Lift Traffic Design: Calculation or Simulation?

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Abstract. Lift traffic design has become an integral part of tall building design. Typically, design calculations and/or simulations are iterated many times from early sketches until lifts are in use. Each iteration requires a significant effort from the parties involved in the design, namely, architects, consultants, developers and often also lift suppliers. Therefore, lift traffic design should be carried out with the most appropriate method to minimize the effort. Traffic calculation based on uppeak roundtrip is a well-known method and fast to execute but its validity is limited to collective control systems and simple building configurations. Lift traffic simulation, on the other hand, allows complex building models, traffic patterns and lift products such as destination control systems, double-deck lifts and multi-car lift systems. Simulations usually have long runtime and are susceptible to statistical inaccuracies possibly unknown to the designer. Hence, some combination of calculation and simulation is desirable to benefit from both methods, but they should provide consistent results. This paper re-establishes the link between traffic calculation and simulation with a collective control system, which sets the standard for using both methods consistently in lift traffic design with both collective and destination control systems.

1 INTRODUCTION

Lift traffic design has become an integral part of tall building design to guarantee efficient vertical transportation. It has been based on morning uppeak traffic in office buildings, which is the most difficult traffic pattern for a lift group with a collective control system. Thus, if the lift group can handle uppeak traffic adequately, then other traffic peaks follow. Two design parameters have been used: handling capacity (*HC5*), *the maximum sustainable number of passengers per specified time period that a lift group can transport for a specific traffic mix under specified loading constraints*, and, uppeak interval (*INT*), *the average time between successive car departures from the main entrance floor* [1]. Handling capacity can be interpreted as a passenger demand that a lift group can handle without uncontrollably increasing lobby queues and passenger waiting times. Throughout the years, similar but slightly different design criteria for handling capacity and interval have been applied to building projects [e.g. 1,2,3].

Handling capacity and interval are derived from lift roundtrip time (*RTT*), which depends on lift technical parameters and random variables. The randomness arises from uncertain passengers' destinations and random passenger arrival times. The random variables determining roundtrip time, i.e., *average highest reversal floor* (*H*) and *probable number of stops* (*S*), have exact formulae and depend only on *the average number of passengers* (*P*) *in the car at departure from the main entrance floor* and *the number of served floors* (*N*) [1]. The random variables can be derived by assuming either uniform or random passenger inter-arrival times [3,4].

The advent of new lift products to boost uppeak traffic such as the Destination Control System (DCS) has raised the need for lift traffic simulation, which models a lift group and its control system as well as any combination of incoming, outgoing and interfloor traffic [5,6,7]. For example, pure uppeak traffic assumed in calculation consists of 100% incoming traffic. In practice, uppeak traffic typically contains also outgoing and interfloor traffic. Traffic surveys have shown specific traffic mixes that often occur in office buildings: uppeak traffic with 85% incoming, 10% outgoing and 5% interfloor traffic, lunch traffic with 40% incoming, 40% outgoing and 20% interfloor traffic or lunch traffic with 45% incoming, 45% outgoing and 10% interfloor traffic [8,9].

To use both calculation and simulation in lift traffic design, as well as to keep new designs consistent with the old ones, the methods should produce consistent results. Due to intrinsic differences between the methods, the results cannot be exactly equal. Consistency, however, should be reached statistically if the underlying, often unspoken, assumptions were understood properly and replicated between the methods to the greatest extent possible. Calculation can be linked to simulation by observing that *P* passengers transported during a roundtrip represent an average value. The connection is expressed more formally in hypothesis *H1*:

H1 *Uppeak traffic simulation, with passenger demand equalling handling capacity, results in such average number of passengers in the car at departure from the main entrance floor and average roundtrip time that are close to parameter P and calculated roundtrip time.*

Once consistency has been established, lift traffic simulation can reliably be used to derive results important to the design process and in relation to calculation. For example, simulation can be used to verify handling capacity for a general traffic mix or a control system, for which roundtrip time formulae have not been developed. For such purposes, uppeak roundtrip can be generalized for any traffic mix as follows [10]:

- *Roundtrip begins when a lift starts up and ends when the lift starts up again after reversing its travelling direction twice;*
- *Lift utilization during a roundtrip is described by the maximum number of passengers in the car at departure from any floor in any direction;*
- *Handling capacity corresponds to the passenger demand, where average lift utilization reaches P passengers.*

Throughout this paper, series of simulations with KONE Building Traffic Simulator (KONE BTS™) are conducted to test different hypotheses [11]. Lift and building parameters listed in Appendix A are used in all simulations. In each simulation, passenger demand is kept constant for 240 minutes. Simulation quantities occurring in the first 15 minutes and the last five minutes are removed from the results to avoid the statistical effects of initial and end transients [10]. To minimize the possibility of incorrect statistical inferences, each simulation is replicated 20 times.

The rest of this paper is organized as follows. Section 2 discusses in detail lift traffic design with a collective control system. In Section 3, attention is directed to the DCS, which has become the *de facto* standard for tall office buildings. Section 4 concludes the paper.

2 LIFT TRAFFIC DESIGN WITH A COLLECTIVE CONTROL SYSTEM

2.1 Assumptions

Lift traffic calculation considers the operation of a lift with the following assumptions:

A1 Passengers are independent with respect to their destinations and arrival times;
A2 The lift loads *P* passengers on the main entrance floor and closes its doors;
A3 The lift transports the passengers to their destinations by stopping on *S* upper floors;
A4 The lift becomes vacant on floor *H* and reverses its travelling direction;
A5 The lift expresses back to the main entrance floor and opens its doors.

In lift traffic simulation, passenger arrivals are usually modelled with a Poisson process, which satisfies assumption *A1*, but passenger inter-arrival times are exponentially distributed [e.g. 11].

Traffic calculation assumes *P* passengers to be transported during every roundtrip as stated in assumption *A2*. Lift traffic simulation, on the other hand, needs an exact definition for passenger capacity (*PC*): *the maximum number of passengers allowed in the car during simulation*. The two methods can be linked by these two parameters,

$$P = CF \times PC, \tag{1}$$

where capacity factor *CF* defines the target filling rate of a lift. It is worth noticing that culture strongly affects how many passengers actually accept boarding a lift. Thus, the designer needs to carefully select passenger capacity for a particular car size.

Queuing theory and simulations have been used to show that the service of a lift group with a collective control system in pure uppeak traffic saturates if utilization factor, i.e., average number of passengers transported during a roundtrip, exceeds 80% of passenger capacity [3,4]. Therefore, capacity factor should not assume a value higher than 80% although lower values may be used to reserve more space to the passengers. Eq. 1 leads to a hypothesis stronger than *H1*:

H2 *Calculation and simulation are consistent if Eq. 1 holds with capacity factor of at most 80%.*

Assumption *A2* states that *P* passengers board the lift sequentially within time Pt_p. Then, door closing delay time elapses and doors start to close. In simulation, at most PC passengers board the lift depending on queue length. If no new passenger arrivals occur after a passenger transfer and before lift doors are closed, the lift starts its travel. Contrary to calculation, a new passenger arrival may occur in simulation during this time. For example, a passenger, who arrives during door closing delay time, boards the lift normally but resets the closing delay. Simulation may also allow door re-opening. Thus, passenger loading may contain delays that are not modelled in calculation.

The modelling of lift operation is mostly related to assumptions *A3* and *A4* with the usual technical parameters: *the time to travel between two floors* (t_v) *with standard floor-to-floor distance at rated speed v*, *the time consumed in stopping* (t_s) and *average one way passenger transfer time* (t_p) [1]. The calculated *S* and *H* are usually real numbers and do not represent physical quantities, but each roundtrip in simulation has a discrete number of stops and reversal floor.

According to assumption *A5*, a vacant lift expresses to the entrance floor without any delay. As a result, new roundtrips start exactly at average intervals. For a collective control system, passenger demand realizes only in an up-call on the main entrance floor. Without proper uppeak detection, the control system cannot dispatch more than one lift to serve the demand. Therefore, control systems are usually capable of dispatching additional lifts automatically to the main entrance floor to enable simultaneous passenger loading with more than one car [8].

2.2 Testing consistency between calculation and simulation

Hypotheses *H1* and *H2* are tested by simulating pure uppeak traffic with groups of one to eight lifts and passenger demands equal to the calculated handling capacity of the lift group. Simulated uppeak performance is described in Table 1 by the average number of passengers per roundtrip (*P*), the average number of stops per uptrip (*S*), the average reversal floor (*H*) and the average roundtrip time (*RTT*). In addition, average passenger waiting time (*WT*) and its proportion to the calculated interval (*INT*) are shown. The values indicate means and 95% confidence limits in parenthesis for the observed averages in simulations replicated 20 times. Due to the long simulation with constant passenger demand, the confidence intervals are narrow, less than ±1% from the means, except in the case of average waiting time.

Testing the hypotheses turns out to be more complicated than it sounds. Generally, calculation and simulation results are close to each other. However, the calculated values shown in Appendix A deviate statistically significantly from simulations since they do not belong to the confidence intervals. On the other hand, the simulated values are usually within 5% of the calculated ones, which could be considered an acceptable accuracy from a practical point of view.

Table 1: Simulated means and 95% confidence limits of uppeak roundtrip variables

L[N]	P[N]	S[N]	H[N]	RTT[s]	WT[s]	WT/INT[%]
1	15.7 (±0.14)	9.1 (±0.11)	12.5 (±0.05)	181.3 (±1.4)	87.0 (±4.7)	47.2 (±2.5)
2	15.1 (±0.13)	8.7 (±0.09)	12.3 (±0.04)	174.7 (±1.2)	54.3 (±2.4)	58.9 (±2.6)
3	15.1 (±0.12)	8.6 (±0.07)	12.3 (±0.04)	173.9 (±1.1)	38.0 (±1.5)	61.8 (±2.4)
4	15.8 (±0.11)	8.9 (±0.07)	12.4 (±0.04)	178.3 (±1.0)	31.1 (±1.3)	67.4 (±2.7)
5	16.2 (±0.15)	9.1 (±0.09)	12.4 (±0.04)	180.7 (±1.3)	22.9 (±1.2)	61.9 (±3.3)
6	16.5 (±0.11)	9.2 (±0.06)	12.4 (±0.03)	183.2 (±0.9)	15.1 (±0.8)	49.0 (±2.4)
7	17.1 (±0.08)	9.5 (±0.04)	12.5 (±0.03)	187.0 (±0.7)	9.7 (±0.4)	36.7 (±1.4)
8	17.9 (±0.08)	9.8 (±0.05)	12.5 (±0.03)	192.0 (±0.7)	7.8 (±0.4)	33.6 (±4.0)

Passenger arrival process seems one source for the observed deviations. Its effect can best be seen in the results for (a group of) one lift since the interaction of multiple lifts do not affect the process. Both the average number of transported passengers (15.7) and roundtrip time (181.3 seconds) are below the expected values of 16 passengers and 184.6 seconds, respectively. However, traffic calculation based on the Poisson process gives roundtrip time of 182.7 seconds, which belongs to the 95% confidence interval for the simulated mean roundtrip time [4]. Thus, in the case of one lift, simulation is consistent with calculation according to a strict statistical criterion.

Lift groups with two to eight lifts show an increasing trend in the number of passengers and roundtrip time with respect to the number of lifts, which can be attributed to the automatic returning of idle lifts. In the simulations with two- and three-car groups, automatic returning empties the lobby in a more efficient manner than calculation assumes. The results with four or five lifts match closely with calculation, which indicates that the automatic returning corresponds to, on average, the efficiency required by calculation. On the other hand, the returning of only one lift at a time in large groups may leave some lifts to stand idle on upper floors. Consequently, the number of passengers per roundtrip becomes clearly greater than the expected 16 passengers. If the control system is configured to return automatically two idle lifts, simulation with the eight-car group results in 15.6 passengers per roundtrip and roundtrip time of 176.6 seconds, which are close to calculation. As a conclusion, simulation seems consistent with calculation but, to prove it with a statistical argument, requires additional measures to fine-tune lift group operation.

2.3 An example of an inconsistent uppeak simulation

Regardless the difficulties in showing consistency between calculation and simulation, inconsistency between them becomes evident if capacity factor CF is set at 100%, i.e., $PC = P = 16$. Roundtrips in simulations with a six-car group are very close to calculation since the lifts always transport 16 passengers. The average number of stops per uptrip equals 9.5, average reversal floor is 12.7 and average roundtrip time is 185.8 seconds. However, the lift group undergoes saturation, which is indicated by an average waiting time much longer than interval, 180.3 seconds, as well as by an infinitely growing lobby queue. These simulation results imply that the lift group cannot handle the specified passenger demand while calculation results suggest the contrary.

2.4 Lunch traffic simulation

Lunch traffic performance of a six-car group is studied to find out the relation of uppeak and lunch traffic handling capacity as well as between uppeak interval and lunch traffic average waiting time.

Uppeak handling capacity of this group equals 12% of population in five minutes with 100 persons on each floor and interval 30.6 seconds, which represents a standard office building design [e.g. 1]. Lunch traffic consisting of 40% incoming, 40% outgoing and 20% interfloor traffic is simulated with increasing passenger demands from 10% to 16% in five minutes. Simulations are conducted with both a full collective control based on lift estimated time of arrival on a call floor (ETA) and a highly efficient full collective control, optimizing lift routes in real time with a genetic algorithm (OPT) [3,12]. The ETA can be shown to provide passenger service quality similar to Elevate ETA-control [13]. Table 2 shows average lift utilization for generalized roundtrips, the corresponding average roundtrip times, average passenger waiting time and average passenger time to destination.

Table 2: Lunch traffic results for a six-car group

Demand [%/ 5-mins]	P [N]		RTT [s]		WT [s]		TTD [s]	
	ETA	OPT	ETA	OPT	ETA	OPT	ETA	OPT
10	6.9	7.1	160.1	159.9	23.2	18.3	80.2	77.8
11	8.5	8.6	179.3	180.3	26.2	19.9	88.3	84.8
12	10.1	10.3	198.2	199.3	29.4	21.8	96.1	91.2
13	11.8	12.0	218.0	221.0	32.9	23.8	104.1	98.4
14	13.7	13.7	236.5	240.8	36.8	25.9	111.7	103.3
15	15.4	15.2	254.0	258.4	41.6	28.8	120.0	109.2
16	16.7	16.6	268.8	274.6	49.6	32.7	130.4	115.7

Average lift utilization exceeds 16 passengers, i.e., parameter P in calculation, between passenger demands of 15% and 16%, which indicates 25-30% higher handling capacity than in uppeak. Accordingly, lunch traffic handling capacity would be more than sufficient if 11% passenger demand was the target for a standard office. With 11% demand, average passenger waiting times are also shorter than uppeak interval, even with the ETA. However, the modern OPT provides average waiting times shorter than interval up to 15% demand. In addition, average waiting times with the OPT are 20-30% shorter than with the ETA across all simulated demands.

3 LIFT TRAFFIC DESIGN WITH A DESTINATION CONTROL SYSTEM

3.1 Uppeak calculation

The DCS affects lift group performance in uppeak by grouping passengers that are travelling to the same destination into one lift. As a result, the number of stops during roundtrip decreases and handling capacity increases. The original derivation of DCS traffic calculation considered a group of L lifts as a large car carrying $L \times P$ passengers and serving $2N$ floors in two up-trips [14]. A slightly modified version replaced L by a look-ahead factor k in the range of two to four lifts [3]. Maximum handling capacity with the DCS, however, can be achieved by dynamic zoning, which dedicates each lift to serve a particular range of N/L floors [15].

The effect of the DCS can also be understood through the effective number of lifts $\hat{L}$ serving a destination floor. In a collective control system, all lifts serve all upper floors, i.e., $\hat{L} = L$. When the DCS boosts uppeak to the maximum, only one lift serves an upper floor, i.e., $\hat{L} = 1$. The DCS can dedicate any number of lifts per upper floor, which implies that the number of effective lifts can vary from one to L, i.e., $\hat{L} \in [1, \dots, L]$, and can even be a real number for calculation purposes. Interestingly, it is also inversely proportional to the number of zones Z into which the served floors are divided by the dynamic zoning,

$$\hat{L}Z = L. \tag{2}$$

The following uppeak formulae for the DCS are based on a variable number of zones and consider a large car of size $Z \times P$. Probable number of stops for the DCS ($\hat{S}$) becomes

$$\hat{S} = \frac{N}{Z}\left[1 - \left(\frac{N-1}{N}\right)^{ZP}\right]. \tag{3}$$

Average highest reversal floor ($\hat{H}$) models the number of passengers ($\hat{P}$) that is equivalent to a lift with a collective control system stopping $\hat{S}$ times [15]. This parameter can be solved from probable number of stops by using the inverse S-P method [3],

$$\hat{P} = \ln\frac{N-\hat{S}}{N} \Big/ \ln\frac{N-1}{N}, \tag{4}$$

$$\hat{H} = N - \sum_{i=1}^{N-1}\left(\frac{i}{N}\right)^{\hat{P}}. \tag{5}$$

Roundtrip time for the DCS, $\widehat{RTT}$, is calculated according to the usual formula (see Appendix A), but probable number of stops and average highest reversal floor are replaced by eqs. 3 and 5.

Eqs. 3-5 reduce to traditional calculation if the number of effective lifts per floor equals L or, equivalently, the number of zones equals one. Thus, DCS calculation describes lift group performance with increasing levels of uppeak boosting up to the maximum. On average, each lift serves a zone of N/Z floors, stops $\hat{S} \leq S$ times during uptrip and reverses its travelling direction on floor $\hat{H} \leq H$. As a drawback of uppeak boosting, the DCS increases the time between successive lift departures to a destination floor and, consequently, also passenger waiting times. Service interval $\widehat{INT}$, the average time between successive lift departures to a destination floor, describes this effect:

$$\widehat{INT} = \frac{\widehat{RTT}}{\hat{L}} = \frac{\widehat{RTT}}{L/Z}. \tag{6}$$

The use of DCS calculation as well as the effect of increasing the number of zones are demonstrated by a five-car group. The results are shown in Table 3. In this case, the DCS increases handling capacity up to 79% by reducing probable number of stops to less than one third.

Table 3: Uppeak calculation results for a five-car group

Z [N]	$\hat{S}$ [N]	$\hat{H}$ [N]	$\hat{P}$ [N]	$\widehat{RTT}$ [s]	$\widehat{HC5}$ [p/5-mins]	$\widehat{HC5}/HC5$ [%]	INT [s]	$\widehat{INT}$ [s]
1	9.4	12.6	16.0	184.6	130.0	100.0	36.9	36.9
2	6.0	12.0	7.7	145.9	164.5	126.5	29.2	58.3
3	4.2	11.3	4.9	124.7	192.5	148.1	24.9	74.8
4	3.2	10.6	3.6	111.7	214.8	165.2	22.3	89.4
5	2.6	10.0	2.8	103.0	233.0	179.2	20.6	103.0

3.2 Uppeak traffic simulation

To show the validity of DCS calculation, pure uppeak traffic is simulated with a five-car group. Population on each floor is assumed 100 persons. Then, uppeak handling capacity ($\%HC5$) of this lift group equals 10% with a collective control system ($Z = 1$) and at most 17.9% with the DCS ($Z = 5$). Simulation results are shown in Table 4 below with a standard DCS, which minimizes the total passenger time to destination, and with a DCS applying dynamic zoning (DZ), which increases the number of zones according to the measured passenger demand.

Table 4: Uppeak simulation results for a five-car group

Demand [%/ 5-mins]	P[N]		RTT[s]		WT[s]		TTD[s]	
	DCS	DZ	DCS	DZ	DCS	DZ	DCS	DZ
10	9.6	9.5	110.2	109.9	20.5	20.7	70.3	70.4
12	12.5	10.7	119.7	102.9	22.4	24.0	76.7	74.2
14	15.6	12.4	128.8	102.1	25.3	30.6	83.9	82.0
16	19.8	15.2	156.5	109.8	181.4	35.5	254.3	90.8
18	20.0	16.7	160.5	106.7	230.3	39.4	305.4	95.2

The results confirm that the DCS can improve uppeak handling capacity greatly, as indicated by calculation results. The standard DCS reaches 14% handling capacity, which falls between handling capacities calculated with $Z = 2$ and $Z = 3$ (see Table 3). This result is also in line with the recommendation of choosing look ahead factor k between two and three [3]. The DZ, on the other hand, reaches at least close to the calculated maximum of 17.9%.

With the DZ, roundtrip time does not increase monotonically as with the standard DCS but decreases in jumps. A jump point corresponds to an increase in zones. For example, 10% passenger demand is easily handled by the standard DCS and, hence, the DZ does not take any action. For 12% passenger demand, the DZ defines two zones with 6.5 served floors and 2.5 lifts serving each upper floor on average, which decreases average roundtrip time from 109.9 seconds to 102.9 seconds. Thus, by increasing the number of zones gradually, the DZ maintains roundtrip time near the value provided by the standard DCS for 10% passenger demand. Passenger waiting times increase steadily but with a rate far from the rate of calculated service interval.

3.3 Lunch traffic simulation

Lunch traffic consisting of 40% incoming, 40% outgoing and 20% interfloor traffic is simulated with a five-car group as above. In addition to the standard DCS, simulations are conducted with Advanced DCS (ADCS), which applies a new passenger interface concept to upper-floor passenger terminals: an allocated lift is not shown on a terminal display but indicated to the waiting passengers later upon its arrival [16]. This allows the control system to optimize call allocations and adapt to changing conditions until the last moment. Table 5 shows the simulation results.

Table 5: Lunch traffic simulation results for a five-car group

Demand [%/ 5-mins]	P[N]		RTT[s]		WT[s]		TTD[s]	
	DCS	ADCS	DCS	ADCS	DCS	ADCS	DCS	ADCS
10	8.2	8.6	173.7	180.5	35.7	31.0	89.6	87.9
11	9.6	10.1	188.4	197.6	38.2	33.7	95.4	94.0
12	11.0	11.5	200.0	211.1	40.3	35.8	100.5	99.1
13	12.6	13.1	213.4	226.5	42.8	38.2	106.5	104.9
14	14.0	14.7	222.9	239.5	45.6	40.4	111.9	110.1
15	15.5	16.1	235.0	249.7	48.4	42.8	117.5	114.6
16	16.8	17.4	244.8	262.8	52.8	46.3	124.1	120.7

According to the average lift utilization P, lunch traffic handling capacity with the DCS is about 15%. However, average passenger waiting times with such high demands exceed 40 seconds and are not acceptable. This shows clearly that the main challenge of the DCS lies in passenger waiting times during lunch traffic. The ADCS, on the other hand, decreases passenger waiting times consistently across all passenger demands by more than 10%. As a result, the ADCS raises the limiting passenger demand, where waiting times are still acceptable, from 11% to 13%.

4 IMPLICATIONS TO LIFT TRAFFIC DESIGN

Showing consistency between lift traffic calculation and simulation turned out to be more complex than hypothesized and only partially successful. However, uppeak traffic offers a way to anchor traffic simulation to quantities that can be verified by calculation. Instead of looking at immediate simulation results, statistically sound validation of traffic simulation could be based on individual roundtrips. Nevertheless, to have any hope of the methods being consistent, their parameters must be linked: average number of passengers in the car at departure from the main entrance floor in calculation should not be more than 80% of passenger capacity in simulation.

Traffic calculation is widely adopted, but, as such, valid only for a collective control system. Due to its simplicity, calculation is also an ideal tool for quickly evaluating numerous vertical transportation alternatives for a speculative building. Traffic simulation, on the other hand, was originally developed to test control systems and to analyse lift group performance under varying traffic conditions. Simulation is the only tool to accurately estimate lift performance and reliably design lift products such as the DCS, which do not have widely accepted uppeak formulae and for which uppeak is not the limiting traffic mix.

The proposed DCS traffic calculation could be applied to lift traffic design with some care. Observations arising from the studied office building could serve as guidelines to follow. In this case, lift traffic design targeted at 12% handling capacity and interval of 30 seconds for a collective control system. These requirements were satisfied by a group of six lifts. Lunch traffic performance was verified to be good with average waiting time less than 30 seconds with 11% passenger demand. Speculatively, performance with the DCS was simulated for a group of five lifts, which showed 14% uppeak handling capacity and acceptable waiting times with 11% lunch traffic demand. Thus, in this case, the DCS enables a design with a reduced number of lifts.

Based on these observations, acceptable lift traffic design with the DCS could be achieved (at least) in two ways by using traffic calculation:

1) Target a lower uppeak handling capacity and higher interval with a collective control system, e.g., 10% instead of 12% and 40 seconds instead of 30 seconds;
2) Target a higher uppeak handling capacity with DCS traffic calculation using 2.5-3 zones, e.g., 14% instead of 12%, but target the same interval as with a collective control system.

Both of these conditions were satisfied by the studied five-car group. Before applying the method more widely, however, the generality of the above rules should be carefully assessed.

Commonly accepted design criteria for DCS traffic calculation would allow the development of selection graphs and expert systems that would genuinely take into account the strengths of the DCS. While not replacing simulation in detailed lift traffic studies, these approaches would allow fast evaluation and feedback of proposed vertical transportation alternatives during concept design. Lift traffic simulation would then, for example, validate the design, provide more detailed analysis based on tenant requirements and evaluate special control options.

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BIOGRAPHICAL DETAILS

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Appendix A

Table A1: Building and lift parameters

Parameter	Symbol	Value
Number of populated floors	N	13
Average interfloor distance	d_f	4.0 m
Number of lifts in group	L	1…8
Floor population (*L*=6)	U_i	100
Passenger capacity	PC	20
Average number of passengers in the car at departure from the main entrance floor	P	16
Rated speed	v	2.5 m/s
Acceleration and deceleration	a	1.0 m/s^2
Jerk	j	1.0 m/s^3
Average one way passenger transfer time	t_p	1.0 s
Door opening time	t_o	2.0 s
Door closing time	t_c	2.7 s
Door pre-opening time	t_{pre}	0.0 s
Door closing delay time	t_{cd}	2.0 s
Start delay	t_{sd}	0.6 s
Time consumed in stopping	t_s	10.8 s
Door reopen by landing call		None
Number of lifts returned to the lobby		1

Table A2: Uppeak formulae [3] and results for $P = 16$ and $N = 13$

Parameter	Equation	Value
Probable number of stops	$S = N[1 - ((N-1)/N)^P]$	9.4
Average highest reversal floor	$H = N - \sum_{i=1}^{N-1} (i/N)^P$	12.6
Roundtrip time	$RTT = 2Ht_v + (S+1)t_s + 2Pt_p$	184.6 s
Handling capacity (*L*=6)	$HC5 = 300 \times P \times L/RTT$	156.0 p/5-mins
Interval (*L*=6)	$INT = RTT/L$	30.8 s
Average waiting time	$AWT = [0.4 + (1.8\,P/PC - 0.77)^2] \times INT$	26.1 s