KONE

The heart of your building™

Janne Sorsa
E-mail: janne.sorsa@kone.com
Henri Hakonen
E-mail: henri.hakonen@kone.com
Address:
Marja-Liisa Siikonen
E-mail: marja-liisa.siikonen@kone.com

ABSTRACT

Elevator planning is based on up-peak and calculation of handling capacity to meet the building traffic flow demand. With a collective control system based on up and down call buttons, up-peak is the most demanding traffic situation considering the elevator handling capacity. If elevators can handle the up-peak situation, they have enough handling capacity for other traffic situations. With control systems based on destination operation panels at the lobby (DCS), up-peak handling capacity can be increased close to down-peak handling capacity. The equations used in calculating up-peak round trip time with conventional collective control are not valid. In this article, a method to select the elevators with a destination control system is introduced so that the service level will be good in all traffic situations.

Keywords: Simulation, dispatching, destination control, optimization, handling capacity

1   INTRODUCTION

In a conventional control system up and down call buttons are used. The control system knows that there is one or more passengers waiting at a floor where the landing call was given, and that the passengers are destined either up or down depending on the given call. The control system has to decide which elevator to dispatch to the call floor, often the elevator that produces shortest waiting times. The best car can be searched continuously, or fixed immediately when the call is registered. On the entrance floor passengers can enter any of the loading cars and give the car call to the destination floor. Each car can get many car calls and stops on the way up. Because of the car call stops, the up trip times become long. It has been found through simulations and in practice that with conventional control system handling capacity is smallest in up-peak. In down-peak it is 50-80% greater, and during mixed lunch-hour traffic (40% in, 40% out, 20% inter-floor) and the two-way traffic pattern is 20-40% greater than in up-peak (see Figure 1).

Up-peak handling capacity is usually calculated from a well-known round trip time equation (Barney 2003) when planning a conventional control system. In this equation, it is assumed that passengers are destined to upper floors according to the population distribution in the building. All elevators have the same probabilities for car calls to each floor.

With destination keypads, the control system has more information in call allocation. The control system knows the arrival floor and the destination floor of a passenger, and the exact number of passengers waiting at each floor. At the entrance floor, the control system gathers passengers with the same destinations in the same car. Thus the number of stops during the up trip can be reduced to decrease the round trip times. With shorter round-trip times, the up-peak handling capacity becomes greater as with conventional control. The same up-peak equation that is used for a conventional control system is not valid for destination control, since passengers cannot enter any car that arrives at the floor. There are equations for estimating the up-peak round trip time for destination control (Schröder, 1990). In the following sections, the handling capacities of these equations are compared to other theoretical and simulated handling capacities, and a suggestion for calculating the up-peak handling capacity is introduced.
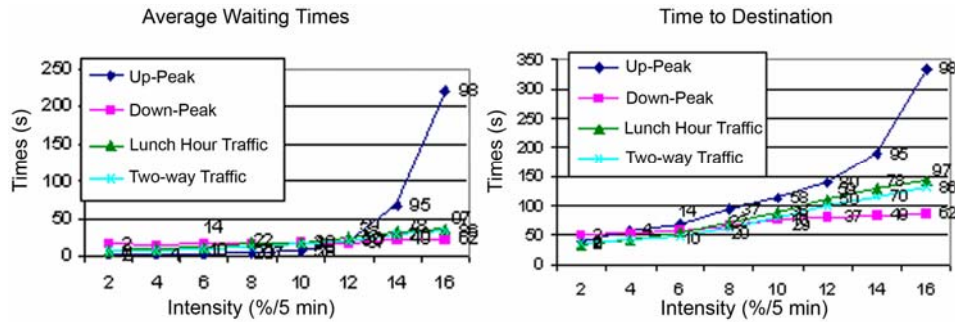
Figure 1. Waiting Times and Time to Destination using conventional control system.

2   ELEVATORING CALCULATION WITH DESTINATION CONTROL SYSTEM

Schröder (1990) derived formulas for probable stops and reversal floor, as shown in eqns (1) and (2), to calculate the handling capacity for a destination control system. He assumed that the control system assigns destination calls up to one and half round-trips and the number of served floors is 2N instead of N with a conventional control system. All destination calls are assumed to be distributed evenly between all elevators. The expected number of stops during an up-trip for all cars is calculated for one huge elevator of size LP, where L is the number of elevators and P is number of passengers in one elevator. For one car, the expected number of stops is obtained by dividing it by the number of elevators.

$$S_d = \frac{2N}{L}\left[1-\left(1-\frac{1}{2N}\right)^{LP}\right] \tag{1}$$

$$H = N - \sum_{i=1}^{N-1}\left(\frac{i}{N}\right)^{S_d} \tag{2}$$

According to Schröder the expected number of stops is used in the formula to calculate the highest expected reversal floor H. With these formulas, the calculation the expected number of stops was calculated for two up-trips, whereas the highest reversal floor was calculated for one up-trip. Clearly this contradiction affects the calculation by overestimating the expected reversal floor, which results in longer round trip times and a lower handling capacity. The corrected formula for the expected number of stops is shown in eqn (3), where the number of served floors is again N instead of 2N in eqn (1) .

$$S_d = \frac{N}{L}\left[1-\left(1-\frac{1}{N}\right)^{LP}\right] \tag{3}$$

Traditionally the expected number of stops (Barney, 2003) is calculated using the car load P instead of LP and is not divided by the number of elevators L. To find an equivalent load Pe where a conventional system makes as few

stops as the destination system, the traditional formula using load Pe and eqn (3) are equalized. According to Roschier (2003), Pe becomes

$$P_e = \frac{\ln(1 - S_d / N)}{\ln(1 - 1/N)} \qquad (4)$$

Equivalent load Pe is then used instead of the expected number of stops Sd to calculate the highest expected reversal floor in eqn (2). Equations (3) and (4), however, produce about the same values since Pe is quite small. With small loads almost every person inside a car causes a stop, and the number of stops is close to the number of persons inside car. This explains why Schröder has used Sd in calculating the highest reversal floor.

3   MAXIMUM HANDLING CAPACITY WITH DCS

Another approach to estimate maximum handling capacity with a destination control system is to define the served floors for each elevator separately. After the served floors of each elevator have been determined, the round-trip time and handling capacity for each elevator are immediately available by applying up-peak formulas for collective control. By combining the performance parameters of elevators, the performance of the whole elevator group can be calculated. It can be assumed that only one elevator serves each floor because the destination control system gathers passengers with the same destination floors in one elevator. This assumption is valid because the control system knows passengers' destinations. In addition, it is assumed that there are enough passengers in the lobby to fill all the cars up to an 80% load.

3.1   Optimizing contiguous zones

One possibility to define served floors is zoning, as described in So and Chan (1997). The basic version of their dynamic zoning algorithm selects for each elevator a contiguous range of served floors. The highest floor to be served by each elevator is found by balancing the round trip times in each zone. Even though they do not discuss the destination control system, the basic idea is applicable for defining the maximum handling capacity of a destination control system. Each zone consists of a range of served floors. It is assumed that the served floors are adjacent to each other and one elevator serves the zone. There are in total L zones and L elevators. Only the highest floor (N_i) of each zone needs to be determined. The decision problem is to find L-1 terminal floors of the zones. The terminal floor of the highest zone is naturally the highest floor of the building (or the elevator group), thus with no loss of generality $N_L = N$. The lowest floor of zone i is simply $N_{i-1}+1$, and the lowest floor of the lowest zone is simply the first floor above main entrance. Note that zone 0 is the main entrance floor: $N_0 = 0$. It is required that $0 < N_1 < N_2 < ... < N_L$, i.e. that the zones are strictly above each other. The population of zone i, i = 1,..., L, is calculated with eqn (5) below, where u_j is the population of jth floor and U_i is the total population inside zone i.

Janne Sorsa & Henri Hakonen & Marja-Liisa Siikonen

$$U_i = \sum_{j=N_{i-1}+1}^{N_i} u_j \qquad (5)$$

The round-trip time is calculated for each elevator separately with the traditional formula (Barney, 2003). In calculating the expected number of stops and expected reversal floor, the height of the zone must be taken into account (So and Chan, 1997). The absolute handling capacity given in persons per five minutes (hci), and the relative (HCi) handling capacity given in per cent of population in five minutes with car capacity C for zone i (elevator) are shown in eqns (6) and (7).

$$hc_i = 80\% \frac{300C}{RTT_i} \qquad (6)$$

$$HC_i = \frac{hc_i}{U_i} \qquad (7)$$

Balanced service within all zones is the objective of solving the terminal floors as an optimization problem. So and Chan (1997) concentrate on minimizing the variance of the round trip time.

$$\min_{N_i} \sum_{i=1}^{L} \left[RTT_i - RTT_{average} \right]^2 \qquad (8)$$

A more appealing optimization objective is the variation of the relative handling capacity (eqn 9). Equal relative handling capacities between the zones also guarantee equal service level on all floors.

$$\min_{N_i} \sum_{i=1}^{L} \left[HC_i - HC_{average} \right]^2 \qquad (9)$$

If the zones do not overlap, i.e. only one elevator serves each floor, the relative handling capacities of the zones vary greatly. In practical cases, the total number of floors is not always divisible by the number of elevators, which results in an unequal number of served floors. This results in an unbalanced service between the zones. If overlapping of the zones is allowed, the handling capacities become quite balanced though not necessarily equal. The disadvantage of overlapping is the reduced handling capacity: every additional stop for one elevator increases its round trip time much more than reduced demand decreases the round trip time of another elevator.

3.2 Optimizing discrete floor segments
The first logical extension to the optimization problem defined above is to relax the restriction that elevators serve only adjacent floors. The decision variable

changes from the terminal floor of the zone to logical 0/1-variables: xij equals 1 if elevator i serves jth floor, otherwise 0. Now the meaning of Ni changes from the highest floor of the zone to the actual number of floors served by elevator i.

The formulas to count the number of floors and passengers the elevator serves has to be adapted to new decision variables. The restriction that exactly one elevator serves each floor is expressed in eqn (12). If the constraint of eqn (12) is relaxed, some floors may receive service from more than one elevator. However, this situation is not studied in the following.

$$N_i = \sum_{j=1}^{N} x_{ij} \tag{10}$$

$$U_i = \sum_{j=1}^{N} u_j x_{ij} \tag{11}$$

$$\sum_{i=1}^{L} x_{ij} = 1, \quad \forall j \tag{12}$$

When calculating the expected number of stops and average reversal floor for the round-trip formula, the decision of whether elevator serves the floor or not, has to be taken into account. Corrected formulas are shown below in eqns (13) and (14). In practice, the number of stops will be low and close to the number of served floors (Ni), especially with equal floor population. Respectively, the reversal floor will usually be the highest served floor of the elevator.

$$H_i = N - \sum_{j=1}^{N-1} \left(\sum_{k=1}^{j} \frac{u_k}{U_i} x_{ik} \right)^P \tag{13}$$

$$S_i = N - \sum_{j=1}^{N} \left(1 - \frac{u_j}{U_i} x_{ij} \right)^P \tag{14}$$

The cost functions of eqns (8) and (9) are also used when optimizing floor segments.

3.3 Numerical example

Table 1 below shows the up-peak calculation of an elevator group for eight elevators with a nominal car capacity of 24 persons. The building has 19 floors above the main entrance floor, each floor has a population of 100 persons (except the main entrance), and the average floor height is 4.25 m. The results are shown for a conventional control system and a destination control system. Both Schröder's original formula using eqns (1)and (2) and the corrected DCS formula with eqns (2) and (3) are applied as well as the proposed DCS formula using modified eqn (2), and eqns (3) and (4).

The optimization problem is a non-linear integer programming problem, which is known to be hard to solve. The optimization problem can be solved using a genetic algorithm. The genetic algorithm is applied slightly differently when optimizing contiguous and discrete floor segments.

Table 1. Calculated up-peak performance parameters with different equations

	Conventional	Schröder	Suggested	Simulated
S	12.2	4.7	2.4	2.4
H	18.5	16.1	14.0	12.6
RTT (seconds)	202.3	131.7	106.4	100.8
HC (persons / 5 min)	227.8	349.8	432.9	463.2
HC (% / 5 min)	12.0%	18.4%	22.7%	24.4%

The served floors of each elevator are shown in Figure 2 below with all the studied optimization problems. The two far left arrangements show the results of the contiguous zoning algorithm that balance the round trip time (Zoning 1) and the relative handling capacity (Zoning 2). The effect of the cost function is already clearly visible in this simple optimization problem. Nearly equal round-trip times force the lowest zone to be extremely high with very small handling capacity.

In the other two examples, the served floors are divided among elevators around the building by optimizing discrete floor segments. The used cost function has a remarkable effect on the served floor segments. When balancing the relative handling capacity, the lowest part of the building (floors 2...10) are handled by three elevators. All other elevators serve two floors, which are not adjacent as in "Zoning 2" but three or more floors apart, to balance the relative handling capacity.

Figure 2. Optimal served floors solved with all methods

Janne Sorsa & Henri Hakonen & Marja-Liisa Siikonen

Statistics of the optimal solutions depicted in Figure 2 are shown in Table 2 below. The average round-trip times are very close to each other in all solutions, between 100 and 110 seconds. The variance of round trip times is very small in cases where it was the target of optimization. The shortest round-trip time and maximum handling capacity are reached with contiguous zoning and by minimizing the variance of handling capacity. With this solution, the total handling capacity of the elevator group more than doubles compared to conventional control. On the other hand, by choosing discrete floor segments freely, variance of the round-trip time or the handling capacity can get smaller compared to contiguous zoning.

Table 2. Statistics of up-peak performance parameters

	Contiguous Zones		Discrete Floor Segments	
	Min Var HC%	Min Var RTT	Min Var HC%	Min Var RTT
S	*2.4*	2.4	2.4	2.4
H	*12.6*	14.8	13.9	15.7
RTT (seconds)	*100.8*	106.7	104.6	110.0
HC (persons / 5 min)	*463.2*	431.9	447.8	419.2
HC (% / 5 min)	*24.4%*	22.7%	23.6%	22.1%
Var RTT	*148.8*	7.6	168.4	5.8
Var HC%	*12.2*	345.9	6.0	255.6

The maximum handling capacity of an elevator group exceeds the calculated DCS-handling capacity (see Table 1). Balancing the relative handling capacity of contiguous zones (Min Var HC%) produces the shortest average round-trip time and greatest handling capacity. With a real DCS elevator group, the theoretical maximum handling capacity cannot probably be reached and the formulas in eqns (2), (3)and (4) give a good approximation of the maximum handling capacity. However, the achievement of this development was to show a method for estimating the maximum handling capacity of an elevator group, regardless of the control system used.

4 ELEVATOR GROUP PARAMETER COMPARISON

It was shown that theoretically DCS can more than double handling capacity compared to a conventional control system. The example was made for a group of eight elevators, and 19 served floors. Figure 3 shows how the number of elevators, number of floors and car size affect the relative handling capacity increment between conventional and DCS control systems. The results have

been computed using the proposed eqns (2)-(4)) for an up-peak traffic situation and by altering only one parameter at a time. The basic group consists of eight elevators with a 24-person capacity and 24 upper floors.

According to Figure 3 below, relative boosting with a DCS system increases the most by the number of elevators. If relative boosting is about 30% with two cars (12 floors), it can be 120% with a ten car group. With a duplex group, car size and number of served floors have only a minor effect on boosting. For bigger elevator groups, a certain number of floors maximizes the boosting. For example, with a group of eight elevators, around 12 upper floors seems to give the maximum boost. If there are only two elevators, the maximum boost is reached with eight upper floors (or less). Increasing the number of floors from 8 to 28 decreases relative boosting by 10-30%. On the other hand, increasing the car size from 13 to 24 persons increases the relative boosting by 10-30%.
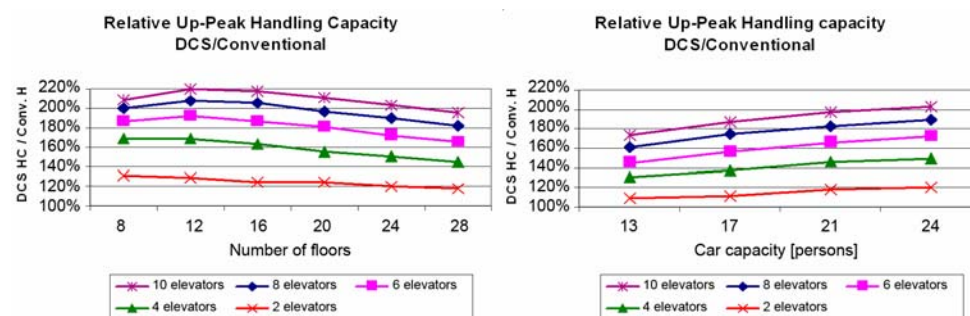

Figure 3. Relative effect of elevator group parameters on DCS boosting

5   SELECTION CRITERIA FOR DCS

According to Section 3, contiguous zoning of floors with equal relative handling capacities produces an even service in the building with maximum handling capacity. In practice, calculating the DCS up-peak handling capacity can easily be made manually. Divide the building into L zones where L is the number of elevators, and set the zone limits so that the relative handling capacities become equal. The sum of absolute handling capacities of all zones gives the maximum handling capacity with DCS. Another possibility is to calculate a close approximation from eqns (2)-(4).

With an advanced destination control system, elevator handling capacities during up-peak and down-peak are about the same since they are mirror effects from the traffic point of view. During two-way and mixed lunch hour traffic pattern waiting times are longer, but the handling capacities are close to that of up- and down-peak. This effect is shown in Figure 4 where the same building is analyzed as in Figure 1.
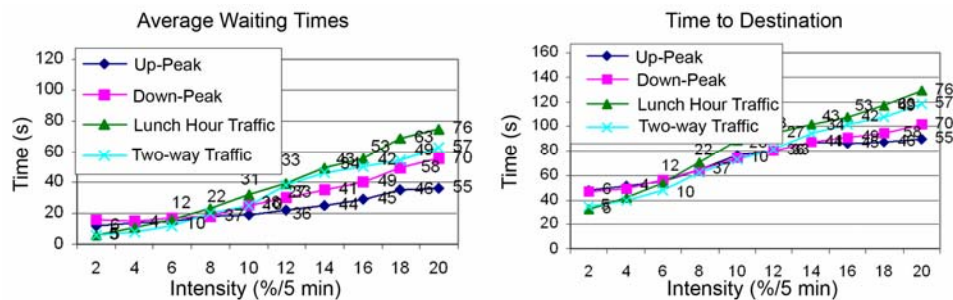
Figure 4. Waiting Times and Time to Destination using DCS system

Elevator planning in western countries is based on a general idea that an elevator should be able to handle all traffic situations with a good service level. Recommendations for handling capacities and intervals are based on peak traffic situations in different building types. The recommendations come from experience and they are more or less standardized among elevator companies and elevator consultants. According to the introduction, if an elevator group with a conventional control system is able handle the up-peak traffic, elevators can handle other traffic situations as well, even if the traffic peaks are somewhat heavier in other traffic situations. Thus up-peak is usually calculated.

From traffic measurements made by the group control system (TMS9000), the traffic peaks seem to match the usual handling capacity recommendations (Figure 5). In hotels, the traffic is mostly two-way and the heaviest demand is in the morning when people go to the lobby, or to the restaurant to have breakfast and back to their rooms. In this hotel, there is a restaurant at the top of the building. The highest measured traffic peaks are about 12% of the fully booked hotel. In residential buildings, the morning down-peak when people leave their homes for work or school, is the most demanding traffic situation. Measured traffic peaks have been about 4-5% of the residents. In office buildings, the demand is often heaviest during a mixed lunch hour traffic pattern, about 12 -15% of the population in five minutes. The heaviness of the traffic peak depends on the office type, and whether the working hours are fixed or flexible.
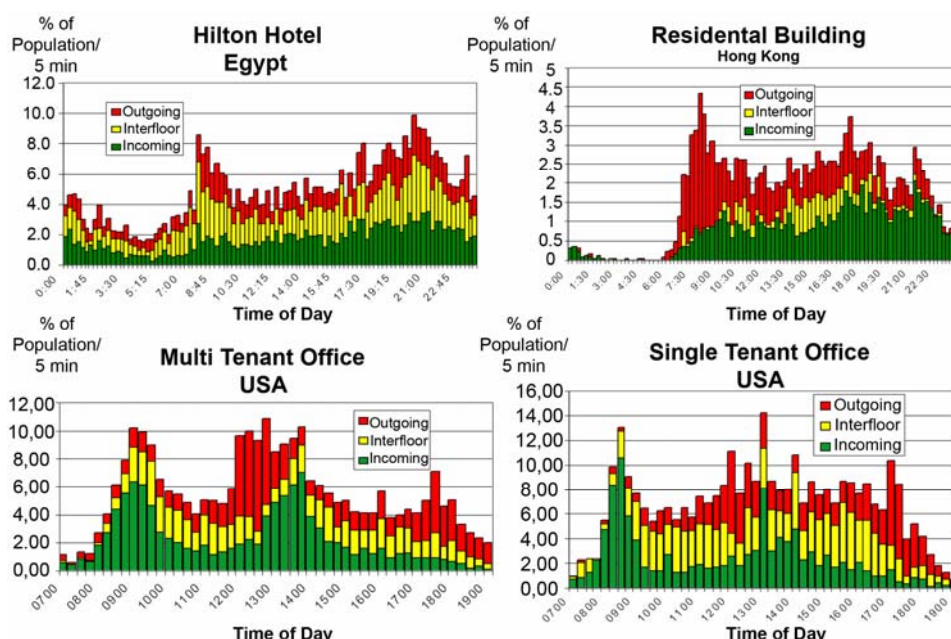
Figure 5. Measured daily traffic patterns

With an advanced DCS system, the handling capacity is about the same in all traffic situations. If elevators are planned according to the up-peak situation, as is the case for offices, with DCS there is no extra handling capacity for heavier lunch hour traffic as with the conventional control system. Lunch hour traffic can be 20-40% heavier than morning up-peak. This is the reason why office building handling capacity recommendations should be 20-30% greater to be able to handle all traffic situations with a destination control system. In hotels, a 12 % two-way traffic handling capacity with about 40% car load factor is often required. With DCS this corresponds to about 20% greater handling capacity in up-peak. In residential buildings, the morning down-peak with an intensity of 5-7.5% in five minutes corresponds to the same intensity in up-peak. When planning a DCS system up-peak can be used, only the recommendations should partly be modified. Table 4 below shows the KONE up-peak handling capacity recommendations for conventional and destination control systems to guarantee a good service level throughout the day.

Table 4. Handling capacity recommendations for good service level.

Building type	Conventional Control	Destination Control
Single tenant office	13-16	15-19
Multi tenant office	12-15	14-18
Hotel	12-16	14-18
Residential building	5-7.5	6-9

6   CONCLUSION

In this article, it was shown that with an advanced destination control system the up-peak handling capacity can be even doubled in up-peak. The result was derived using an optimization method that estimates the maximum handling capacity of an elevator group. The served floors were divided between elevators so that only one elevator serves each destination floor. The maximum handling capacity of an elevator group is obtained with contiguous zones where the number of zones equals the number of elevators. The shortest average round-trip time and greatest handling capacity is obtained by balancing the relative handling capacity between zones. If overlapping of served floors is allowed, the handling capacities of elevators become more equal but smaller.

Known methods to calculate DCS up-peak handling capacity were studied. All these methods give slightly smaller handling capacity than the previous optimization method. With a real DCS elevator group, the proposed equations give a good approximation of the maximum handling capacity. The planning of elevator groups can be made either using the proposed formula, or by zoning the served floors in to a number of contiguous zones that equals the number of cars in group. The relative handling capacities within each zone should then be balanced. In planning elevators with a DCS control system, 20-30% higher up-peak handling capacity recommendations should be used. This concerns specially buildings with heavy two way or mixed traffic patterns, such as offices and hotels.

With a destination control, the up-peak handling capacity can be boosted 10-120% depending on the elevator arrangement. The parameter that affects most to the boosting is the number of cars in group. The more there are elevators in group, the greater the relative boosting effect. On the other hand, relative boosting decreases by the number of served floors.

REFERENCES

Barney, G.C. (2003), Elevator Traffic Handbook: Theory and Practice, Spon Press, London and NewYork, ISBN 0-415-27476-1, 438 p.

Schröder, J. (1990). Elevator Calculation – Probable Stops and Reversal Floor "M-10", Elevator World, No. 3, pp. 40-46.

Roschier, N-R. (2003). Up-Peak Handling Capacity by Destination Control, KONE Internal Report, 10 p.

So, A.T.P. and Chan, W.L. (1997). Comprehensive Dynamic Zoning Algorithms, Elevator World, No. 9, pp. 99-103.