

On Traffic Planning Methodology

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ABSTRACT

Measurements in office buildings show that passenger traffic intensity is often highest during the lunch hour period. Up-peak boosters are used to increase handling capacity during heavy incoming traffic. Boosters decrease round trip time and the number of stops elevators make. Control methods such as floor zoning, or guiding passengers with the same destination to the same cars are used. If up-peak boosters are used at the planning stage, handling capacity during the lunch hour period becomes critical. During mixed interfloor traffic pattern, efficient call allocation algorithms provide better service than up-peak boosters. This paper considers traffic planning methods and the cabability of different control algorithms to handle lunch hour traffic.

1. GENERAL

In elevator planning, usually up-peak traffic is used to define the number of elevators, their sizes and speeds in a new building. Only recommendations for the handling capacity and interval vary according to building type. Does this guarantee good service during the daily mixed traffic pattern?

The recommendations are derived from experience and are quite standardized for elevator groups in office buildings, hotels, and residential buildings. Typical performance recommendation for 'good' handling capacity for single tenant office buildings is 16 per cent, whereas 13 per cent would apply to multi-tenant office buildings. Some typical performance recommendations for different building types are given in Table 1.

Table 1. Performance recommendations for good service in different types of buildings.

Building Type	Working Hours	Handling Capacity [% of Population/5 min]	Interval [s]
Multi-tenant Office	Flexible	12-17	25-32
Hotel		12-17	25-40
Apartment		5-7.5	40-90

With KONE TMS9000 control system, passenger traffic is measured floor by floor and by passenger travel direction through out the day. A measured traffic profile in a multi-tenant office building with heavy traffic is given in Figure 1. The figure shows passenger arrival rate as a per cent of the population in five minutes intervals for different times of day. In office buildings there are usually two up-peaks, one in the morning and one after lunch time. Flexible working hours create a heavy down-peak before the lunch hour (Figure 1b). Traffic intensity peaks involve about 11 per cent of the population in the building. In measured single tenant office buildings with heavy traffic, the lunch traffic peak can be 20-30 per cent higher than in up-peak In single tenant buildings, there can be about twice as much inter-floor traffic as in multi-tenant buildings.

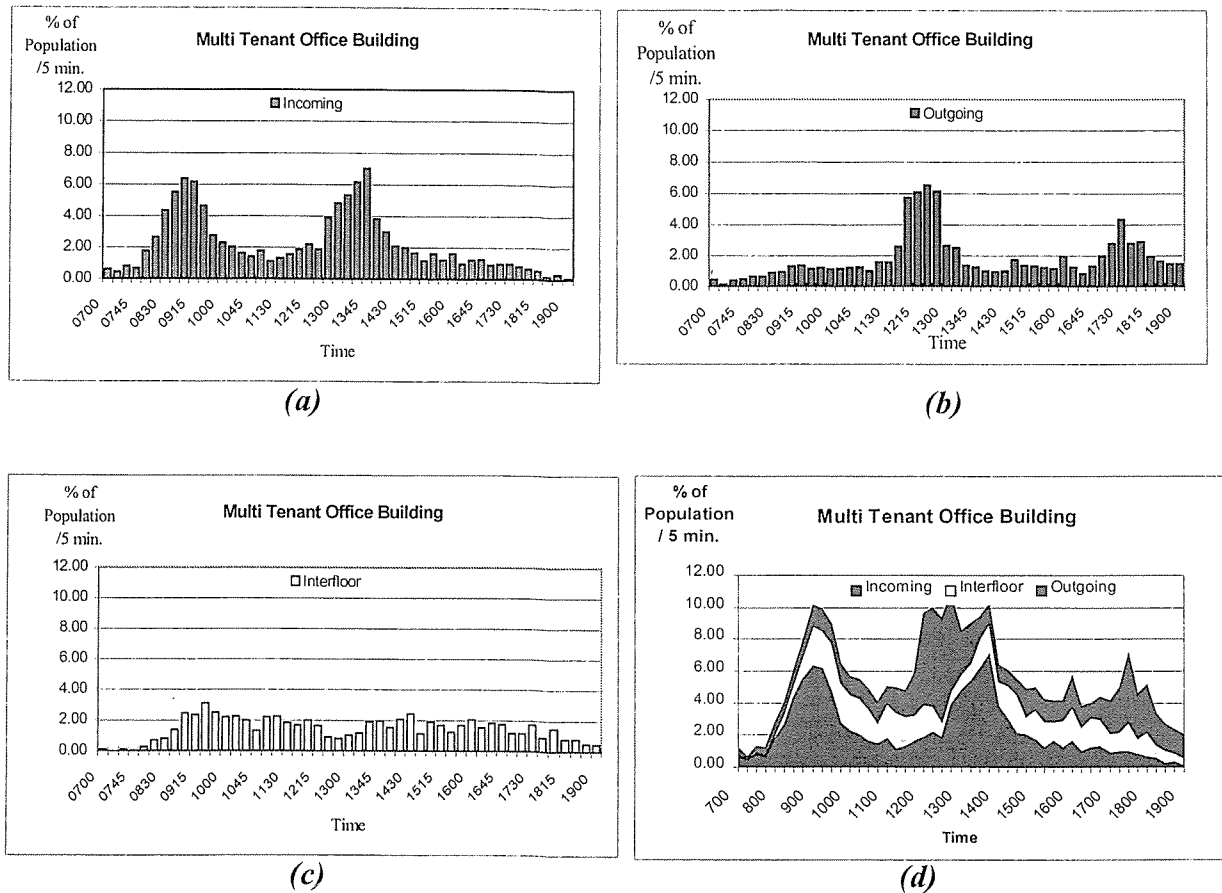


Figure 1. Passenger arrival profile measured in a multi-tenant office building in Paris: (a) up-peak, (b) down-peak, (c) inter-floor traffic, and (d) stacked total traffic.

2. UP-PEAK PLANNING

For the up-peak analysis, the number of floors and entrance floors, floor heights, and the population on each floor are defined. Elevator round trip time (RTT) is calculated according to the number of probable stops during an up trip. For a building with N floors, the well known equation for the up peak round trip time is (Barney 1981)

$$RTT = 2Ht_v + (S + 1)t_s + 2Mt_m \quad (1)$$

where H is the average highest floor reached, S is the probable number of stops during an up trip, and M is the number of passengers carried each trip. Time to travel one floor distance with contract speed is t_v , time associated with each stop is t_s , and t_m is the average time for a passenger to enter or leave the car.

The handling capacity and interval are defined on the basis of the round trip time. When these parameters meet the recommended values for the specified building type, the proposed outline specifications of the elevator group are correct. Interval is the average time between successive car departures from the main entrance floor and correlates with passenger waiting time

$$I = RTT/L \quad (2)$$

where L is the number of elevators in a group. Interval increases with greater car load as shown in Figure 2a. During incoming traffic, waiting times are less than interval until the car load factor reaches about 80 per cent. Not all passengers fit into the cars leaving from the entrance floor any more, and waiting times increase rapidly. This is the level where maximum

handling capacity is reached. Up-peak handling capacity shows how many passengers an elevator group can transport within five minutes with an 80 per cent car load factor

$$HC = 0.8 * CC * 300/I \quad (3)$$

where CC is the car size in passengers and 300 is a scale factor for five minutes. Up-peak traffic is the most difficult traffic situation for elevator handling capacity since cars are filled already at the entrance floors. In other traffic situations, cars remain less filled with the same traffic intensity (Figure 2b). Typical lunch hour traffic in a multi-tenant building consists of 40 per cent incoming, 40 per cent outgoing, and 20 per cent inter-floor traffic. With a normal elevator control system, during the lunch hour about 20-40 percent more traffic, and during down-peak 40-80 per cent more, can be handled than in up-peak. If the traffic intensity is higher during lunch hour traffic, as often happens in office buildings, the normal control system is able to handle lunch hour traffic even if the elevator group is planned for up-peak traffic. The reason is that in traffic situations other than up-peak, the elevators get less filled, and car calls do not dominate elevator routes. Then the group control system has a strong impact on the passenger service level.

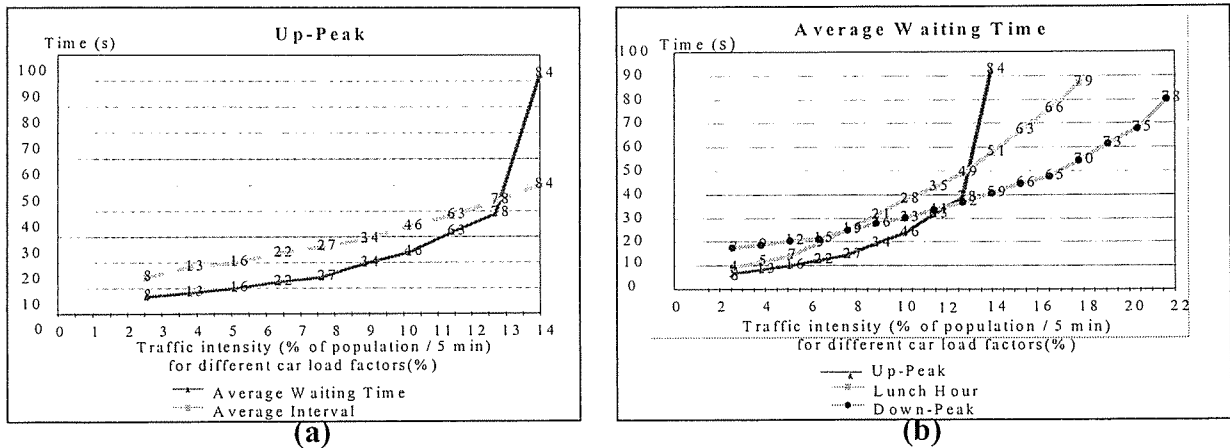


Figure 2. Interval and passenger waiting times during up-peak (a), and waiting times during up-peak, mixed lunch hour traffic, and down-peak (b).

3. UP-PEAK BOOSTERS

3.1 Temporary Zoning

In up-peak, handling capacity can be increased, i.e. boosted, by reducing the number of stops during the up trip. The total time including waiting time and ride time inside the car, journey time, becomes shorter with zoning. The elevator group can, for instance, be zoned so that one half of the elevators serve the lower part of the building, and the other half serves the upper part. At the entrance floor, car calls are accepted only to served floors of the car. The served floors of each car are indicated above the landing doors. Since the number of stops falls, round trip times become shorter and handling capacity increases during up-peak. Although the round trip time with zoning is shorter, the service interval and passenger waiting times become longer compared to a non-split group. The *service interval* is related to the passenger waiting times at the entrance floor. In a case of two zones with an equal number of cars, the service interval equals the average round trip time divided by half of the elevators ($L/2$)

$$I_{\text{service}} = (RTT_1 + RTT_2)/L \quad (4)$$

where RTT_1 and RTT_2 refer to the round trip times of the low and high rise zones, and L is the total number of elevators in a group. If eqn (2) is used to calculate the interval, it shows how often elevators leave from the entrance floor, but not how often a passenger gets a new car to serve the destination floor. With up-peak boosters, eqn (2) shows the *departure interval* of elevators which is not related to passenger waiting times.

3.2 Dynamic Sectoring

The fewer floors an elevator has to serve during the up trip, the shorter the round trip time becomes. Also the shorter the round trip time, the more up-peak handling capacity increases. The served floors of an elevator group can be split into as many sectors as there are elevators in the group. The service interval and waiting times become longer since a waiting passenger cannot enter any elevator, but has to wait for a specific car. If there are as many zones as there are elevators in a group, the service interval equals the average round trip time

$$I_{\text{service}} = (RTT_1 + RTT_2 + RTT_3 \dots RTT_L) / L \quad (5)$$

where RTT_i refers to the round trip time of the i th served zone. In dynamic sectoring the active zone that has waited the longest is served first by the first arriving car to the lobby. This reduces passenger waiting times to some extent.

3.3 Destination Control

In the destination control system passengers with the same destination floor are gathered in the same car. The number of stops during up trip is reduced, and handling capacity increases. Passengers give the destination call already at the landing floor. The control system indicates to the passenger which car to enter. Passenger can enter only a certain elevator, not any elevator in the group. The service interval of the destination system equals the average round trip time of all elevators, as shown in eqn (5). With destination control, the average round trip time and service interval is longer than with dynamic sectoring since the average reversal floor in up-peak is higher with destination control.

3.4 Up-Peak Service Comparison

The correlation of service interval and passenger waiting times of different control systems during pure up-peak can be seen in Figure 3. Passenger waiting time is here defined from the moment the passenger arrives at a floor until he enters a car. Journey time is the time taken, including waiting and ride time, to the passenger's destination floor. A control system where all floors are served by all elevators always returns vacant cars to the lobby during up-peak, and passenger can enter any of the cars. In this case, the service interval and waiting times are the shortest, but journey time is the longest. Long journey and round trip times reduce handling capacity. With zoning, passenger waiting times become longer, but the traffic intensity where waiting times start to increase rapidly, i.e. handling capacity, is higher.

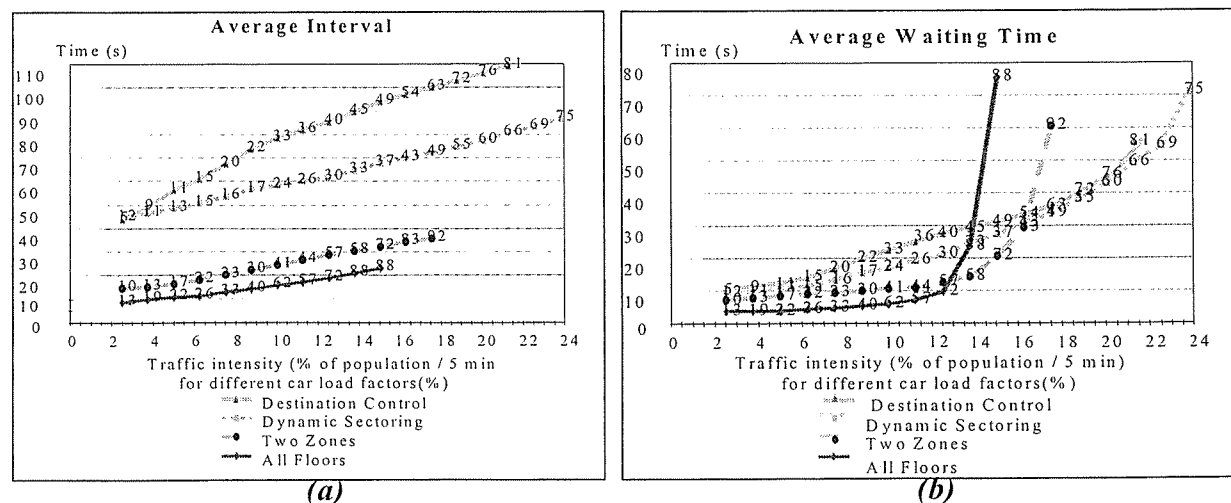


Figure 3. Service interval (a) and passenger waiting times (b) for four different controls.

4. DOUBLE-DECK ELEVATORS

4.1 General

In local double-deck elevator groups, up-peak handling capacity is increased by stopping the elevators only at every other floor during the up trip. At the entrance floor, passengers are guided to choose either the upper or lower deck, which serves even or odd floors above the main entrance. As soon as an elevator stops at a landing call at an upper floor above the entrance floors, car calls are accepted to any floor. For inter-floor and down traffic, the number of stops is doubled compared to the incoming traffic at the entrance floors.

4.2 Up-Peak Planning

A general form of the up-peak round trip time for double deck elevators with N floors above the main entrance is obtained by modifying eqn (1). A double deck elevator transports $2M$ passengers when leaving from the entrance floor, and has $N/2$ stops. The probability that a person exits the elevator at floors $2k-1$ or $2k$ is

$$P_{2k,d} = U_{2k-1}/U + U_{2k}/U \quad (6)$$

where $U = (U_1 + U_2 + \dots + U_N)$ is the total population at all floors served. Then the average highest floor reached is (Aalto 1988)

$$H_d = 2 \left[N/2 - \sum_{k=1}^{N/2-1} \left(\sum_{j=1}^k P_{2j,d} \right)^{2M} \right] \quad (7)$$

With equal population at each floor eqn (7) becomes

$$H_d = 2 \left[N/2 - \sum_{k=1}^{N/2-1} (2k/N)^{2M} \right] \quad (8)$$

The probable number of stops during the up trip is

$$S_d = N/2 - \sum_{k=1}^{N/2} (1 - P_{2k,d})^{2M} \quad (9)$$

which with equal population at each floor reduces to eqn (10)

$$S_d = N/2 \left[1 - (1 - 2/N)^{2M} \right] \quad (10)$$

To obtain the passenger transfer times during unloading the car, unloading during the coincidence stops of upper and lower deck have to taken into account. The probability that a passenger exits from the upper deck to an even floor is

$$P_{2j,s} = U_{2j}/(U_2 + U_4 + \dots + U_N) \quad (11)$$

and the probable number of stops for the upper deck is

$$S_s = N/2 - \sum_{j=1}^{N/2} (1 - P_{2j,s})^M \quad (12)$$

which with even population distribution reduces to

$$S_s = N/2 \left[1 - (1 - 2/N)^M \right] \quad (13)$$

In case of even population, S_s is equal for even and odd decks. Assuming that the loading time, t_m , in a single deck elevator is equal with the unloading time, the total passenger transfer time, t_{md} , in a double deck lift is (Kavounas 1989)

$$t_{md} = 1/2 [0.5 + 0.5 S_c / S_d + (1 - S_c / S_d)] t_m = (2 - S_c / S_d) t_m \quad (14)$$

where S_c is the number of coincident stops. For even population distribution t_{md} is

$$t_{md} = \left[2 - \frac{1}{1 + (1 - 2/N)^M} \right] t_m \quad (15)$$

Using the previous equations, the round trip time of a double deck elevator in up-peak traffic becomes

$$RTT_d = 2H_d t_v + (S_d + 1)t_s + 2Mt_{md} \quad (16)$$

Up-peak interval and handling capacity for a double deck group are obtained using the RTT_d of the previous equation in eqns (2) and (3), respectively.

4.3 Service Capability in Other Traffic Situation

Figure 4a compares up-peak round trip times obtained by simulation and from eqn (16). The calculated round trip time matches the simulated time well. The simulated building had 26 floors, and three double deck elevators with a 21/21-person car size served the floors. In simulation, two seconds transfer time was assumed for a passenger to enter and exit a car. According to eqn (15), in a double sized car the average passenger transfer time in and out time varies from 1.49 to 1.16 seconds when car load increases from 1 to 42 persons.

Figure 4b shows the waiting times during up-peak, lunch hour and down-peak. For incoming traffic, the number of stops is halved. In up-peak, the handling capacity of double deck elevators is boosted in the same way as with up-peak boosters. If the up-peak situation is used in planning double deck elevators, the capability to handle other traffic situations should be considered. With double deck elevators, handling capacity during lunch hour will be about the same as in up-peak. As the traffic intensity in an office building during lunch hour traffic can be 20-30 per cent higher, at the planning stage, up-peak handling capacity should have 20-30 per cent higher recommendations than the handling capacity of single deck lifts in up-peak.

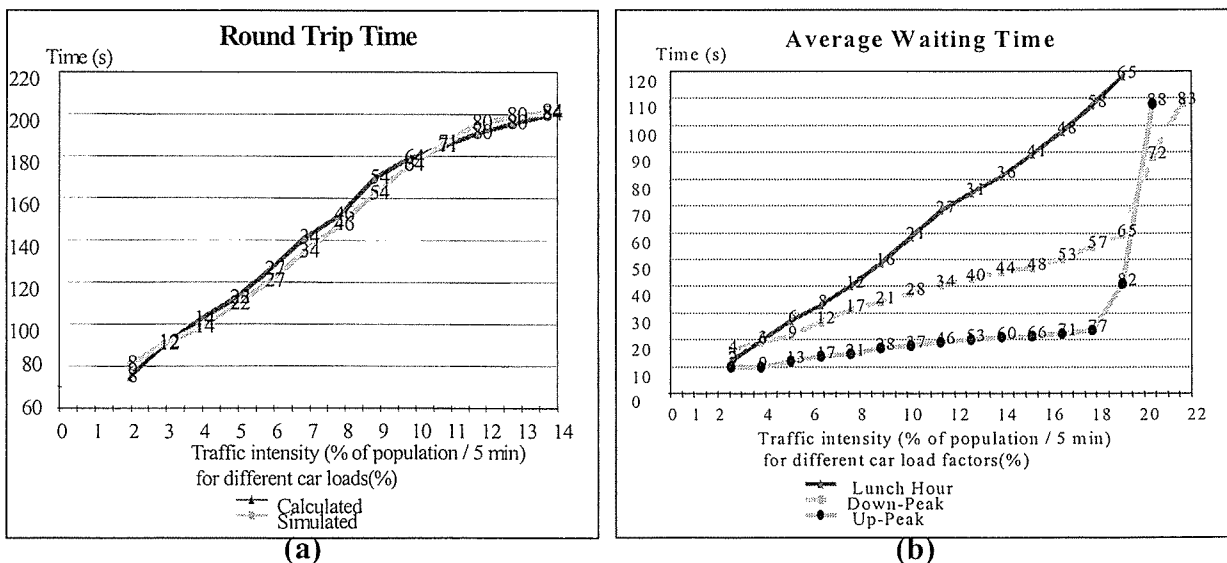


Figure 4. Double deck analysis: simulated and calculated round trip time (a), and passenger waiting times in up-peak, lunch hour traffic, and down-peak (b).

5. SERVICE LEVEL DURING MIXED TRAFFIC PATTERN

5.1 Elevator Routing

Up-peak boosters improve passenger service when most of the passengers leave from entrance floors. Figure 1 shows that during the day most of the traffic is mixed with an inter-floor and outgoing traffic component. How to improve the service during the mixed inter-floor traffic pattern?

Allocation of landing calls to elevators in an optimal way has long been an acute problem (Closs 1970). This problem appears especially in control systems where landing calls are allocated continuously. With K landing calls and L elevator, there are totally L^K different ways (routes) to allocate landing calls to elevators. A straight way would be to go through all route alternatives and select the route that gives the best value to the optimization target, such as waiting time, journey time, and handling capacity. In continuous call allocation, calls are allocated several times within a second. In a case of 20 floors and 8 elevators, if half of the landing calls were active, the number of routes would be over 10^{17} . If processing of one route took one microsecond then processing of all route alternatives would take more than 4000 years. Landing calls are allocated a few times in a second and calculation of all routes is impossible with modern microprocessors.

5.1 Genetic Algorithm

With the processing power of modern computers, however, it is possible to solve in real time problems that were impossible ten years ago. Even though not all routes can be calculated, combinatorial optimization techniques can be utilized to search for a global optimum without calculating all possible routes. One efficient method to find the best call allocation is Genetic Algorithm, which imitates natural evolution to inherit the best genes from selected parents to new generations.

Figure 5 shows some routes in a case of four active landing calls and four elevators. An allocation of a landing call to a car forms a gene, and a combination of genes where each call is allocated to a car forms a chromosome. The maximum number of routes in this case is $4^4=256$. To start, random routes are generated. A few best routes of the initial routes are selected. A new generation from the selected routes is created using inheritance, crossing over and mutation. Once again, the best routes are selected, and next generation is created. After some generations, the solution converges to the same, optimal solution (Tyni 1999).

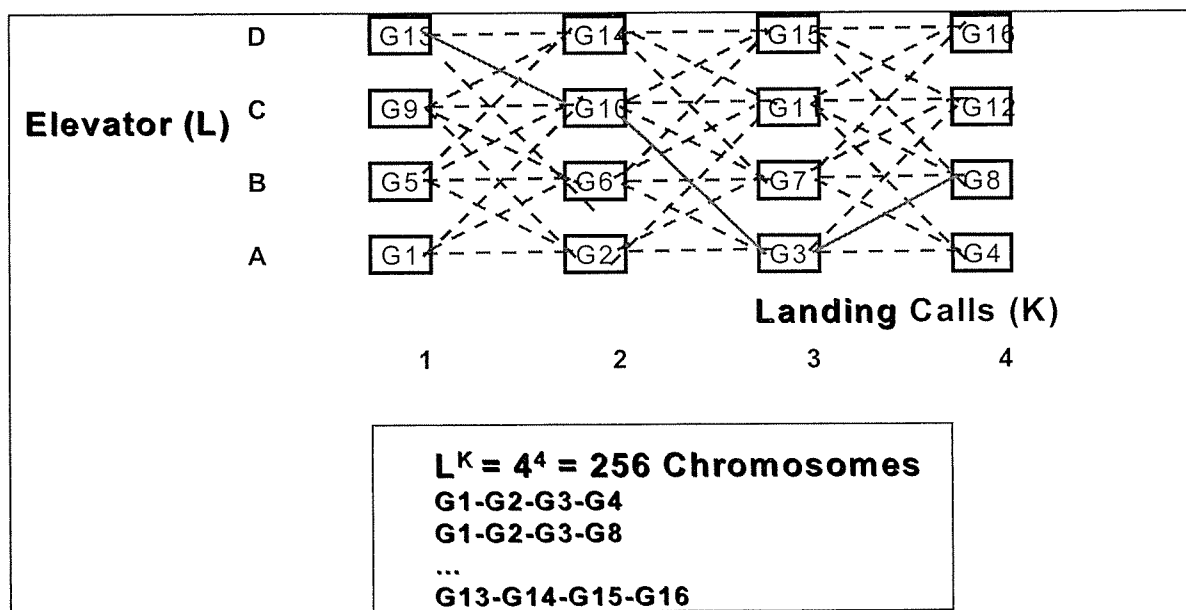


Figure 5. Possible routes to allocate landing calls 1-4 to elevators A-D.

6. DISCUSSION

For single deck elevator groups without any boosting, elevator planning with up-peak traffic situation provides good service in all traffic situations, as shown in Figure 2b. If an up-peak booster is used at the panning stage, and the same performance criteria is used as for single deck elevators, lunch hour handling capacity becomes critical and waiting times long, as shown in Figure 4b. Up-peak handling capacity should be 20-30 per cent higher than for the single decks. To guarantee short passenger waiting times, criteria for the service interval value exist. Different recommendations should be used for the departure interval, and for the passenger waiting interval which often is denoted as half of the interval. Table 2 shows an example of possible recommendations for a multi-tenant building with flexible working hours.

Table 2. Performance recommendations for good service.

Building Type	Group	Handling Capacity [% of Population/5 min]	Service Interval [s]
Multi-tenant Office	Single Deck	12-17	25-32
	Double Deck	14.5-20	25-45
	With Booster	14.5-20	25-90

7. CONCLUSION

This paper discusses elevator planning. Planning with up-peak traffic is sufficient if the performance criteria is set at a correct level. If up-peak boosters are used at the planning stage, higher value for the handling capacity is recommended so that the elevators are able to handle lunch hour traffic. Confusion between the service interval, departure interval and waiting interval should be clarified. Up-peak boosters improve the service during up-peak, but measured traffic in real buildings is more or less mixed during the day. During a mixed inter-floor traffic situation, the most efficient service is obtained by continuous call allocation. Landing call allocation algorithms are now reaching their ultimate limit with modern computer technology and combinatorial searching methods, such as Genetic Algorithms.

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BIOGRAPHICAL DETAILS

Marja-Liisa Siikonen received the degree of Master of Science in Technical Physics, and the degrees of Licentiate and Doctor of Technology in Applied Mathematics from Helsinki University of Technology. In 1984 she joined KONE Elevators, and currently works as Manager in Traffic Planning.