Call-Giving Devices in Lift Traffic Design with a Destination Control System

Janne Sorsa[1], Mikko Kontturi[2] and Mirko Ruokokoski[3]

[1]KONE Industrial Ltd, Keilasatama 3, FI-02150 Espoo, Finland
[2]KONE Industrial Ltd, Hissikatu 3, FI-05830 Hyvinkää, Finland
[3]KONE Corporation, Keilasatama 3, FI-02150 Espoo, Finland

Keywords: lift traffic design, destination control system, call-giving device, queuing theory, simulation

Abstract. In a Destination Control System (DCS), passengers use specific terminals in lift lobbies to give their calls. Often, a building security system is integrated with the lift control system: after having granted access at a security gate, passenger's home floor is automatically sent to the lift control system as a passenger call. Immediately after registering the call, the lift control system allocates a lift to the call and announces it on a display attached to the terminal or the gate. So far, passenger interaction with these call-giving devices has been overlooked in lift traffic simulation, which typically assumes an infinite-capacity queue for the devices and does not model passenger walking from the devices to the lifts. Standard passenger service quality parameters such as waiting time are defined from when a passenger either registers a call on a landing or joins a queue. Thus, in the case of the DCS, service quality measures include queueing, interaction and walking time. This paper introduces a queue-theoretic model for call-giving devices based on average interaction time and verifies it by simulations. The model predicts queue saturation, which allows to define handling capacity of call-giving devices with 80% utilization factor. The effect of walking distance on passenger service quality is studied by gradually increasing the distance from zero up to a remote location corresponding to security gates. Usage data of call-giving devices from operational lift groups with the DCS is analysed and compared to the current practices of lift traffic design.

1 INTRODUCTION

A Destination Control System (DCS) was introduced to the market in the 1990s and is nowadays provided by all major lift manufacturers. In the original concept, lift lobbies were equipped with passenger terminals with a keypad and display, which passengers used to input their destination floors [1]. The terminals have evolved into touchscreen displays with customizable user interfaces. Often, the building security system and security gates are integrated with the lift control system and act as call-giving devices. Also new call-giving and guidance concepts different from the original ones have been developed [2,3]. Given that the DCS is in use in numerous high-rise buildings and the *de facto* standard for new offices, it is surprising to find that practically nothing has been published about call-giving devices and passengers' interaction with them [4].

Passenger's interaction with call-giving devices starts before operating them by choosing a device, approaching it and preparing to use it. The passenger may need to swipe an access card to unlock the device. When using a typical terminal, the passenger first reads and interprets instructions to use it and, then, inputs the destination floor. The interaction is simplified if the security system automatically sends the destination floor to the lift control system after granting access to the passenger at a gate. The lift control system allocates a lift to the passenger and immediately shows it on the display attached to the call-giving device. After correctly interpreting the shown information, the passenger walks to the allocated lift and waits for its arrival. The display may still show the allocated lift for some time, the duration of which may be required by accessibility standards [5]. The shown information may delay the next passenger to start the interaction.

Current practice in lift traffic design neglects passenger interaction with call-giving devices. However, more realistic assessment of lift group performance could be obtained if lift lobbies and passenger interaction with the devices were considered properly in lift traffic simulations. Building Traffic Simulator (KONE BTS™) is capable of modelling call-giving device queues and lobby layout, which makes it a unique tool to study the effect of interaction and walking on lift group performance [6]. Standard measures for passenger service quality include *walking time* to the allocated lift and *standing time* in front of it [7,8]. Fig. 1 adds *queueing time* and *interaction time* to the beginning of a passenger journey from the moment when a passenger joins a call-giving device queue until registering a call. While lift traffic simulations can be conducted without considering the time spent before standing in front of a lift, it is always present in DCS installations. Therefore, this paper aims at bridging the gap between simulation and real-world installations as well as establishing guidelines about how call-giving devices should be considered in lift traffic design.

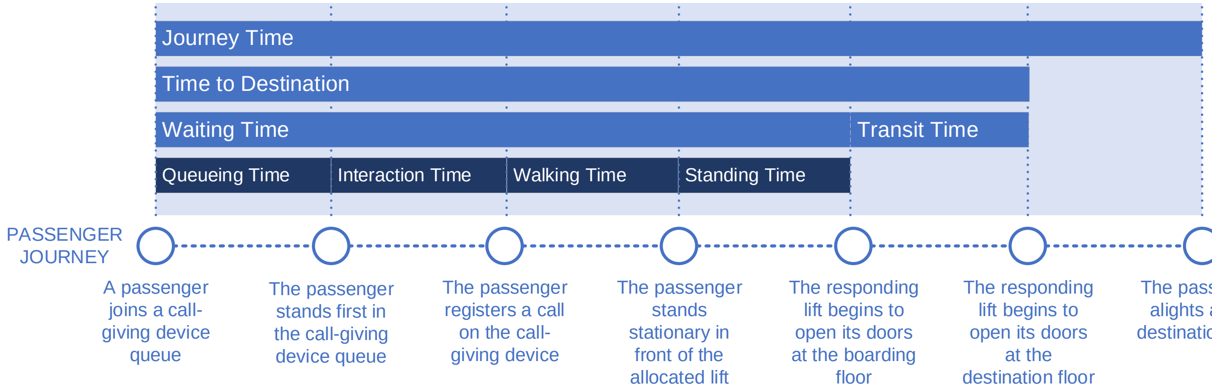

Figure 1 A passenger journey in a lift group with a destination control system

The rest of this paper is organized as follows. Section 2 presents a queue-theoretic model of call-giving devices and numerically shows queue saturation. Section 3 aims at validating the saturation in lift traffic simulation. In Section 4, the effect of passenger walking time on lift group performance is studied systematically. Section 5 utilizes lift monitoring system data to derive real-world evidence on passenger interaction with call-giving devices. Section 6 concludes the paper.

2 CALL-GIVING DEVICE QUEUES

Call-giving devices in a lift lobby can be considered as a multi-server queueing system. Lift passengers first arrive at the queue and then interact with the devices for some time. In office buildings, passenger arrivals have been found to follow a Poisson process during morning uppeak [9,10]. For simplicity, an M/M/c queue model is adopted for call-giving devices, where passengers arrive according to a Poisson process and are served by a single queue on c servers with exponentially distributed service times [11]. In practice, lift passengers form separate queues in front of each device, i.e., c single-server M/M/1 queues, and, upon arrival at the lobby, choose one based on queue length, for example. On the other hand, a passenger standing in a queue may jockey to another queue [12]. Thus, passenger behaviour may differ from the model assumptions in practice.

Utilization factor ρ in an M/M/c queue is related to arrival rate λ passengers per five minutes, service rate μ passengers per five minutes and the number of servers,

$$\rho = \lambda/(c\mu), \tag{1}$$

where service rate μ is the inverse of average interaction time T given in seconds, $\mu = 300/T$. The queue is stable if utilization factor ρ is less than one. Mean queue length L_q is given by [11],

$$L_q = P_0\rho\left(\frac{\lambda}{\mu}\right)^c / c!\,(1-\rho)^2, \tag{2}$$

where P_0 is the probability of no passengers in the system, i.e., a passenger can be served immediately,

$$P_0 = 1\Big/\left[\left(\sum_{m=0}^{c-1}\frac{(c\rho)^m}{m!}\right) + \frac{(c\rho)^c}{c!(1-\rho)}\right]. \tag{3}$$

The mean queue length can be expressed as a function of the utilization factor and the number of servers if the relationship of arrival and service rate in Eq. 2 is substituted by $c\rho$ according to Eq. 1. Table 1 illustrates mean queue lengths for up to six servers with varying utilization factors. The mean queue lengths start to increase uncontrollably when utilization factor exceeds 80%, which can then be used as the definition of a saturation point.

Table 1 Mean queue lengths for M/M/c queues

Utilization factor ρ [%]	**Mean queue length L_q for c servers [persons]**					
	1	**2**	**3**	**4**	**5**	**6**
20	0.05	0.02	0.01	0.00	0.00	0.00
40	0.27	0.15	0.09	0.06	0.04	0.03
60	0.90	0.68	0.53	0.43	0.35	0.29
80	3.20	2.84	2.59	2.39	2.22	2.07
90	8.10	7.67	7.35	7.09	6.86	6.66
95	18.05	17.59	17.23	16.94	16.68	16.45

Mean queue waiting time W_q in seconds can be derived from the mean queue length by Little's rule,

$$W_q = 300 \times L_q/\lambda. \tag{5}$$

Table 2 shows mean queue waiting times for M/M/c queues, which increase when varying interaction times from 0.001 to 5.0 seconds and utilization factors from 80% to 95%. The results clearly demonstrate exponentially increasing mean queue waiting times for utilization factors higher than 80%, which indicates queue saturation. Interaction time 0.001 seconds is impossible in practice but is included here to demonstrate how a queue with infinite capacity results in zero mean queue waiting time as currently assumed in lift traffic simulations.

The saturation point can be used to define handling capacity for a set of call-giving devices as a maximum sustainable number of passengers that can use the devices in five minutes,

$$HC5 = 0.8 \times c \times \mu = 0.8 \times 300 \times c/T. \tag{4}$$

The 80% saturation point is typically not considered in security gate handling capacities [e.g. 13].

3 CALL-GIVING DEVICE QUEUES IN LIFT TRAFFIC SIMULATION

Building Traffic Simulator models passenger journeys in a multi-storey building of any complexity by a network of building hotspots, through which virtual agents navigate from their origins to their destinations [6,14]. In the case of the DCS, each call-giving device in a lift lobby is associated with a hotspot having three-dimensional coordinates. An agent first chooses the starting point of her journey from the available call-giving devices. Device interaction time T is modelled as a constant delay, after which the agent registers the call, lift control system allocates a lift to it and the agent walks to the allocated lift. Walking times from the devices to the lifts constrain call allocation for subsequent passenger arrivals on a particular floor. A new passenger can be allocated to a lift if her estimated time of boarding occurs before a specified maximum stopping time has elapsed since the first passenger on the same floor boarded the lift. Thus, maximum stopping time sets the limit to how long a lift may wait for new passengers before closing its doors and departing. In the simulations that follow, maximum stopping time is set at 15 seconds.

Table 2 Mean queue waiting times with varying interaction time and utilization factor

Interaction time *T* [s]	Utilization factor ρ [%]	Mean queue waiting time W_q for *c* servers [seconds]					
		1	**2**	**3**	**4**	**5**	**6**
0.001	**80**	0.004	0.002	0.001	0.001	0.000	0.000
	90	0.009	0.004	0.003	0.002	0.002	0.001
	95	0.019	0.009	0.006	0.005	0.004	0.003
1.0	**80**	4.0	1.8	1.1	0.7	0.6	0.4
	90	9.0	4.3	2.7	2.0	1.5	1.2
	95	19.0	9.3	6.0	4.5	3.5	2.9
2.0	**80**	8.0	3.6	2.2	1.5	1.1	0.49
	90	18.0	8.5	5.4	3.9	3.1	2.5
	95	38.0	18.5	12.1	8.9	7.0	5.8
3.0	**80**	12.0	5.3	3.2	2.2	1.7	1.3
	90	27.0	12.8	8.2	5.9	4.6	3.7
	95	57.0	27.8	18.1	13.4	10.5	8.7
4.0	**80**	16.0	7.1	4.3	3.0	2.2	1.7
	90	36.0	17.1	10.9	7.9	6.1	4.9
	95	76.0	37.0	24.2	17.8	14.0	11.5
5.0	**80**	20.0	8.9	5.4	3.7	2.8	2.2
	90	45.0	21.3	13.6	9.8	7.6	6.2
	95	95.0	46.3	30.2	22.3	17.6	14.4

Call-giving device queues are studied for a five-car group that has a handling capacity of 14% of population per five minutes with the DCS (detailed building and lift parameters can be found in [15]). The number of call-giving devices and interaction times with a device are varied. With an interaction time of five seconds, a call-giving device can handle 48 passengers in five minutes. Passenger walking times are kept at zero by positioning all call-giving devices and lifts at the same coordinates. Pure uppeak traffic is simulated with increasing passenger demands from 10% to 16% of population per five minutes. Each passenger demand is simulated for 240 minutes, from which quantities occurring in the first 15 minutes and the last five minutes are excluded to avoid the statistical effects of initial and end transients [16]. Simulations are repeated 20 times to improve the accuracy of the results. For each simulated passenger demand, Table 3 shows queue utilization factors (ρ) calculated using Eq. 1, average number of passengers in the car at departure from the main entrance floor (*P*), average roundtrip time (*RTT*), average queueing time (*QT*), average standing time (*ST*), average waiting time (*WT*) and average time to destination (*TTD*).

In the cases, where passenger interaction time with call-giving devices are set at zero seconds, call-giving device queues do not show any sign of saturation as can be expected. Average queueing time increases uncontrollably only if passenger demand exceeds handling capacity and the lift group itself saturates. Passenger demand 15% provides interesting insights when studying the repeated simulations in detail. Due to the timing of random passenger arrivals, the lift group saturated in three out of the 20 simulations, resulting in very long average queueing and standing times . The remaining 17 simulations experienced no queueing at call-giving devices and average standing time was only about 35 seconds. Thus, depending on the random sequence of passengers, the lift group may be able to handle passenger demands above handling capacity without showing any alarming values in passenger service quality measures.

Table 3 Lift group performance in uppeak traffic with varying interaction times

	***T* [s]**	***c***	**Passenger demand [% / 5 min]**						
			10	**11**	**12**	**13**	**14**	**15**	**16**
***ρ* [%]**	**0**	**3**	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	5	**3**	72.2	79.4	86.7	93.9	101.1	108.3	115.6
		6	36.1	39.7	43.3	46.9	50.6	54.2	57.8
***P* [N]**	**0**	**3**	9.7	11.1	12.6	14.2	16.1	18.1	19.9
		6	9.7	11.2	12.6	14.3	15.9	18.1	19.9
	5	**3**	9.7	11.2	12.7	14.3	15.6	15.7	15.6
		6	9.7	11.2	12.6	14.3	16.0	17.9	19.9
***RTT* [s]**	**0**	**3**	112.2	116.9	121.7	126.5	132.3	140.1	159.8
		6	112.0	117.0	121.7	126.9	131.4	140.2	158.8
	5	**3**	112.1	117.7	122.3	127.4	130.8	131.7	130.9
		6	112.0	117.1	121.8	127.0	131.8	137.7	155.2
***QT* [s]**	**0**	**3**	0.0	0.0	0.0	0.0	0.0	29.4	529.3
		6	0.0	0.0	0.0	0.0	0.0	32.5	459.5
	5	**3**	2.5	3.8	6.2	15.7	167.3	630.0	1047.5
		6	0.2	0.2	0.3	0.5	0.6	9.4	393.8
***ST* [s]**	**0**	**3**	20.9	22.3	23.7	25.7	28.8	47.6	120.1
		6	21.1	22.3	23.8	25.7	29.0	47.2	119.4
	5	**3**	21.2	22.3	23.8	25.3	26.6	26.6	26.9
		6	21.0	22.2	23.8	25.5	28.5	39.0	101.8
***WT* [s]**	**0**	**3**	20.9	22.4	23.7	25.7	28.8	81.0	678.1
		6	21.1	22.4	23.8	25.7	29.0	87.7	637.3
	5	**3**	28.7	31.1	35.0	46.0	198.9	661.7	1079.4
		6	26.2	27.5	29.2	31.0	34.1	54.9	526.5
***TTD* [s]**	**0**	**3**	71.2	75.0	78.6	83.0	88.9	145.5	753.2
		6	71.4	75.0	78.7	83.1	88.9	152.3	711.6
	5	**3**	78.9	83.8	89.8	103.5	257.9	721.0	1138.5
		6	76.5	80.2	84.0	88.5	94.0	118.2	598.7

Lift group performance with six call-giving devices and five-second interaction time closely follow the results with zero-second interaction time, which follows from the fact that six call-giving devices even with a five-second interaction time have much higher handling capacity than the lift group, 22% of population per five minutes. Furthermore, average waiting time and time to destination are slightly more than five seconds longer than in the cases with zero interaction time. Thus, the modelling of passenger interaction with call-giving devices adds a constant delay almost equal to the parameter value to both passenger service quality measures.

Three call-giving devices with an interaction time of five seconds have a handling capacity of only 11% of population per five minutes. The results show the saturation of device queues in many ways. First, queue utilization factor for 11% passenger demand is about 80%, which indicates approaching saturation. Second, average queueing time for call-giving devices is already on a higher level for 12% passenger demand but clearly saturated for 13% passenger demand. Third, with high passenger demands from 14% to 16% per five minutes, lift group performance measures and passenger standing time stop increasing but remain at the level reached by 14% passenger demand. In this case, congestion at call-giving devices makes lift group performance look better since call registration stalls and lift control system cannot allocate the lifts to their capacities. Thus, in the case of too few call-giving devices, lift group saturation may go unnoticed.

4 PASSENGER WALKING TIME IN LIFT TRAFFIC SIMULATION

The impact of walking distances between call-giving devices and lifts on lift group performance and passenger service quality is studied by the same simulation setup as in the previous section. In all cases, interaction time T is kept at zero seconds and the number of call-giving devices at six. The walking distance is varied from 0 to 60 meters in 5-meter steps, and it is translated to a walking time by assuming a constant walking speed of 1.0 m/s. Simulation results are shown in Table 4.

Average number of passengers in the car at departure from the main entrance floor (*P*) and average roundtrip time (*RTT*) indicate that lift group handling capacity remains at 14% of population per five minutes up to a walking distance of 20 meters. Both measures are about the same for distances between 0 and 20 meters while, for the distances of 40 and 60 meters, they become clearly higher. Based on average roundtrip time with 14% passenger demand, a walking distance of 40 meters reduces handling capacity by 8.4 % and 60 meters by 16.3 %. The results indicate that the lift control system starts to lose its ability of allocating passengers going to the same destination to the same elevator due to walking time and maximum stopping time constraints in call allocation.

For passenger demands up to lift group handling capacity, 14% of population per five minutes, and for walking distances between 0 and 20 meters, average standing time (*ST*) remains about the same and average waiting time (*WT*) increases about as much as average walking time. In addition, average standing time decreases with walking distances longer than 20 meters. This indicates that the earlier the call is given to the lift system, the better for user experience, regardless of the loss in handling capacity. Average time to destination (*TTD*), on the other hand, increases slightly more than the distance grows for walking distances longer than 20 meters, which results from longer roundtrips.

The situation changes when passenger demand exceeds handling capacity: average waiting time increases much faster than the distance grows as lift group saturates and passengers start to queue for a call-giving device. The saturation can be seen in dramatically increasing average queueing times (*QT*) on call-giving devices especially for 40-meter and 60-meter walking distances.

As a short summary, call-giving devices can safely be located at distances up to 20 meters from lifts, and it may not be necessary to take the distances into account in simulations to correctly evaluate the performance of a lift group with a destination control system. Nevertheless, walking distances longer than 20 meters should be considered in simulations since they influence handling capacity.

Table 4 Passenger service quality in uppeak with different walking distances

	Walking distance [m]	Passenger demand [% / 5 min]						
		10	**11**	**12**	**13**	**14**	**15**	**16**
***P* [N]**	**0**	9.6	11.0	12.4	14.0	15.8	17.7	19.9
	5	9.3	10.7	12.1	13.7	15.5	17.5	19.9
	10	9.4	10.8	12.3	13.8	15.6	18.3	19.9
	20	9.6	11.0	12.4	14.0	15.7	18.7	20.0
	40	10.1	11.6	13.2	15.0	17.4	19.9	20.0
	60	11.7	13.3	15.0	16.7	19.0	20.0	20.0
***RTT* [s]**	**0**	112.0	117.0	121.7	126.9	131.4	140.2	158.8
	5	107.5	112.3	116.6	121.4	127.3	135.3	160.0
	10	108.5	112.9	118.1	122.8	128.6	143.2	160.7
	20	110.4	114.8	119.4	123.8	129.7	147.4	161.2
	40	116.8	122.0	127.3	133.3	143.5	160.8	161.7
	60	135.2	139.2	144.0	148.7	157.0	161.6	162.4
***QT* [s]**	**0**	0.0	0.0	0.0	0.0	0.0	32.5	459.5
	5	0.0	0.0	0.0	0.0	0.0	14.2	467.3
	10	0.0	0.0	0.0	0.0	0.0	56.0	543.2
	20	0.0	0.0	0.0	0.0	0.0	57.3	582.0
	40	0.0	0.0	0.0	0.0	0.2	215.2	646.0
	60	0.0	0.0	0.0	0.0	2.7	278.5	710.8
ST [s]	**0**	21.1	22.4	23.8	25.7	29.0	47.2	119.4
	5	21.5	23.1	25.1	27.1	30.2	41.8	117.5
	10	21.5	23.7	25.3	27.8	31.1	62.8	117.3
	20	19.3	21.3	23.0	25.1	28.8	67.7	109.2
	40	17.6	19.7	22.1	25.8	36.7	87.5	92.2
	60	13.2	15.0	17.9	22.7	42.1	71.6	73.4
***WT* [s]**	**0**	21.1	22.4	23.8	25.7	29.0	87.7	637.3
	5	25.6	27.1	29.2	31.4	34.6	63.8	649.9
	10	30.2	32.4	34.1	36.8	40.3	146.1	735.4
	20	37.1	39.2	41.0	43.3	47.4	167.8	778.5
	40	54.2	56.6	59.4	63.8	76.7	402.4	850.3
	60	66.4	68.9	72.7	79.0	111.3	477.4	918.8
***TTD* [s]**	**0**	71.3	75.0	78.7	83.1	88.9	152.3	711.6
	5	74.1	77.8	82.0	86.7	92.9	126.4	725.0
	10	78.9	83.4	87.6	93.0	99.5-	212.9	811.0
	20	87.0	91.2	95.2	100.0	107.2	236.9	854.4

	40	107.7	112.7	118.2	125.9	144.0	478.3	926.8
	60	128.9	133.0	139.0	147.6	184.7	554.0	995.8

5 CALL-GIVING DEVICE USAGE BASED ON LIFT MONITORING SYSTEM DATA

Call-giving usage patterns and passenger interaction time at a device are derived from lift monitoring system data of two lift groups. Group 1 has automatic call-giving at four parallel security gates that lead to the lift lobby. Gate 1 is the nearest and Gate 4 the furthest from the main building entrance. Group 2 has six touchscreen passenger terminals, where users manually select the desired destination floor from a list. The terminals are located around the lift lobby. Terminal 1 and 6 are the closest to the main entrance while Terminal 4 and 5 are the furthest. Table 5 shows walking distances between each call-giving device and lift for both lift groups.

Table 5 Walking distances between call giving devices and lifts

Group / Device	Walking distance from a call giving device to a lift [m]							
	Lift 1	**Lift 2**	**Lift 3**	**Lift 4**	**Lift 5**	**Lift 6**	**Lift 7**	**Lift 8**
1/1	6	8	11	13	6	8	11	13
1/2	6	8	11	13	6	8	11	13
1/3	6	8	11	13	6	8	11	13
1/4	6	8	11	13	6	8	11	13
2/1	7	9	10	18	20	22	N/A	N/A
2/2	10	7	4	7	9	13	N/A	N/A
2/3	13	9	7	5	8	11	N/A	N/A
2/4	22	20	18	10	9	7	N/A	N/A
2/5	18	15	12	7	7	7	N/A	N/A
2/6	8	7	7	13	16	19	N/A	N/A

Samples of more than 2000 calls placed at the main lobby were gathered from both lift groups for the period of one working week during the most intense period of morning uppeak traffic. Call-giving interval and time difference between two consecutive calls at the same device closely corresponds to passenger interaction time at a device if one passenger immediately follows another to the device and gives a call. Thus, an exceptionally long call-giving interval does not necessarily mean that a passenger was somehow troubled with the call-giving. More likely, the device was unused for a moment before the next passenger approached it or, in the case of security gates, the counter-flow of outgoing passengers blocked the incoming flow for a while.

Fig. 2 shows the distributions of call-giving intervals for each device in both lift groups, which clearly resemble gamma distributions with long tails extending greatly above 16 seconds. However, the least used devices have almost flat distributions probably arising from long periods, during which they are not used. Most frequently, call-giving intervals fall around 4.5 and 5.0 seconds for security gates and terminals, respectively. Some of the distributions have slightly raised peaks around 10 seconds, which may correspond to passengers whose first attempts to use a device failed.

Table 6 summarizes passenger call statistics for each device. Calls are not distributed evenly to the available devices but clearly chosen by the proximity of the device along passengers' paths from the entrance to the lift lobby. This behaviour should be considered already in the design stage when positioning devices to maximize their usage, to ensure enough devices and to enable efficient use of lift groups.

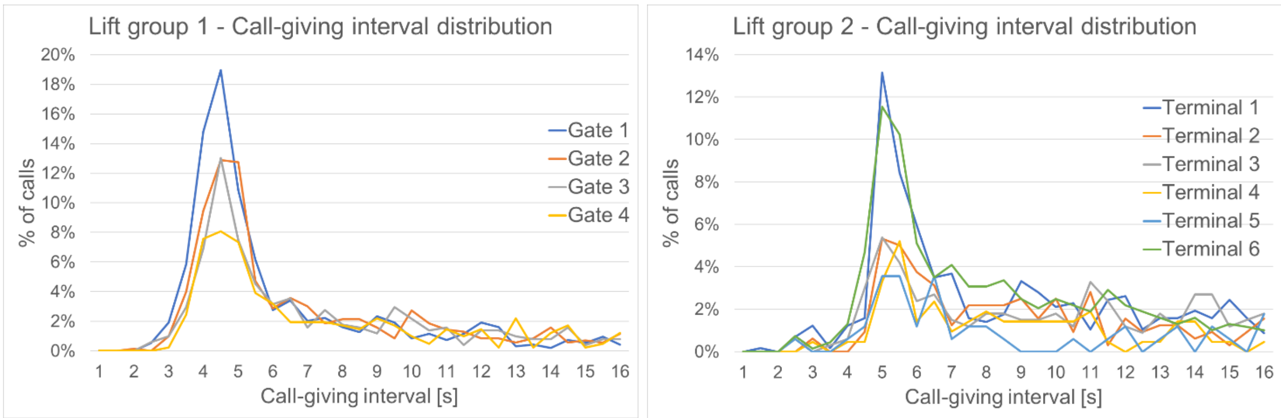

Figure 2 Call-giving interval distributions for each device

Call-giving intervals indicate possible interaction times with devices for design purposes. Mean call-giving intervals are high due to the long tails. Median values are lower than means but still too high to represent typical interaction times except possibly in the case of Gate 1 in Group 1. The shortest call-giving intervals are about two seconds for almost all devices, which indicates that experienced users can, at least in theory, use the devices quickly. However, such short intervals were rare exceptions in the data and cannot be considered typical interaction times. For design purposes, four seconds can be assumed for security gate interaction time and five seconds for touchscreen passenger terminals based on the observed statistics. With these interaction times, handling capacity of a security gate becomes 60 passengers in five minutes and, respectively, 48 passengers in five minutes for touchscreen passenger terminals by using Eq. 4.

Table 6 Call statistics for the call giving devices at the main lobby

Group / Device	Number of calls	% of calls	Call-giving interval [s]			Walking time [s]	Standing time [s]	Waiting time [s]
			Mean	Median	Min			
1/1	939	36.8	8.0	4.9	2.1	9.4	14.4	22.7
1/2	698	27.3	10.9	6.3	1.8	9.4	15.2	23.5
1/3	507	19.9	14.9	8.2	2.1	9.3	13.9	21.9
1/4	409	16.0	18.5	11.6	2.9	9.3	14.7	22.8
2/1	570	24.9	13.2	9.4	1.5	13.7	11.5	22.8
2/2	319	14.0	28.4	18.1	2.6	8.5	11.0	17.4
2/3	334	14.6	25.7	15.4	2.2	8.5	12.2	19.0
2/4	211	9.2	37.2	26.4	3.0	12.2	12.3	22.8
2/5	168	7.3	50.0	30.3	2.3	9.7	12.9	20.7
2/6	684	29.9	13.7	8.3	2.2	11.2	11.1	20.0

Finally, passenger service quality statistics demonstrate the effect of walking time. First, walking time seems to mostly explain the differences between the devices with respect to average waiting times. Average standing times are rather constant and independent on device locations, 14-15 seconds for Group 1 and 11-12 seconds for Group 2, which indicates that walking distances do not affect call allocation. Second, in these lift groups, average passenger waiting times are excellent, below 25 seconds, but, average standing times are even better, less than 15 seconds. Since standing times can be taken as a measure of user experience, waiting times reported by a lift monitoring system may lead to incorrect conclusions about lift group performance.

6 CONCLUSIONS

This paper studied the effect of call-giving devices on the destination control system by explicitly modelling passenger interaction with a device and walking between the devices and lifts. A queueing-theoretic model and lift traffic simulations showed that a call-giving device queue saturates when utilization factor exceeds 80%, which can be used to define call-giving device handling capacity. The simulations showed an important result that time to interact with a device and walking to the allocated lift do not negatively affect lift group handling capacity and passenger service quality if walking distances between the devices and the lifts remain below a practical limit of 20 meters. However, if walking distances are increased beyond 20 meters, the lift control system starts to lose its ability of allocating passengers traveling to the same destinations to the same lifts, which reduces lift group handling capacity. Finally, call-giving intervals, i.e., times between consecutive passenger calls, were derived from lift monitoring system data for the most intense morning uppeak traffic to determine typical passenger interaction times for call-giving devices. In lift traffic design, interaction times of four seconds for a security gate and five seconds for a touchscreen passenger terminal could be assumed as realistic design parameters.

Based on the results, lifts with a destination control system could be designed and commissioned in three steps, which would evaluate lift group performance independent of call-giving device locations and actual passenger demands:

1) Carry out lift traffic design according to the current practice and design criteria, if walking distances between the lifts and call-giving devices does not exceed 20 meters. Otherwise, account for the distances in design criteria or simulate vertical transportation along with detailed lobby layouts and passenger walking paths.
2) Select the number of call-giving devices by assuming realistic interaction time to match passenger demand and position them in attractive locations with respect to building entrances.
3) Verify lift group performance by simulating the same traffic patterns as in the design stage with a real-time simulator, where virtual passengers travel in the actual lift system.

The results of this paper directly apply to the studied destination control system. Nevertheless, also other destination control systems need to cope with call-giving device locations and passenger interaction with them, although practical control system implementations most likely vary and affect options available to fine-tune lift group performance. As the effect of call-giving devices on lift group performance is largely unknown, they should also be incorporated into other simulation models and design standards.

REFERENCES

[1] J. Schröder, “Elevatoring Calculation – Probable Stops and Reversal Floor “M10” Destination Hall Calls + Instant Car Assignment”. *Elevator World*, Vol. 38, No. 4, 40-46 (1990).

[2] M-L. Siikonen, J. Sorsa, and T. Susi, KONE Polaris Hybrid. *Elevator World*, Vol. 60(7), 2012, 108-112.

[3] R. Barker, “Harmonized Elevator Dispatching and Passenger Interfaces”. *Elevator World*, Vol. 66, No. 11, 82-90 (2018).

[4] J. Sorsa, and M-L. Siikonen, "Double-Deck Destination Control System. *Elevatori*, Vol. 37(5), 2008, 42-56.

[5] CBSC, *2019 California Building Code*. California Building Standards Commission, The United States of America (2019).

[6] M-L. Siikonen, T. Susi, and H. Hakonen, "Passenger traffic flow simulation in tall buildings". *Elevator World*, Vol. 49, No. 8, 117-123 (2001).

[7] ISO, *ISO 8100-32:2020 – Lifts for the transportation of persons and goods – Part 32: Planning and selection of passenger lifts to be installed in office, hotel and residential buildings*. International Organization for Standardization, Switzerland (2020).

[8] G. Barney, "Towards agreed traffic design definitions". *Elevator World*, Vol. 53, No. 2, 108 (2015).

[9] N.A. Alexandris, *Statistical models in lift systems*. Ph.D. thesis, The Victoria University of Manchester, Institute of Science and Technology (1977).

[10] J-M. Kuusinen, J. Sorsa, M-L. Siikonen, and H. Ehtamo, "A study on the arrival process of lift passengers in a multi-storey office building". *Building Services Engineering Research and Technology*, Vol. 33, No. 4, 437-449 (2012).

[11] S.M. Ross, *Introduction to Probability Models*. Academic Press, San Diego, CA, USA (2014).

[12] E. Koenigsberg, "On Jockeying in Queues". *Management Science*, Vol. 12, No. 5, 412-436 (1966).

[13] M. McGovern, "How to Calculate Turnstile Lane Needs for Any Facility". https://www.linkedin.com/pulse/how-calculate-turnstile-lane-needs-any-facility-mike-mcgovern/ (accessed 15.02.2020)

[14] J. Sorsa, "Lift traffic design: calculation or simulation?". *Proceedings of 10th Symposium on Lift and Escalator Technologies*, Northampton (2019).

[15] H. Hakonen, and M-L. Siikonen, "Elevator traffic simulation procedure". *Elevator World*, Vol. 57, No. 9, 180-190 (2009).

[16] T. Susi, J. Sorsa, and M-L. Siikonen, "Passenger Behavior in Elevator Simulation". *Elevatori*, Vol. 34, No. 5, 28-37 (2005).

BIOGRAPHICAL DETAILS

Janne Sorsa is the head of People Flow Planning in KONE Major Projects. He obtained the degree of D.Sc. (Tech.) in operations research in 2017 from Aalto University School of Science. 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.

Mikko Kontturi studied computer science at Tampere University of Technology, Finland and works as people flow planning expert in KONE Major Projects organization. He has been with KONE for more than a decade, and during the last 12 years has globally been responsible for people flow analysis and solutions for high rise buildings as well as training of people flow planning.

Mirko Ruokokoski graduated from the Department of Engineering Physics and Mathematics, Helsinki University of Technology in 2008. Currently, he is finalizing his doctoral thesis at Systems

Analysis Laboratory in the Aalto University, School of Science and Technology. He joined KONE in 2012 and has been working for R&D.