# DYNAMIC ZONING IN ELEVATOR TRAFFIC CONTROL

W.L. Chan, Albert T.P. So
Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong
K.C. Lam, City University of Hong Kong

## ABSTRACT

Zoning is one conventional way to make an existing elevator system adapt to different traffic patterns. However, zoning is generally either fixed permanently or static based on time scheduling where the floors being grouped into zones are predetermined during the design stage. In this paper, a new algorithm is discussed that can provide the feature of dynamic zoning for an elevator system based on the real time traffic patterns. The objectives are to achieve maximum handling capacity of the system and minimum waiting/travelling time for passengers. Information related to real time zoning can be delivered to passengers by LED display boards installed at each landing above landing doors. A computer simulation has revealed that this new algorithm can at least improve both the handling capacity and passenger waiting/travelling time by at least 12% under most traffic conditions.

## 1 INTRODUCTION

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

In a modern high rise building, each lift car is not usually required to service every level, 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]. More 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, called the express zone terminal. A major advantage of zoning is the increase of the elevator system handling capacity. 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 during a pre-scheduled period of time during the day. The period usually coincides with the peak traffic situation or rush hours and the elevators service all floors outside this period.

The merit of zoning is not controversial. However, the existing control patterns of zoning are pre-determined 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. The assumption here is that zoning is only effective for up-peak and down-peak conditions while interfloor traffic is minimal. Hence, our algorithms for dynamic zoning concentrate on the two major traffic patterns.

## 2 KNOWLEDGE OF TRAFFIC PATTERNS

Before a decision on the zoning details is arrived at, information related to the real time elevator traffic patterns is absolutely necessary. That consists of two aspects.

First of all, the traffic mode has to be determined, up-peak, down-peak, interfloor or off-peak. As it has been mentioned in section 1, zoning will be effective during two modes, i.e. up-peak and down-peak. There are different ways to identify up-peak and down-peak traffic modes. There are two parameters proposed by Beebe [2] that can 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 also two parameters [2] 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 summarised in a paper presented by the authors in Elevcon'93 [3]. Another way is the employment of artificial neural networks (ANN) continuously monitoring the elevator system [4]. All relevant data are retrieved from the computerised supervisory control system and normalised 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 identified. In conventional elevator design, 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. Of course, an ANN can be employed to keep track of the variations in traffic demand of each floor. Anyway, the accuracy of the information obtained can be quite crude because the algorithms are working on a statistical basis rather than strict one-one correspondence.

## 3 ALGORITHMS OF DYNAMIC ZONING

Here, 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. 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 consist of one upper floor only. Also, no duplicate zone is possible. Duplicate zone means two cars service the same zone. 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 below:

1st car serving 0/F(MT), 1/F, ... , $n_1$/F;
2nd car serving 0/F(MT), ($n_1$+1)/F, ... , $n_2$/F;
.

.
jth car serving 0/F(MT), ($n_{j-1}$+1)/F, ... , $n_j$/F;
.

.
mth car serving 0/F(MT), ($n_{m-1}$+1)/F, ... , N/F.

A strict rule is: $0 < n_1 < n_2 \bullet\bullet < n_j < \bullet\bullet < n_{m-1} < N$ . 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 $RTT_j$. The mathematical problem becomes the minimisation of the following cost function:

$$\underset{n_1 \, , \, \dots \, , \, n_{m-1}}{Min} \quad \sum_{j=1}^{m} RTT_j^{\;4} \tag{1}$$

The reason of using a power of four is to impose a greater penalty on the non-uniform distribution of RTT's. It is preferably to have a smaller value for the sum of RTT's but it is more preferably to have a uniform distribution of RTT's rather than small RTT's in general but one or two large RTT's. The general formula of $RTT_j$ is shown below:

$$RTT_j = 2 \, H_j \, t_v + ( \, S_j + 1 \, ) \, t_s + 2 \, P \, t_p \tag{2}$$

$t_v$ is conventionally defined as the interfloor flight time 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. $t_p$ is the average passenger transfer time, which is arbitrarily chosen as 1.2 second in our case. These are all constants in equation (2). The remaining three parameters, $H_j$ (highest reversal floor of jth zone), $S_j$ (expected number of stops of jth zone) and P (number of passengers in the car), are variables and they need to be determined on a real time basis. For simplicity, all cars are of same contract capacity and same 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 condition, P(up-peak) can conventionally be assigned to be 80% of the contract capacity of the lift car. H(up-peak) and S(up-peak) can be formulated for each zone in accordance with CIBSE guide [5] for unequal floor population using rectangular PDF.

$$H_j\ (up\text{-}peak) \;=\; n_j - \sum_{k=n_{j-1}+1}^{n_j-1} \left( \sum_{l=n_{j-1}+1}^{k} \frac{U_l}{U_j} \right)^P \qquad where\ n_0 = 0 \tag{3}$$

$$S_j\ (up\text{-}peak) \;=\; \left[\, n_j - n_{j-1} \,\right] - \sum_{k=n_{j-1}+1}^{n_j} \left( 1 - \frac{U_k}{U_j} \right)^P$$

$$where \qquad U_j \;\triangleq\; \sum_{k=n_{j-1}+1}^{n_j} U_k \tag{4}$$

### 3.2 Down-peak traffic condition

Under down-peak traffic condition, Strakosch's approach is adopted [6,7]. P(down-peak) is assigned as the contract capacity of the lift car. H(down-peak) and S(down-peak) are shown below:

$$\begin{aligned} H_j\ (down\text{-}peak) &= n_j \\ S_j\ (down\text{-}peak) &= \frac{3}{4}\, S_j\ (up\text{-}peak) \end{aligned} \tag{5}$$

## 4 MATHEMATICAL PROGRAMMING UNDER INEQUALITY CONSTRAINTS

A closer investigation into the constraints of n's detailed in section 3 and the cost function in equation (1) 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 [8]. A brief review of the method is included in the following section.

### 4.1 The theory

A general mathematical programming problem on vector $x = [x_j : j=1,..,n]$ is:

$$\begin{aligned} &Min \quad f(x) \\ &subject\ to\ m\ constraints:\quad g_i(x) \le b_i \quad (i = 1, 2, \ldots, m) \end{aligned} \tag{6}$$

The inequality constraints can be transformed into equation constraints by the addition of a non-negative slack variable, $u_i^2$, to each one to obtain:

$$\begin{aligned} g_i(x) + u_i^2 &= b_i \\ i.e.\quad g_i(x) + u_i^2 - b_i &= 0 \end{aligned} \tag{7}$$

Thus, the problem becomes the minimisation of f(x) subject to m equation constraints $g_i(x) + u_i^2 - b_i = 0$. The Lagrange function, $F(x, \lambda, \mathbf{u})$, can be formed as shown below:

$$F(x, \lambda, u) = f(x) + \sum_{i=1}^{m} \lambda_i \left[ g_i(x) + u_i^2 - b_i \right] \tag{8}$$

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

$$\begin{aligned} &\frac{\partial F}{\partial x_j} = 0 = \frac{\partial f}{\partial x_j} + \sum_{i=1}^{m} \lambda_i \frac{\partial g_i}{\partial x_j} \quad ; \ j = 1, 2, .., n \\ &\frac{\partial F}{\partial \lambda_i} = 0 = g_i(x) + u_i^2 - b_i \quad ; \ i = 1, 2, .., m \\ &\frac{\partial F}{\partial u_i} = 0 = 2\lambda_i u_i \quad ; \ i = 1, 2, .., m \qquad or \\ &\lambda_i u_i^2 = \lambda_i \left[ b_i - g_i(x) \right] = 0 \end{aligned} \tag{9}$$

There is also an extra condition which must be satisfied at a constrained minimum, viz. $\lambda_i \ge 0$. The conditions stipulated in equation set (9) are known as the Kuhn-Tucker conditions.

## 4.2 The implementation

Going back to the zoning problem, implementation is illustrated for the up-peak situation only because that of down-peak situation follows similarly. It is observed that the constraints with n's shown in section 3 are strict inequalities. This is not according to the general form of programming as shown in expression (6). Hence, they are modified into the following form:

$1 \le n_1 ;\ n_1 + 1 \le n_2 ;\ n_2 + 1 \le n_3 ;\ \bullet\bullet ;\ n_j + 1 \le n_{j+1} ;\ \bullet\bullet ;\ n_{m-1} + 1 \le N$ .

The Lagrange function, F, becomes:

$$\begin{aligned} F(n, \lambda, u) &= \sum_{j=1}^{m} RTT_j^4 + \lambda_1 (1 - n_1 + u_1^2) \\ &+ \sum_{j=2}^{m-1} \lambda_j (n_{j-1} + 1 - n_j + u_j^2) \\ &+ \lambda_m (n_{m-1} + 1 - N + u_m^2) \end{aligned} \tag{10}$$

The necessary conditions are then summarised below as:

$$\begin{aligned} 0 &= \frac{\partial \left[ \sum_{j=1}^{m} RTT_j^4 \right]}{\partial n_1} - \lambda_1 + \lambda_2 \\ 0 &= \frac{\partial \left[ \sum_{j=1}^{m} RTT_j^4 \right]}{\partial n_i} - \lambda_i + \lambda_{i+1} && \textit{for } i = 2 \,..\, m-2 \\ 0 &= \frac{\partial \left[ \sum_{j=1}^{m} RTT_j^4 \right]}{\partial n_{m-1}} - \lambda_{m-1} + \lambda_m \\ 0 &= 1 - n_1 + u_1^2 \\ 0 &= n_{i-1} + 1 - n_i + u_i^2 && \textit{for } i = 2 \,..\, m-1 \\ 0 &= n_{m-1} + 1 - N + u_m^2 \\ 0 &= \lambda_i u_i \quad \textit{and} \quad 0 \le \lambda_i && \textit{for } i = 1 \,..\, m \end{aligned} \tag{11}$$

$$\frac{\partial \left[ \sum_{j=1}^{m} RTT_j^4 \right]}{\partial n_i} = 4 \sum_{j=1}^{m} \left[ RTT_j^3 \left( 2 \frac{\partial H_j}{\partial n_i} t_v + \frac{\partial S_j}{\partial n_i} t_s \right) \right]$$

It should be noted that $n_i$'s are discrete in nature and therefore the partial derivative of H and S with respect to $n_i$ should be evaluated by increasing $n_i$ by 1 while keeping all $n_j$'s constant, s.t. $j \neq i$, and calculating the corresponding changes in each H and S. The final $n_j$, j = 1, .. , 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. The effectiveness of dynamic zoning can be demonstrated by a computer simulation.

## 5 COMPUTER SIMULATION

In order to test the advantages of introducing dynamic zoning into a conventional elevator system, a computer simulation has been carried out. A building of 15 storeys is served by a group of four cars. The technical data is shown below:

Interfloor distance = 4 m
Average floor area = 1000 $m^2$
Contract capacity = 16 passengers (1250 kg)
Door opening time = 0.8 second
Door closing time = 2 seconds
Passenger transfer time = 1.2 second
Contract speed = 2 m/s
Single floor flight time = 2 seconds

Both up-peak and down-peak situations have been tested and the following results are available for ten different trial executions:

Up-peak situation -
Reduction in average passenger waiting time = 14%.
Reduction in average passenger travelling time = 12%.
Improvement in passenger handling capacity within a period of five minutes = 13%.

Down-peak situation -
Reduction in average passenger waiting time = 17%.
Reduction in average passenger travelling time = 15%.
Improvement in passenger handling capacity within a period of five minutes = 15%.

Random interfloor traffic situation -
Increase in average passenger waiting time = 6%.
Increase in average passenger travelling time = 23%.
Reduction in passenger handling capacity within a period of five minutes = 11%.

## 6 CONCLUSION

It has been shown in the paper that dynamic zoning can improve an existing elevator system for both up-peak and down-peak situations by reducing the average passenger waiting/travelling time and increasing the total handling capacity. Zoning should be dynamic because it is ineffective for other traffic patterns such as peak interfloor condition etc. During the two up-peak and two down-peak durations within a working day, the dynamic zoning algorithm is automatically switched in. During the rest of the time where random interfloor traffic is dominating, zoning should be cancelled for more flexible operation.

A good monitoring system is necessary to 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 network becomes a necessity because the network can adapt to the changes within the system such as the utilisation mode of the building, the habit of the passengers and the drifting of rush hours etc. A computer simulation has revealed that the improvement can exceed 12% in almost all cases. As a further step, zoning can be extended to certain cases of interfloor traffic if the interflow is limited to certain consecutive floors. This is the case when certain numbers of consecutive floors belong to a single tenancy.

## 7 REFERENCES

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## 8 ACKNOWLEDGEMENTS

The project has been financially support by the Croucher Foundation Research Grant #905046 "Application of Neural Network on Recognition of Elevator Traffic Patterns for Intelligent Group Supervisory Control".

## BIOGRAPHICAL DETAILS

Mr. W.L. Chan received BSc(Eng) and MPhil from University of Hong Kong. He joined the China Light & Power Company Ltd. after his graduation. Now, he is a Lecturer in the Department of Electrical Engineering of Hong Kong Polytechnic University. Mr. Chan is a Chartered Engineer, Member of I.E.E., Member of I.E.E.E., Publication Secretary and Honourable Advisor of IAEE (HK Branch).

Dr. Albert T.P. So received BSc(Eng), MPhil and PhD from University of Hong Kong.

After his graduation, he had been with Hong Kong Government for seven years and joined the Department of Building & Construction of City Polytechnic of Hong Kong. Now, he is a University Lecturer in the Department of Building Services Engineering of Hong Kong Polytechnic University. Dr. So is a Chartered Engineer, Members of I.E.E., C.I.B.S.E. and H.K.I.E. He is also the Regional Coordinator of IAEE, the General and Academic Secretary of IAEE (HK Branch).

Mr. K.C. Lam received BSc from National Taiwan University and MSc from University of Manchester Institute of Science and Technology. Now, he is a University Lecturer in the Department of Building & Construction of City University of Hong Kong.