Impact of the Load-Area Bypass Feature on Passenger Service Quality

Diana Andrei, Mirko Ruokokoski

KONE Corporation, Keilasatama 5, 02150 Espoo, Finland

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Abstract. A lift stop is unnecessary if a lift stops to serve a call, but no passengers enter or exit the lift. There are many reasons for such a situation. For example, a passenger accidentally makes a call to the wrong floor, or a lift stops to pick up passengers, but no one enters the lift car since the waiting passengers consider the car full. In this paper the focus is only on the latter mentioned case. Traditionally, such unnecessary stops are reduced by using a load bypass feature. In this feature, a lift starts bypassing registered landing calls when the car is loaded over a configurable limit, called bypass load. When there are only passengers travelling, the load bypass feature works well in eliminating unnecessary stops. Nevertheless, when passengers transport light objects with them such as luggage or shopping carts, the floor area of a lift car may be fully occupied but the load is still below the bypass load limit and as a result, unnecessary stops may occur. If information about floor area usage of a lift car is available, i.e., what is the occupied percentage of the lift floor area by passengers and their belongings, then unnecessary stops will be better prevented. This paper studies how the number of unnecessary stops is dependent on different factors such as traffic intensity and pattern, and how much passenger service quality is improved in conventional control buildings when the floor occupancy information of lifts is used, in addition to load, in the bypass feature by analysing simulation results from a large set of hypothetical instances. The set is formed by varying traffic intensity, traffic pattern, number of objects transported and their sizes, lift group size, as well as the floor occupancy threshold and measurement error.

1 INTRODUCTION

Have you ever experienced a lift stop where nobody came in nor exit the lift car? Your lift ride to the destination floor is unnecessarily delayed. Frustrating, isn't it? Unnecessary lift stops are not just annoying for the passengers directly witnessing them but in general they negatively affect the service quality of all passengers. Unnecessary stops occur for several reasons, which are described with subtlety in Section 2. This paper considers only situations where the group controller brings a full lift to a landing and no passengers exit the car and none of the waiting passengers cannot board it because there is no room for them.

According to ISO standard 8100-32:2018 [1], "Means shall be provided to prevent an overloaded LCU from attempting to move away from a landing". Here LCU is an acronym for load-carrying unit. In practice this means that each lift is equipped with a load weighing device. Lift manufactures have used load weighing devices for a long time, in addition to their original safety purpose, among others to cut down unnecessary stops, which is referred to as *load bypass feature* [2]. In this feature, a lift starts bypassing registered landing calls when the car is loaded over a configurable limit, called *bypass load*. When there are only passengers travelling without any belongings, the load bypass feature works well in eliminating the unnecessary stops.

The situation changes quite much when passengers transport light objects with them like luggage, trolleys, stretchers, shopping carts, beds etc. Without loss of generality, this paper considers only luggage. It may happen that the floor area of a lift is fully occupied but the load is still below the bypass load limit, and as a result, unnecessary stops may occur. This issue has been recognized a long time ago. Strakosch [3] puts it in his book this way: "Elevator manufactures should be challenged to develop a means to reliably recognize when an elevator is filled by area rather than by weight, as is the current practice". Despite this open challenge and the fact that the issue has been known for a long time, it remained untouched for many years. Thanks to recent advances in computer vision hardware and software, the issue has gradually started to receive attention, both in industry (e.g., [4,5]) and academia (e.g., [6-13]).

This paper assumes that the floor occupancy information of lifts is available in the lift group controller and is used, in addition to load information, in the bypass feature which is in this case referred to as *load-area bypass feature*. No information about waiting passengers at lift lobbies is assumed to be known, except landing calls given by them. The feature is detailed in Section 3.

As far as we know, all previous papers either describe the issue on a general level without going into details, focus on development of a computer vision method for it, propose a new lift group control system using floor occupancy information of lifts, and/or report some experimental results. None of them though carries out a comprehensive analysis of how often unnecessary stops occur, whether they dependent on different factors, and how much key performance indicators are improved in conventional control buildings when using the load-area bypass feature in comparison with the load bypass feature, which is the main contribution of this paper.

This paper is organized as follows. Section 2 discusses in detail the reasons behind unnecessary stops and gives a definition for an unnecessary stop. Section 3 describes the load-area bypass feature together with key performance indicators used to assess its impact. Section 4 presents considered scenarios. Section 5 analyses the simulation results, and a conclusion follows in Section 6.

2 UNNECESSARY STOPS

Unnecessary stops occur for diverse reasons, and they can originate from all common call types: car calls, landing calls, and destination calls.

Consider first car calls. An unnecessary stop occurs if a passenger presses the wrong car call button, intentionally or accidentally, and none of the co-riders is going to that floor and no new passenger will board the car at the landing where the car call was given to. Suppose now that the given car call is correct. In this case an unnecessary stop may still occur if the passenger, who gave the call, for some reason exits the car at a wrong floor, for example too early before the lift reaches the destination floor of that call.

Consider next landing calls. An unnecessary stop occurs if a passenger gives a landing call in the wrong direction and none of the waiting passengers, including forthcoming passengers, is going in that direction from that landing and there is no car call given to that floor in the lift that will arrive to serve that call. For example, that may happen if the passenger presses both landing call buttons in the hope of getting a lift to arrive sooner, as the well-known misconception goes.

Suppose again that the call is correct. If now for some reason the passenger leaves the lobby before the serving lift arrives, for example, due to frustration with waiting, then an unnecessary stop may occur. Or the passenger just misses the serving lift due to poor signalization, for example, hall lanterns are dim, an audible lift arrival gong sound is quiet, or the lift lobby is overcrowded and getting in the serving lift in time is not possible. An unnecessary stop occurs, too, if the lift group control system dispatches a full car to the call and as a result, there is no room for the passenger.

Likewise, destination calls may result in unnecessary stops. In the worst case, there will be two unnecessary stops, one at the origin floor of the call and another at the destination floor.

A lift can travel from one floor to another without serving any passengers due to parking commands and such stops should not be considered as unnecessary. Therefore, in this paper, a lift stop is classified as *unnecessary* if during the stop no passengers leave or enter it and the load of the lift is greater than zero. In literature a few different names have been used for unnecessary stops: *useless stop* [2, 3], *redundant stop* [7,8], *wasted stop* [12, 13], and *false stop* [14].

As mentioned in Section 1, this paper considers only such unnecessary stops that originate from situations where the lift group controller brings a full lift to a landing and no passengers exit the car and the waiting passengers cannot board it because there is no room for them. Hence, unnecessary stops caused by other reasons including misbehaviour of passengers, congestion, parking commands, and poor signalization are left out of the scope.

3 LOAD-AREA BYPASS FEATURE AND KEY PERFORMANCE INDICATORS

This section begins with reconsidering the load bypass feature since it is used as a reference point. In this feature, a lift starts bypassing registered landing calls in its current direction of travel when the car is loaded over the bypass load limit, and bypassing happens until the car has enough room for more passengers, that is, the load is again below the limit. Usually, the bypass load limit is set to 60 – 80 % of the rated load of a lift, for example, to take into consideration cultural and building type differences in loading.

The load-area bypass feature uses floor occupancy information of lifts in addition to load information. Technically speaking, in the load-area bypass feature a lift starts bypassing registered landing calls if either A) measured load (in person) is greater than or equal to bypass load limit; or B) measured floor occupancy ratio (space demand of passengers and their luggage / rated load) is greater than predefined area threshold. Bypassing occurs until both measures - load and floor occupancy ratio - are below their limits.

The impact of the load-area bypass feature is measured by several key performance indicators (KPIs) including average waiting time (AWT) and average time to destination (ATTD) of passengers, carload factor (CLF), car area factor (CAF), as well as the number of unnecessary lift stops (ULS) and the number of unnecessary intermediate stops (UIS) of passengers. This paper reports passenger-based statistics rather than call-based statistics, e.g., waiting time of a passenger continues if the passenger is not able to enter the responding lift.

Carload factor is the largest load (in person) during the round trip of the lift in percentage of the rated load (in person). CLF is averaged over round trips. It is assumed in this paper that the weight of each piece of luggage is zero. Thus, load includes only passengers. *Car area factor* is the largest area (in person) occupied by passengers and luggage during the round trip of the lift in percentage of the rated load (in person). CAF is averaged over round trips, too. *Intermediate stop* (IS) of a passenger is a lift stop that occurs during a journey of the passenger except for stops at the origin and destination floors.

4 CONSIDERED SCENARIOS

To examine how much KPIs are improved when using the load-area bypass feature compared with use of the load bypass feature, and how they are dependent on different factors, a large set of hypothetical instances are formed, simulated and the resulting logs are analysed. The set is formed by varying lift group size, proportion of passengers with luggage, their luggage size, traffic pattern and intensity, as well as value of the floor occupancy threshold and measurement error. The following subsections give detailed information about the defined scenarios.

4.1 Lift group size

Four different low-rise hotel buildings are considered. Each building has one lift group, named as L2, L4, L6, and L8, respectively. The corresponding buildings are referred to by these group names, too. In each building the ground floor, which is indexed as 0, is the entrance floor, and populated floors start from floor 1. Lift groups are sized by following a common practice and two traffic patterns are considered. A traffic pattern can be characterized by ratios of traffic components: incoming, outgoing, and interfloor passengers [15].

Incoming passengers leave from the entrance floor and are destined to the populated floors of the building. *Outgoing* passengers leave the populated floors and travel to the entrance floor. *Interfloor* passengers travel only between the populated floors. Table 1 presents the proportions of the traffic components for traffic patterns used in the sizing of the lift groups. In these sizing simulations, all passengers travel without any belongings.

Table 1 Traffic patterns used in sizing simulations

Traffic pattern	**Traffic components [%]**		
	Incoming	**Outgoing**	**Interfloor**
Up peak	100	0	0
Two-way	50	50	0

More specifically, lift parameters and building populations are selected so that at traffic intensity of 12% of population / 5 minutes, AWT is less than 30 seconds and CLF is less than 80% in both traffic conditions. Lift and building parameters are shown in Table 2.

Table 2 Building information and lift parameters

Parameter / Group	**L2**	**L4**	**L6**	**L8**
Number of populated floors	6	13	21	24
Population per floor	57	59	54	57
Floor height [m]	3.6	3.6	3.6	3.6
Number of lifts	2	4	6	8
Rated load [persons]	13	17	24	26
Rated speed [m/s]	1.6	2.0	3.0	3.0
Acceleration [m/s2]	0.8	0.8	0.8	0.8
Jerk [m/s3]	1.2	1.2	1.2	1.2
Door width [mm]	1100	1100	1200	1300
Door closing time [s]	3.1	3.1	3.4	5.0
Door opening time [s]	1.4	1.4	1.4	2.3
Passenger transfer times [s] (in + out)	2.1	2.1	2.0	1.9
Photocell delay [s]	0.9	0.9	0.9	0.9
Start delay [s]	0.7	0.7	0.7	0.7
Advance door opening speed [m/s]	0.3	0.3	0.3	0.3
Advance door opening distance [m]	0.15	0.15	0.15	0.15

In addition, groups are equally balanced, i.e., their AWTs are about the same. Table 3 gives the AWT and CLF of the sizing simulations for all groups and both in up peak and two-way traffic patterns as well as in the last row the number of calls in percentage that have waiting time < 60 s for all groups in up peak traffic. For excellent service level it is recommended that in up peak traffic 98% of all waiting times should be below 60s [16] and AWT should be below 15s [17]. From Table 3 one sees that L2 provides excellent and other groups good service level, but very close to excellent.

Table 3 AWT, CLF and cumulative percentage of waiting times at 60 s in sizing simulations at 12 % traffic intensity for all groups and both traffic patterns (except the cumulative %)

KPI	Traffic pattern / Group	L2	L4	L6	L8
AWT [s]	Up peak	14.7	15.2	15.5	15.1
	Two-way	17.7	19.1	19.2	18.6
CLF [%]	Up peak	35.2	52.6	54.2	61.5
	Two-way	25.6	34.8	36.5	39.5
# Waiting times < 60 s [%]	Up peak	99.5	97.4	95.8	95.7

4.2 Passenger group ratios and luggage size

Two separate passenger groups are considered: passengers without luggage and passengers each with one piece of luggage, referred to as *without luggage* and *with luggage* groups, respectively. Ratios of 10%, 20%, 30%, and 50% are considered for with luggage group. For example, 10% means that 10% of the population travel with one piece of luggage each and 90% of the population travel without any luggage.

Three luggage sizes are defined, 1, 2, and 3 units. 1 unit corresponds to the size of a single person. For example, size 2 means that the space demand of a passenger with luggage is 3 passengers. As mentioned in Section 3, the weight of each piece of luggage is zero.

4.3 Traffic patterns and intensity

Several different traffic patterns are studied. Table 4 presents the proportions of the traffic components for each considered traffic pattern and for both passenger groups.

Table 4 Traffic patterns used in analyses

Traffic pattern	Passenger group	Traffic components [%]		
		Incoming	Outgoing	Interfloor
Down peak	With luggage	0	100	0
	Without luggage	0	100	0
Two-way	With luggage	50	50	0
	Without luggage	50	50	0
Mixed	With luggage	25	25	50
	Without luggage	25	25	50
Hotel	With luggage	0	100	0
	Without luggage	45	55	0

Traffic intensity is varied, starting from an arrival rate of 4% of population / 5 minutes, stepwise increasing the rate 1% amount at a time, and ending at the arrival rate of 15%. At each intensity, traffic is simulated for 120 minutes to reduce the variance of the results.

4.4 Bypassing trigger values

In load-based bypassing, it is assumed that there is no error in the load measurement, and load is measured in the number of passengers. 80% of the rated load, rounded to nearest integer, is used as a trigger value, and its value for each group is given in Table 5 in the last row.

Table 5 Trigger values for both area-based and load-based bypassing

Bypass feature, Trigger policy / Group	L2	L4	L6	L8
Area-based, No space for 1 passenger	0.924	0.942	0.959	0.962
Area-based, No space for 2 passengers	0.847	0.883	0.917	0.924
Area-based, No space for 3 passengers	0.770	0.824	0.875	0.885
Area-based, No space for 4 passengers	0.693	0.765	0.834	0.847
Load-based, ~ 80 % load [persons]	10	14	19	21

In area-based bypassing, four different trigger values are investigated, no space for 1, 2, 3, or 4 passengers. Their values for each group are listed in Table 5 in the first four data rows. Some uniformly distributed error is considered in the measurement of floor occupancy of a lift: 0 %, 5 %, and 10 %. For example, if the total space demand of passengers and luggage is 15 in a 20-person car after a stop, and the measurement error is 5 %, then the measured floor occupancy is uniformly sampled from range [0.7125 (=15/20*0.95), 0.7875 (=15/20*1.05)].

5 SIMULATION RESULTS

The formed set of scenarios contains 34 560 different instances in total. All of them are simulated in Building Traffic Simulator, [18, 19], which is KONE's internal tool used for traffic analyses as well as in research and development activities.

Group controller is *conventional control* with up and down call buttons at every landing, except the highest and lowest levels where on both is only one landing call button. Readers interested in the technical details of the controller are referred to reference [20].

Section 5.1 analyses instances in which only the load bypass feature is on, to see how much there are unnecessary stops in general, are they dependent on different factors such as traffic pattern and intensity, and how much AWT and ATTD of passengers vary between with luggage and without luggage passenger groups. Section 5.2 in turn investigates the impact of the load-area bypass feature on the KPIs.

5.1 Simulation results for scenarios with the load bypass feature

In instances with the load bypass feature, there are 13,159,539 lifts stops and out of them 698,577 are unnecessary, Table 6. This means that 5.31% of lifts stops are unnecessary.

Table 6 Number of lift stops and # ULS both in absolute and relative values in the load bypass scenarios

# Lift stops	# ULS	# ULS [%]
13,159,539	698,577	5.31

Fig. 1 gives the histogram of the relative number of ULS per considered scenario with the load bypass feature and cumulative % (on the secondary axis). From this figure one observes that ULS occur quite rarely, in 88.06% of instances their relative number is less than 5%, but there are some scenarios where ULS occur often; in 117 scenarios more than 50% of lift stops are unnecessary.

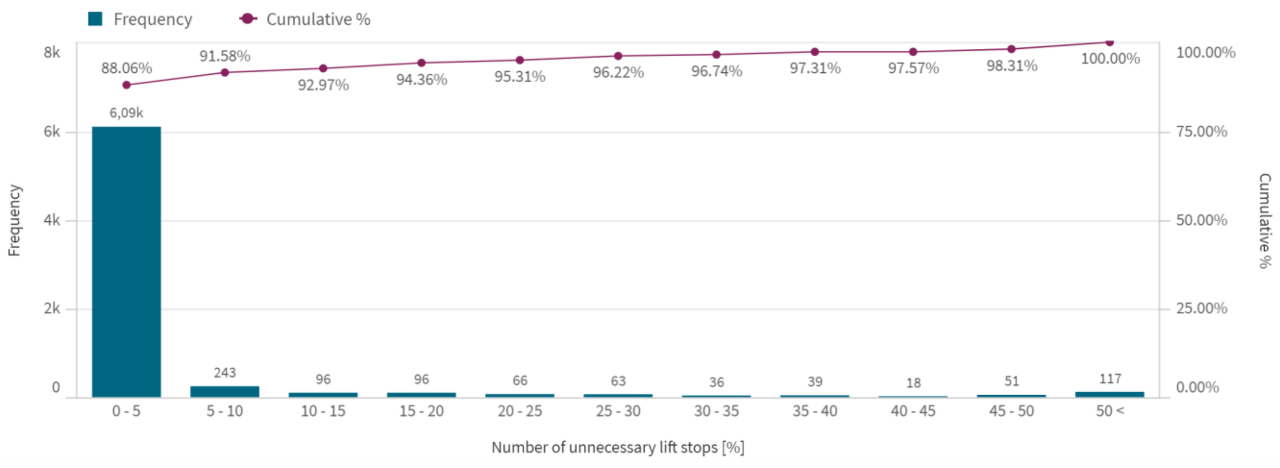

Figure 1 Histogram of the relative number of ULS per scenario and cumulative %

In instances with the load bypass feature, 13,854,492 passengers are served in total, they experience 38,627,808 ISs, and out of them 7,650,306 are unnecessary, i.e., 19.81% are unnecessary, Table 7.

Table 7 Number of passengers served, IS and UIS in the load bypass scenarios

# Passengers	# IS	# UIS	# UIS [%]
13,854,492	38,627,808	7,650,306	19.81

Fig. 2 displays the histogram of the number of UIS in instances with the load bypass feature and cumulative %. The majority of passengers, 87.55%, do not see any UIS during their journeys, but some passengers experience lots of them; 96 passengers face 21 unnecessary intermediate stops.

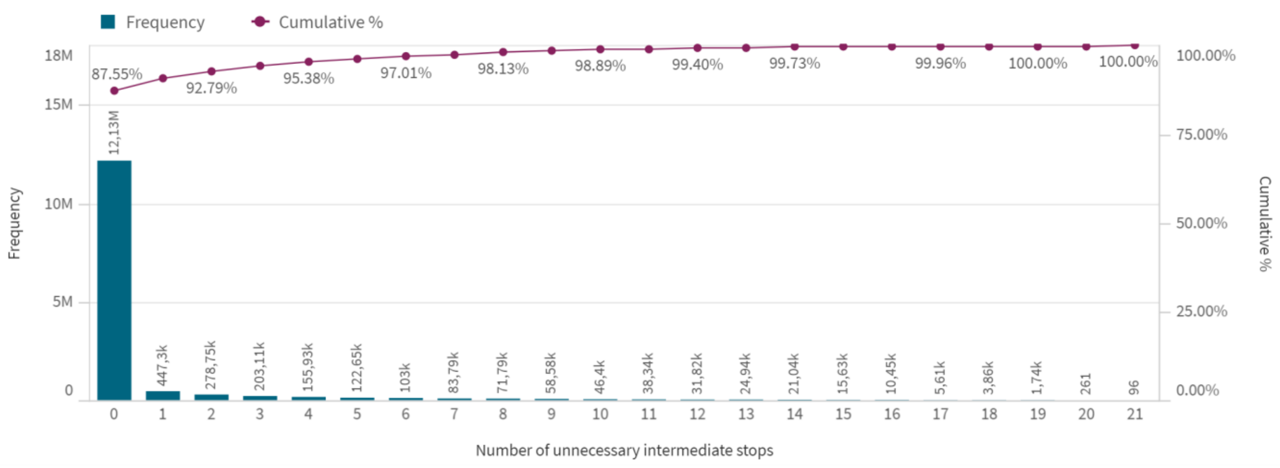

Figure 2 Histogram of the number of UIS and cumulative %

Consider next how the unnecessary lift stops are dependent on different factors. Fig. 3 shows the number of ULS both in absolute values (bars) and relative values (line, on the secondary axis), per traffic intensity over all instances with the load bypass feature. It is clear from this figure that the number of ULS increases as a function of traffic intensity and in an exponential fashion, though the growth rate seems to be decreasing.

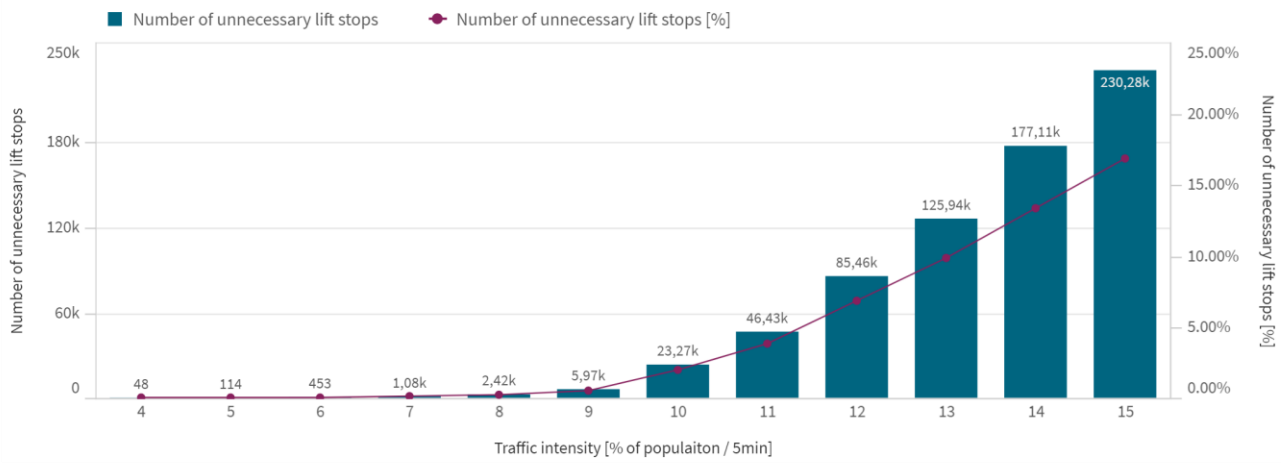

Figure 3 Number of ULS in the load bypass scenarios per traffic intensity

Table 8 reports the number of ULS per traffic pattern over all instances with the load bypass feature, both in absolute and relative values. According to it, down peak generates the largest number of ULS, followed by the hotel traffic. The reason is that in both traffic patterns the proportion of outgoing traffic component is large, and outgoing passengers are travelling to a single point, the entrance level located at the lowest level.

Table 8 Number of ULS per traffic pattern over all instances with the load bypass feature

Traffic pattern	Down peak	Hotel	Mixed	Two-way
# ULS	323,922	265,095	54,237	55,323
# ULS [%]	10.42	8.23	1.47	1.76

ULS are not only dependent on traffic intensity and pattern, but they are also dependent on how many passengers travel with luggage. In Fig. 4, the left-hand side bar chart illustrates the number of ULS per ratio of luggage passenger group over all instances with the load bypass feature whereas the right-hand side illustrates the number of ULS per luggage size over all instances with the load bypass feature. Based on this figure one can say that the more passengers with luggage there are and the bigger luggage size, the more unnecessary stops there are.

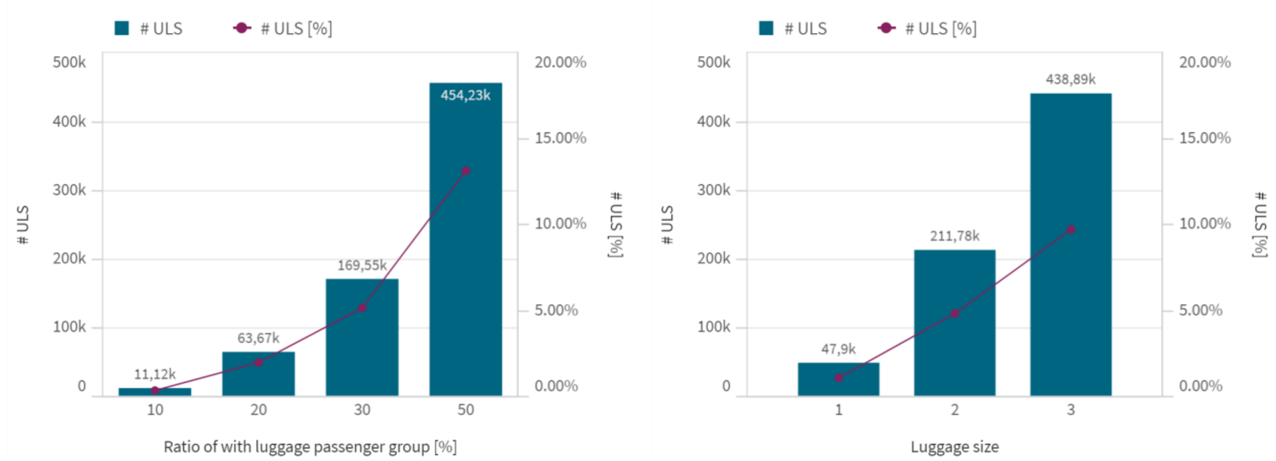

Figure 4 Number of unnecessary lift stops per ratio of luggage passenger group (left) and per luggage size (right) in instances with the load bypass feature

Fig. 5 depicts the number of ULS per floor and per traffic pattern for group L8. Only a single group is considered now since each building has a different number of floors. Results for other groups are similar. From this figure one sees that the largest number of ULS occur at the lowest populated levels. To be precise, for down peak, hotel, and two-way traffic patterns the largest number is at level 1 or 2, but for the mixed traffic it is at a bit higher, at level 5 or so.

One of the major reasons is that in call allocation, for each lift, the service order of car calls given inside of it and landing calls asssigned to it is determined according to a full collective control [20,21]. In general, the collective control works as follows: “The lift stops to answer both car calls and landing calls in the lift direction of travel, in floor sequence. When no more calls are registered in the lift direction ahead of the lift, the lift moves to the furthest landing call in the opposite direction, if any, reverses its direction of travel, and answers the calls in the new direction” [2]. Thus, for example in down peak, each lift starts serving landing calls downwards from the highest call allocated to it after dropping off passengers and reversing its direction of travel at the entrance level.

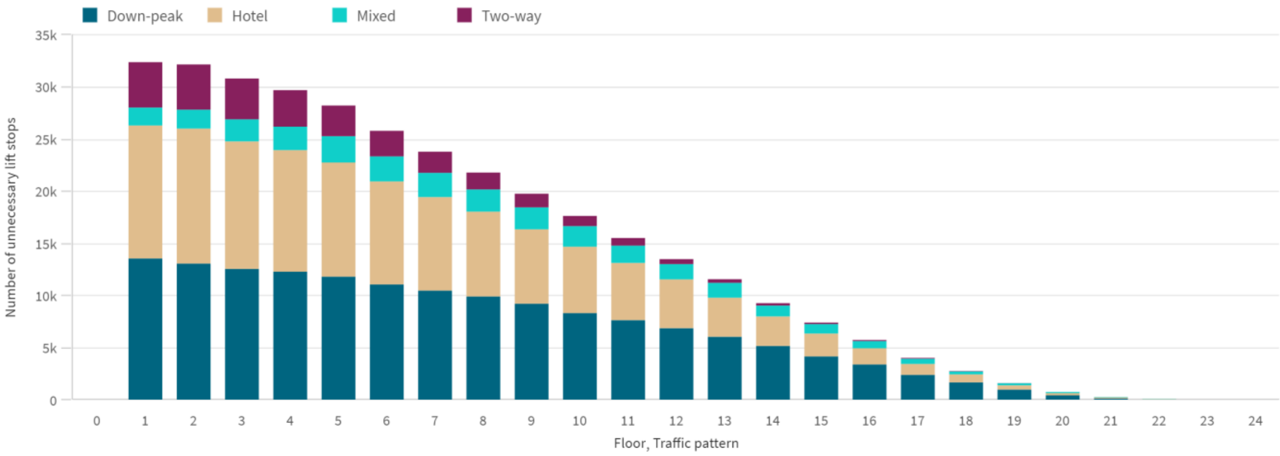

Figure 5 Number of unnecessary lift stops per floor and traffic pattern for L8 group

It follows from this ULS distribution that service quality is not fairly distributed between the levels, as can be verified from Fig. 6 that shows AWT per floor and direction over all the load bypass scenarios. For example, AWT at level 1 downwards is more than tenfold higher compared with the highest levels.

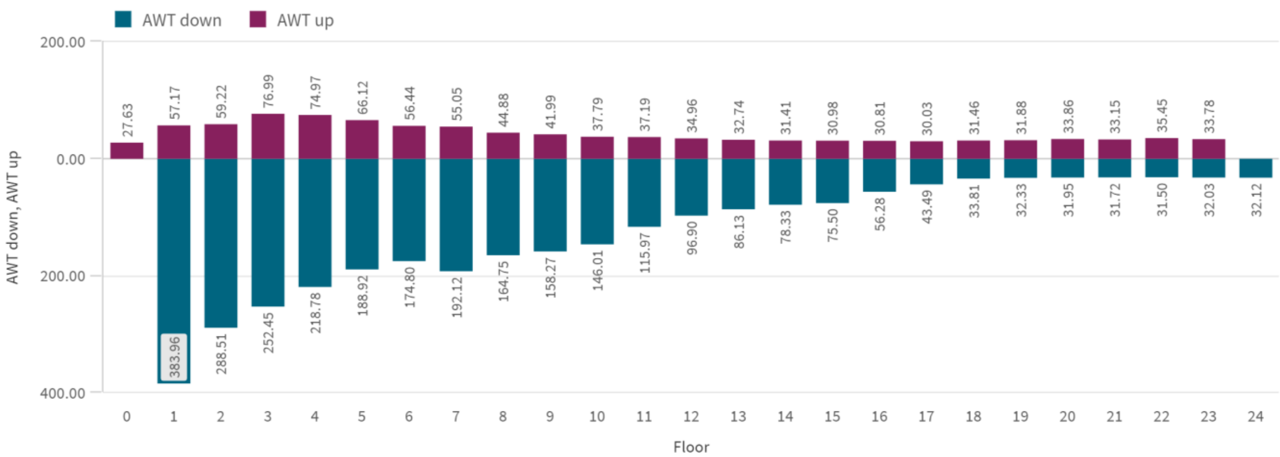

Figure 6 AWT per floor and direction over all instances with the load bypass feature

Neither is service quality fairly distributed between different passenger groups. AWT and ATTD per luggage size and space demand are provided in Fig. 7. Recall that luggage size x means that the space demand of with luggage passenger is x+1 units and the space demand of passenger without luggage is 1. It is clear from this figure that the larger the belongings of passengers are, the longer their waiting times and times to destinations are. For example, in scenarios where luggage size is 3, AWT (ATTD) of passengers travelling without any belongings is 134.26 (197.57) seconds but AWT (ATTD) is 416.17 (483.90) seconds for passengers travelling with luggage.

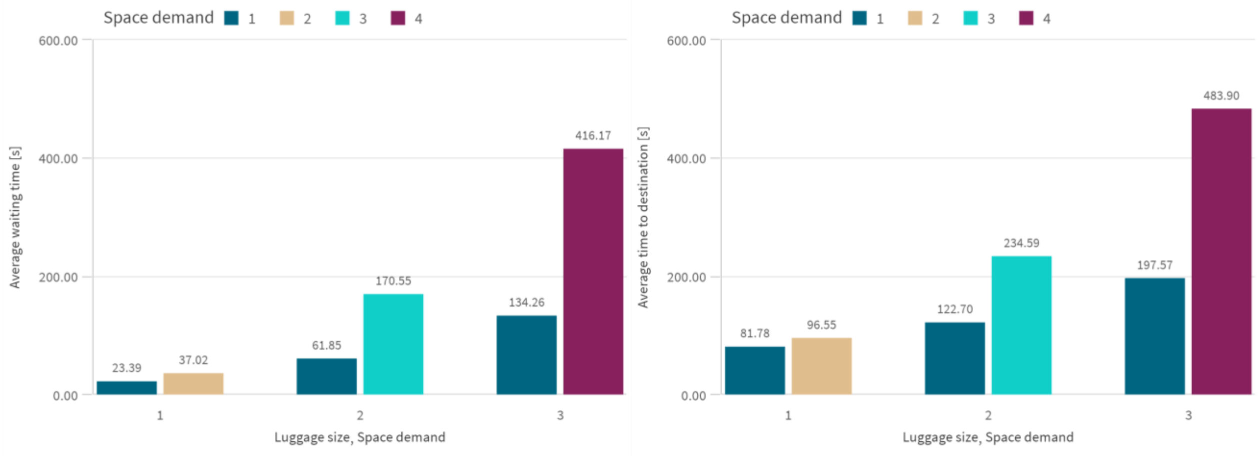

Figure 7 AWT (left) and ATTD (right) per luggage size and space demand over all instances of the load bypass feature

5.2 Impact of the load-area bypass feature

This section investigates the impact of the load-area bypass feature on the KPIs. Overall improvements are reported in Table 9. # ULS and # UIS for the load-area bypass feature are averages over different trigger values used in the feature.

Table 9 Overall improvements of the load-area bypass feature on the KPIs

Feature / KPI	AWT	ATTD	# ULS	# UIS	CLF [%]	CAF [%]
Load bypass	109.84 s	171.48 s	698,577	7,650,306	21.52	34.40
Load-area bypass	24.16 s	79.26 s	33,027.00	298,730.75	21.03	33.71
Improvement [%]	78.00	53.78	95.27	96.10	2.28	2.01

According to this table, the impact of the load-area bypass feature on AWT and ATTD is significant. Overall AWT is reduced by 78% and ATTD by about 54%. The reduction is dependent on traffic pattern and intensity as can be seen from Table 10 and Fig. 8, respectively.

Table 10 AWT and ATTD improvements of the load-area bypass feature per traffic pattern

Traffic pattern	Down peak	Hotel	Mixed	Two-way
AWT improvement [%]	86.88	87.08	32.30	61.54
ATTD improvement [%]	67.93	69.46	15.39	32.40

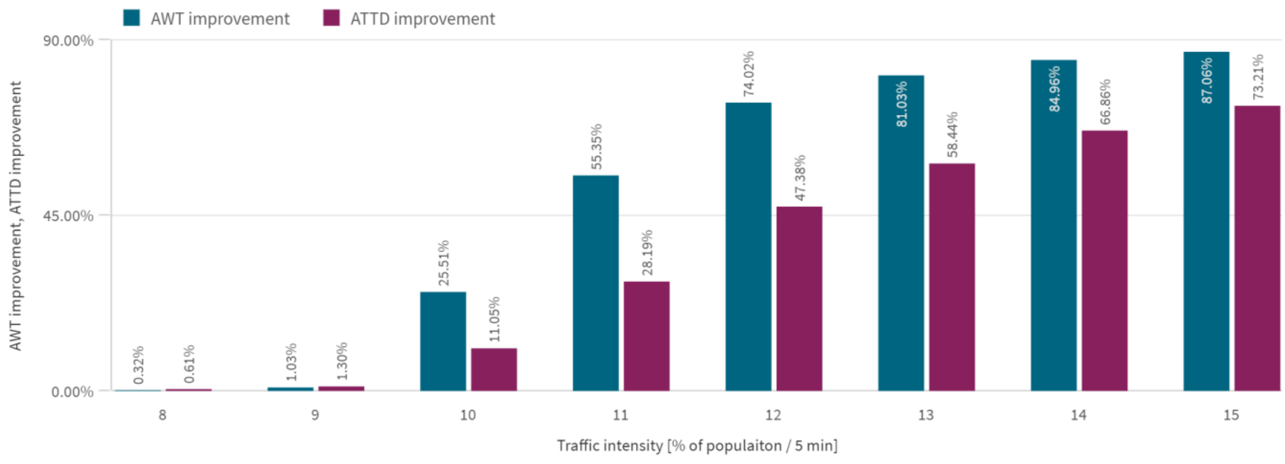

Figure 8 AWT and ATTD improvements of the load-area bypass feature per traffic intensity

According to Table 11, improvements in AWT and ATTD are also slightly dependent on the trigger value used in the load-area bypass feature.

Table 11 AWT and ATTD improvements of the load-area bypass feature per trigger value

Trigger value	No space for 1	No space for 2	No space for 3	No space for 4
AWT improvement [%]	75.96	78.23	78.84	78.97
ATTD improvement [%]	51.91	53.83	54.53	54.86

The load-area bypass feature does not only shorten waiting times and times to destinations, but it also makes the service fairer between floors and between different passenger groups, as can be verified from Fig. 9 and 10, respectively, in comparison with Fig. 6 and 7.

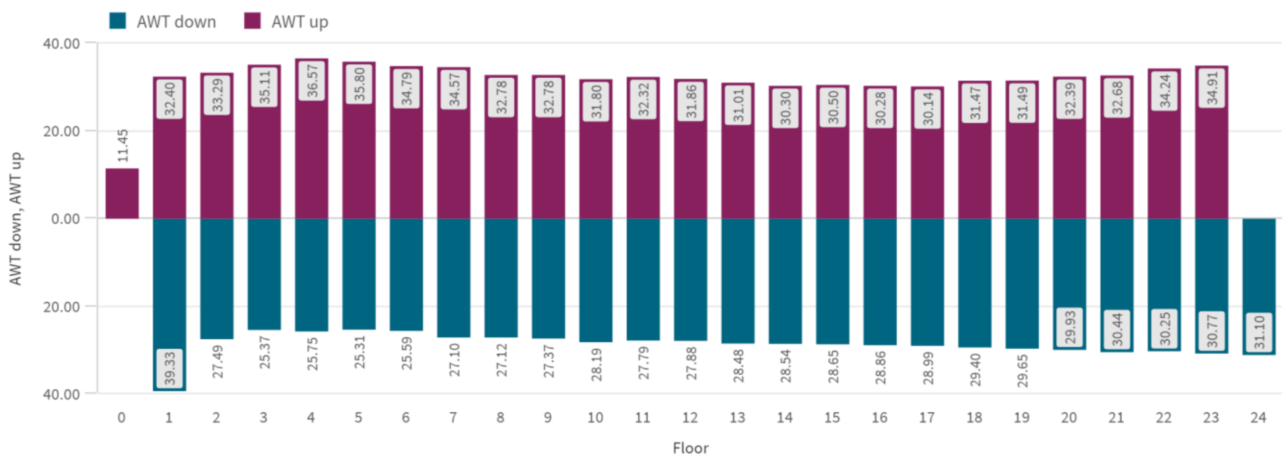

Figure 9 AWT per floor and direction over all instances of the load-area bypass feature

The impact of the load-area bypass feature on the number of ULS (UIS) is very big; more than 95% (96%) of unnecessary stops are eliminated in general. The reduction is dependent on traffic patterns as can be seen from Table 12. As before, # ULS for the load-area bypass feature is average over different trigger values used in the feature.

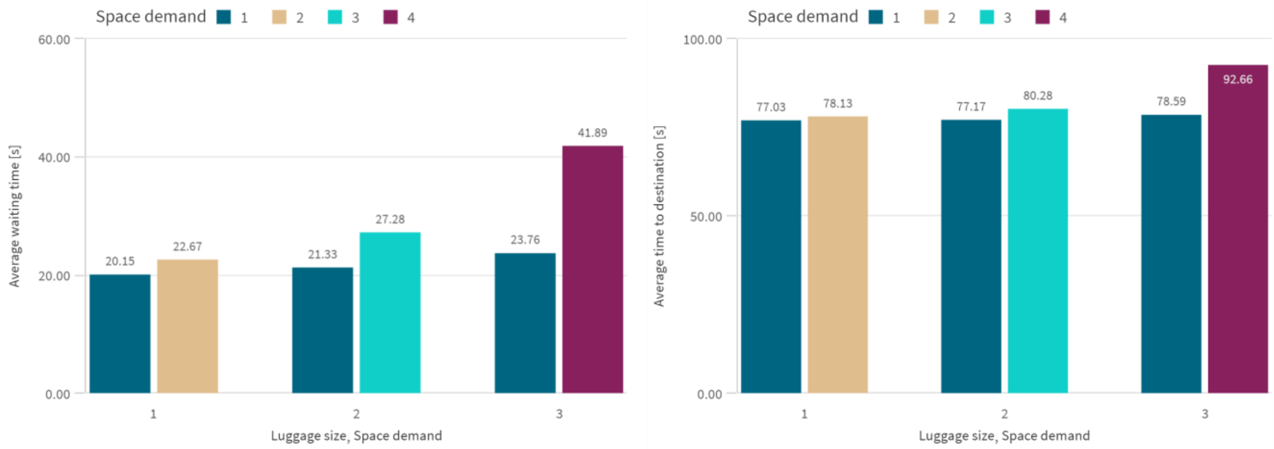

Figure 10 AWT (left) and ATTD (right) per luggage size and space demand over all instances of the load-area bypass feature

Table 12 Reduction in # ULS per traffic pattern in instances with load-area bypass feature

Traffic pattern	**Down peak**	**Hotel**	**Mixed**	**Two-way**
# ULS	10,320.00	12,555.25	7,282.00	2,869.75
Improvement [%]	96.81	95.26	86.57	94.81

The following example gives an explanation for why the reduction in the number of ULS is worse in mixed traffic.

Consider a simple situation. Travel direction of lift A is upwards, it is full, it is about to stop at level X, which is above the entrance floor, to serve a car call, and it has car calls above level X. If now someone gives a landing call from level X upwards, the landing call cannot be allocated to lift A since it is full, thus it is allocated to some other lift, say B. Suppose that during the stop at level X, some passengers leave lift A, but the load of it is still above the bypass load limit. Allocation of the landing call cannot be changed from B to A since bypass load is considered in the call allocation; calls are allocated up to bypass load of the lift. Nevertheless, the waiting passengers enter the first lift in their direction of travel, and they load the car up to rated capacity. Therefore, if all passengers behind the landing call entered lift A and lift B has no car calls to level X, then unnecessary stop occurs; when lift B arrives at level X, there is nobody entering or exiting the car. Such situations occur only when there is interfloor traffic.

The reduction in the number of ULS is also dependent on the trigger value of area-based bypassing as can be seen from Table 13.

Table 13 Reduction in the number of ULS per trigger value of the load-area bypass feature

Trigger value	**No space for 1**	**No space for 2**	**No space for 3**	**No space for 4**
# ULS	80,861	31,686	12,579	6,982
Improvement [%]	88.42	95.46	98.20	99.00

From a ULS reduction point of view, the smaller the trigger value, the better. Nevertheless, setting the trigger value too low likely negatively affects handling capacity. Therefore, one good option is to set the trigger value based on luggage size.

The reduction in the number of ULS is dependent on the measurement error, too, Table 14. As before, here # ULS is average over different trigger values used in the feature.

Table 14 Reduction in # ULS per measurement error value of the load-area bypass feature

Measurement error [%]	**0**	**10**
# ULS	9,550.75	14,525.00
Improvement [%]	95.90	93.76

According to Table 9, in general it seems that the load-area bypass feature has a small impact on CLF and CAF. A possible reason is that when a lift stops to pick up more passengers, all of them are loaded or up to rated load of the lift, independent of trigger values used in the feature.

6 CONCLUSION

A stop is unnecessary if a lift stops to serve a call, but no passengers enter or exit the lift. Such stops are not just annoying for the passengers directly witnessing them but in general they negatively affect the service quality of all passengers. There are many reasons for occurrence of them. In this paper the focus was on situations in which lift stops to pick up passengers, but nobody enters the car since the waiting passengers consider the car full and nobody exits the car.

This paper studied whether the number of unnecessary stops is dependent on different factors and how much passenger service quality is improved in conventional control buildings when the floor occupancy information of lifts is used, in addition to load, in the bypass feature by analysing simulation results from a large set of hypothetical instances.

Simulation results with the load bypass feature showed that the number of unnecessary lift stops is dependent on traffic intensity and pattern, the number of passengers with luggage, and luggage size. Results also pointed out that service quality can be unfairly distributed between floors and passenger groups due to the unnecessary stops.

Simulation results with the load-area bypass feature demonstrated that the majority of the considered unnecessary stops can be eliminated and service quality can be significantly improved. The reduction is dependent on multiple factors such as traffic intensity, traffic pattern, trigger value, and the measurement error. The load-area bypass feature does not only improve service quality, but it also makes the service fairer between floors and between passengers with and without belongings.

It is, though, difficult to estimate the impact of load-area bypass feature in a certain real building as it is dependent on so many different factors, as was seen. Also, things left out the scope probably influence the results a lot. Thus, to get a better understanding about the real impact, experiments in real buildings need to be conducted.

Other future research includes use of information in a lift group controller about how many passengers are waiting at lift lobbies as well as what are their space demands in reducing unnecessary stops further, and an impact investigation of load-area bypass feature on different building types such as shopping malls and during construction of buildings.

REFERENCES

[1] ISO 8100-20:2018, *Lifts for the transport of persons and goods - Part 20: Global essential safety requirements (GESRs)* (2018).

[2] Barney G., Al-Sharif L., *Elevator Traffic Handbook: Theory and Practice*. 2nd ed., Routledge, Taylor & Francis Group (2016).

[3] Strakosch G. R., *The Vertical Transportation Handbook*. 3rd ed., John Wiley & Sons (1998).

[4] O'Laughlin J., "Improving Elevator Performance by Monitoring Elevator Cab Volume". *Elevator World*, Nov 1 (2008).

[5] CabVision, Adams Elevators, [https://www.adamscanada.ca/Specific_pdfs_HW/cabvisionSellSheet_web.pdf], available on June 7, 2022.

[6] Vareljian V., Zou J., "Intelligent Elevator Control by Application of Computer Vision". In Proceedings of the 2006 conference on *Advances in Intelligent IT*: *Active Media Technology 2006*, pp. 182-187 (2006)

[7] Sahin Y.G., Uzunbayir S., Akçay M.B., Yildiz E., "Real-Time Monitoring of Elevators to Reduce Redundant Stops and Energy Wastage". In Proceedings of the 2013 *International Conference on Systems, Control and Informatics*, 264-269 (2013).

[8] Mohamudally F., Inn C. S., Yeong L. S., and Chong C. W., "Estimating free space in an elevator's confined environment". TENCON 2015 - 2015 IEEE Region 10 Conference, 1-6 (2015)

[9] Zou J. and Zhao Q., "Occupancy detection in elevator car by fusing analysis of dual videos". In Proceedings of the *2017 13th IEEE Conference on Automation Science and Engineering (CASE)*, 906-911 (2017)

[10] Feigang T., Kaiyuan L., Lifeng L., Yang W., "An Intelligent Detection System for Full Crew of Elevator Car". In proceedings of the *2018 11th International Conference on Intelligent Computation Technology and Automation (ICICTA)*, 183-185 (2018)

[11] Yamauchi T., Ide R., Sugawara T., "Fair and Effective Elevator Car Dispatching Method in Elevator Group Control System using Cameras". *Procedia Computer Science*, Vol. 159, 455-464 (2019)

[12] Wang S. et al, "Smart Elevator Dispatching and Optimization through Deep Learning of Usage Patterns". In Proceedings of the *2019 IISE Annual Conference*, 1498-1503 (2019).

[13] Wang S. et al, "Smart dispatching and optimal elevator group control through real-time occupancy-aware deep learning of usage patterns". *Advanced Engineering Informatics*, Vol 48, pp 101286 (2021)

[14] Gerstenmeyer S., Peters R., Smith R., "Departure Delays in Lift Systems". *Transportation Systems in Buildings*, Vol. 2, No. 1 (2018).

[15] Siikonen M.-L., "Elevator traffic simulation". *Simulation*, Vol. 61, No. 2, 257-267 (1993).

[16] Fortune J. W., "Elevatoring high rise buildings". International Conference on Tall Buildings, Singapore (1984).

[17] Siikonen M.-L., "Planning and Control Models for Elevators in High-Rise Buildings". PhD Thesis, Helsinki University of Technology (1997)

[18] Leinonen, R., "Building Traffic Simulator." Master of Science thesis, Helsinki University of Technology (1999).

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

[20] Tyni T., Ylinen J., "Genetic algorithms in elevator car routing problem". In *Proceedings of the Genetic and Evolutionary Computation Conference, GECCO 2001* (2001).

[21] Ruokokoski M., Sorsa J., Siikonen M.-L., and Ehtamo H., "Assignment formulation for the Elevator Dispatching Problem with destination control and its performance analysis", *European Journal of Operational Research*, Volume 252, Issue 2, 397-406 (2016).

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BIOGRAPHICAL DETAILS

Diana Andrei graduated from the Department of Mathematics and Systems Analysis at Aalto University with a PhD degree in science (technology) in 2021. She joined KONE in 2020 and works as a Senior Data Scientist under Mirko Ruokokoski supervision.

Mirko Ruokokoski graduated from the Department of Engineering Physics and Mathematics, Helsinki University of Technology in 2008. Currently, he is finishing his doctoral thesis at Systems Analysis Laboratory in the Aalto University, School of Science and Technology. He joined KONE in 2012 and currently leads one data science team in Services and Solutions R&D unit.