People Flow Analysis in Lift Modernization

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Abstract. The modernization and retrofitting of lifts in a large building presents unique challenges. Current trends in offices, such as flexible working times and workplaces, overpopulated office floors and increased communication requirements, can initiate lift modernization, which aims at keeping the building competitive. The requirements of lift modernization vary case by case according to the building type, the condition of equipment and the data available from the existing installation. This article describes three levels of people flow analysis and their benefits to customers. The levels require an increasing involvement to acquire data and perform analysis. This article can also be used as a handbook for choosing the proper level of analysis for a particular modernization project.

1 INTRODUCTION

At the moment, there are more than 14 million lifts and escalators in operation around the world. About one million new devices are installed every year. The lift modernization market increases with the number of aging devices. Modernization is very demanding when key components of a lift system prone to wear, such as the motor, drive, doors or control system, are replaced by new ones, and other good quality components are re-used. Successful modernization depends on careful planning. Therefore, the existing technical solution and the usage of the building need to be very well understood beforehand to be able to select and engineer the optimum new solutions.

The research on people flow analysis concentrates on new buildings [e.g., 1]. Not much research has been published on the principles of lift modernization, or how to estimate the improvement potential in buildings with aging lifts. Modernization is often concerned with many entrance floors, and new control systems such as destination control [2, 3]. In such cases, uppeak calculation is of limited value since it applies only to conventional control and buildings with one entrance floor. Regardless of its limitations, uppeak calculation quickly indicates whether the performance of the existing lifts is within an acceptable range and a further study is worth conducting. Then, simulation of the people flow and new equipment gives a better insight of the effects of the renovation [e.g., 4].

The analysis techniques for modernization are the same as those applied for new buildings. However, the performance of the existing equipment can be measured, and the measured data can be used instead of estimates of important parameters, which often are uncertain for the analysis of a new building. This increases the accuracy of the analysis. The people flow analysis of a modernization is based on the comparison of the existing and the new system, the situation before and after the modernization. Such a comparison shows the potential of the new equipment and provides performance indicators for building owners when deciding on the scope of the modernization.

In this paper, people flow planning service for lift modernization is divided into three levels depending on the complexity of the analysis: (1) basic, (2) advanced, and (3) consultation. A basic analysis follows the well-known principles, which are nowadays applied routinely for new buildings in the design phase. An advanced analysis is based on site surveys that collect data on lift performance, vertical people flow and passenger service quality [5]. A consultation service further widens the scope of the analysis to horizontal people flow, which can be measured by modern lobby sensors. The consultation can then utilize the wealth of data and recommend new arrangements in building guidance as well as in the location of attractions.

2 MODERNIZATION PLANNING SERVICES AND NEEDS

For a long time, lift planning has been based on morning uppeak, which has been considered the worst-case traffic condition for a lift group. This has been true with a conventional control system with up and down call buttons. In uppeak traffic, the destination control system (DCS) can handle more passengers than the conventional control [3]. The worst traffic condition for lifts with the DCS is mixed traffic, which occurs especially in office buildings during lunch-time. Nowadays, lift modernization is often initiated because passenger demand in a building has increased beyond the handling capacity of the existing lifts. Such a situation occurs when either the usage of the whole building or its occupancy levels change. In a typical modernization, the conventional control is replaced with the DCS to eliminate queuing in uppeak.

Modern building architecture prefers multi-purpose buildings and open offices. Personal working places and rooms are changed to meeting rooms or open office areas. A recent study on offices showed that open office spaces create value for users, tenants, and developers [6]. In such an agile workplace, seats can be freely occupied for the time needed, and when vacated can be occupied by another person. The survey revealed that end users spend an average of 54% of their total work time in open office spaces. Another modern trend is office hotels, where anyone can rent a room or a seat for some hours or days. Nowadays, canteens, cafeterias, restaurants and meeting rooms are often placed on any floor around the building. Many companies also encourage employees to expand their professional networks with common get-together hours with free coffee.

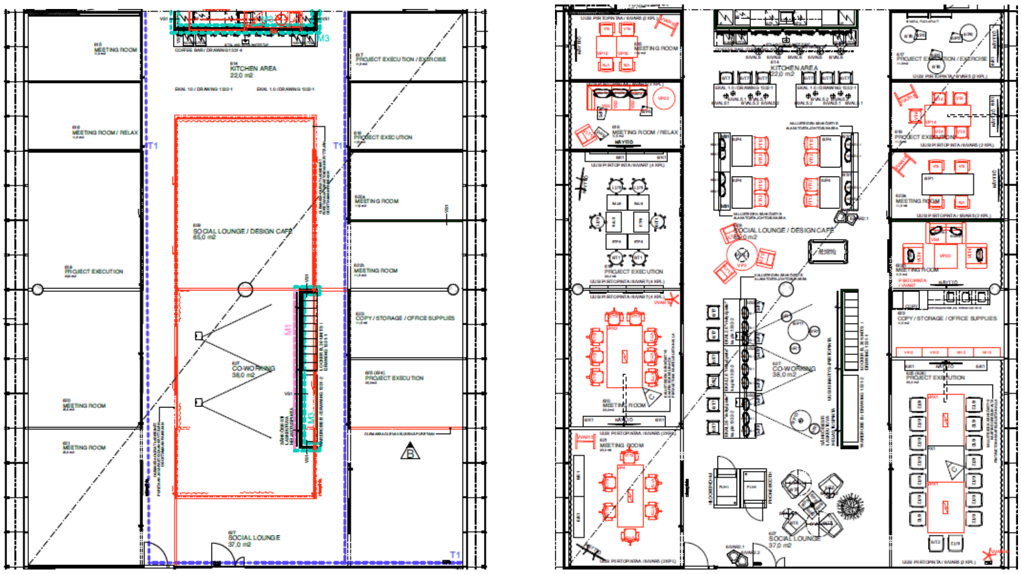

Figure 1 The renovation of a traditional office floor (left) to an open office (right)

The new office trends described above increase interfloor traffic in the building and affect the lift service quality and should thus be taken into account in the renovation process of an office building. As an example, a building with 14 office floors was recently renovated. In the renovation, four office floors were dedicated to open office space (Fig. 1). Also, the restaurant on the lowest floor and one of the renovated floors started to offer free coffee to all employees. After the renovation, the open office area attracted more people to visit the building. They wanted to meet others face-to-face, and, after the renovation, it was easier to find a free seat on the open office floors. The four-lift group which served the building had offered excellent service in the building with 15 seconds waiting times on average before the renovation. After the renovation, the number of passenger journeys had increased by more than 50%, from about 2 250 to 3 500 journeys per day as measured by the lift group [7]. This increased average waiting times to over 20 seconds.

3 BASIC ANALYSIS

Basic analysis follows the footsteps of a typical analysis for a new building and can be done without measurements on site. In addition, standard design criteria for lift groups can be applied [1, 7]. Such benchmarks are important in competing with new buildings. The main input parameters are building population based on floor areas and default lift parameters. Also, typical traffic patterns are used in the analysis. A basic analysis can be done as the first step if working practices, new tenants, restaurants, or other changes to floor utilization increase people flow inside the building.

The effect of the control system on passenger service quality can be studied with a lift traffic simulator such as the Building Traffic Simulator (KONE BTS™) [4]. Typical traffic mixes are simulated with constant passenger demand for at least two hours [9, 10]. For example, in offices the typical traffic mixes are morning uppeak with 100% incoming traffic and lunch traffic (e.g., 45% incoming, 45% outgoing and 10% interfloor traffic).

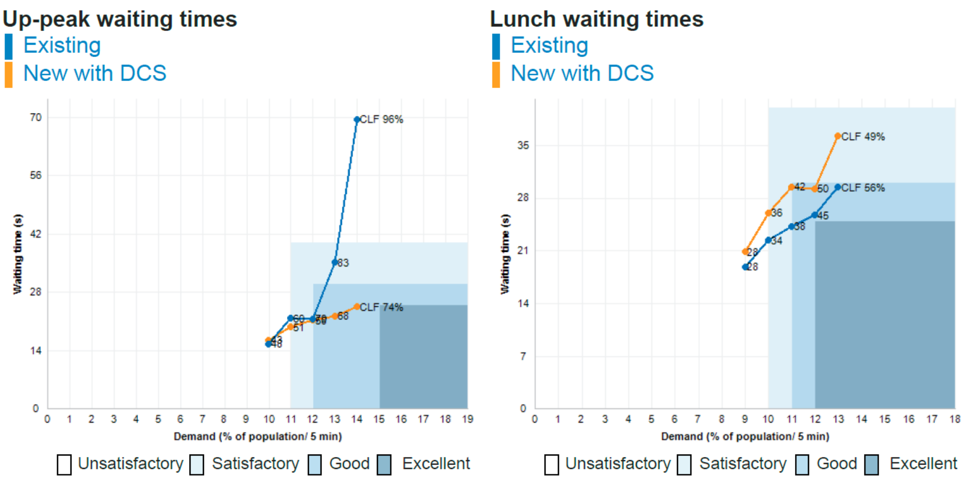

Figure 2 Average passenger waiting times with the conventional and destination control

The results in Fig. 2 show that the DCS can handle more traffic than existing control with the same service quality. CLF refers to car load ratio, i.e. the maximum filling of the car during a roundtrip. Here it is given as per cent of the rated passenger capacity. In uppeak traffic, average waiting times with the conventional control start to steeply increase after passenger demand exceeds 12% of population in five minutes. This result also shows that the handling capacity of the conventional control is 12%. With the DCS, this lift group saturates in uppeak at about 17% demand. Thus, the DCS can handle about 30% larger population or passenger demand compared to the existing group with the conventional control in uppeak traffic. In lunch traffic, average waiting times are a bit longer with the DCS compared to the existing system but remain below 40 seconds.

4 ADVANCED ANALYSIS

If lift components have come to the end of their life cycles, a deeper analysis with a lift traffic simulator is needed. The performance of the current equipment, people flow and passenger service quality should be measured. In the past, a stopwatch and pen and paper have been the only measurement methods in performance studies, but this approach is too laborious for extensive site surveys. Instead, e.g. smartphones with stopwatch and applications with accelerometer offer more efficient ways to measure lift speed, acceleration, jerk and door parameters. An automated device to collect data is preferable, but the use of such may not always be permitted [5]. In the following, the ways of measuring different simulation parameters are described in detail. The measurements aim at a simulation model that closely reproduces the current passenger service quality and lift operation. Such a model can then be applied to provide a realistic prediction of the effect of the modernization.

4.1 Lift cycle

Lift parameters may be considered as simple and straightforward to measure on site, but this is not necessarily the case. The parameters are related to the performance or cycle time, as shown in Fig. 3: door opening and closing time, door closing or photocell delay, motor- and drive-related start delay, lift flight time, door pre-opening or advance door opening time, and passenger transfer time.

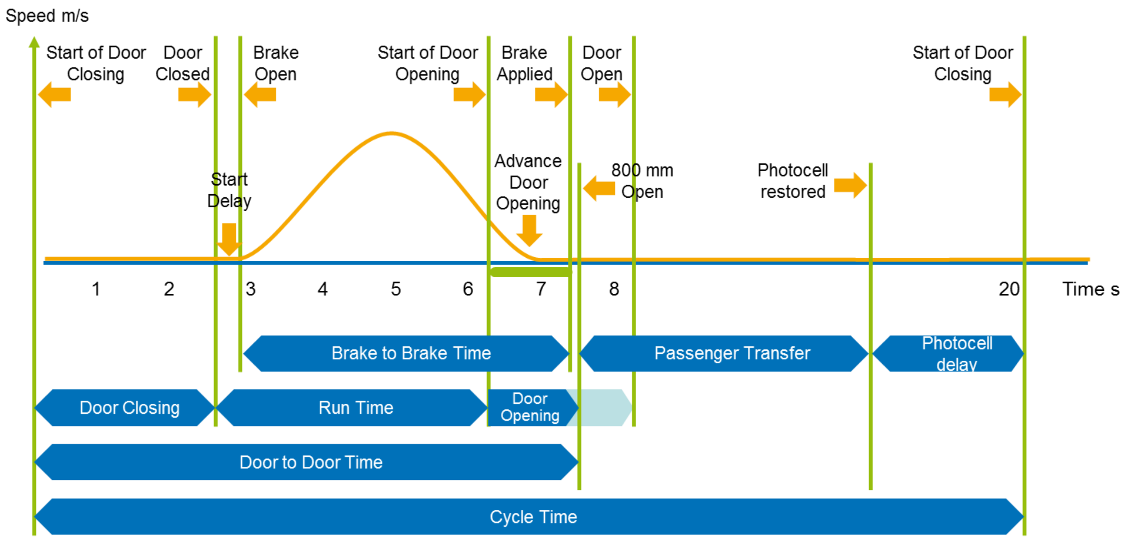

Figure 3 Lift cycle time definitions

Door opening and closing times are probably the easiest parameters to measure even with a stopwatch. Door opening time is often interpreted as until 800 mm open, when passengers can be assumed to start boarding or alighting. Door closing delay is a bit more complicated to measure, but, in the best case, could be seen from lift control parameters. Door pre-opening time is rather difficult to measure accurately. Therefore, if pre-opening is clearly visible, a half-a-second reduction in the performance time can be assumed by default.

People flow analysis requires values for rated speed, and acceleration and jerk so that the lift flight time can be accurately modelled. Usually, acceleration and jerk are not readily available but need to be measured or estimated. An accelerometer provides the most accurate estimations. It is also worth noticing that the flight time model of people flow analysis tools assumes symmetric acceleration and jerk rates during lift acceleration and deceleration. This is not necessarily the case in reality. For example, the approach of a lift to a floor may take longer than assumed by the final jerk. This can be counteracted by higher jerk rates during other parts of the flight. Therefore, an approach where only the time of final approach is measured may result in unrealistically poor lift performance [11].

Passenger transfer time is not exactly a lift parameter. However, passenger transfers constitute a major part of a lift cycle and can be estimated from lift cycles. The key is to understand its role: passenger transfer time is the average time for a single passenger to enter or leave a lift. Thus, if measurement data contains records of how long the doors had been open as well as how many passengers entered and exited during a particular stop, the average transfer time is readily available. If such data does not exist, it is possible to apply commonly used values or to try different values in the simulation to match the simulation results to the actual performance. In practice, two passenger may board a lift side-by-side. Thus, instead of two passengers boarding at, say, 1.0 second per person, the transfer time might be in the range of 1.0 to 1.5 seconds instead of 2.0 seconds.

4.2 Vertical people flow

The easiest way to measure vertical people flow is to observe and record the number of incoming and outgoing passengers in a lift lobby as they board and alight the lifts. However, this method misses interfloor traffic completely. An observer can also travel inside a lift to mark down interfloor passengers [12]. Passengers entering and exiting a lift can also be counted automatically either by a lift or by a 3D-camera-based device that is mounted in the lift ceiling [5].

If passenger counts are associated with the corresponding lift arrival and departure direction, the counted passengers per stop can be aggregated for period t to form statistics of passengers in to or out from a lift on floor i upwards or downwards, e.g., $P_{it,InUp}$. Traffic components, i.e., incoming, outgoing, and interfloor traffic, are then calculated as follows in absolute terms for E entrance floors and N floors in total in the building [7],

$$P_{t,inc} = \sum_{i=1}^{E} P_{it,InUp}, \tag{1}$$

$$P_{t,out} = \sum_{i=1}^{E} P_{it,OutDown}, \tag{2}$$

$$P_{t,intf} = \sum_{i=E+1}^{N} \left[P_{it,InUp} + P_{it,OutDown}\right]. \tag{3}$$

It is straightforward to manipulate these values into a form that can be input to a lift traffic simulator. Usually the traffic components are given as percentages. Passenger demand is given either as persons or as a percentage of the building population per five minutes. Period length, for which the described traffic definition is assumed constant, is typically 5 or 15 minutes. Five-minute periods may describe the changes in traffic more accurately but may be vulnerable to random variations. On the other hand, 15-minute periods are statistically more reliable since the longer periods allow multiple roundtrips for each lift. Fig. 4 shows a typical traffic profile or template for daily traffic in a single-tenant office building [7].

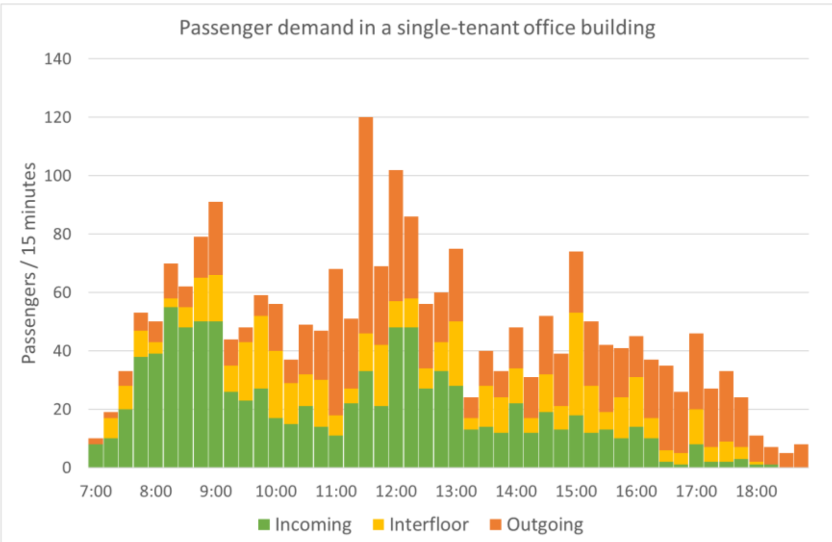

Figure 4 Measured daily vertical people flow

The above model has some limitations. First, it is applicable to a typical high-rise building, where the entrance floors are located at the bottom of the building and all populated floors above them. Second, the model misses traffic between the entrance floors. Third, the sizes of passenger batches travelling together towards the same destination floors cannot be directly observed from the passenger counts, but they can be estimated [13]. Regardless of these limitations, this current *de facto* standard model is sufficiently accurate in describing vertical people flow in tall buildings.

4.3 Building population and floor probabilities

The population on each floor can be defined according to the actual number of occupants, e.g., workplaces in offices, instead of an area-based estimation as in the basic analysis. In addition, a building security system can be used to estimate the absence rate or the number of visitors. If the building or floor usage is planned to change, the population can also be taken into account with such changes.

The automated passenger counts during lift stops can also be used to define building population and, in more complex cases, individual floor usage probabilities. The population, i.e., the number of occupants inside a building, until period T is given in Eq. 4 as the sum of differences between incoming and outgoing passengers. The total population can then be defined as the maximum of these momentary populations over the whole day.

$$POP_T = \sum_{t=1}^{T} \left[P_{t,inc} - P_{t,out} \right], \tag{4}$$

The method is demonstrated in Fig. 5, which shows the cumulative number of occupants in the building for all 15-minute periods of the day. As this example is an office building, the drop in the population after 11:00 signifies the beginning of lunch-time. After lunch, the population does not reach the highest level, about 300 persons. Probably this observation does not mean that many people leave the office after lunch. Instead, many use the stairs to return to their floors, which remains unobservable for the passenger counting in the lifts. Due to this kind of unobservable people flow, the population needs to be reset at some time in the day. In this case, the population can be assumed to reach zero at midnight. In other building types, where such a natural zero-level cannot be assumed, it is possible to find a daily minimum value and shift the population values accordingly.

Figure 5 The cumulative number of occupants (left) and examples of floor probabilities (right)

Individual floor populations can be derived from the detailed floor counts, as shown in Eq. 5. They are important parameters in defining probability distributions from which the traffic simulator generates the origin and destination floors of passengers. These probability distributions vary in time, which is also demonstrated in Fig. 5. The figure depicts two probabilities throughout the day: one that describes the bias between two entrance floors, and another that is the probability of an upper floor being an origin or a destination floor. The proportion of the lower entrance varies from 30% to 90%, where the high percentage during lunch-time is explained by the restaurant on that floor. The population on the upper floor of this example varies between 3% and 12% of the total population if the statistically volatile morning and evening periods are excluded.

$$POP_{iT} = \sum_{t=1}^{T} \left[P_{it,OutDown} + P_{it,OutUp} - P_{it,InDown} - P_{it,InUp} \right] \tag{5}$$

Thus, the probabilities of different floors being passengers' origin or destination is dynamic rather than static as assumed in the standard simulation models. Such situations can be modelled by simulating separately the most important periods of daily traffic, e.g., uppeak and lunch traffic, during which floor probabilities can be assumed constant.

4.4 Passenger service quality

A lift monitoring system such as KONE E-Link can provide data and statistics about lift cycles and passenger calls among other parameters. Especially the observed passenger service quality, such as passenger waiting times, is of great value. The current global trend is that on entrance floors a great percentage of people have their eyes and mind focused on their cell phones. This habit has the effect of making the waiting time seem psychologically shorter than it really is. This is just the opposite when a waiting passenger is alone on an upper floor with eyes focused on the hall lantern. In this latter situation, the wait can seem longer than it really is.

Omitting the psychological effects, the measured service parameters can be compared against the simulated values to validate the simulation models. In such a simulation, all control parameters need to be set as close to the site as possible. In addition, simulations can be repeated several times to achieve statistical accuracy. The site data could be collected for several days and combined into an average template, but such a model loses the relationship between the observed service quality and actual events.

In Fig. 6, an example of matching uppeak and lunch traffic simulation models with the monitoring system data is shown. The data is taken from the renovated office with KONE Hybrid DCS, which poses an additional challenge [14]. Passenger service quality is described by call time on the upper floors since only up and down call buttons are available there. The entrance floor lobbies are equipped with destination keypads, which allows the comparison of passenger waiting times.

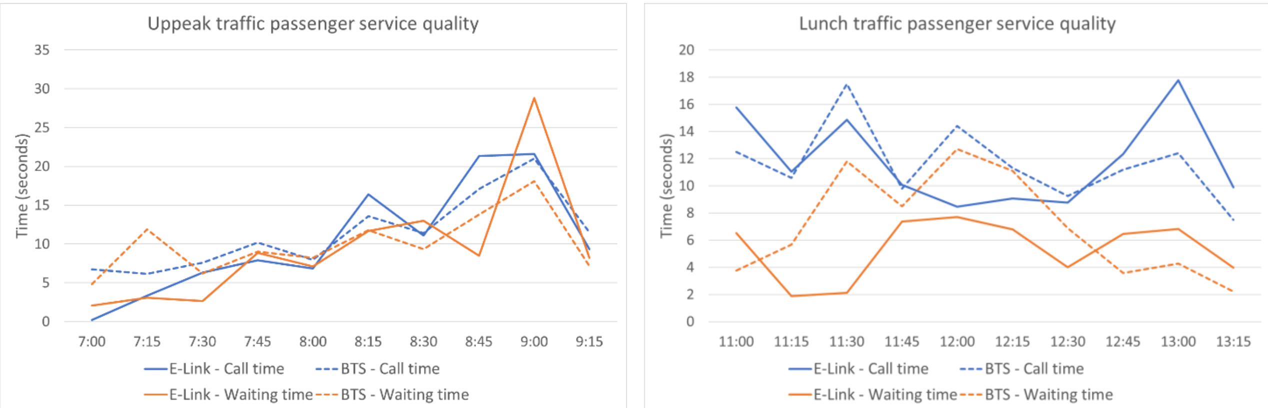

Figure 6 Passenger service quality by a lift monitoring system and a traffic simulation

According to the figure, the simulated values follow the monitoring system data quite well. However, some differences are visible, especially in average waiting times related to destination calls. This may be partly explained by tailgating, i.e., passengers who do not give the call but follow their friends to the lifts. With the assumption of individual arrivals, the simulated waiting and call times become much longer than actually recorded. It turns out that lunch traffic simulation needs to model passenger batch arrivals with the average batch size of 1.5 passengers, which was observed in this building in an earlier study [15]. The batch arrivals has been found a critical step in modelling the real traffic [16].

The average waiting and call times for the whole period can be seen in Table 1. On a statistical level, the simulated averages closely match the actual averages.

Table 1 Overall passenger service quality in uppeak and lunch traffic

	Uppeak		Lunch	
	E-Link	**BTS**	**E-Link**	**BTS**
Average Waiting Time [s]	11.4	12.9	5.7	8.2
Average Call Time [s]	14.4	13.8	12.2	12.6

5 CONSULTATION

The third level of planning service is the most comprehensive one, called building consultation service. The planning concerns not only vertical transportation but planning the entrance floor and transportation device layout to support smooth people flow in the building.

Consultation begins when an expert visits the site to study the current people flow. To determine the vertical transportation and horizontal movement of people, sensors or cameras can be installed in the main entrance floor corridors, doorways, lift lobbies and escalators. The study is based on current user routes and possible plans of future population.

Typical user groups and their routes are sketched in Fig. 7. Information about passenger journeys reveals bottlenecks and even typical passenger behaviour in the building. After becoming aware of the current people flow, both the building owner and the service provider can develop their new plan on a firm basis. The next step in the consultation service is to create a proposal for how the situation can be improved.

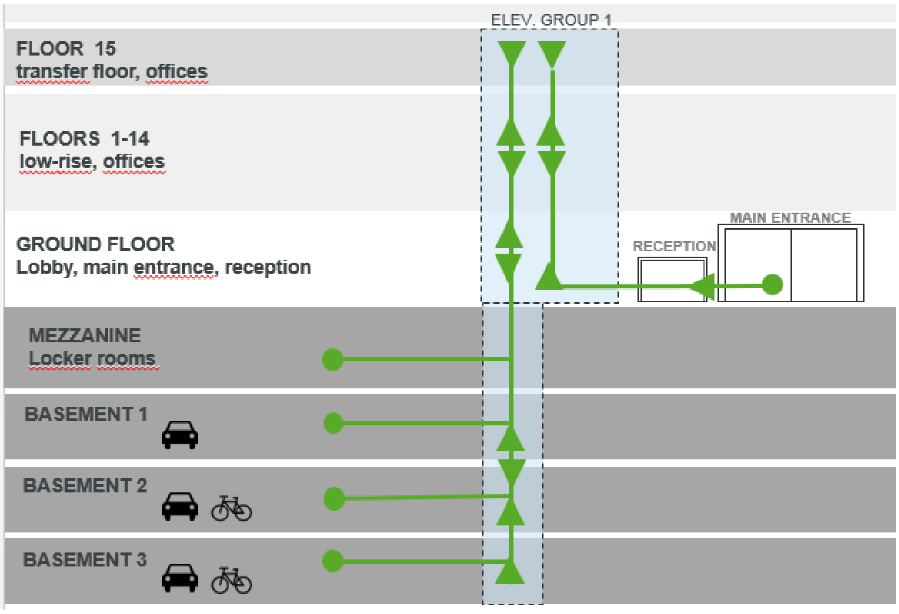

Figure 7 Example user groups and their typical routes in a building

In preparing the proposal for a modernization plan, the location of turnstiles, access control devices and destination keypads can be compared by simulations. Building traffic can be modelled with modern 3D simulation techniques (Fig. 8) [4]. The building layout is defined from architectural drawings showing the rooms, walls and corridors of the building [17]. In horizontal movement, people avoid colliding with each other, walls and other obstacles on the way. They move through doors, turnstiles and lift doors when they are open. In vertical movement, calls given by passengers from the call giving devices are allocated to lifts using real control system algorithms and software. Lift dynamics and lift models describe the physical movement of lifts in the building. Passenger traffic is generated for different user groups utilizing the measured traffic or floor populations. The journey times of different user groups as well as momentary densities in the building reveal the best plan for floor layouts. As a result of modelling the whole building traffic, the most advantageous floor layout, doors, turnstiles and transportation solutions can be proposed for the basis of the modernization.

Figure 8 A 3D model of people flow in a transit station

6 SUMMARY

In this paper, three levels of people flow planning services for lift modernization are discussed. Modernization is a current trend, for instance in Europe, where the lift market is mature. Only some components or the whole lift group can be modernized. According to the need, different levels of studies and modernization plans are proposed. Replacing the control system with a new one requires at least a basic analysis, but if it includes also access control or turnstiles, advanced or consultation level planning may be necessary.

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BIOGRAPHICAL DETAILS

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Janne Sorsa is Head of People Flow Planning in KONE Major Projects, Finland. He obtained the degree of D.Sc. (Tech.) in applied mathematics in 2017 from Aalto University School of Science, Finland. He has developed optimization models and numerical algorithms for lift group control systems. His research interests include all aspects of modelling people flow in buildings such as transport planning, simulation, behaviour, human factors and evacuation.