Overview of the Book "People Flow in Buildings"

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Keywords: Elevator; lift; escalator; passengers; people flow; batch size; calculation; simulation

Abstract. Recently a book called "People Flow in Buildings" dealing with lift traffic was published [1]. The book is based on the author's experience and involvement in planning vertical traffic solutions and includes numerous figures and examples related to elevator and escalator design in buildings. This article highlights some of the novelties of the book including traffic measurement methods, measured results of daily traffic profiles, and passenger batch arrivals. The book also explains the modelling of traffic and validation of simulation. The ISO 8100-32:2020 standard, "Planning and selection of passenger lifts to be installed in office, hotel, and residential buildings", is utilized in the examples. The book ends with current evacuation standards and provides examples of evacuation practices in some of the tallest buildings in the world. The present article explains the motivation and background of authoring the book and introduces some of the main findings.

1 INTRODUCTION

The author began her career with elevator traffic and control systems in 1984. At the time, a book called "Lift Traffic Analysis, Design and Control" had recently been published by Barney and Dos Santos [2], which gave an excellent and inspiring starting point to become acquainted with elevator traffic. Later, when planning vertical traffic solutions in buildings, "Vertical Transportation: Elevators and Escalators" by Strakosch [3] gave a perspective on elevator design.

In the 1980s, elevator control technology experienced a revolutionary switch from relay controls to embedded microprocessor systems. At first, the call allocation principles of the relay controls were transferred to the microprocessor systems, the first ones being in the Assembler and PLM-language. Microprocessors and PC board-based control systems offered a whole new area to apply mathematical methods in call allocation and in optimizing landing and car calls to elevators. Artificial Intelligence with learning and fuzzy logic were used to enhance the call allocation. Neural networks and genetic algorithms were applied directly in call allocation.

The benefits of having the destination keyboard already at the landing, not inside the car, was shown in two theses published by Manchester University in the 1970s [4,5]. Up-peak handling capacity could be increased by adding the passenger destination information already for the call allocation phase. At the end of the 1970s, Manchester University introduced lift traffic training courses for elevator consultants and manufacturers. The technology to move to destination control systems was not mature in the 1980s. At the beginning of the next decade, Schröder patented the first application of a destination control system, M10, which could be realized in a real-time control system [6]. The application included a description of the control principle and a keypad showing how the destination call could be given at the lobby. In this application, the destination call was immediately fixed to a car. This application was distinct from the other major elevator-control principles of the time.

Along with the advanced control systems of the 1990s, more daily people-flow profiles and traffic statistics were measured from various types of buildings, which increased the knowledge of the traffic in buildings and consequently affected elevator planning in buildings [7]. The up-peak calculation method assumed only that car calls were served sequentially. With simulations, the efficiency of group-control software could be examined by simulating different traffic situations. Up-peak, mixed lunchtime traffic and evening down-peak were typical traffic situations to be studied for office buildings. In addition, an evacuation situation could be simulated to discover the evacuation or the egress times when passengers use different transportation means in evacuation. The new ISO 8100-32: 2020 standard [8] sets the basics for how simulation can be used in vertical design and standardizes the definitions of the terms, and the inputs and outputs for the simulation. However, it still lacks standardization of the performance of elevator traffic simulators themselves.

During her work, the author has experienced this ground-breaking change in elevator control systems and vertical planning. The book “People Flow in Buildings” describes how the technology from relays to software-based systems has changed the solutions and design methods over the last 30-40 years. The book includes figures from real projects in which the author has been involved. The scenarios of future elevator solutions are the author´s own visions.

2 FIVE PARTS OF THE BOOK

The book is divided into five main subjects. The first two parts concentrate on measurement methods and statistics of people flow as well as control systems and transportation solutions in buildings. The third part summarizes elevator uppeak calculation equations, evacuation analysis and horizontal people flow. The last two parts of the book describe the simulation method and its use in elevator planning.

2.1 People flow measurement methods and results

The first part describes the estimation of population and various ways to measure people flow in buildings. In the early 1990s when the vertical people counting in elevators started, cameras were simple and did not have a memory, which hindered the use of sophisticated image-processing methods. Access control systems in buildings were not common and were not suitable for people counting at that time. For safety reasons, however, every elevator had a load-weighing device and photocell devices or a safety ray in the car door opening. The load-weighing device prevented the cars from overloading, and the photocells prevented the doors from closing when people were between the doors. With the photocell ray, the number of people passing through the door opening could be counted, but not the direction of whether a passenger was moving in or out of the car. By utilizing the two devices together, the number of entering and exiting passengers could be counted quite accurately.

A lot of information on daily passenger traffic patterns in buildings was obtained by the advanced control systems utilizing people-counting methods. Since the number of passengers travelling up and down varies from building to building, the results were not directly comparable. By scaling the passenger arrival rates to the population on the served floors, consistent data could be obtained which could be compared between different buildings. Typical daily passenger traffic profiles of various types of buildings are presented in the book. Figure 1 shows a typical daily profile of a residential building.

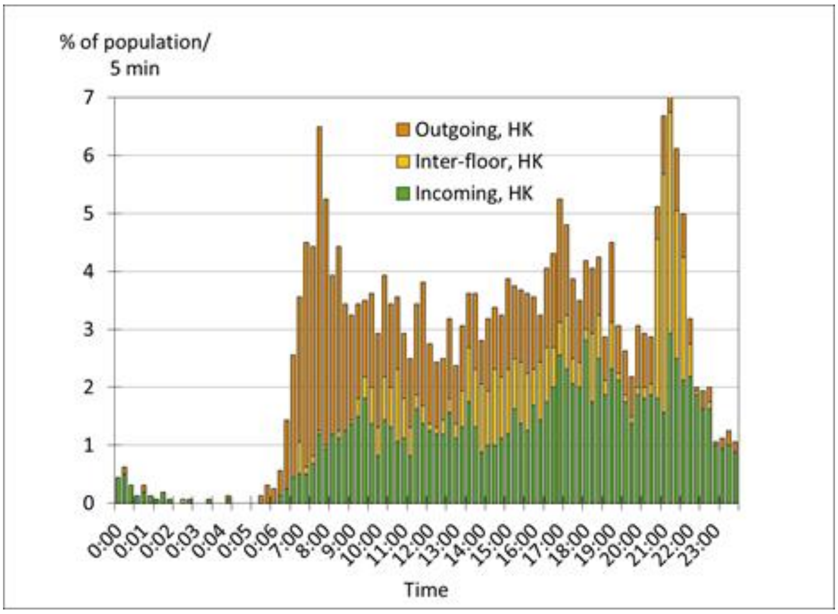

Figure 1 Daily traffic in a residential building in Hong Kong

The most recent studies reveal that people move in batches [9]. The batch sizes are the biggest in resort hotels, cruise ships, and residential buildings. In office buildings, the batch sizes are greatest during lunchtime, just when the amount of people moving with elevators is the greatest. Based on observations, rough values for the mean batch sizes in various types of buildings are proposed in Table 1. The movement in batches decreases the number of elevator stops and thus also makes the handling of lunch hour traffic easier than previously expected. If individual passenger arrivals in simulation are changed to batches, the effect should be considered in the elevator design criteria.

Table 1 Mean passenger batch size distribution for different times of a day

Type	Traffic pattern	Mean batch size
Office	**Uppeak**	1.0
	Lunch-peak	1.5
Hotel – business	**Two-way**	1.5
Hotel – resort	**Two-way**	2.0
Residential	**Two-way**	1.5
Commercial	**Two-way**	1.2
Cruise ships	**Incoming**	1.7

2.2 Solutions of vertical transportation technology

The second part of the book explains the group control principles. Two main group control principles, continuous and immediate call allocation, are explained. The operation of multi-car systems, such as double-deck elevators, Odyssey, TWIN and MULTI, are briefly described.

The manufacturers in western countries considered that the most efficient approach was the continuous call allocation principle, where the landing calls were reallocated to the best cars several times in a second. Continuous call allocation was used in the relay-based group controls and in the first software-based group controls. An existing landing call was fixed to the best car only when it was so near to the landing call floor it had to start decelerating to the floor.

The continuous call allocation principle required a lot of computing power since the number of possible ways (routes) to allocate N landing calls to a group of L elevators was N^L.

The Japanese manufacturers used the immediate call allocation principle in the first software-based systems. Here the landing call was instantly fixed after the registration to the best car. The allocated car may be delayed, and then another car may become more optimal. On the other hand, the immediate announcement of the serving car is psychologically more convenient to the passengers if they have sufficient time to approach the car. Also, the first applications of destination control were based on the direct announcement of the serving car. Immediate allocation does not require as much computing power as continuous call allocation since searching for the best car needs to be calculated only for $N \cdot L$ routes.

Mathematical methods, such as neural networks, and genetic algorithms were applied in group control systems. These methods could be applied to both immediate and continuous call allocation. With immediate control, processing power can be extended to a wider range of objectives, such as access control, horizontal navigation, and serving of passenger groups.

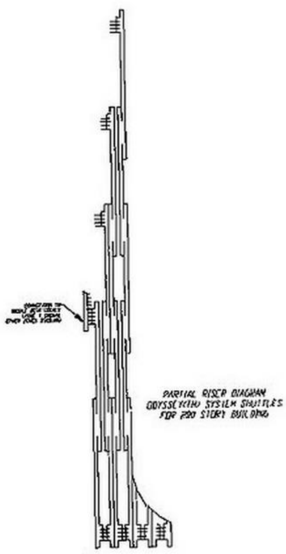

Figure 2 Odyssey system with partial riser diagram shuttles for a 200-storey building

A totally new type of control is required in Multi-Car-Elevator (MCE) systems which was considered by Barker as early as the 1990s, see Figure 2 [10]. Today, MCE systems with a linear motor have become relevant again. With MCEs, special attention must be paid to several cars moving in the same shaft [11,12,13]. The car movements should be synchronized with each other in such a way that they will not collide. Efficient loading of passengers in the lobbies should be arranged. Passenger waiting times are not such a problem as in the traction elevator systems, since the number of cabins in the shaft can be adjusted according to the need. The capacity of the cabins can be small, such as for 4-8 persons. Considering a pandemic, such as Covid-19, small cars could be better for transporting a few persons rather than large, heavy cars.

2.3 People flow calculation methods

Part 3 of the book presents the well-known elevator kinematic equations and different versions of the uppeak formulas. Vertical people-flow calculation with elevators is by far based on up-peak traffic. Several methods to calculate uppeak round trip time are presented with equal and unequal population distributions, with equal or unequal jump distances during an up trip, and with one or several entrances. Also uppeak equations for the round trip time calculation are presented for zoned elevators, for unsymmetric groups, for shuttle lifts, with double-deckers and with a multi-car systems. For the uppeak situation, passenger waiting times and queue lengths are estimated.

In addition to up-peak calculation, the round trip time for an evacuation situation as well as for passenger egress times by elevators and staircases is given. Pedestrian traffic and horizontal people flow in corridors, doorways, and walkways have their own equations and definitions, see Figure 3 [14]. The calculation part ends with handling capacity equations for escalators, moving walkways, turnstiles, ticket stations and destination operation panels.

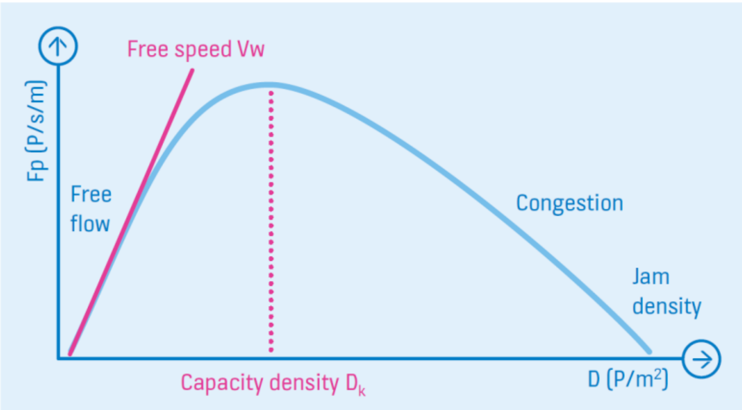

Figure 3 Relation of people flow and people density in walkways

2.4 People flow simulation

Part 4 describes first the types of elevator traffic simulators currently in use. The Monte Carlo and single-elevator group simulations are the most common ones [15,16]. In a single-elevator group, the group control system can be modelled by a generic control principle, or by a real manufacturer control software. A more sophisticated method is to simulate the traffic of the whole building with all transportation devices, not only one elevator group at a time [17]. Along with the evacuation simulation methods, modern game engines and computer hardware, pedestrian movement models have improved and these can be run in real time. The most advanced elevator traffic simulators can model both vertical and horizontal traffic in buildings.

To get a correlation between the simulation and the calculation results, elevator performance parameters were simulated with a conventional collective control system. As an example, the average round trip time and the number of starts are shown in Figure 4 as a function of passenger demand. The pure incoming and outgoing traffic, and the lunchtime traffic (40-40-20) were used. In uppeak, the carload factor of 80% is reached at about 8% passenger demand. With a higher demand than 8%, the number of starts per round trip begins to saturate and remains about constant. In addition to the car capacity, the number of starts per round trip is limited by the number of served floors. In down-peak, the number of starts per round trip can be much smaller than in up-peak. This depends on the efficiency of the control system where the minimum number of starts can be close to N/L. During lunchtime, the number of starts per round trip and the round trip time are the greatest because of heavy traffic in both directions.

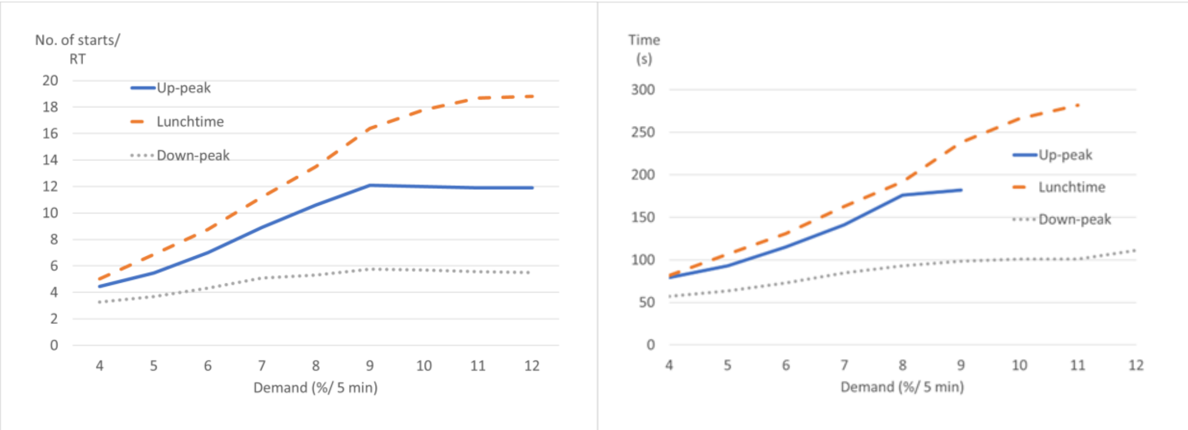

Figure 4 Elevator starts per round trip (left) and roundtrip time (right) with increasing passenger demand for a conventional control system in the example building

The ISO 8100-32:2020 standard and CIBSE Guide D:2020 define peak traffic patterns that were simulated with different group control systems and solutions: conventional and destination control systems with a single-car group and with a double-deck elevator group. The handling capacity of the system is the demand where the service times start to saturate. At saturation in office buildings, the average waiting time exceeds 30 seconds, the average time to destination exceeds 90 seconds, or the carload factor exceeds 80%. The simulated results highly depend on the building, its elevator solution and the control system, and the absolute figures cannot be used as such. Relative handling capacities of different solutions, however, are comparable in different traffic situations. The simulated handling capacities are scaled to the uppeak handling capacity of the single-car system with conventional control. According to Table 2, the relative handling capacity in a single-car lift is 1.0, and with a destination control system (DCS) it is 30% greater than with the conventional control, on average. Similarly, the handling capacity of double-deck lifts is 60 %, and that of the double-deck DCS lifts is twice the handling capacity of a single-car lift system, respectively.

Table 2 Relative handling capacities for three traffic mixes of different elevator control systems

Traffic pattern	Single-car elevator		Double-deck elevator	
	Conventional	**DCS**	**Conventional**	**DCS**
Up-peak	1.0	1.6	2.0	3.0
Lunchtime	1.3	1.3	1.6	2.0
Down peak	1.5	1.5	3.0	3.0
Compromise boosting	1.0	1.3	1.6	2.0

2.5 People flow planning

The last part of the book concentrates on elevator planning in tall buildings. The design criteria accurately define the upper limits for average passenger waiting times and journey times. The required number of elevators, their sizes and speeds are also defined according to the design criteria. Conventionally, the design criteria are given for uppeak when people enter the building. The CIBSE Guide D: 2020 and ISO 8100-32:2020 define waiting time design criteria also for lunchtime and two-way traffic. These are obtained by simulation. The design criteria omit the time for how fast people should exit from the building. The maximum egress time affects the required fire protection in the building and transportation devices. If the building should be evacuated within one hour, the landing doors should be at least one-hour smoke and fire resistant.

On the other hand, the final elevator arrangement in vertical planning is a compromise between several aspects: good passenger service level, the price of the solution, and the size of the selected elevator group. Typical elevator-group dimensions can be estimated according to the ISO and ANSI standards, which are shown in the book.

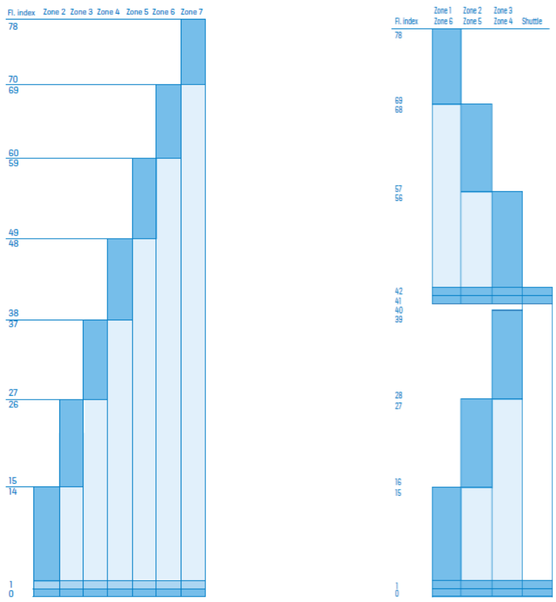

Figure 5 Elevator group arrangements of a supertall building with all lift groups starting from the ground (left), and zoning of a sky-lobby arrangement (right)

The space demand of an example elevator solution for a tall, 312-meter-high building with 10 920 persons was analyzed with six different elevator solutions. Two main elevator arrangements were selected according to the design criteria of ISO 8100-32:2020, see Figure 5. In the first solution, all lift groups start from the ground, and the other is a sky-lobby arrangement.

The relative building-space demand was analyzed with the conventional control, destination control system, with the double-deck destination control system, or with the MULTI-system. In the MULTI solution analysis, the philosophy given by Gerstenmeyer [18] was used:

1) single-car elevator groups using the conventional control
2) single-car elevator groups with the destination control system
3) double-deck groups with the conventional control,
4) double-deck groups with the destination control system,
5) sky-lobby arrangement where all elevator groups use double-deck elevators with the destination control system, and
6) sky-lobby arrangement where the local groups use double-deck elevators with the destination control system and the shuttle group uses the MULTI system

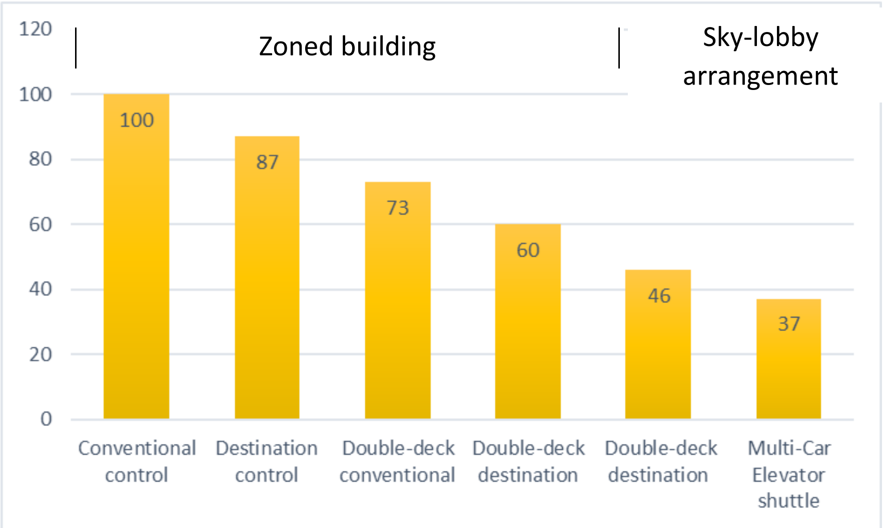

Figure 6 Elevator core space demand with different elevator arrangements

Figure 6 shows the relative space demand of each solution. The results are scaled to the space demand of case 1. The largest space is needed by the single-car elevator group with the conventional control where all elevator groups start from the ground floor. On the other hand, the sky-lobby solution with the MULTI solution in the shuttle group, and the double-deck destination control system in the local groups take only 37 % of solution 1.

With the multi-car solution, passenger waiting times are not a problem since another car moving in the same direction in the same shaft will soon serve the call. The interval and the handling capacity can be adjusted by adding the number of cabins in the shaft. Elevator speed has been the limiting factor in constructing tall buildings because of human characteristics. In the multi-car solution, the speed can be low which enables even taller buildings than today. With a multi-car shuttle, the vision of Frank Lloyd Wright of a mile-high building [19] may become a reality. On the other hand, the MCE cabins should be designed comfortable for passengers, since the passenger journey times to their destinations can become long.

3 SUMMARY

In this article, a few highlights of the book "People Flow in Buildings" were introduced. The given tables and the figures in this article are clarified in more detail in the book.

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BIOGRAPHICAL DETAILS

Marja-Liisa Siikonen is the CEO of MLS Lift Consulting Ltd. She received her M.Sc., Lic. Sc.(Tech), and Ph.D. (Tech) in 1997 from the Helsinki University of Technology, Finland. She retired from KONE Corporation after working for 34 years with control systems and transportation planning. She has published more than 100 articles and 250 patents in the field of people flow and elevator control systems. She is the author of the book "People Flow in Buildings" published in 2021.