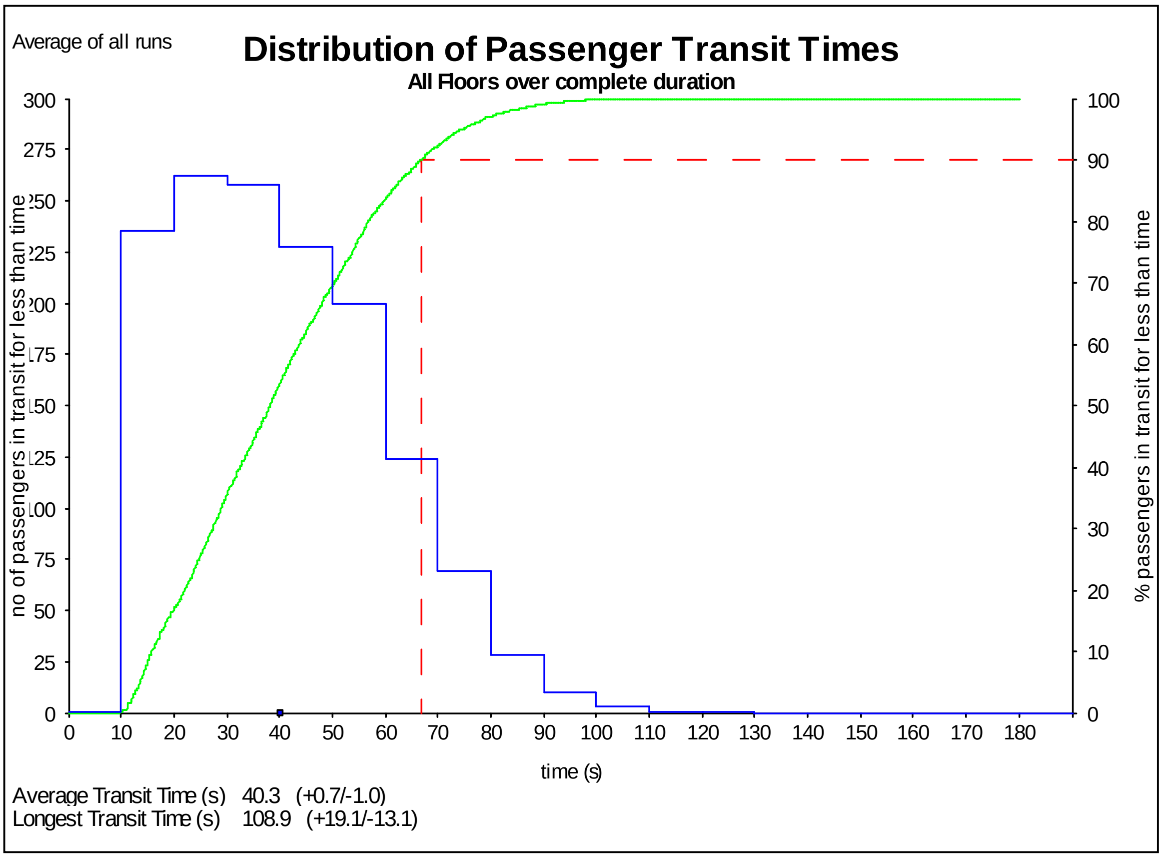

Figure 7. Lunch Transit Times

The waiting times for the 5 car high performance group are between a 4 star and a 5 star building according to the Quality of Service criteria in the 2010 edition of CIBSE Guide D [8].

The transit times for the 5 car high performance group are between a 6 star and 7 star building.

The performance of this group most likely is that of a 5 star building. A prestige building is described as a 5 star building in CIBSE Guide D [8].

FINDINGS AND CONCLUSIONS

The Up Peak Round Trip Time (UPRTT) calculation method uses the parameters of a proposed building and a proposed lift system along with an estimate of anticipated traffic. The anticipated traffic levels used constitute a safety factor. The true traffic level in a building is normally less than that which is proposed in the UPRTT method.

The inclusion of a Safety Factor explains why the UPRTT method works.

Simulation provides a more accurate calculation method than the UPRTT method. The more accurate calculation provided by simulation combined with a more accurate understanding of how people use lifts and more accurate descriptions of traffic patterns permit lift designs to be a better predictor of system performance. The better estimates of performance will lead to designs with fewer lifts.

A building with fewer lifts is more economical and more sustainable.

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2nd Symposium on Lift and Escalator Technologies

Toward a more Efficient Elevator System
An Extended Summary

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International Association of Elevator Engineers

It is appropriate to describe an efficient elevator system in two aspects, namely energy performance and traffic performance. The presenter developed two benchmarking parameters (So et al 2005) to measure the performance or efficiency of an elevator system, the first one on energy performance, i.e. J/kg/m, and the second on traffic performance.

Energy concern has been drawing great attention around the whole world due to the recent climate changes while issues like sustainability and carbon footprint call upon energy savings by all building systems. There are regulations in Europe such as VDI 4707 and in Hong Kong such as Cap 610 Building Energy Efficiency Ordinance that impose conditions on energy consumption of lift systems. However, they all focus on energy efficiency of individual motor drives without any referral to the overall lift system whose performance much more relies on the supervisory traffic control system rather than individual drives. With a view to it, a benchmarking parameter was developed, J/kg/m, (Lam et al 2006) that can evaluate energy performance from a holistic and systematic point of view. A system can then be appreciated by having an intelligent traffic control. Besides energy, traffic performance is the second, but equally important, factor to evaluate a lift system. The quantitative parameter to evaluate it is "Average Journey Time" which is the sum of "Average Travel Time" and "Average Waiting Time", which was further enhanced by the presenter (So et al 2002a, So et al 2002b).

Various technologies were developed by the presenter to improve traffic performance. It is believed that if the supervisory controller can clearly identify the number of passengers waiting for lift service at each landing lobby, dispatching of cars to serve calls could certainly be much more effective. A computer vision based system to count the number of passengers at lobbies and inside cars was developed (So et al 1992). Of course, if the destination of all these passengers are known, traffic control could become perfect. That has been successfully implemented with the use of "destination based control" for almost two decades by some manufacturers. Even without passenger counting, the supervisory control could be improved by at least knowing the type of traffic pattern at a particular instant, such as up-peak, down-peak, two-way or single VIP floor etc. A neural network based system was developed by the presenter to deal with that so that past traffic patterns could be intelligently recorded and compared with current patterns on a real time basis to enhance control (So et al 1995). Having known the traffic patterns, intelligent supervisory control is the obvious solution. Zoning, usually static, has been a traditional method to improve traffic by reducing the round trip time of journeys. The mathematics of dynamic zoning was developed by the presenter, which could be implemented on a high speed computer (Chan et al 1995, So et al 1997, So et al 2001). Dynamic zoning makes control more efficient and flexible. With all intelligent control algorithms, increasing the speed of elevators may be the final way to immediately improve handling capacity by shortening the round trip time. Computational fluid dynamics was employed by the presenter to study the mechanical performance of ultra high speed lifts up to a speed of 25 m/s which still does not exist in the world till now (Yang et al, 1998, Shen et al 2004, Bai et al 2005).

Various technologies were also developed by the presenter to improve the energy performance of lift systems. A series of graphs and the method to obtain the graphs to describe the overall performance of a lift car and its drive were developed, including the voltage, current, power quality, vibration, speed, energy consumption and displacement etc. The system is called "Elevgraphy" and the article published in *Building Services Research and Technology* of CIBSE (So et al 2000) made him awarded the Carter Bronze Medal in 2003. To facilitate the implementation of energy conservation measures on lift and escalator systems, the presenter has been a member of Task Force of the Hong Kong Government since 1997 to compile the Code of Practice for and Guidelines on Energy Efficiency of Lift and Escalator Installations (1998 version, 2003 version and 2007 version). He was also the Chairman of the sub-committee to compile the part on Lifts and Escalators inside the Code of Practice for Energy Efficiency of Building Services Installation which will become mandatory from September, 2012 onwards (EMSD 2012). To facilitate the monitoring of lift and escalator systems, in particular their energy performance, the presenter carried out a one-year long consultancy project for the Architectural Services Department of HKSAR Government in 2007 to develop three sets of common protocols for effective communication between the elevator systems and building management systems, which are LonWorks, BACnet and XML based. Later, based on the outcomes of the project, the presenter helped ASHRAE Standing Standard Project Committee 135 to develop a set of objects on BACnet specifically for lifts and escalators (So et al 2011a, So 2011b, 2011c). Last but not least, the presenter developed an intelligent counterweight adjustment system based on continuous lift traffic monitoring, analysis and simulation to arrive at the optimal counterweight setting of a particular lift car to achieve minimum energy consumption (So et al 2012) over a period of time with the help of his parameter, J/kg/m.

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