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Intelligent supervisory control for lifts: dynamic zoning

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It is generally accepted that a good lift system must provide the passengers with the best quantity, normally referring to handling capacity, and quality, normally referring to waiting time and/or journey time, of services with the most economical solution. To fulfil such an objective, the lift system must be adaptable to the everchanging traffic patterns of the building. Zoning has been one conventional way to achieve the goal. However, zoning is generally either fixed permanently or in other words, static, based on time scheduling where the floors being grouped into zones are predetermined during the design stage. In this paper, a new concept is introduced where zoning becomes a dynamic performance of a lift system, continuously changing with respect to the changing traffic patterns. The objectives are to achieve maximum handling capacity and minimum waiting/travelling time for passengers during up-peak, down-peak and heavy interfloor traffic conditions. Two algorithms, namely 'Uniform RTT' and 'Demand Matching', have been developed for intelligent control of the dynamic zoning scheme. Comparison with a normal system without zoning is based on an available commercial software package using the same traffic patterns. Computer simulations on a pseudo building with 12 floors and three cars have revealed a significant improvement in the waiting time, journey time and handling capacity of passengers for most of the cases. The original concept of dynamic zoning was presented during an international lift conference.

1. Introduction

It is generally known that lift traffic patterns are changing significantly during the daily operations, from up-peak, down-peak to heavy interfloor and even off-peak, etc. Conventional lift system design has had much emphasis on up-peak traffic. Hence, the design of a good lift traffic controller becomes a very important job if the target of optimal control is required for the whole day. Here, optimal control refers to highest handling capacity and shortest waiting time and travelling time of passengers. Zoning is a classical way to achieve part of the aims to improve the performance of a lift system.

In a modern high-rise building, a lift car is normally not required to service every floor, as this would imply a large number of stops during each car trip, and consequently long journey times for the passengers in the car.[1] Commonly, a lift car serves only a number of floors clustered together to form a zone. The floors served are usually adjacent, although some buildings may have split subzones where the occupants of each subzone are associated with each other and can be expected to generate some interfloor movements. A group of cars serving a high rise zone also provides service to and from the main terminal, travelling express between this floor and the lowest floor in the zone, known as the express

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zone terminal. The major advantage of zoning is the increase of the handling capacity of the lift system.

At present, zoning in a high-rise building may either be static or time-scheduled. Static zoning refers to the permanent assignment of a group of cars to service a number of floors usually adjacent in the building. Time-scheduled zoning refers to temporary zoning of the building within a pre-scheduled period of time during the day. The period usually coincides with the peak traffic situation or rush hours and the lifts service all floors outside this period. The merit of zoning is not controversial. Actually, it has been implemented in lots of commercial and domestic buildings. However, the existing control patterns of zoning are either pre-determined or fixed on a time-schedule basis, or in other words, they are not adaptable to the real-time traffic patterns. This shortfall initiates our research into the idea of dynamic zoning.[2]

The concept of primitive dynamic zoning for up-peak only has been developed so that lifts make less stops per round trip and cars return to lobby faster. This scheme is known as Channeling[3] which is designed to alleviate lobby congestion during heavy up-peak traffic periods. For example, a building with five cars can be divided into four sectors of contiguous floors. As a lift returns to the main terminal during an up-peak period, it is assigned to service one of the four sectors. Passengers can easily determine which floors each car is serving by checking the screens of the information display system next to or above each lift entrance. The same car may not necessarily serve the same sector on successive trips and care is taken to ensure that each sector will receive equal service by the assignment of sectors in a 'round-robin' manner. Under this mode of operation, cars are usually able to accommodate all people waiting at the main terminal to travel to the assigned sector and it is quite seldom to have a queue waiting at the main terminal. According to Powell,[3] Channeling may lengthen the average waiting time during up-peak by 20%, reducing the average service time by 25% and reducing the average round trip time by almost 30%. However, the original Channeling system was only designed for the up-peak condition and the choice of grouping floors into sectors was very limited. Actually, it was predicted in the paper[3] that in the most sophisticated implementation, the Channeling option could be made to be dynamic by varying the number of sectors and floors within each sector as a real-time response both to sudden changes in passenger traffic and to passenger behaviour based on historical records. But no further publication on this extreme option has been seen over the years. This flexible option is in fact equivalent to the concept of dynamic zoning mentioned in this paper.

Another existing lift control system involving grouping of floors to be serviced by a lift car is called Miconic-10.[4] This system is based on the earlier recognition of more complete traffic data for better traffic management. Instead of pressing the destination car call button inside the lift car by the passenger, the car call button is pressed at the lift lobby, thus termed lobby destination call. A car is instantly assigned to this lobby destination call and the passenger needs to wait and get aboard that particular car. Since, the supervisory system can receive complete information on the destinations before the boarding process is completed, passengers whose destination is common can be grouped together and served by the same car. If every passenger behaves well and presses the car call button once, the supervisory system can even estimate the precise number of passengers going to any one destination floor. According to Schroder,[4] the M-10 system may boost up-peak handling capacity of a high-performance six to eight car group by 40–60% by promoting coincident exiting stops. This can reduce the number of stops per round trip by a factor of two and permit cars to reverse at lower floors than possible with conventional dispatch systems. At heavy traffic, the M-10 system may have 22% shorter waiting time, 45% shorter destination time and twice the conventional handling capacity. However, the beauty of the M-10 is also its drawback. If every passenger behaves as expected and the system is fully loaded for the whole day, M-10 can fulfil its goal. Otherwise, its performance can be quite poor.

Without precise knowledge of destination calls, dynamic zoning seems to be a good choice. In this paper, the mathematical algorithms of dynamic zoning are presented for up-peak, down-peak and the more general heavy interfloor conditions. Floor assignment is totally flexible and it is easily implemented for modern lift systems. To demonstrate the advantages of dynamic zoning over conventional control, computer simulations using a popular software package on market, Elevate 3.0, have been carried out, revealing that significant improvements on the waiting time, the transit time (i.e., journey time) and the handling capacity of the system.

2. Knowledge of traffic patterns

Before a decision on the zoning details is arrived at, information related to the real time lift traffic patterns is absolutely necessary. The pattern consists of two factors. After a particular traffic pattern has been identified, the associated zoning scheme will be switched in for the most optimal supervisory control.

First of all, the traffic mode has to be determined i.e., up-peak, down-peak, interfloor or off-peak. There are different ways to identify up-peak and down-peak traffic modes. Two parameters were proposed by Beebe that could identify the occurrence of up-peak traffic pattern, namely the Up–Down Stop relationship and the Up-stop/Up-landing Call relationship. Similarly, there are two parameters that can identify the occurrence of down-peak traffic pattern, namely the Down–Up Stop relationship and the Stops-Landing Call relationship. The details have been summarized in a paper presented at an international congress, Elevcon'93.[5] Another way is the employment of artificial neural networks (ANN) that continuously monitor the lift system.[6] All relevant data are retrieved from the computerized supervisory control system and normalized into a range [0, 1] and fed into the input nodes of the ANN. A well trained ANN can identify the possible traffic modes based on the real time data.

Secondly, the traffic demand of each floor needs to be estimated. In conventional lift design,[7] the demand of each floor correlates with the population of that floor and the assumption is particularly valid for up-peak traffic. In our case, this assumption can still be used. For a more advanced approach, the change of car weight and/or the car door opening time associated with each stop at each landing can be used to estimate the instantaneous traffic demand of that landing, or a computer vision based passenger counting system can even be employed.[8–10]

3. Algorithms of dynamic zoning for up-peak and down-peak

It is assumed that the traffic demand of each floor is known. A commercial building with N number of floors, excluding main terminal (MT = 0/F), is considered. Within the 5-minute duration of up-peak, total demand of the building is U and the demand of the kth floor is U_k. It should be noted that U and U_k can deviate much from the actual population of the building and they can change significantly within a working day. The building is served by a group of m numbers of lift cars. All lift cars can service all the N+1 floors. For simplicity, it is assumed that every zone does not overlap with another zone, although a zone may, besides the MT, consist of one upper floor only. Also, no duplicate zone, which means two cars servicing the same zone, is allowed. Every car services the main terminal because the zoning is designed for up-peak and down-peak modes instead of interfloor modes. Naturally, m number of cars can divide the building into m number of zones. When the traffic is neither in up-peak nor down-peak mode, zoning is cancelled and every car services the whole building. A clearer picture of the zoning arrangement is shown as:

- 1st car serving 0/F(MT), 1/F, . . ., n_1/F;
- jth car serving 0/F(MT), $(n_{j-1} + 1)$/F, . . ., n_j/F ($j = 2, \ldots, m - 1$);
- mth car serving 0/F(MT), $(n_{m-1} + 1)$/F, . . ., N/F.

A strict rule is: $0 < n_1 < n_2 \cdots < n_j < \cdots < n_{m-1} < N$. The objective of dynamic zoning is to find an optimal solution of the $(m - 1)$ number of n's during the two modes of traffic flow. The round trip time of the jth car is denoted by RTT_j.[2] The general formula of RTT_j is:

$$RTT_j = 2 H_j t_v + (S_j + 1) t_s + 2 p_j t_p \qquad (1)$$

The interfloor flight time, t_v, which is equal to interfloor distance divided by rated speed. t_s is conventionally defined as the stop time which combines the single floor flight time, the door operational time and the interfloor flight time. The average passenger transfer time, t_p, in our case, is arbitrarily chosen as 1.2 s. These are all constants in Equation (1). The mathematical problem then becomes the minimization of either of the following two cost functions:

$$\underset{n_1,\ldots n_{m-1}}{Min} \sum_{j=1}^{m} (U_j - HC_j)^2 \qquad (2)$$

$$\text{where } HC_j = \frac{300}{RTT_j}(0.8CC_j)$$

$$\underset{n_1,\ldots,n_{m-1}}{Min} \; \sigma(RTT_j \,|_{j=1}^{m}) = \sqrt{\frac{\sum_{j=1}^{m}(RTT_j - \overline{RTT})^2}{m}}$$

$$\text{where } p_j = \begin{cases} \dfrac{U_j RTT_j}{300} & \text{if } \dfrac{U_j RTT_j}{300} < CC_j \\ CC_j & \text{if } \dfrac{U_j RTT_j}{300} \geq CC_j \end{cases} \qquad (3)$$

$$U_j = \sum_{k=n_{j-1}+1}^{n_j} U_k$$

$$\overline{RTT} = \frac{1}{m}\sum_{j=1}^{m} RTT_j$$

CC_j is the contract capacity of the jth car. Here, p_j is the number of passengers in each round trip and it is not simply equal to 80% of the contract capacity because it very much depends on the number of floors being serviced by the jth car. If the arrival rate exceeds the handling capacity, the number of passengers inside each car will be restricted by the overall contract capacity of the car. Equation (2) optimizes on the difference between handling capacity and demand and thus it concentrates on *demand matching*. The reason of using the standard deviation for all the m RTT's in Equation (3) is to ensure a uniform distribution of RTT's so that the waiting time of most passengers can be more or less identical. It will be fair to each passenger waiting at a lift lobby and asking for services. The cost function in Equation (3) thus concentrates on *uniform RTT*. The remaining three parameters in Equations (2) and (3) i.e., H_j (highest reversal floor of jth zone), S_j (expected number of stops of jth zone) and p_j, are variables that need to be determined on a real-time basis. For simplicity, all cars are of identical contract capacity and identical contract speed because they are originally designed for servicing the whole building and there should be no discrimination between individual cars.

3.1 Up-peak traffic condition

Under up-peak traffic conditions, H_j (up-peak) and S_j (up-peak) can be formulated for each zone in accordance with CIBSE guide[7] for unequal floor population using rectangular probability distribution function i.e., the arrival rate of passengers at the main terminal is uniform, and regular with respect to time.

$$H_j(up\text{–}peak) = n_j - \sum_{k=n_{j-1}+1}^{n_{j-1}} \left(\sum_{l=n_{j-1}+1}^{k} \frac{U_l}{U_j} \right)^{p_j} \qquad (4)$$

$$\text{where } n_0 = 0$$

$$S_j(up\text{–}peak) = \left[n_j - n_{j-1}\right] - \sum_{k=n_{j-1}+1}^{n_j} \left(1 - \frac{U_k}{U_j}\right)^{p_j} \qquad (5)$$

3.2 Down-peak traffic condition

Under down-peak traffic conditions, Strakosch's approach is adopted.[2,11] H_j is equal to n_j while $S_j = 0.75 * S_j$ (up-peak). p_j (down-peak) is assigned to be the contract capacity of the lift car because the duration of down-peak tends to be shorter[7] and the demand is much higher.[2] Then, most lift cars will be fully loaded and each lift tends to reach the top floor of its servicing zone for each round trip until passengers of the higher floors have all been serviced.

4. Equations of the heavy interfoor traffic condition: a general approach

The method adopted follows Alexandris' development as detailed in Section 7.1.3 of Barney's book.[2] They are listed here for the sake of completeness. The same building with N floors above the main terminal is considered. The total population of the building is given by U while the population of the ith and jth floors is given by U_i and U_j respectively. The rate of passenger arrivals to the ith floor is given by λ_i and the lift cycle time is given by T. Here, T is constantly set to 30 s which has been the conventional guideline for waiting time in a middle class commercial building. The probability that no call from the ith floor to the jth floor is given by:

$$pr_{ij} = e^{-\lambda_i T \frac{U_i}{U}} \text{ for } i,\ j = 0, 1, 2, \ldots, N \qquad (6)$$

Furthermore, $pr_{ii} = 1$ and that implies it is very certain that no call will be registered from the ith floor to itself. The assumption that all passengers going to the main terminal will leave the building has to be modified in this case. It is assumed that no passenger will leave the building during such a heavy interfloor condition. All passengers from the ith floor going to the main terminal desire to travel to the jth floor (destination) which does not belong to the same zone as the departing floor i.e., the ith floor. In other words, the reason why passengers travel to the main terminal is to change to a new lift to go to a floor of another zone. Furthermore, it is assumed that lifts will only travel round trips i.e., from main terminal to the highest reversal floor and then back to the main terminal with a total number of S stops. It should be noted that the algorithms here do not deal with real-time control but only an optimal zoning scheme. Let A_k^j be the event that passengers enter the lift at the kth floor, $k = 0, 1, \ldots, N$ while the jth floor is the highest reversal floor. Assuming that passengers enter the car at the ith floor, the probability, π_{ij}, that the jth floor will be the highest reversal floor is given by:

$$\pi_{i,j} = \left\{ \begin{array}{ll} (1 - pr_{ij}) \prod_{k=j+1}^{N} pr_{ik} & i < j \\ \prod_{k=j+1}^{N} pr_{ik} & i = j \\ 1 & i = j = N \\ 0 & i > j \end{array} \right\} = pr(A_i^j) \qquad (7)$$

$$i,\ j = 0, 1, \ldots, N$$

As the events, $A_0^j, \ldots, A_N^j$ are not mutually exclusive but independent of each other, Poincare's result can be applied and the probability, π_j, that the jth floor will be the highest floor can be given by:

$$\begin{aligned} \pi_j = pr\left(\bigcup_{k=0}^{N} A_k^j\right) &= \sum_{k=0}^{N} pr(A_k^j) - \sum_{\substack{k_1,k_2=0 \\ k_1<k_2}}^{N} pr(A_{k_1}^j) pr(A_{k_2}^j) \\ &+ \sum_{\substack{k_1,k_2,k_3=0 \\ k_1<k_2<k_3}}^{N} pr(A_{k_1}^j) pr(A_{k_2}^j) pr(A_{k_3}^j) \\ &+ \ldots + (-1)^N \prod_{k=0}^{N} pr(A_k^j) \end{aligned}$$

To simplify, the individual probability that the jth floor is the highest floor when passengers enter the lift at the k_ith floor is given by:

$$\pi_{k_i j} = pr(A_{k_i}^j) \qquad (9)$$

The highest reversal floor, H, is then given by:

$$\begin{aligned} H &= \sum_{j=1}^{N} j\pi_j \\ &= \sum_{j=1}^{N} j \left(\sum_{k=0}^{N} \pi_{kj} - \sum_{\substack{k_1,k_2=0 \\ k_1<k_2}}^{N} \pi_{k_1 j} \pi_{k_2 j} + \ldots + (-1)^N \prod_{k=0}^{N} \pi_{kj} \right) \end{aligned}$$

Next, the expected number of stops within a round trip is estimated. The probability, W_{ki}, that at least one passenger wants to go to the ith floor from the kth floor is given by:

$$W_{ki} = 1 - pr_{ki} = 1 - e^{-\lambda_k T \frac{U_i}{U}} \tag{11}$$

The probability, S_i, that the ith floor is a stopping floor is given by:

$$S_i = \sum_{k=0}^{N} W_{ki} - \sum_{\substack{k_1,k_2=0 \\ k_1<k_2}}^{N} W_{k_1 i} W_{k_2 i} + \ldots + (-1)^N \prod_{k=0}^{N} W_{ki} \tag{12}$$

The expected number of stops, S, within a round trip is then given by the summation of all S_i's i.e.,

$$\begin{aligned} S &= \sum_{i=0}^{N} S_i \\ &= \sum_{i=0}^{N} \left(\sum_{k=0}^{N} W_{ki} - \sum_{\substack{k_1,k_2=0 \\ k_1<k_2}}^{N} W_{k_1 i} W_{k_2 i} + \ldots + (-1)^N \prod_{k=0}^{N} W_{ki} \right) \end{aligned} \tag{13}$$

It should be noted that the S calculated above only takes care of the stops which are destination floors and the maximum value of S is N. A floor where nobody alights the car but lots of passengers board the car has not been included. Therefore, the ith floor whose λ_i is not equal to zero will contribute an additional value of '1' to S so that the maximum value of S can be up to '2*N' when the lift car stops during both the up-trip and down-trip. After H and S have been estimated, the 'equivalent round trip time' of a car can be calculated.

4.1 The equivalent round trip time

The number of passengers asking for service at the ith floor is given by $\lambda_i T$ within a period of T seconds. If this ith floor is served by one lift only, the total demand of this floor on that lift will be $\lambda_i T$. If this ith floor is served by n number of lifts, the demand on each lift will be $1/n\ \lambda_i T$. Therefore, overlapping zones assigned to two or more lifts are allowed, thus giving even more flexibility. The distribution of U_i has been known during the design stage when the building owner needs to identify the utilization of the building. λ_i can be obtained in different ways. A statistical analysis can be carried out by sensing the change of weight of a lift car stopping at the ith floor. Normally, it is assumed that each passenger has an average weight of around 75 kg and alighting passengers will go first, followed by boarding passengers every time when a car stops. Another more effective way is to make use of computer vision[8] which is able to estimate the number of passengers waiting at the lobby of each landing under a real-time mode.

Two more parameters that need to be identified are the population and demand at the main terminal. Theoretically, U_0 is undefined because it is impossible to assume a population for the public. However, pr_{i0} for $i = 1, \ldots, N$ can be defined. General traffic patterns can be categorized into three modes, namely up-peak, down-peak and interfloor, by using an artificial neural network.[6] For up-peak mode of traffic, all pr_{ij} will be set to 1 if $i \neq 0$. For down-peak mode of traffic, all pr_{ij} will be set to 1 if $j \neq 0$. For heavy interfloor mode of traffic, it is assumed that nobody leaves or enter the building i.e., all pr_{i0} will be set to 1. Hence, the passengers waiting for service at the main terminal will only be equal to the sum of all passengers from the upper floors whose destinations are not within the zone of their departing floors. Suppose the kth lift among the group of m lifts is assigned a zone of 0/F (main terminal), k_1/F, k_2/F until k_h/F, passengers to jth floor where $j \notin \{k_1, k_2, \ldots, k_h\}$ will contribute to λ_0. Then, $\lambda_i^k\ T$ i.e., demand of kth lift at the ith floor, can be divided into two groups. The first group includes passengers whose destination floors are within the zone and the second group includes passengers whose destination floors are outside the zone. For passengers in the second group, they need to take the lift down to the main terminal and have a 'transit' to another lift serving the zoning including the destination floors. The probability, $(1 - pr_{ij}^{\,k})$, that at least one passenger taking the kth lift travels from the ith floor to the jth floor is a good indicator to separate the passengers into two groups. ${PA_{i1}}^k$, number of passengers of group 1 departing the ith floor and ${PA_{i2}}^k$, number of passengers of group 2 departing the ith floor can be estimated:

$$\underset{i\in\{k_1,\ldots,k_h\}}{PA_{i1}^k} = \frac{\sum_{j\in\{k_1,\ldots,k_h\}}(1-pr_{ij}^k)}{\sum_{j=1}^{N}(1-pr_{ij}^k)}[\lambda_i^k T] \tag{14}$$

$$\underset{i\in\{k_1,\ldots,k_h\}}{PA_{i2}^k} = \lambda_i^k T - PA_{i1}^k$$

Hence, $\lambda_0 T$ can be defined as the sum of all group two passengers of all floors running from 1/F to the N/F of all the m number of lifts.

$$\lambda_0 T = \sum_{k=1}^{m} \sum_{i\in\{k_1,\ldots,k_h\}} PA_{i2}^k \tag{15}$$

Without a real-time simulation, it is quite impossible to estimate the total number of round trips even if all Us and λs are known. Here, what is required is just a suitable zoning arrangement. The contract capacity of each lift car is then assumed unlimited i.e., one round trip is enough to handle all waiting passengers, including those taking 'transit' at the main terminal. In this way, the so-called 'Equivalent Round Trip Time' of each car is calculated. The total number of passengers, PA^k, being handled by the kth car during an equivalent round trip, is given by the sum of all passengers leaving the floors inside the zone of the kth lift and the passengers from other zones into the kth lift's zone with 'transit' at the main terminal.

$$PA^k = \sum_{i\in\{k_1,\ldots,k_h\}} \lambda_i^k T + \sum_{\substack{l=1\\ l\neq k}}^{m} \sum_{q\in\{l_1,\ldots,l_h\}} [\lambda_q^l T] \frac{\sum_{i\in\{k_1,\ldots,k_h\}}(1-pr_{qi}^l)}{\sum_{j=1}^{N}(1-pr_{qj}^l)} \tag{16}$$

The ERTT^k, 'equivalent round trip time' of the kth lift is given by:

$$ERTT^k = 2H^k t_v + (S^k + 1)t_s + 2PA^k t_p \tag{17}$$

All other figures follow conventional definitions as shown below.

$$\begin{aligned} p_j(\text{down}-\text{peak}) &= CC; \\ H_j(\text{down}-\text{peak}) &= n_j \\ S_j(\text{down}-\text{peak}) &= \frac{3}{4}\, S_j(\text{up}-\text{peak}) \end{aligned} \tag{18}$$

The standard deviation of ERTT^k of all cars (k = 1, . . ., m) is then the cost function to be minimized.

5. Numerical methods to handle the problems

A closer investigation into the constraints of n's and the cost functions in Equations (2) and (3) reveals that it is merely a problem with mathematical programming under inequality constraints. The standard Lagrange multipliers together with the Kuhn-Tucker conditions can be used to solve the problem.[12] Mathematical details are attached with this paper as Appendix A.

Regarding the more general equations as discussed in section (4) of this paper, it can be seen that the expressions of ERRT^k consist of quite a number of probability based functions involving exponential functions and series, which are very complicated, making the whole function highly non-linear in characteristics. The conventional method of optimization, such as Newton's Law and Slope of Steepest Descent, etc. is considered not applicable and hence, a probability based optimization method i.e., Genetic Algorithm (GA), is employed. Mathematical details are attached as Appendix B.

6. Computer simulations

In order to test the advantages of introducing dynamic zoning into a conventional lift system, computer simulations have been carried out and

Table 1

Building data Floor name	Floor level (*m*)	Elevator data	Car 1	Car 2	Car 3
Level 0	0.00				
Level 1	3.00				
Level 2	6.00	Capacity (kg)	1000	1000	1000
Level 3	9.00	Speed (m/s)	2.50	2.50	2.50
Level 4	12.00	Acceleration (m/s)	0.80	0.80	0.80
Level 5	15.00	Jerk (m/s)	2.00	2.00	2.00
Level 6	18.00	Home floor	Level 0	Level 0	Level 0
Level 7	21.00	Motor start delay (s)	0.00	0.00	0.00
Level 8	24.00	Door pre-opening time (s)	0.00	0.00	0.00
Level 9	27.00	Door open time (s)	1.80	1.80	1.80
Level 10	30.00	Door close time (s)	2.90	2.90	2.90
Level 11	33.00	Door dwell 1 (s)	0.50	0.50	0.50
Level 12	36.00	Door dwell 2 (s)	0.50	0.50	0.50

the results are compared with that obtained by a commercial software package[15] simulating a conventional control system. A building of 12 storeys, not including the main terminal, is served by a group of three cars. Actually, it is generally believed that dynamic zoning is more effective as the building is getting taller. However, the authors have not got a software package of high performance for handling the Genetic Algorithm based optimization. Hence, a simple computer program was compiled by the authors, resulting in a very time consuming exercise for the GA process. The effort to process a lift system serving 12 storeys was just reasonable with a view to the availability of computer resources.

The technical data is shown in Table 1. All three traffic conditions have been tested and the following results are obtained.

6.1 Up-peak traffic simulation

The passenger traffic data is shown in Figure 1. During up-peak, at 9:00 a.m., all passengers enter the building at the main terminal i.e., Level 0. The arrival rate is 500 passengers per interval of 5 min whereas the simulation is based on the first 100 passengers entering the main terminal during the first minute. The percentage of each floor shown in the first row of the table represents the number of passengers whose destination is that particular floor. Based on such a traffic pattern, the dynamic zoning scheme is shown in Figure 2. Based on the total demand in terms of number of passengers waiting at the main terminal as well as their destination floors, H and S can be obtained and then the handling capacity, HC of each car, with a pre-assumed zoning pattern. By minimizing the summed squared difference between the HC of each car and the total demand to its stopping floors, we are able to change the zoning pattern, in accordance with Equation (2). It has been found that demand matching can always give a more satisfactory result. Figure 3(a) shows the profile of the passenger waiting time without zoning as stimulated by Elevate 3.0. Figure 3(b) shows the same profile with dynamic zoning. It can be seen that the average waiting time is reduced by 34%. Although the longest waiting time is higher with dynamic zoning, it can be seen that most of the passengers have been handled within 80 s with dynamic zoning while it takes almost 120 s for the conventional system. Figure 4(a) shows the corresponding profile of the transit time (i.e., journey time) for a conventional system and Figure 4(b) is that with dynamic zoning. It can be seen that the average transit time can be reduced by 38% with dynamic zoning while the longest transit time is also reduced by 38%.

PASSENGER DATA (Period 1)

Start Time	9:00
End Time	9:01
Loading Time (s)	1.20
Unloading Time (s)	1.20
Passenger Mass (kg)	75
Capacity Factor (%)	100.00
Stair Factor (%)	0.00
Notes	Passengers

Floor Name	*Arrival Rate (Persons /5 mins)*	*Dest. Prob Level 0 (%)*	*Dest. Prob Level 1 (%)*	*Dest. Prob Level 2 (%)*	*Dest. Prob Level 3 (%)*	*Dest. Prob Level 4 (%)*	*Dest. Prob Level 5 (%)*	*Dest. Prob Level 6 (%)*	*Dest. Prob Level 7 (%)*	*Dest. Prob Level 8 (%)*	*Dest. Prob Level 9 (%)*	*Dest. Prob Level 10 (%)*	*Dest. Prob Level 11 (%)*	*Dest. Prob Level 12 (%)*
Level 0	500.00	0.00	3.00	4.00	8.00	10.00	4.00	9.00	5.00	15.00	22.00	5.00	10.00	5.00
Level 1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Level 2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Level 3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Level 4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Level 5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Level 6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Level 7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Level 8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Level 9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Level 10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Level 11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Level 12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Figure 1 Passenger data for up-peak traffic

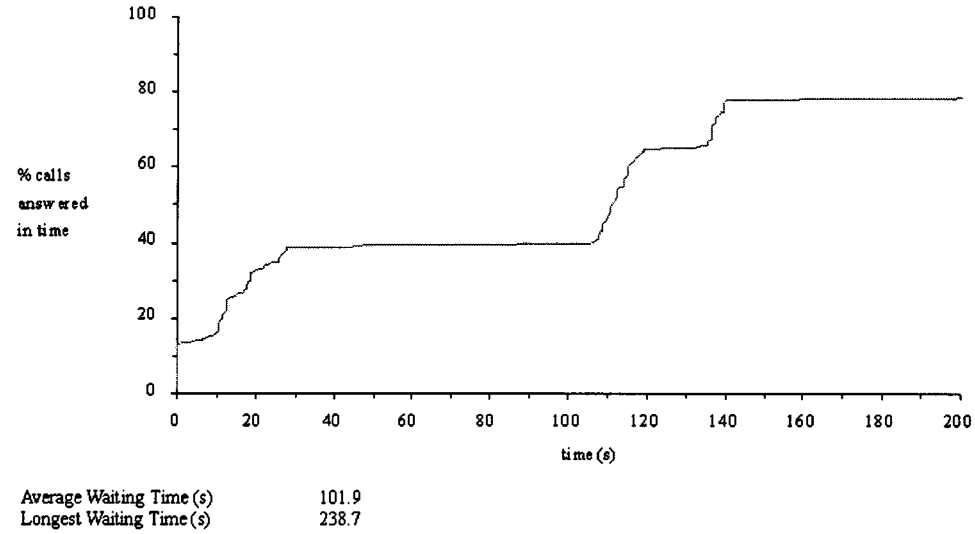
Floor	Car 1	Car 2	Car 3
12	X	X	
11	X	X	
10	X	X	
9	X	X	
8	X		X
7	X		X
6	X		X
5		X	X
4		X	X
3		X	X
2		X	X
1		X	X
M.T.			

Figure 2 Dynamic zoning scheme for up-peak traffic

6.2 Down-peak traffic simulation

The passenger traffic data is shown in Figure 5. During down-peak, at 1:01 p.m., lots of passengers demand services at respective floors. This is a normal situation at lunch time when occupants want to leave the building. The arrival rates are different for different floors. Based on such a traffic pattern, the resultant dynamic zoning scheme is obtained, shown in Figure 6. The process is similar to that described in section 6.1. The main difference is that a different set of equations for H and S have been adopted. Again, demand matching has been used. Figure 7(a) shows the profile of the passenger waiting time without zoning as stimulated by the commercial software package. Figure 7(b) shows the same profile with dynamic zoning. It can be seen that the average waiting time is reduced by 17%. Although the longest waiting time is higher with dynamic zoning, it can be seen that at time $t = 60$ s, 70% calls have been answered with dynamic zoning while less than 50% of the calls have been answered for the conventional system. Figure 8(a) shows the corresponding profile of the transit time (i.e., journey time) without zoning and

a)



b)

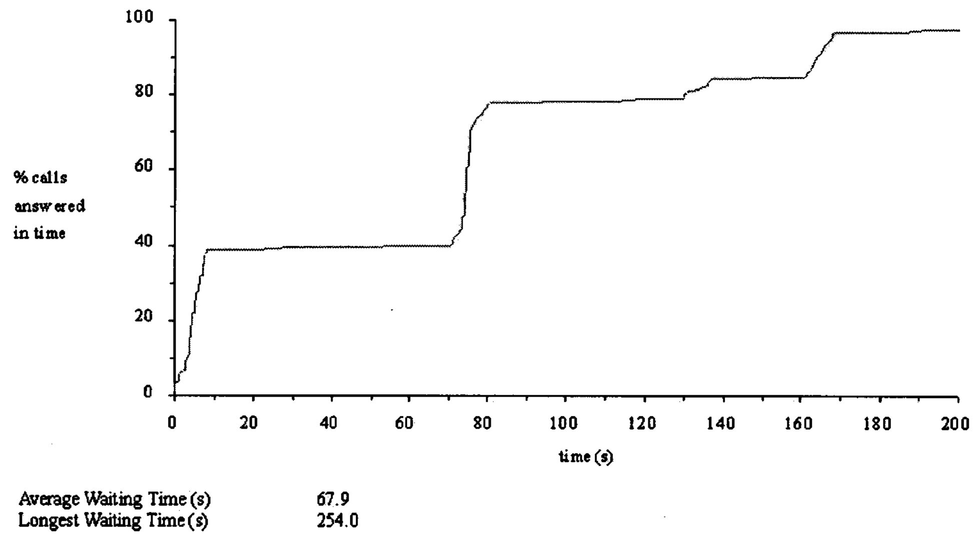
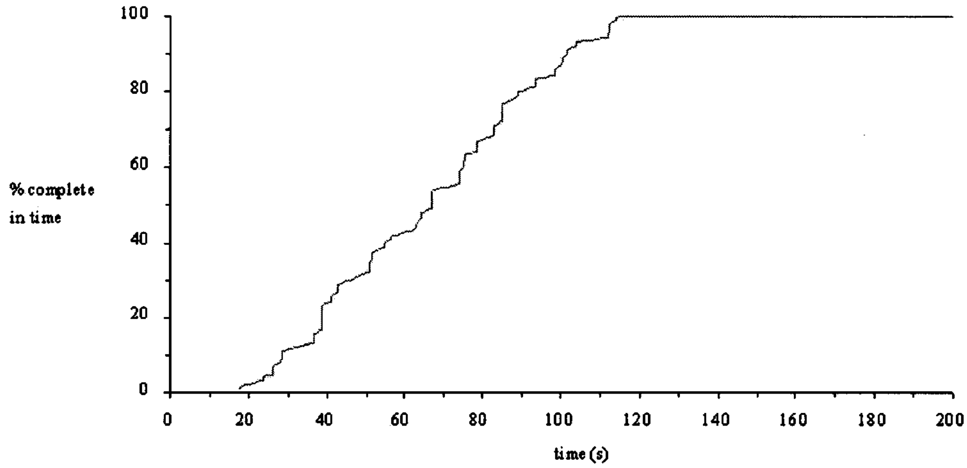


Figure 3(a) Passenger waiting time result for up-peak traffic without dynamic zoning. (b) Passenger waiting time result for up-peak traffic with dynamic zoning.

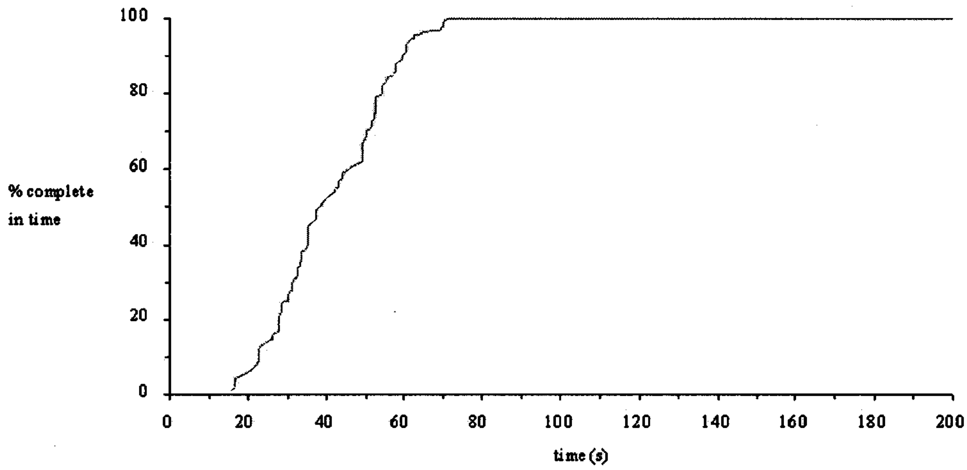
Figure 8(b) is that with dynamic zoning. It is found that that the average transit time is increased by 15% with dynamic zoning while the longest transit time is also slightly increased. That may be due to the fact that during down-peak, lift cars are normally fully loaded within a few floors near to the top of the building or the top of a zone. Then, the number of stops is greatly reduced even without zoning. In this way, dynamic zoning cannot produce its desirable effect. However, from a passenger point of view, the sum of waiting time and transit time should be of major concern. In this way, there is still an improvement of 7% by using dynamic zoning.

a)



Average Transit Time (s) 66.0
Longest Transit Time (s) 114.8

b)



Average Transit Time (s) 41.0
Longest Transit Time (s) 71.5

Figure 4(a) Passenger transit time result for up-peak traffic without dynamic zoning. (b) Passenger transit time result for up-peak traffic with dynamic zoning.

6.3 Heavy interfloor traffic simulation

The passenger traffic data is shown in Figure 9. At 11:00 a.m., passengers are moving around the building and travelling between floors. This is a normal situation in a commercial building when the business activities reach their maximum rate. Based on such a traffic pattern, the resultant dynamic zoning scheme is obtained, shown in Figure 10, based on the sophisticated optimization procedure by the GA based algorithms. In the beginning, a floor zoning pattern is pressumed by random number generation. The demand in terms of total number of passengers at each floor and their destination floors have been

PASSENGER DATA (Period 1)

Start Time	13:01
End Time	13:05
Loading Time (s)	1.20
Unloading Time (s)	1.20
Passenger Mass (kg)	75
Capacity Factor (%)	100.00
Stair Factor (%)	0.00
Notes	Passengers

Floor Name	*Arrival Rate (Persons /5 mins)*	*Dest. Prob Level 0 (%)*	*Dest. Prob Level 1 (%)*	*Dest. Prob Level 2 (%)*	*Dest. Prob Level 3 (%)*	*Dest. Prob Level 4 (%)*	*Dest. Prob Level 5 (%)*	*Dest. Prob Level 6 (%)*	*Dest. Prob Level 7 (%)*	*Dest. Prob Level 8 (%)*	*Dest. Prob Level 9 (%)*	*Dest. Prob Level 10 (%)*	*Dest. Prob Level 11 (%)*	*Dest. Prob Level 12 (%)*
Level 0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Level 1	5.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Level 2	5.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Level 3	10.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Level 4	15.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Level 5	5.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Level 6	15.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Level 7	40.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Level 8	40.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Level 9	5.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Level 10	5.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Level 11	10.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Level 12	10.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

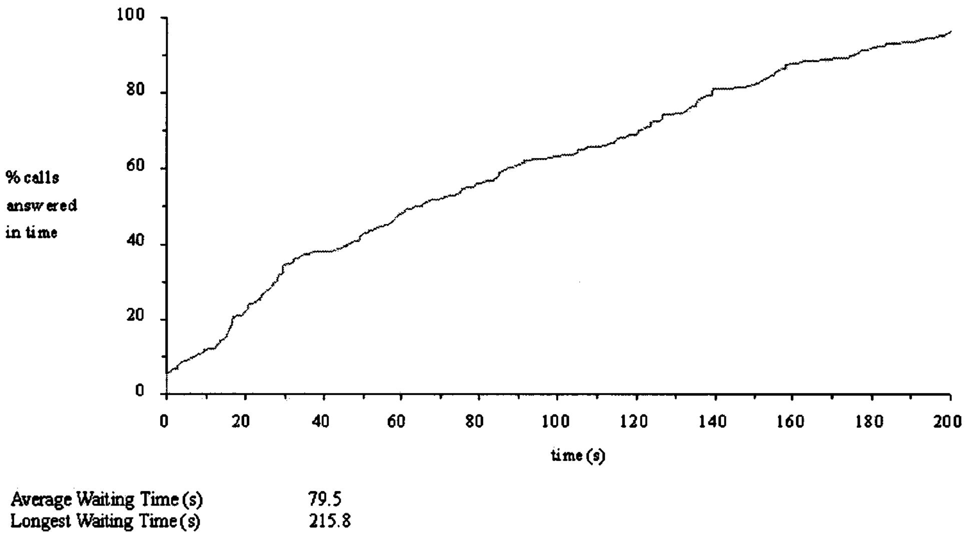
Figure 5 Passenger data for down-peak traffic

Floor	Car 1	Car 2	Car 3
12	X	X	
11	X	X	
10	X	X	
9	X	X	
8	X		X
7	X		X
6		X	X
5		X	X
4		X	X
3		X	X
2		X	X
1		X	X
M.T.			

Figure 6 Dynamic zoning scheme for down-peak traffic

known from the simulation profile. Such data is used to produce the probability, π_{ij}, from the *i*th floor to the *j*th floor. Then, π_j is estimated for every floor, followed by H and S. Finally, the ERTT of every car is found. By minimizing the standard deviation of all ERTT of all cars, we are able to change the zoning pattern with the GA algorithms. Figure 11(a) shows the profile of the passenger waiting time without zoning as stimulated by Elevate 3.0. Figure 11(b) shows the same profile with dynamic zoning. It can be seen that the average waiting time is reduced by 16%. The longest waiting time is also slightly reduced by 3%. Furthermore, it can be seen that less than 90 s are required to answer 80% of the landing calls with dynamic zoning while it takes more than 120 s to perform the same for a conventional system. Figure 12(a) shows the corresponding profile of the transit time (i.e., journey time) without zoning and Figure 12(b) is that with dynamic zoning. It is found that the average transit time is reduced by 13% with dynamic zoning but the longest transit time is slightly increased. That may be a normal trend for a stringent comparison between the two control systems.

a)



b)

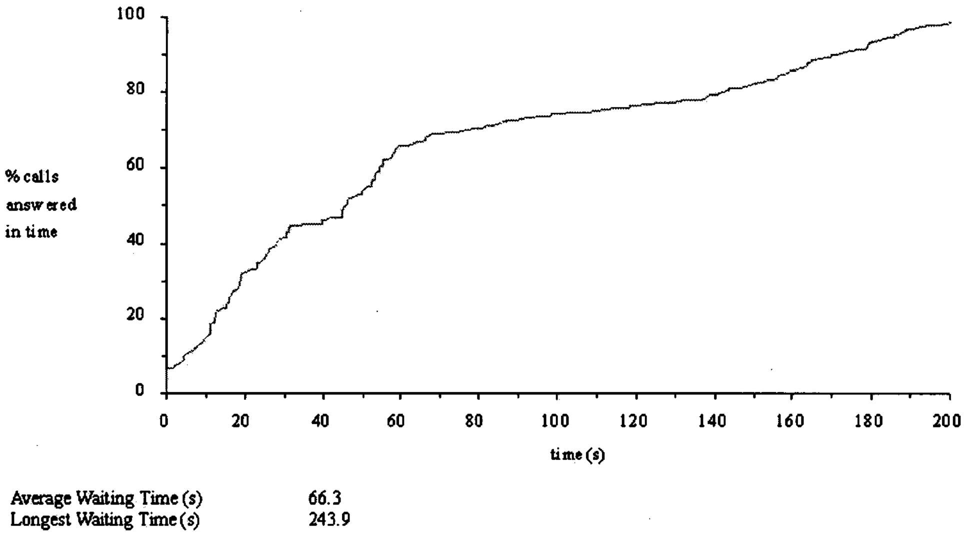


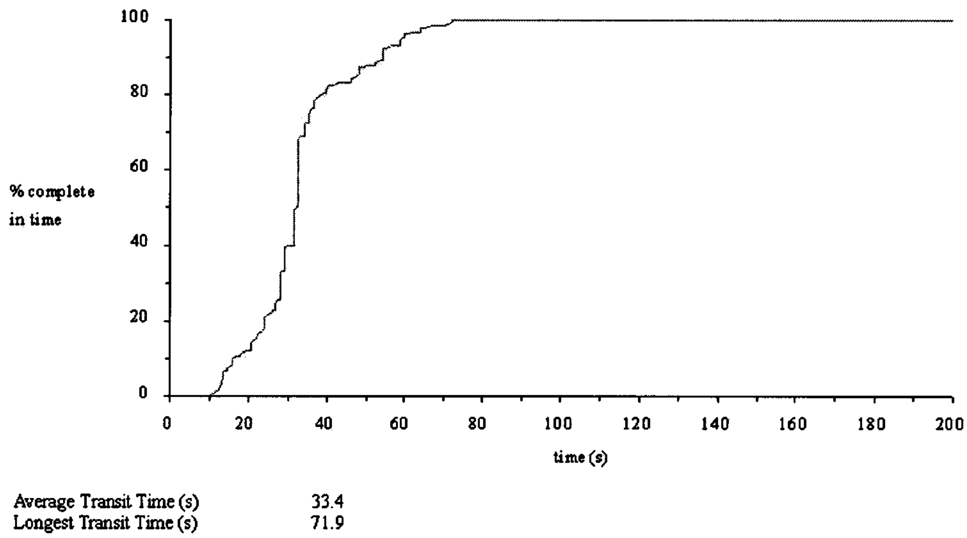
Figure 7(a) Passenger waiting time result for down-peak traffic without dynamic zoning. (b) Passenger waiting time result for down-peak traffic with dynamic zoning.

7. Conclusions

It was first mentioned in the introduction of this paper that zoning has been a conventional practice in lift system design. Primitive zoning techniques were developed in the early 1990s. They formed the foundation of the comprehensive dynamic zoning scheme discussed in this paper. Zoning should be dynamic because a static assignment scheme can only be effective for one specified traffic condition, such as up-peak, but may be ineffective for other traffic patterns such as down-peak, etc.

It has been shown in the paper that dynamic

a)



b)

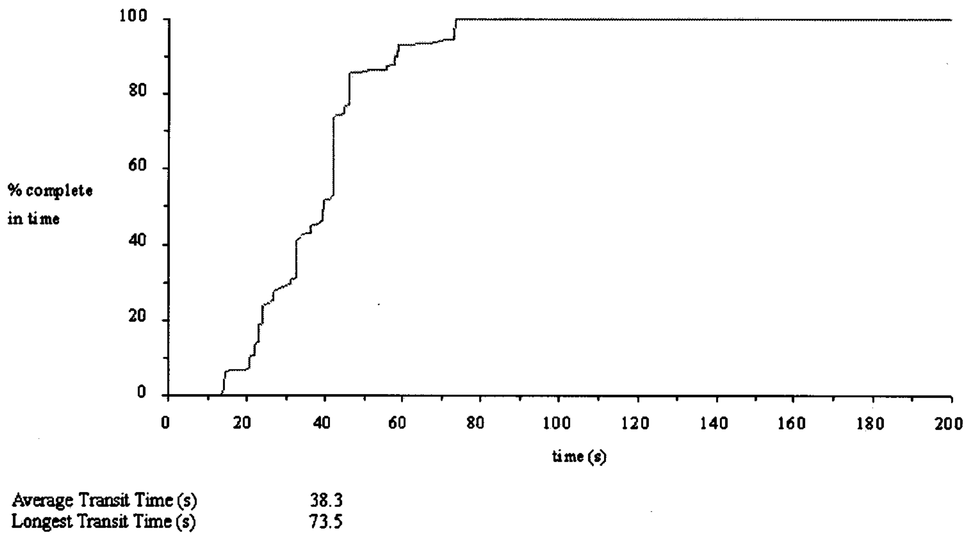


Figure 8(a) Passenger transit time result for down-peak traffic without dynamic zoning. (b) Passenger transit time result for down-peak traffic with dynamic zoning.

zoning can improve an existing lift system for three different traffic conditions normally encountered in commercial buildings i.e., up-peak, down-peak and heavy interfloor situations by reducing the average passenger waiting/travelling time. Dynamic zoning only behaves a little bit poorer for the transit time during a down-peak condition because the number of stops is naturally reduced even with a conventional system without zoning. From the figures, it can be seen that more calls can be handled within a shorter period of time by dynamic zoning. Subject to the fact that the number of passengers has been fixed for the simulation exercise, a shorter time to

PASSENGER DATA (Period 1)

Start Time	11:00
End Time	11:01
Loading Time (s)	1.20
Unloading Time (s)	1.20
Passenger Mass (kg)	75
Capacity Factor (%)	100.00
Stair Factor (%)	0.00
Notes	Passengers

Floor Name	*Arrival Rate (Persons /5 mins)*	*Dest. Prob Level 0 (%)*	*Dest. Prob Level 1 (%)*	*Dest. Prob Level 2 (%)*	*Dest. Prob Level 3 (%)*	*Dest. Prob Level 4 (%)*	*Dest. Prob Level 5 (%)*	*Dest. Prob Level 6 (%)*	*Dest. Prob Level 7 (%)*	*Dest. Prob Level 8 (%)*	*Dest. Prob Level 9 (%)*	*Dest. Prob Level 10 (%)*	*Dest. Prob Level 11 (%)*	*Dest. Prob Level 12 (%)*
Level 0	70.00	0.00	14.30	0.00	0.00	0.00	14.30	14.30	14.30	14.30	0.00	14.30	0.00	14.30
Level 1	10.00	50.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	50.00
Level 2	75.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00
Level 3	50.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00
Level 4	25.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00
Level 5	15.00	33.30	0.00	0.00	0.00	0.00	0.00	33.30	0.00	0.00	0.00	0.00	0.00	33.30
Level 6	10.00	50.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	50.00	0.00	0.00
Level 7	5.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Level 8	20.00	25.00	25.00	0.00	0.00	0.00	25.00	0.00	0.00	0.00	0.00	0.00	0.00	25.00
Level 9	105.00	0.00	0.00	90.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.00
Level 10	10.00	50.00	0.00	0.00	0.00	0.00	0.00	0.00	50.00	0.00	0.00	0.00	0.00	0.00
Level 11	90.00	0.00	0.00	0.00	45.00	55.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Level 12	20.00	25.00	25.00	0.00	0.00	0.00	25.00	0.00	25.00	0.00	0.00	0.00	0.00	0.00

Figure 9 Passenger data for interfloor traffic.

Floor	Car 1	Car 2	Car 3
12		X	X
11	X		X
10	X		X
9		X	X
8	X	X	
7	X	X	
6	X	X	
5	X	X	
4	X		X
3	X		X
2		X	X
1	X	X	
M.T.			

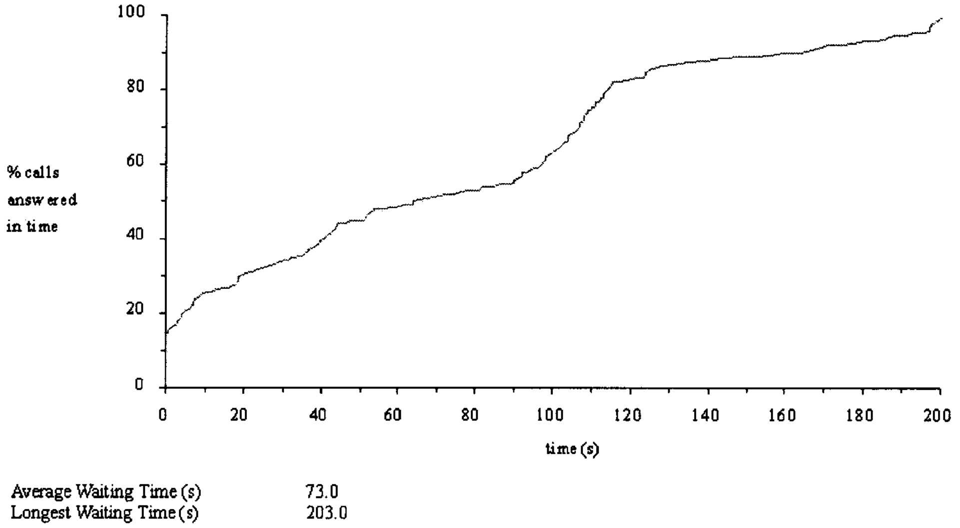
Figure 10 Dynamic zoning scheme for interfloor traffic.

handle more passengers implies a higher handling capacity offered by the system.

The mathematical process for up-peak and down-peak conditions is relatively simple from a computational point of view, the authors have no concern of the relationship between the sensitivity of this method and the total number of floors of the building. However, for the interfloor traffic condition, the computational process is much more sophisticated, in particular, when GA algorithms are employed. It is generally believed that dynamic zoning can improve the situation when the building is taller. However, the computational loading is very much increased as the number of floors being considered is larger. The reason why a 12-storey building is simulated is based on the consideration of the existing availability of computer resources. When a high quality software package handling GA algorithms is available, the authors would like to do the simulation again on a high-rise building, say with 50 storeys or more.

During the two up-peak and two down-peak durations within a working day, the dynamic zoning algorithm can be switched in automatically. LED display panels can be installed above

a)



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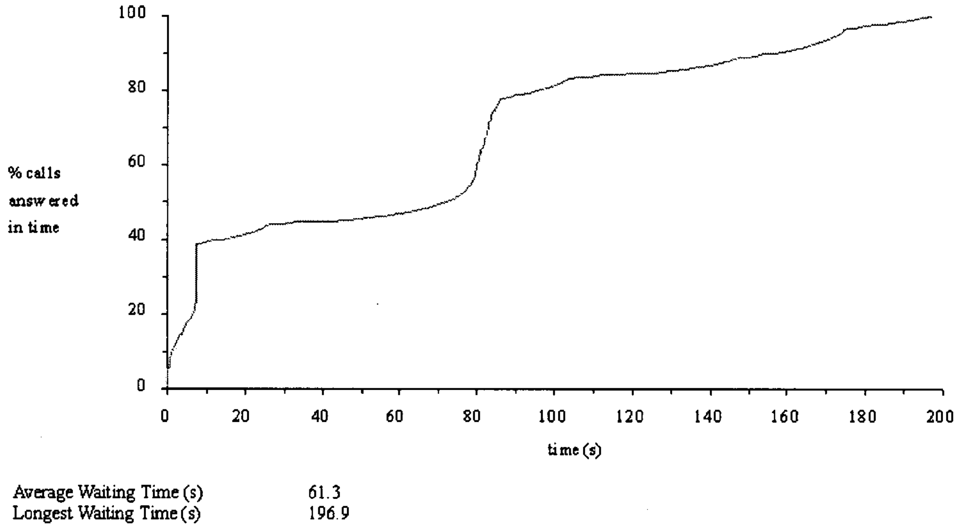
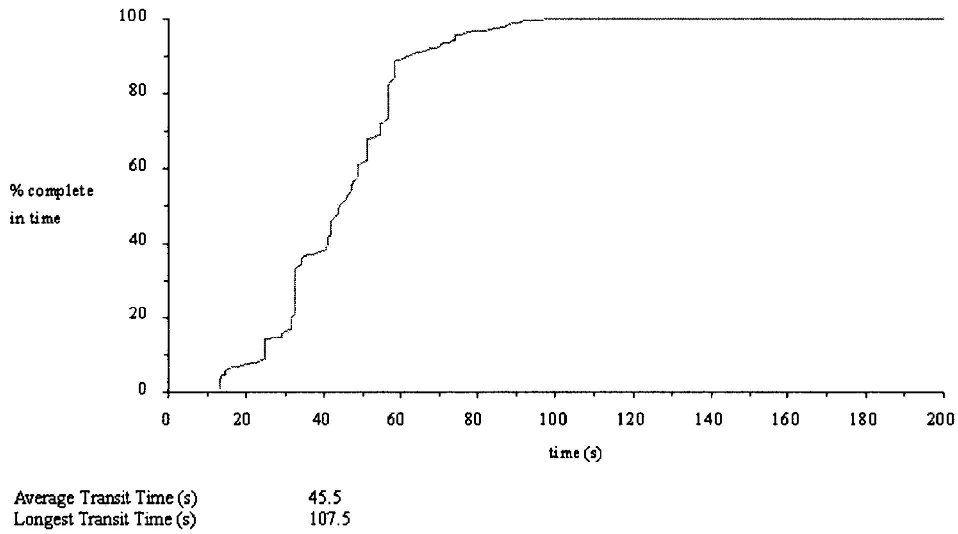


Figure 11(a) Passenger waiting time result for interfloor traffic without dynamic zoning. (b) Passenger waiting time result for interfloor traffic with dynamic zoning.

all landing doors so that the passengers are able to recognize the continuously changing floor numbers being serviced by each lift car. Dynamic zoning offers a flexibility that passengers can enter a car whose services include their destination floors. This is more favourable as compared with the M–10 system where only one car can be entered right after the car allocation at the lift lobby.

Variance analysis[16] was used before to improve car allocation and we have absorbed this idea in our 'Uniform RTT' algorithm. The successful implementation of dynamic zoning very much relies on a good monitoring system to

a)



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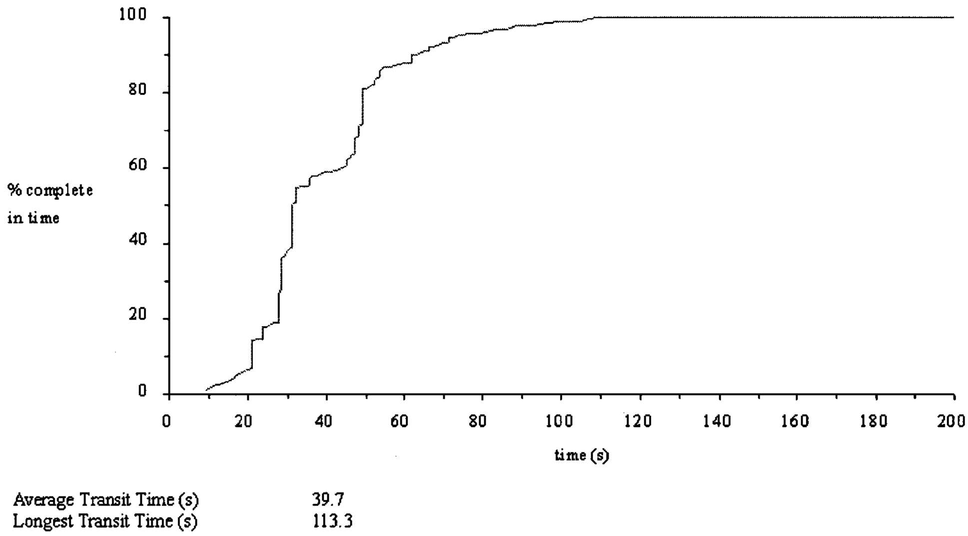

Figure 12(a) Passenger transit time result for interfloor traffic without dynamic zoning. (b) Passenger transit time result for interfloor traffic with dynamic zoning.

evaluate the traffic demand of every floor and identify the mode of traffic on a real-time basis. This highly calls for a machine that can learn and keep itself updated of the traffic patterns. The employment of artificial neural networks[6] and computer vision[8,10] becomes a necessity because the network can reveal the traffic patterns of a building, the habit of the passengers and the drifting of rush hours etc., while the computer vision system can show the passenger demands at each floor i.e., estimating the actual number of passengers asking for services. It is anticipated that dynamic zoning may be a normal supervisory control scheme for lifts in future years when our computational machines become faster and have a larger memory space.

Acknowledgements

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Appendix A

A general mathematical programming problem on vector $\mathbf{x} = [x_j : j = 1, \ldots, n]$ is:

$$\begin{gathered}\text{Min } f(x) \text{ subject to } m \text{ constraints:}\\ g_i(x) \le b_i \ (i = 1, 2, \ldots, m)\end{gathered} \tag{19}$$

The Lagrange function, F($\mathbf{x}$, λ, $\mathbf{u}$), can be formed as shown below:

$$\begin{aligned}&F(\mathrm{x}, \lambda, \mathrm{u})\\ &= f(\mathrm{x}) + \sum_{i=1}^{m} \lambda_i [g_i(\mathrm{x}) + \mathrm{u}_i^2 - b_i]\end{aligned} \tag{20}$$

The necessary conditions to be satisfied at a stationary point are:

$$\begin{gathered}\frac{\partial F}{\partial x_j} = \frac{\partial F}{\partial \lambda_i} = \frac{\partial F}{\partial u_i} = 0\\ j = 1. \ldots, n; \ i = 1, \ldots, m\end{gathered} \tag{21}$$

There is also an extra condition which must be satisfied at a constrained minimum, namely $\lambda_i \ge 0$. The conditions stipulated in Equation set (21) are known as the Kuhn-Tucker conditions.

The general equation sets described above are applied to dynamic zoning for up-peak and down-peak conditions. The up-peak situation is illustrated here because the down-peak situation follows similarly. It is observed that the constraints on the n's in section (3) of this paper are strict inequalities i.e., not in accordance with format of Equation (19). Hence, they are modified into the following form: $1 \leq n_1; \cdot \cdot ; n_j + 1 \leq n_{j+1}; \cdot \cdot ; n_{m-1} + 1 \leq N$.

The Lagrange function, F, becomes:

$$F(n,\lambda,u) = \begin{cases} \sigma(RTT_j \,|_{j=1}^{m}) + G \\ \sum_{j=1}^{m}(U_j - HC_j)^2 + G \end{cases} \quad (22)$$

where

$$G = \lambda_1(1 - n_1 + u_1^2) + \sum_{j=2}^{m-1} \lambda_j (n_{j-1} + 1 - n_j + u_j^2)$$
$$+ \lambda_m (n_{m-1} + 1 - N + u_m^2)$$

The necessary conditions are then summarized as:

$$0 = \frac{\partial[A]}{\partial n_1} - \lambda_1 + \lambda_2 = \frac{\partial[A]}{\partial n_{m-1}} - \lambda_{m-1} + \lambda_m$$
$$0 = \frac{\partial[A]}{\partial n_i} - \lambda_i + \lambda_{i+1} \text{ for } i = 2, \ldots, m-2$$
$$0 = 1 - n_1 + u_1^2; \;\; 0 = n_{m-1} + 1 - N + u_m^2$$
$$0 = n_{i-1} + 1 - n_i + u_i^2 \text{ for } i = 2, \ldots, m-1$$
$$0 = \lambda_i u_i \text{ and } 0 \leq \lambda_i \text{ for } i = 1, \ldots, m$$

where

$$A = \sigma(RTT_j \,|_{j=1}^{m}) \text{ or } \sum_{j=1}^{m}(U_j - HC_j)^2 \quad (23)$$

It should be noted that n_is are discrete in nature and therefore the partial derivative of H_j and S_j with respect to n_i should be evaluated by increasing n_i by 1 while keeping all other n_js constant, s.t. $j \neq i$, and calculating the corresponding changes in each H_j and S_j. However, the final n_j, $j = 1, \ldots, m-1$, obtained may not be integral. They are then rounded up to the nearest integers. Although that will make the solution deviate from the optimal answer, we are just aiming at a guideline rather than a perfect remedy.

Appendix B

The cost function to be minimized for the m number of lifts is given by E such that:

$$E = \frac{1}{m}\sum_{k=1}^{m}(ERRT^k - \overline{ERRT})^2$$
$$\overline{ERRT} = \frac{\sum_{k=1}^{m} ERRT^k}{m} \quad (24)$$

GA[13,14] is a method to help searching for the optimal solution to a complex problem, based on the principles of natural selection. It is basically an automated, intelligent approach to trial and error. Given specific formulae, rules, or arrangements to be optimized, a GA can arrive at a global solution with a higher chance. The algorithm approaches the problem by using the principles of natural selection. This is done by the creation within a machine of 'Population of Individuals' represented by 'Chromosomes', in essence a set of character strings that are analogous to the base4 chromosomes of the DNA. GAs allow us to solve problems that were previously considered too large or complicated and are useful in the very tricky area of nonlinear problems.

In our problem of dynamic zoning, the cost function E to be minimized is the sum of the variance of the equivalent round trip time among the m number of lifts. Each lift is assigned one zone and floors in one zone can be overlapping with floors of another zone. For simplicity, it is assumed that $N = 10$ and $m = 3$. Each zone is represented by a string, x_i $i = 1, \ldots, m$ of N binary variables, '1' implying that particular floor belongs to the zone and '0' vice versa. The following outlines the procedures of GA application:

1) The length of the chromosome string is $N \times m = 30$;

2) The initial population of 10 strings each of 30 binary variables is randomly generated;
3) The value of fitness i.e., *E*, is calculated for each string in the initial population e.g., '0100000000 1011100001 0000110011' decodes to 2/F belongs to the zone of lift no. 1; 1/F, 3/F, 4/F, 5/F and 10/F belong to the zone of lift no. 2; 5/F, 6/F, 9/F and 10/F belong to the zone of lift no. 3. Each of the 10 strings produces a cost function.
4) The next generation of GA begins with reproduction. This is a simple copying operation, subject the values of fitness. Candidates with higher fitness i.e., lower *E*, will have a greater probability of being reproduced in the succeeding generation and those with lower fitness will tend to die out. To visualize how this is done, the 'wheel of fortune' is a very good analogy where each string is assigned a segment size on the wheel. The size is proportional to its value of fitness. For each spin of the wheel i.e., a trial, a string is copied to the breeding population if the wheel stops with the pointer in the segment of that string.
5) The crossover procedure operates on two most appropriately selected strings while the point of crossover is randomly selected, say 15 e.g., 0100000000 1011100001 0000110011 mates with 0100111000 1010101001 0011100001 produces 0100000000 1011101001 0011100001 and 0100111000 1010100001 0000110011.
6) The last operation i.e., mutation, is performed on a bit-by-bit basis. It is assumed that the probability of mutation is arbitrarily chosen as 0.01. With a total of 10 strings in the population, it should be expected that one mutation will occur in only one string for a period of ten generations ($10 \times 0.01 = 0.1$). For example, the mutation of the string '0100000000 1011100001 0000110011' becomes '0100001000 1011100001 0000110011'.
7) The new population is now ready to be assigned values of fitness, and the crossover and mutation cycles are repeated.