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What is This?

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The effect of the building population and the number of floors on the vertical transportation design of low and medium rise buildings

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The design of vertical transportation systems for buildings involves the selection of the number, speed and capacity of the lifts required. It also involves the selection of the most appropriate configuration in terms of zoning, group control algorithm and the use or otherwise of double deckers.

Interval is the classical performance criterion for vertical transportation design, while modern passenger centric performance criteria are now based on passenger waiting time and travelling time. Both types of performance parameters are used in this work.

This work identifies the two most influential demand factors that affect the design output for vertical transportation systems in low and medium rise buildings. These are the total building population and the number of floors served above the main terminal. These are then used to develop general guidelines to find the most optimum configuration for every pair of such parameters. This is then transformed into the form of a 2D chart that can visually aid the designer into using the best configuration for a building.

Practical applications: The importance of this article arises from the fact that it justifies the widely held view that single deck lifts in one group are limited to 20 floors and that the direct travel from ground approach is limited to around 60 floors (after which sky lobbies are needed). It shows that the two most important parameters that affect the design of a vertical transportation system are the total building population and the number of floors above the lobby.

The two dimensional chart included within the article as Figure 3 allows the system designer to immediately assess the most suitable vertical transportation zoning arrangement for the building, the preferred number of zones and the preference for using single decker or double decker lifts.

1 Introduction

Traditionally, the design of a vertical transportation system for a certain building is based on the knowledge of the following parameters:

(1) Building population.
(2) Passenger arrival patterns.
(3) Building usage (office, residential, hospital . . .).
(4) Number of floors.
(5) Car park usage.

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(6) Location of special floors (meeting floors, restaurants . . .).

The vertical transportation design of a building involves the selection of the number, speed and capacity of the lifts to be used. Preferred values for the speed and capacity are specified in ISO4190-1. The term 'lift' (UK) rather than 'elevator' (US) will be used throughout this article.

For simple buildings with a limited number of floors, these lifts are usually arranged in one group of lifts. A group controller allocates the landing calls to each of the lifts operating in the same group.

As the building complexity increases, the single group configuration becomes inadequate. It is then necessary to consider more sophisticated configurations such as two groups of lifts or even three groups of lifts, whereby each group is dedicated to a certain number of floors. The terms *zone*, *sub-zone* or *sector* have been used interchangeably to refer to a group of contiguous floors that are served by the same group of lifts. This can either be a permanent grouping or could be activated for certain times during the peak. In this article the term *zone* will used throughout to refer to such a group of contiguous floors that are served by one group of lifts.

Further enhancements involve the use of double decker lifts (in place of the conventional single decker lifts) or enhancement of the methodology used to allocate the landing calls to the various lifts in the group.

Thus the design of the vertical transportation system comprises four distinct activities:

(1) Identifying the number, speed and capacity of the lifts within a specific group.
(2) Identifying the number of group of lifts and their arrangement within the building. For each group, the floors which will be served by each group of lifts are also identified (referred to as a zone). If the zoning arrangement is not permanent, the operating times for such an arrangement also need to be identified.
(3) Identifying the group control algorithm that will allocate the landing calls to each of the lifts in a certain group (e.g. conventional group control).
(4) Identifying the need for double decker lifts where appropriate [1,2].

This piece of work is restricted to office buildings based on the morning up-peak. It first identifies the most salient demand parameters of a building and uses these parameters to guide the selection process. The term *lobby* is used to refer to the floor from which all the incoming traffic originates. Another term that is commonly used is the *main terminal*.

The scope of this work has also been restricted to low rise and medium rise buildings (up to 60 floors). Buildings with more than 60 floors require a completely different approach (e.g. sky lobbies) and are beyond the scope of this work [3].

2 Performance assessment

Any design process requires a performance assessment criterion or a pass/fail criterion. Such a criterion can be used to decide whether the selected design is adequate or not.

The classical performance criterion used in the design of vertical transportation systems is the interval. Interval is used as the measure of quality of service and is defined as the time between consecutive arrivals of the lifts in the lobby during the morning up-peak.

The demand placed on the lift system must also be defined. This effectively represents the quantity of service and is represented by the passenger arrival rate that the lift system can handle in the busiest 5 min of the day (also referred to as the 5-min handling capacity).

The lift system can be thought of as a passenger processing facility, the input of

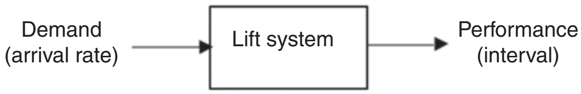

Figure 1 Demand and performance model of a lift system

which is demand and the output of which is interval, as shown in Figure 1 below.

Being a lift-centric rather than a passenger-centric performance assessment parameter, the interval has a number of serious limitations as a performance measure:

(1) It does not account for the waiting time that passengers spend in the lobby waiting for the lift.
(2) If passengers are being left behind in the lobby and are forced to queue, the interval will not account for this fact.
(3) The interval does not reflect the time that passengers spend travelling in the lift car.

In recognition of the limitation of the interval as a measure of performance of a vertical transportation system in meeting the demand of a certain building, passenger-centric measures are being proposed and used [4,5]. The most widely used and accepted passenger-centric *de facto* standard is the passenger average waiting time, passenger transit time and passenger time to destination. These are defined as follows:

(1) Passenger average waiting time is the average time that all passengers spend waiting in the lobby.
(2) Passenger average transit time is average time that passengers spent travelling in the lifts.
(3) Passenger average time to destination is the average time that passengers spend waiting and travelling the lift; in other words it is the sum of the previous two parameters.

The work in this article uses both the classical and the modern performance assessment parameters to arrive at feasible lift configurations for the various buildings that are analysed.

There are a number of rules of thumb that are widely used within the industry [6]. For example, it is recognized that a single group of lifts can only serve upto around 16–18 floors, and a group of double decker lifts can only serve 20 floors in one group [1]. One of the aims of this piece of work is to build a solid basis for this selection process.

3 Calculation and simulation

Most of the traffic analysis work currently carried out in designing vertical transportation systems is based on two broad categories: Calculation or simulation.

Calculation has been traditionally used to arrive at the value of the classical performance parameter: the interval. A mathematical model has been built that describes the behaviour of the lift system. A mathematical model is a set of equations and relationships, which describes (to some level of detail), the behaviour of the system. This is usually based on certain simplifications and assumptions.

Most of the existing methods are based upon a mathematical model of the lift system, which has been developed by many researchers, the earliest of which was the derivation of the mean value of the number of stops (S) in one lift journey [7]. The model was completed by other researchers, by deriving the mean value highest reversal floor (H) [8–12]. The arrival rate of passengers was identified as a Poisson process, rather than a uniform density function [12]. A good review of such a model with analysis of some special cases is given in [13].

An analysis of the down peak case (outgoing traffic) is given in [14]. More refinement on this model has been introduced in order to obtain more accuracy in calculations [15] where a third parameter is introduced, called the lowest call express (LCE). The differing probabilities of one floor jump and two floor jumps, where the speed is not achieved in one floor jump is considered in [16] and the model adjusted accordingly.

Unfortunately, these models do not take into consideration the control algorithm, and assume a collective control scheme. Adjustment of the formulae for different control algorithms under up peak situation is carried out in [17], whereby their performance is analytically based on the performance index for conventional methods.

Simulation is the modern method of arriving at the passenger-centric performance parameters such as waiting time, transit time and total time to destination [18,19], although some work has been done to use calculation to arrive at the travelling time [20].

Both calculation and simulation tools have been used in this piece of work to identify the classical and modern performance parameters for each suggested configuration.

4 Modelling demand parameters

The vertical transportation traffic design has been traditionally based on the morning-peak-5-min period. During these 5 min a certain percentage of the building population is assumed to arrive in the main lobby(ies) requiring transport to one of the upper floors.

During these 5 min a number of passengers require to be transported to the upper floors. This becomes more onerous as the number of passengers arriving in 5 min increases or as the number of floors above the lobby increase. Thus it is posited that the two most important parameters that affect the design of the vertical transportation system are:

(1) The number of passengers arriving in the lobby in the peak 5 min.
(2) The number of floors above the lobby (assuming they are all populated with equal populations).

Two previous pieces of work were developed in order to be used as simple-rule-of-thumb methods in [21] and [22]. However, they did not address the issue of zoning and were only intended for low rise buildings.

It is worth noting that the number of passengers arriving in the lobby in the peak 5 min is the product of the total building population and the arrival rate. The arrival rate is the percentage of the building population arriving in 5 min and is also referred to as the handling capacity. If a constant arrival rate is assumed for the design, then the two most critical parameters become:

(1) The total building population (assuming a constant arrival rate of say 12% or 15% of the building population in the busiest 5 min).
(2) The number of floors above the lobby.

In effect this states that where two buildings have the same total populations but a different number of floors above the lobby, then the demand of the higher rise building will be more onerous. Moreover, where two buildings have the same number of floors above the lobby, but different total populations, then the demand of the higher population building will be more onerous.

Obviously, other parameters will have an effect, but are less important. For example, the floor-to-floor height in an office building will generally be in the order of 4 m and will not deviate dramatically from that figure for a real life building (3.6–4.2 m). In a similar manner, passenger transfer times will always be in the range of 1.2 s per passenger, and will not deviate dramatically from this figure. Passenger transfer time is the time taken by one passenger to board (or alight) from the lift.

The analysis in this article will be limited to the following for simplicity and brevity:

(1) Office buildings. The work described here will be restricted to office buildings. The two most widely used arrival rates have been applied, namely 15% and 12% (percentage of the building population arriving in the lobby in the busiest

5 min of 12% or 15% of the total building population will be assumed).

(2) Up peak traffic pattern (incoming traffic): The traffic design will be based on an up-peak traffic pattern (incoming traffic into the building from the lobby).

(3) A limit has been placed on the number of floors above the lobby of around 50 floors. Above 50 floors the classical design of travelling 'direct-from-ground' ceases to be feasible due to the increase in core space used for lifts, and sky lobbies have to be introduced. This is beyond the scope of this work.

(4) A maximum number of lifts in one group has been set to 10 lifts. This assumes that certain measures are taken that will ensure that passengers have sufficient time to approach the next lift arrival (use of early lift arrival announcement systems or destination group control).

5 Analysis methodology

In order to analyse this problem and find the effect of the total building population and the number of floors above ground, the following approach has been followed:

(1) Set a performance parameter for the vertical transportation system.

(2) Take each combination of total building population and number of floors above lobby. There are 10 cases of total building population and 4 cases of floors above lobby leading to 40 combinations. However, six combinations are disallowed due to the low resultant per floor population, resulting in 34 effective practical combinations.

(3) Design a suitable lift configuration that will achieve the performance parameters set in 1 above for the combination selected in 2 above.

(4) Repeat the design procedure in 3 above until designs have been found for all the 34 combinations.

(5) The results are then plotted on a chart to show the most suitable configuration for each combination.

This process has been documented in the form of a flowchart in more detail as shown in Figure 2 below.

The following numbers of floors above lobby have been used: 10, 20, 30, 40 and 50 floors.

The following numbers of total building populations have also been used based on an arrival rate of 15%: 500, 1000, 1500, 2000, 2500, 3000, 3500, 4000, 4500 and 5000 persons. These would be equivalent to total populations of 625, 1250, 1875, 2500, 3125, 3750, 4375, 5000, 5625 and 6250 persons respectively at an arrival rate of 12%. As far as the lift system is concerned a total building population of 2000 person with an arrival rate of 15% is identical to a building with a total building population of 2500 person with an arrival rate of 12%. In both cases, 300 passengers will arrive in the lobby in the busiest 5 min period. These combinations have been tabulated in Table 1 above.

6 Traffic analysis

The design of the vertical transportation system for each case has been carried out as follows:

(1) A basic traffic analysis based on the interval and the handling capacity is carried out to determine the required number of lifts with their capacity and speed. A target interval of 30 s or less is used. An arrival of 15% in the busiest f5 min is used along with the total building populations of 500/1000/1500/2000/2500/3000/3500/4000/4500 and 5000 persons.

(2) A further analysis is then carried out to assess the average waiting time, average transit time and the average time to destination. The average waiting time is the average time spent by passengers

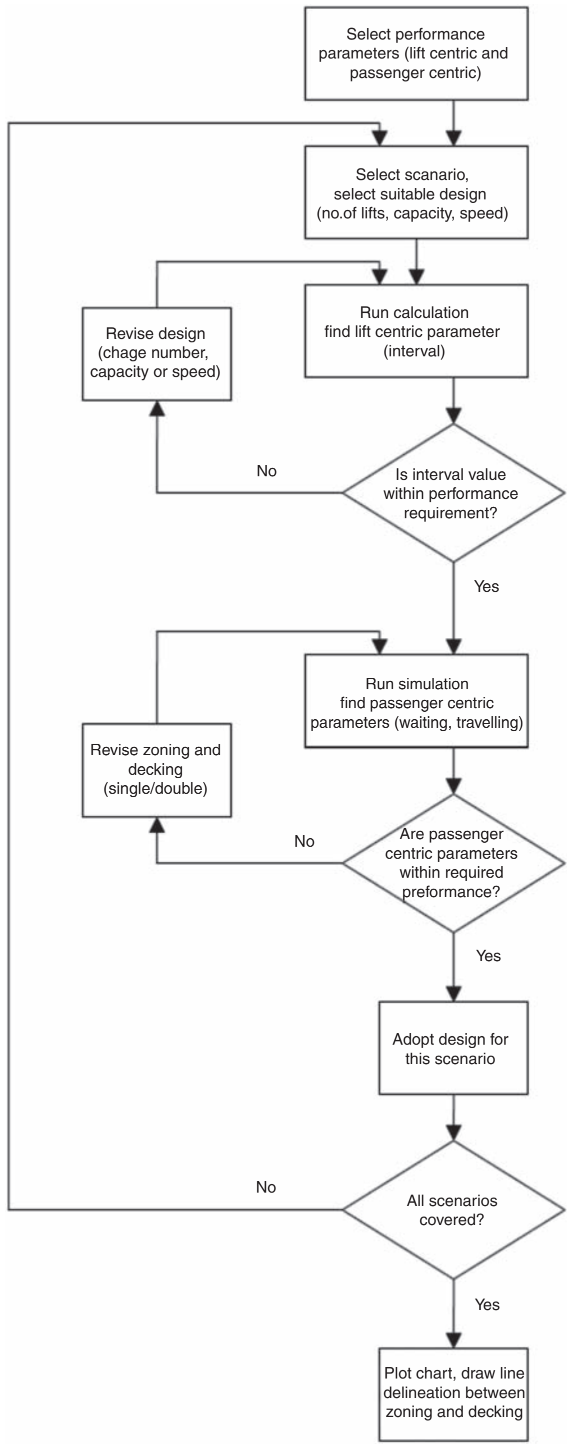

Figure 2 Flowchart for the process of producing the chart

Table 1 Possible and improbable combinations of total building population and number of floors

	Total building population in persons (at 15% arrival rate)									
Floors	500	1000	1500	2000	2500	3000	3500	4000	4500	5000
10	■	■	■	■	■	■	■	■	■	■
20	i/p*	■	■	■	■	■	■	■	■	■
30	i/p*	i/p*	■	■	■	■	■	■	■	■
40	i/p*	i/p*	i/p*	■	■	■	■	■	■	■

■Possible combination. *Improbable configuration due to the low population per floor (i.e. less than 50 per floor).

waiting for the lift in the lobby. The average transit time is the average time spent travelling in the car by the passengers. The average time to destination is the sum of the average waiting time and the average transit time. A target of 30 s for average waiting time, 60 s for the average transit time and 90 s for the average time to destination has been used based on the current industry *de facto* standard of 30/60/90.[3,5]

7 Traffic analysis tool

Elevate software revision 7.18 TC has been used for the traffic analysis used to arrive at the results in this article [5]. Default values for the traffic analysis parameters within elevate have been used unless otherwise specified below.

The software has been used in two steps:

7.1 Step 1: Calculation mode

The first step involves the use of calculation to ensure that the lift-centric parameters meet the required performance (i.e. the interval). This step is carried out using the enhanced up peak calculation mode within elevate. The calculation methodology for this mode can be summarised in the following equation:

$$\tau = 2 \cdot H \cdot \left(\frac{d_f}{v}\right) + (S+1) \cdot \left(t_f - \frac{d_f}{v} + t_{do} + t_{dc} + t_{sd} - t_{ao}\right) + P\left(t_{pi} + t_{po}\right) \quad (1)$$

where: τ is the round trip time in s, H is the highest reversal floor (where floors are numbered 0, 1, 2, ..., N, S is the probable number of stops (not including the stop at the ground floor), d_f is the typical height of one floor in metres, v is the top rated speed in metres per second, t_f is the time taken to complete a one floor journey in seconds assuming that the lift attains the top speed v, P is the number of passengers in the car when it leaves the ground floor, t_{do} is the door opening time in s, t_{dc} is the door closing time in s, t_{sd} is the motor start delay in s, t_{ao} is the door advance opening time in s (where the door starts opening before the car comes to a complete standstill), t_{pi} is the passenger boarding time in s, t_{po} is the passenger alighting time in s.

The interval is then found by dividing the round trip time by the number of lifts in the group of lifts. This equation is implemented within elevate under the so-called 'Enhanced up-peak calculation mode'. In this mode, the arrival rate of the passengers (and hence the handling capacity of the lift system) is set as a user input and the outputs are the interval and the car loading. More details on this calculation method can be found in [6] and [7].

7.2 Step 2: Simulation mode

Step 2 involves the running of a simulation of the design arrived at in step 1 above. It aims at finding the passenger centric parameters, namely the passenger travelling time, the passenger transit time (i.e. journey time) and the total time to destination (i.e. total journey time which is the sum of the two previous parameters). This simulation is carried out using the simulation mode with the Group Collective mode (up peak 2). Under this simulation mode, the system is exposed to a constant arrival of 15% for 15 min with pure incoming (up peak) traffic only. The group collective mode describes how the calls are allocated to the cars, and in this case this is the classical mode by which cars just pick up passengers and deliver them to their selected destinations. The up peak 2 setting forces any available car to return back to the lobby and to immediately open its doors to allow passengers to board (regardless of the availability of other lifts in the lobby for boarding).

In simulation mode, elevate runs a real-time time-slice simulation [23]. At the end of every time-slice, the software updates the status of all passengers and the status of all lifts (whether stationery or moving). The data from each time-slice affects the next time-slice. Data is accumulated from all time-slices and displayed at the end of the full simulation.

For both modes of calculation and simulation, the following values have been assumed for the traffic analysis parameters:

(1) Floor to floor heights: 4 m.
(2) Passenger transfer time: 1.2 s.
(3) Acceleration: 1 m/s^2.
(4) Jerk: 1.2 m/s^3.
(5) Other parameters have been given the default value from elevate.

The following two examples show how two configurations were arrived at by the use of calculation and then simulation.

Example 1

This example is used to illustrate the design process in relation to the zoning problem.

Let us assume a building with a total population of 2000 persons equally spread over 10 floors above the lobby (200 persons per floor). The traffic analysis is first carried out by the use of calculation in order to arrive at the interval.

The following parameters have been used:

- Enhanced up peak mode.
- RTT losses: 0%
- Door opening time: 1.9 s
- Door closing time: 2.8 s
- No advanced door opening
- Acceleration: 1 m/s^2

Table 2 Passenger centred performance results for un-zoned and various zoned configurations

#		Average waiting time (s)	Average transit time (s)	Average time to destination (s)
1	One zone with eight lifts	105.1	102.5	207.6
2	Two zones with a total of eight lifts, four lifts for the lower zone and four lifts for the upper zone	8	59.2	67.2
3	Two zones with a total of seven lifts, four lifts for the lower zone and three lifts for the upper zone	15	65.7	80.7
4	Two zones with a total of six lifts, three lifts for the lower zone and three lifts for the upper zone	26.1	67.6	93.7

- Jerk: $1.2\,m/s^3$
- Passenger transfer time: 1.2 s
- Start delay: 0.5 s
- Passenger mass: 75 kg
- Height of floors: 4 m (except ground floor: 5 m)
- 100% of population present (i.e. 0% absent)

Using 8 lifts rated at 2000 kg (26 persons) and running at 2.5 m/s, gives an interval of 20.9 s at a car loading of 80.5%. Under the classical assessment criterion of using the interval only, this arrangement would be satisfactory and would provide an excellent level of service.

A second assessment is then carried out to assess the performance from the point of view of the passenger. Under this scenario, the performance shows that under up peak (incoming traffic) conditions at a constant arrival rate of 15% for a duration of 15 min, the average waiting time, average transit time and average time to destination are 105.1, 102.5 and 207.6 s respectively. These are unacceptable figures and well exceed the industry *de facto* standard of 30, 60 and 90 s (average waiting time, average transit time, average time to destination).

The parameters used in the simulation mode are as follows:

- Simulation mode: Group collective, up peak 2 mode.
- Number of simulations: 10.
- Door dwell time: 3 s.

One method to reduce the transit time and hence the time to destination is to zone the lifts during the morning up peak. Zoning restricts one group of the lifts to serving a group of lower contiguous floors and the other group of lifts to serving a group of upper contiguous floors. This zoning (or sectoring) is only applied during the morning up peak. Outside the peak all lifts revert to serving all floors.

The results of such zoning are shown in Table 2 above. The zones have been set to an equal number of floors in this case (lower zone serving 1 to 5; upper zone serving 6 to 10; all lifts serving Ground). This is not necessarily the optimum solution and it is generally accepted that the lower zone could cover a larger number of floors to account for the fact of the longer distance the lift serving the upper zone would have to travel.

The zoned solution with eight lifts in total, whereby four lifts serve the lower zone (1 to 5) and the other four lifts serve the upper zone (6 to 10) provides an excellent performance. However, dropping the number of total lift to seven provides a good performance that is within the 30/60/90 criterion, despite the fact that the average transit slightly exceeds the 60 s mark. Using six lifts in total exceeds the 30/60/90 criterion. Hence using seven lifts in two zones is the selected configuration that uses the smallest number of lifts while approximately meeting the 30/60/90 criterion.

Table 3 Passenger centred performance results for various configurations

#	Arrangement	Zone	Average waiting time (s)	Average transit time (s)	Average time to destination (s)
1	Three zones of 19 single deckers rated at 2000 kg and running at 2.5 m/s, 4 m/s and 6 m/s respectively	1 (6 lifts)	21.9	101.1	123.1
		2 (6 lifts)	47.2	114.2	161.4
		3 (7 lifts)	21.4	117.2	136.6
2	One zone of 12 double decker lifts rated at 2000 kg per deck and running at 6 m/s		17.4	59.6	77
3	Two zones of 5 and five double decker lifts rated at 1600 kg/ deck and running at 3.5 m/s and 6 m/s respectively	1 (5 lifts)	29.3	59.1	88.4
		2 (5 lifts)	23.6	63.4	86.9

The analysis above has only been based on the morning up peak. It is generally accepted that if the configuration meets the 15% morning arrival rate, it can comfortably meet a mixture of inter-floor lunchtime patterns. This however must be confirmed for any specific building.

Example 2

This example is used to illustrate the design process in relation to the use of double deckers.

Let us assume a building with a total population of 4000 persons equally spread over 30 floors above the lobby (133 persons per floor). The traffic analysis is first carried out by the use of calculation in order to arrive at the interval.

The first attempt is made to use three zones of single deck lifts. Six lifts are used for the lower zone (serving floors 1 to 10), six lifts are used for the middle zone (serving floors 11 to 20) and seven lifts are used for the upper zone (serving floors 21 to 30). The lower zone lifts are rated at 2000 kg and running at 2.5 m/s. The middle zone lifts are also rated at 2000 kg and running at 4 m/s. The upper zone lifts are rated at 2000 kg and running at 6 m/s. Despite the fact that the three zones meet the lift centric performance parameters (interval is around 30 s) and despite the fact that a total of 19 single deck lifts are used rated at 2000 kg, the passenger centric performance is poor and far exceeds the 30/60/90 criterion (see Table 3). Increasing the number of lifts above 19 will be detrimental to the core space. Thus double deckers have to be considered as an alternative.

So an attempt is made at using one zone of double deckers. Using 12 double decker lifts rated at 1600 kg/ deck and running at a speed of 6 m/s, produce a good interval of 20.6 s, at a car loading of 79%. The passenger centric parameters are also within the required limits (see Table 3). However, the use of 12 lifts in one group can be very confusing for passengers and difficult to access and could lead to crowded large lobbies (even if destination control systems have been used). It also takes up a lot of valuable lobby space that can be use for other purposes on the upper floors. So an attempt is made at zoning the double deckers into two zones.

Two zones of double deckers can be shown to produce a feasible solution. The lower zone comprises 5 double deckers rated at 1600 kg and running at 3.5 m/s serving floors 1 to 15. The upper zone comprises 6 double deckers running at 6 m/s serving floors 16 to 30. The passenger centric performance parameters are within the requirements of the 30/60/90 criterion (as shown in Table 3). So this solution has many advantages over the single double decker zone as follows:

(1) It makes each group smaller and thus less confusing for passengers.

(2) It reduces the overall number of double decker lifts from 12 to 11.
(3) It reduces the capacity of the double decker lifts from 2000 kg per deck to 1600 kg per deck.
(4) It releases the lobby space that would have been used by the lower zone lifts to be used for other purposes.
(5) It reduces the speed of half the lifts from 6 m/s down to 3.5 m/s.

The following parameters have been used in the traffic analysis:

- Double decker general analysis.
- RTT losses: 0%
- Door opening time: 1.9 s
- Door closing time: 2.8 s
- No advanced door opening
- Acceleration: 1 m/s^2
- Jerk: 1.2 m/s^3
- Passenger transfer time: 1.2 s
- Start delay: 0.5 s
- Passenger mass: 75 kg
- Height of floors: 4 m (except ground floor: 5 m)
- 100% of population present (i.e. 0% absent)

A comparison of the results from the three options is shown in Table 3.

8 Results

The design methodology followed in the two examples in the last section has been used as the basis for compiling the data, which is shown in tabular form in Table 4 and plotted in the chart shown in Figure 3.

The criteria for deciding to adopt one zoning or decking scheme over another are as follows:

(1) Limiting the maximum number of lifts in one group to 8 in case of conventional group control and to 10 in the case of destination control.
(2) Minimizing the amount of building core space used.
(3) Meeting the passenger centric performance parameters as well as the lift centric performance parameters.

In general the speeds of the lifts have been selected by dividing the total lift travel by 20 (roughly setting a criterion that a lift must travel between the terminal floors in around 20 s) which is a widely accepted industry criterion.

When assessing whether a design meets the lift centric or passenger centric performance criteria, a certain tolerance is placed on the limits. For examples, an interval of 33 s is deemed acceptable, despite the fact that it exceeds the 30 s target. Similarly, a total time to destination of around 94 s is deemed acceptable despite the fact that it exceeds the 90 s target.

The following conclusions can be drawn from the graph shown in Figure 3:

(1) The number of passengers arriving in the lobby in the busiest 5 min is an important factor in deciding the design of the vertical transportation system that can achieve the required performance. Based on either a 15% arrival rate or 12% arrival rate, this can be expressed as the total building population. In fact that x-axis could be expressed as the number of passengers arriving in the lobby in 5 min. However, it is more convenient to use the total building population and assume a certain arrival rate as a percentage of that population (e.g. 12% or 15%).
(2) The other important factor in deciding the design of the vertical transportation system is the number of floors above ground. As can be seen from the figure, for the same total building population, as the number of floors increase, more complex configurations

Table 4a List of all scenarios with design details

Number of Floors	10										20								
Population at 15%	500	1000	1500	2000	2500	3000	3500	4000	4500	5000	1000	1500	2000	2500	3000	3500	4000	4500	5000
Population at 12%	625	1250	1875	2500	3125	3750	4375	5000	5625	6250	1250	1875	2500	3125	3750	4375	5000	5625	6250
Configuration	S1	S1	S2	S2	S3	S3	S3	D1	D2	D2	S2	S2	S3	S3	S3	D1	D2	D2	D2
Number of Lifts	4	6	6	10	10	10	12	8	10	11	8	10	12	15	17	10	10	10	11
Group 1																			
Number of Lifts	4	6	3	5	4	4	4	8	5	5	4	5	4	5	6	10	5	5	5
Size of Lifts (kg)	1600	1600	1600	1600	2000	2000	2000	2000	1600	1600	1250	1250	1250	1600	1600	2000	1600	1600	2000
Speed of Lifts (m/s)	2	2	2	2	2	2	2	2.5	2	2	2.5	2.5	2.5	2.5	2.5	4	2.5	2.5	2.5
Floors Served	1-10	1-10	1-5	1-5	1-4	1-4	1-4	1-10	1-5	1-5	1-11	1-11	1-7	1-7	1-8	1-20	1-10	1-10	1-10
Group 2																			
Number of Lifts			3	5	3	3	4		5	6	4	5	4	5	6		5	5	6
Size of Lifts (kg)			1600	1600	2000	2000	2000		1600	1600	1250	1600	1250	1600	1600		1600	1600	2000
Speed of Lifts (m/s)			2.5	2.5	2	2	2		2.5	2.5	4	4	3.5	3.5	3.5		4	4	4
Floors Served			6-10	6-10	5-7	5-7	5-7		6-10	6-10	12-20	12-20	8-14	8-14	9-15		11-20	11-20	11-20
Group 3																			
Number of Lifts					3	3	4						4	5	5				
Size of Lifts (kg)					2000	2000	1600						1250	1600	1600				
Speed of Lifts (m/s)					2.5	2.5	2.5						4	4	5				
Floors Served					8-10	8-10	8-10						15-20	15-20	16-20				
Group 4																			
Number of Lifts																			
Size of Lifts (kg)																			
Speed of Lifts (m/s)																			
Floors Served																			

Legend: S1: One zone/single deck; S2 Two zones/single deck; S3 Three zones/single deck; S4 Four zones/single deck;
D1: One zone/double deck; D2: Two zones/double deck.

Table 4b List of all scenarios with design details

Number of Floors	30								40							50
Population at 15%	1500	2000	2500	3000	3500	4000	4500	5000	2000	2500	3000	3500	4000	4500	5000	2500
Population at 12%	1875	2500	3125	3750	4375	5000	5625	6250	2500	3125	3750	4375	5000	5625	6250	3125
Configuration	S2	S3	S3	D1	D1	D2	D2	D2	S4	S4	D2	D2	D2	D2	D2	D2
Number of Lifts	12	15	20	10	10	11	12	13	20	22	12	12	13	14	15	13
Group 1																
Number of Lifts	6	5	6	10	10	5	6	6	5	5	6	6	6	7	7	6
Size of Lifts (kg)	1600	1600	1600	1600	1600	1600	1600	2000	1250	1250	1600	1600	1600	1600	1600	1600
Speed of Lifts (m/s)	3.5	2	2	6	6	3.5	3.5	3.5	2.5	2.5	4	4	4	4	4	5
Floors Served	1-15	1-11	1-10	1-30	1-30	1-15	1-16	1-15	1-10	1-10	1-20	1-22	1-20	1-21	1-20	1-25
Group 2																
Number of Lifts	6	5	7			6	6	7	5	5	6	6	7	7	8	7
Size of Lifts (kg)	1600	1600	1600			1600	2000	2000	1250	1250	1600	1600	1600	1600	1600	1600
Speed of Lifts (m/s)	6	4	4			6	6	6	4	4	8	8	8	8	8	10
Floors Served	16-30	12-21	11-20			16-30	17-30	16-30	11-20	11-20	21-40	23-40	21-40	22-40	21-40	26-50
Group 3																
Number of Lifts		5	7						5	6						
Size of Lifts (kg)		1600	1600						1250	1250						
Speed of Lifts (m/s)		6	6						6	6						
Floors Served		22-30	21-30						21-30	21-30						
Group 4																
Number of Lifts									5	6						
Size of Lifts (kg)									1250	1250						
Speed of Lifts (m/s)									8	8						
Floors Served									31-40	31-40						

Legend: S1: One zone/single deck; S2 Two zones/single deck; S3 Three zones/single deck; S4 Four zones/single deck;
D1: One zone/double deck; D2: Two zones/double deck.

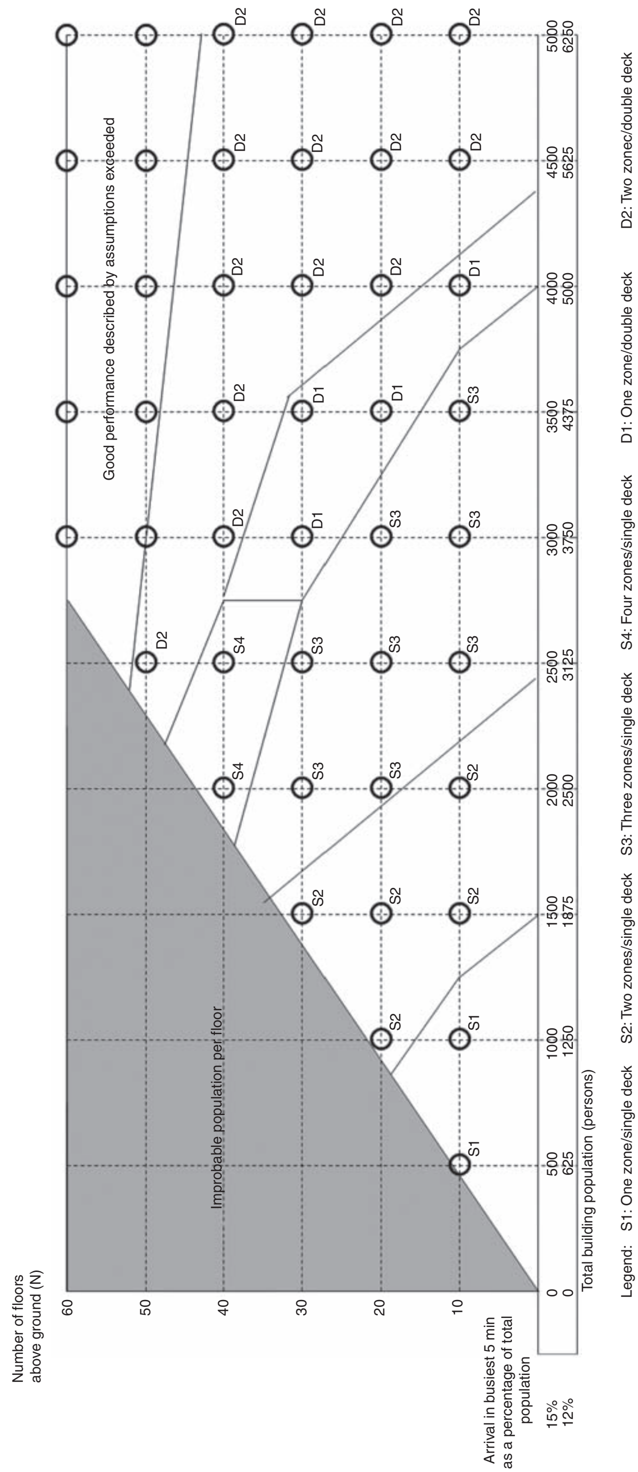

Figure 3 Graphical representation of the most suitable lift configurations for the various combinations of total building population and number of floors

are needed in terms of an increase in the number of zones or the use of double deckers. For example assuming a total building population of 2000 persons (and an arrival rate of 15%), then two zones of lifts are needed for between 10 floors (7 lifts) and 20 floors (10 lifts), whereas three zones are needed for 30 floors above the lobby (15 lifts) and four zones are needed for 40 floor above the lobby (20 lifts).

(3) It has been assumed that the lowest realistic floor population for an office building is 50 persons per floor. This results in the shaded area that is labeled as improbable floor areas. For example, for a total building population of 1000 persons over 40 floors is an improbable combination as it implies an unrealistic floor population of 25 persons.

(4) It can be seen from the graph that the maximum number of floors that can be served by a single group of lifts in one zone is around 16 floors. This confirms the widely known rule of thumb in the industry.

9 Conclusion

The vertical transportation design for a building requires the finding a suitable lift configuration. Each configuration specifies the number, speed and capacity of the lifts in each group. It also specifies the grouping of the lifts and floors into zones, as well as any special features in terms of the use of double decker lifts and group control algorithms.

The two most important parameters that drive demand in a vertical transportation system in a building are the total building population and the number of floors served above ground. For a certain total building population, the arrival rate for the busiest 5 min results in a certain number of passengers arriving in the lobby in a 5-min period.

Each configuration has been arrived at by using the classical performance parameter, the interval, with a target value of 30 s. The analysis is then also carried out using simulation to assess the passenger-centric parameters of waiting time, transit time and total time to destination with a target value of 30, 60 and 90 s respectively.

Using the two demand parameters and the results from the analysis, a chart has been developed that can be used to guide the selection of the best vertical transportation configuration.

The work in this article has been restricted to office buildings. This is in recognition of the fact that office buildings are in general the most onerous in terms of the vertical transportation system requirements. The other main restriction in this work has been the fact that it has been based on the morning up peak (incoming traffic) only.

Future work is planned to assess other types of buildings such as hospitals, hotels, apartments, stadia, theatres and educational establishment and to assess performance under mixed traffic configurations.

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