NEW DEVELOPMENTS IN ELEVATOR TRAFFIC ANALYSIS

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ABSTRACT

In this paper, certain algorithms in elevator traffic analysis have been verified by site measurements and improvements have been made. Beebe, in 1980, proposed several measuring parameters to identify the occurrence of up-peak and down-peak conditions. Site measurements in Hong Kong have been carried out to test the validity and usefulness of these parameters. Regarding improvements to existing algorithms, studies into the inverse S-P estimation and bunching factors of different orders for traffic status identification introduced by Al-Sharif were made. In this paper, a few suggestions have been proposed for improving the two methods to make them more practical in real applications at least in the Hong Kong environment and hopefully, applicable in other places throughout the world.

1. INTRODUCTION

Lifts are installed in buildings to satisfy the vertical transportation needs of their occupants and visitors and are necessary by virtue of a human comfort and convenience, or by statutory regulations. The passengers of elevators aim at both quantity and quality of services. The handling capacity of an elevator system should be as large as possible from a quantity of service point of view. Whereas, the waiting time of passengers should be as short as possible from a quality of service point of view. Both demand for a comprehensive and large-scale system which is not favourable from a financial and economic point of view. Thus, a compromise should be achieved to satisfy the requirements of all parties concerned, namely the landlords and the passengers. Our goal is to improve the performance of an existing elevator system by an appropriate group supervisory control. Different control modes have been developed to optimally suit different traffic patterns so that the efficiency and capacity of the elevator system can be extended to the maximum. The control modes have to be triggered on by certain numerical parameters that can describe the current status of the elevator system and it is one job of elevator traffic analysis. We are trying to address four areas within elevator traffic analysis, namely up-peak traffic, down-peak traffic, bunching and Inverse SP-method respectively, where new developments have been made on the identification of the four situations by the research team jointly organised by City Polytechnic of Hong Kong and Chevalier (Hong Kong) Ltd. Before we look deeply into the details, it is preferable to have a brief revision on the basic definitions [1] of the four areas.

1.1 Up-peak traffic

An up-peak traffic condition exists when the dominant or only traffic condition exists when the dominant or only traffic flow is in an upward direction with all or the majority of passengers entering the lift system at the main terminal of the building. Up-peak occurs in considerable strength in the morning when prospective lift passengers enter a building intent on travelling to destinations on the upper floors of the building. To a lesser extent, an up-peak occurs again at the end of the midday break. It has been believed by many experts that, if a lift system can cope efficiently with the morning up-peak, it will cope with other patterns of traffic, such as down-peak and random interfloor traffic.

1.2 Down-peak traffic

A down-peak traffic condition exists when the dominant or only traffic flow is in a downward direction with all or the majority of passengers leaving the lift system at the main terminal of the building. To some extent, the down-peak is the reverse of the morning up-peak occurring at the end of the working day, and to a lesser extent at the start of the midday break. The evening down-peak is usually more intensive than the morning up-peak with up to 50% higher demands and with durations of up to 10 minutes.

1.3 Bunching

Bunching in elevator systems occurs when the intervals between lift arrivals at main terminals vary widely, and this increases waiting time by the passengers. When the time interval between cars leaving the main terminal is not equal, bunching occurs and degrades the performance of the elevator system. It has been proposed that the reason for the rapid increase of average waiting time (AWT) at loads above 50% is caused by the effects of bunching [2]. A typical case of bunching can be seen in elevator systems when the lifts start following each other (or even frog-leaping), as they answer adjacent calls in the same direction. This has a detrimental effect on passenger waiting time and the ultimate case is when all the lifts in the group move together, acting effectively as one huge lift with a capacity equal to the summation of the capacities of all the lifts in the group.

1.4 S-P Relation and Inverse S-P Relation

With the advent of lift remote monitoring and self logging facilities in lift controllers, it is desirable to be able to derive the actual particulars of passengers using the elevator system from the logged data describing the lift activity, and thus be able to derive the various traffic patterns for various floors. In the design of lift systems, the traditional method has been based on calculating the round trip time (RTT), which relies on calculating the probable number of stops, S [3] and the highest reversal floor [4]. The probable number of stops, S, is given as a function of the number of passengers boarding the car, i.e. the S-P method. It has been proposed by Al-Sharif [5] that this method can be reversed, in order to find the probable number of passengers boarding from the knowledge of the number of stops.

2. SOURCES OF SITE DATA

All the experimental data obtained for supporting the theoretical developments in this paper have been taken from the elevator systems of two reputable commercial buildings in Hong Kong. The first one is Tsimshatsui Centre which is a typical commercial building located at the down town of Hong Kong. It is a medium rise building with 12 floors above main terminal. The elevator system under survey, consisting of four cars each with a contract capacity of 20, serves the offices from 4/F to 12/F and the main terminal. The second one is Peninsula Centre of similar nature and location as Tsimshatsui Centre. The building has 13 floors above main terminal. The elevator system under survey, consisting of four cars each with a contract capacity of 16, serves the offices from 5/F to 13/F and the main terminal.

3. IDENTIFICATION OF UP-PEAK TRAFFIC CONDITION

There are two parameters proposed by Beebe [6] that can identify the occurrence of up-peak traffic pattern, namely the Up-down stop relationship and the Up-stop/Up-landing call relationship.

3.1 Relationship between up and down stops

Beebe proposed that a graph of the number of up-stops divided by down stops divided against time of a day should show a marked peak during an up-peak condition. This phenomenon can be made use of to identify the existence of up-peak situation. Fig. 1 shows the graph of the ratio for data taken at Tsimshatsui Centre and Fig. 2 shows similar result for Peninsula Centre. Each mark on the graph represents a measuring interval of 5 minutes. Both graphs give a marked peak at around 9:00-9:05 a.m. and this fully complies with the rush hour pattern of commercial firms in Hong Kong.

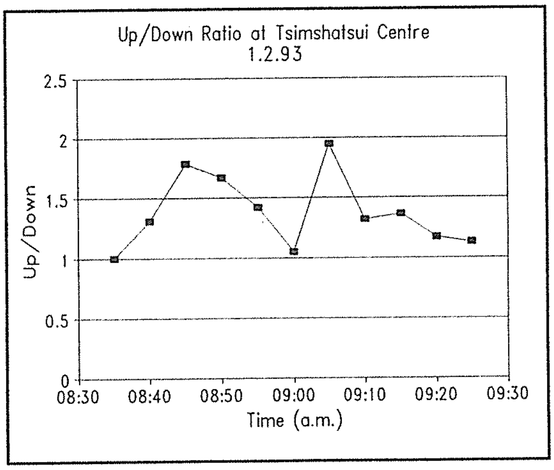

Fig. 1

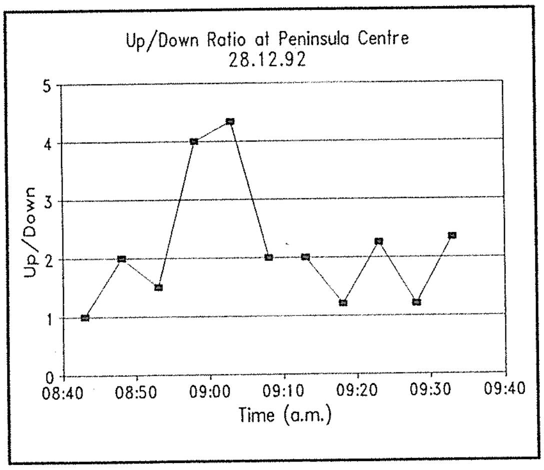

Fig. 2

3.2 Relationship between up stops and up landing calls

Beebe proposed that the ratio of up stops to up landing calls at the marked peak should yield the value of number of stops per round trip, S, used in the up-peak traffic design calculation. S can be calculated if the number of floors (N) above main terminal and the number of passengers (p) carried in the car during up-peak are known. A modified version S_m is got if the distribution of population density (U_i for the ith floor) of the building is known as well.

$$S = N\left[1 - \left(\frac{N-1}{N}\right)^p\right] \qquad S_m = N\left[1 - \frac{1}{N}\sum_{i=1}^{N}\left(1 - \frac{U_i}{U}\right)^p\right] \qquad (1)$$

Fig. 3 shows the result obtained for Tsimshatsui Centre where N = 9 and p = 20*0.8 = 16 giving S = 7.63. However, from Fig. 3, it can be seen that the peak ratio at 9:05 a.m. is 1.9 which is far away from S = 7.63. However, if the ratio is multiplied by 4, Beebe's proposal becomes valid, as shown in Fig. 4 where the horizontal line representing the expected number of stops is being touched by the ratio line. It appears that the proposed algorithm is perfectly valid when there is only one lift car in the system. Hence, it the number of lift cars increase, the ratio should be appropriately multiplied by the number of lift cars in the system to suit the expected number of stops.

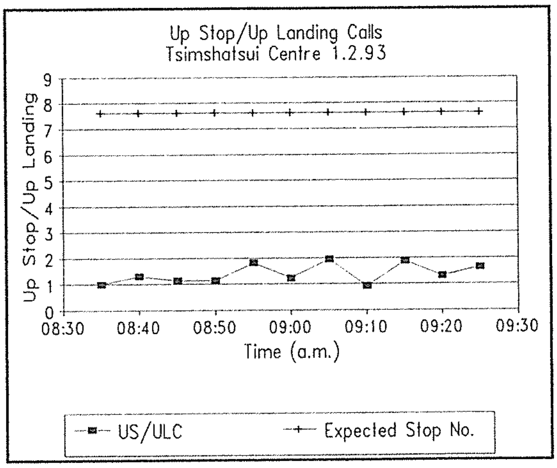

Fig. 3

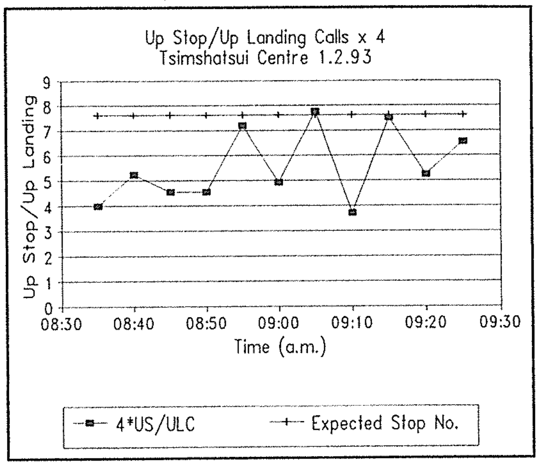

Fig. 4

4. IDENTIFICATION OF DOWN-PEAK TRAFFIC CONDITION

There are also two parameters proposed by Beebe [6] that can identify the occurrence of down-peak traffic pattern, namely the Down-up Stop relationship and the Stops-Landing Call relationship.

4.1 Relationship between down and up stops

During the down-peak traffic, the building occupants start to leave from all floors towards the main terminal. Passengers enter the elevator system at every floor and thus the number of down landing calls becomes very high. The number of up landing calls is small and should diminish as the building becomes empty. Therefore, Beebe proposed that a graph of down stops divided by the up-stops plotted against time of the day should show a dramatic rise. The situation can clearly be shown by Fig. 5 when one lift car is being considered and the peak at 6:00 p.m. becomes more dominant when the whole elevator system is considered, as shown in Fig. 6. Therefore, this parameter can be considered a very effective means of identifying the occurrence of down-peak traffic.

4.2 Relationship between all stops and all landing calls

Beebe further proposed that all stops divided by all landing calls should tend towards unity as the condition continued. The reason behind is that the majority of the down-peak passengers have a common destination stopping floor. This can be verified by Fig. 7. It can be seen that when the down-peak occurs at around 6:00 p.m., the ratio approaches unity but it never reaches the unity value. The group supervisory control should be aware that when the ratio drops to about 1.3, the down-peak situation occurs.

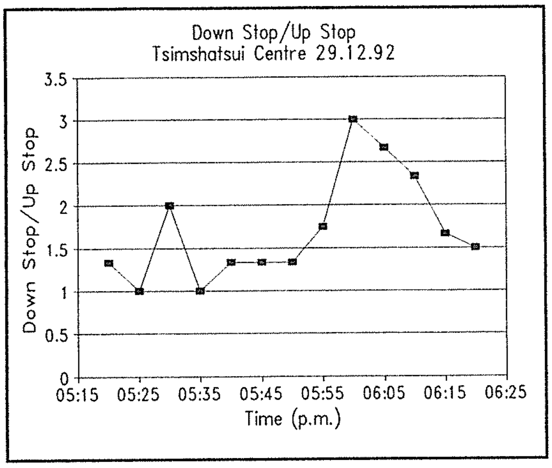

Fig. 5

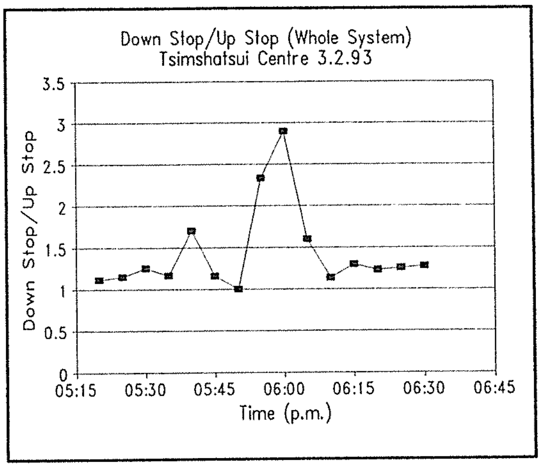

Fig. 6

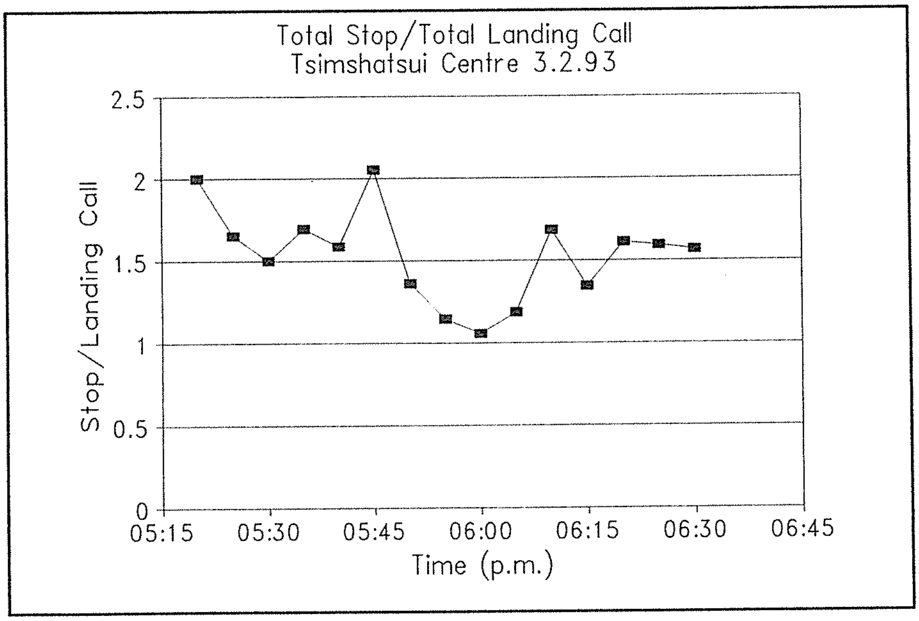

Fig. 7

5. BUNCHING

In principle, if the cars leave the main terminal in unequal time intervals, bunching occurs. This situation can degrade the performance of the elevator system, particularly during the up-peak and down-peak situations. In order to identify the condition of bunching, Al-Sharif [7-8] published two papers to explain the definition and application of bunching factors.

5.1 1st and 2nd order bunching coefficients

Al-Sharif defined the time between the departure of lift number i and lift number (i+1) as $t_{i,i+1}$. Thus, the difference between this time and an ideal time for reference can be an effective measure of how much bunching is prevailing the elevator system. As we are aware, the ideal situation is that every lift car departs from the main terminal at equal interval given by the desirable round trip time (RTT) divided by the number of cars (L) in the system. The first order bunching coefficient BC1 is given by the summation of all the differences divided by that of the worst case, i.e.

$$BC1 \triangleq \frac{\left| t_{1,2} - \frac{RTT}{L} \right| + \cdots + \left| t_{L-1,L} - \frac{RTT}{L} \right| + \left| t_{L,1} - \frac{RTT}{L} \right|}{2\,(L-1)\left(\frac{RTT}{L}\right)} \tag{2}$$

Al-Sharif considered a major drawback to BC1 was that it gave equal weighting to small and larger deviations of departure intervals from the ideal value. He penalised large deviations by introducing BC2 which is given below:

$$BC2 \triangleq \sqrt{\frac{\left\{ t_{1,2} - \frac{RTT}{L} \right\}^2 + \cdots + \left\{ t_{L-1,L} - \frac{RTT}{L} \right\}^2 + \left\{ t_{L,1} - \frac{RTT}{L} \right\}^2}{L\,(L-1)\left(\frac{RTT}{L}\right)^2}} \tag{3}$$

5.2 Imperfections of the bunching coefficients

During our site investigation, BC1 and BC2 defined above work well when the system is not deviating from the ideal case by a large amount. However, when the deviation is large, the two coefficients may give false information. First of all, if the lift number is fixed, the departure by lift number i from the main terminal may be missed if the next departure right after that of lift number (i-1) is lift number (i+1) instead of lift number i. In this case, the lift number should be floating. That means, i is incremented once a lift has departed from the main terminal. But this approach causes another problem. If the lift of number k never reaches the main terminal due to some problem at the upper floor, such as passenger disturbance or door jamming etc., the two BC's will only return a slightly larger value if the other lift cars behave well. In my opinion, this situation should be considered as a bunching case as well and a penalty should be given to the coefficients. Also, the current BC's are formulated based on the assumption that within one RTT, all the lift cars should have returned to the main terminal once. This is not the case in realistic situation. Some lift cars may travel slower than the others because of the uneven distribution of car stops and passengers and thus one lift car may have reached the main terminal once while the other lift car may have reached the main terminal within the same period of time. Finally, if the design is perfect and when it is during real up-peak situation, the calculated RTT can have a value very near to the real RTT of operation. But it is not the normal case in Hong Kong as we sometimes have bunching even during the off-peak situation. That means the real operational RTT of the elevator system does not comply with the desirable RTT based on the design calculation which is:

$$RTT = 2\,H\,t_v + (S+1)\,t_s + 2\,P\,t_p \tag{4}$$

5.3 Modification to BC1 and BC2 by adaptive RTT

The problems mentioned above can be solved by re-defining the RTT in the two expressions for BC1 and BC2. An adaptive RTT value is used instead of the calculated RTT which is fixed during the design stage. By this adjustment, the coefficients can display the true picture of bunching under any situations including up-peak, down-peak and off-peak. The adaptive RTT is similar to a Proportional-Integral-Differential controller tuning the real time RTT on a real time basis. The input variable to the controller is the round trip time of each car trip within the elevator system and the output is the adaptive ARTT. The PID mode of control can be expressed below as:

$$v = v_o + K e + \frac{K}{T_i} \int_0^t e \, dt + K \, T_d \frac{d e}{d t}$$

$$\text{where} \left\{ \begin{array}{l} v = \textit{output signal} \\ v_o = \textit{offset under zero input} \\ e = \textit{error} \ (= \textit{input} - \textit{output} \ ) \\ T_i = \textit{integral action time constant} \\ T_d = \textit{derivative action time constant} \end{array} \right. \qquad \textbf{(5)}$$

As we are working on a digital environment and the ARTT is adjusted for each time step, the ARTT at the nth step is given by:

$$ARTT\,(n) = ARTT(n-1) + k_p \left[\, RTT(n) - CRTT \, \right] + k_i \sum_{j=n-1}^{n-5} \left[\, RTT(j) - CRTT \, \right] + k_d \left[\, RTT(n) - RTT(n-1) \, \right] \qquad \textbf{(6)}$$

$$\text{where} \left\{ \begin{array}{rl} ARTT(n) & = \textit{ARTT at nth time step} \\ CRTT & = \textit{designed RTT by calculation} \\ RTT(n) & = \textit{measured RTT at nth time step} \\ k_p & = \textit{proportionalconstant} \ (\ = 0.02 \ \textit{in our case}) \\ k_i & = \textit{integralconstant} \ (\ = 0.001 \ \textit{in our case}) \\ k_d & = \textit{derivativeconstant} \ (\ = 0.005 \ \textit{in our case}) \end{array} \right.$$

Fig. 8 shows the ARTT obtained during the site measurement on 16.12.92 for the four lift cars at Tsimshatsui Centre.

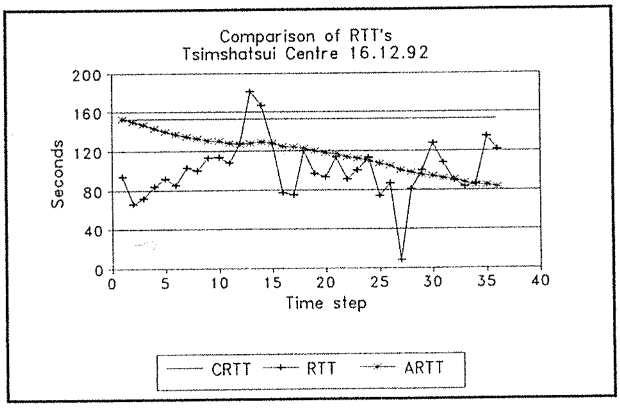

Fig. 8

During our site implementation of ARTT and subsequently the ABC's, it was found that when bunching occurred at the up-peak situation, ABC2 got particularly high values compared with the traditional BC2. It has also been found that in Hong Kong, bunching does not necessarily occur during the up-peak and down-peak hours. Very often, heavy interfloor traffic results in bunching when some lift cars move around the upper floors continuously. This situation can also be revealed by the ABC's. Also, a new value for ABC1 or ABC2 can be returned whenever L+1 number of lift cars depart from the main terminal. We do not need to force all lift cars reach the main terminal within a period of CRTT. These are the merits of the modified BC's.

6. S-P AND INVERSE S-P RELATIONS

Al-Sharif [5] did mention a lots of merits if the number of passengers inside the lift cars are known to the group supervisory control system. Several methods exist, including the utilisation of load weighing devices, the utilisation of photocells [9], the use of sensitive pads [10] and the employment of computer vision [11]. However, they are either very expensive in nature or not available on every system. It is preferable to be able to derive the number of passengers, from the lift activity and any other necessary signals. Jones [3] derived the basis S-P formula for us and it can be reversed to find the probable number of passengers as a function of the number of stops:

$$S = N\left(1 - \left(\frac{N-1}{N}\right)^{p}\right) \quad \Rightarrow \quad p = \left(\frac{\ln\left(\frac{N-S}{N}\right)}{\ln\left(\frac{N-1}{N}\right)}\right) \tag{7}$$

Al-Sharif also made use of the inverse S-P relation to derive the up traffic patterns [12].

6.1 Imperfections with the existing inverse S-P method

In order to examine the validity of the inverse S-P method, surveys were conducted at Tsimshatsui Centre, Great Eagle Centre and Peninsula Centre which are typical commercial buildings in Hong Kong. Fig. 9 shows the result at Great Eagle Centre and Fig. 10 shows the result at Tsimshatsui Centre as illustrative examples. It can be found that the inverse S-P method is quite accurate during the off-peak time but the deviation from the actual passenger number becomes great as the traffic becomes heavier.

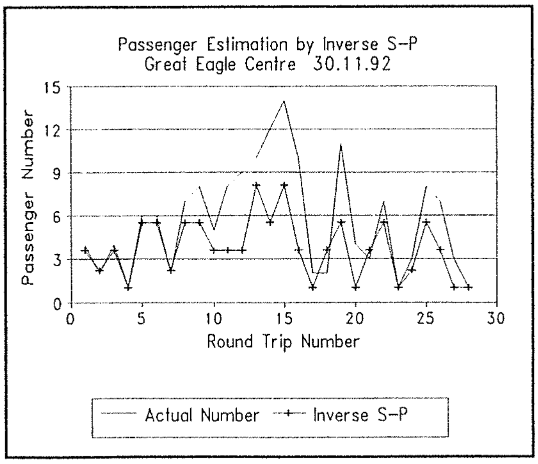

Fig. 9

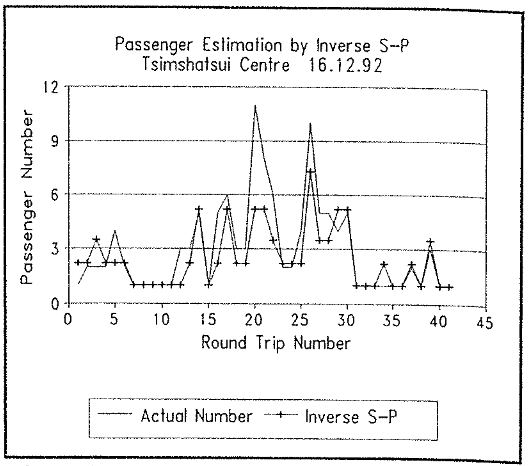

Fig. 10

There may be two reasons for this phenomenon. The first one is due to the fact that the inverse S-P method has not considered the contract capacity of the lift car. In other words, the number of stops made by the car within one round trip directly give a figure of the number of passengers. However, if the contract capacity is larger, the same number of stops should imply a larger number of passengers and vice versa. The second one is due to the fact that the S-P relationship is based on an assumption that all the floors are equally populated, which is usually false in real life. Therefore, adjustment to the existing inverse S-P method is a necessity for better estimation.

6.2 Improvements to the existing inverse S-P method

First of all, the contract capacity (CC) of the lift car is being taken account of. It is obvious that the larger the lift car is, the more passengers can be carried. An adjustment factor K can be used to adjust the values of the probable number of passengers to make it more reliable in describing the real traffic condition. K should be found by simulation or by statistics when the traffic pattern of an elevator system has been studied in depth. One simple estimation of K is given by:

$$K = \frac{CC}{\dfrac{\ln\left(\dfrac{1}{N}\right)}{\ln\left(\dfrac{N-1}{N}\right)}} \tag{8}$$

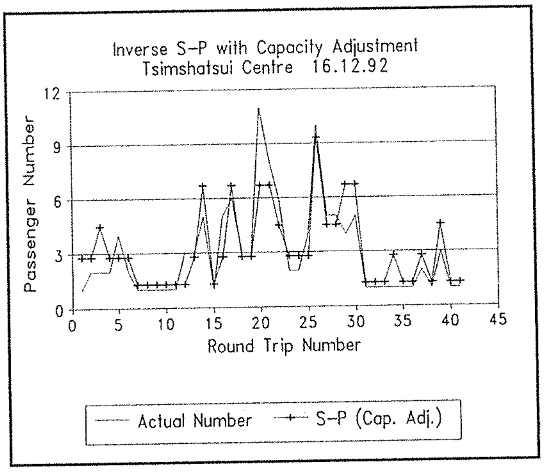

Fig. 11

The result at Tsimshatsui Centre is processed again by setting K = 20/15.6 = 1.28, as shown in Fig. 11. It can be seen that the probable number of passengers estimated by the adjustment of contract capacity fits the actual number of passengers better. Next, the problem of unequal floor population is considered. Traditionally, when unequal population is assumed, the expected number of stops for N floors above main terminal is given [1] by:

$$S = N\left[1 - \frac{1}{N}\sum_{i=1}^{N}\left(1 - \frac{U_i}{U}\right)^{p}\right] = N - \sum_{i=1}^{N} a_i^{p} \tag{9}$$

$$\text{or} \quad \sum_{i=1}^{N} a_i^{p} - N + S = f(p) = 0 \qquad \text{where} \quad a_i = 1 - \frac{U_i}{U}$$

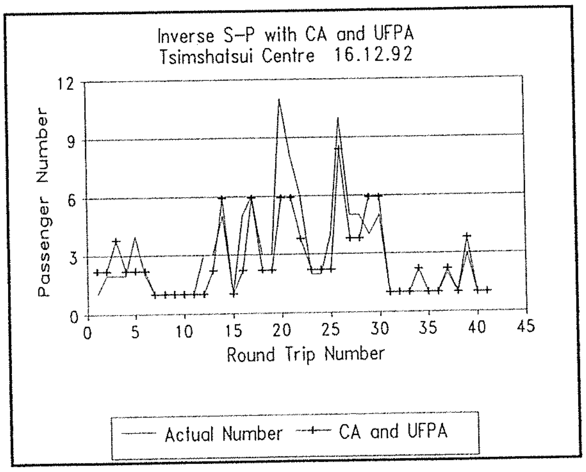

Fig. 12

If the distribution of population within the building is known, the only unknown variable in equation (9) is p. The job becomes the estimation of p provided that S is known for a certain round trip. The method of Interval Halving [13] is used to solve this equation f(p) = 0. It is based on a searching procedure to locate an interval over which f(p) changes sign. Of course, other optimisation methods such as Hill-searching and Newton's Method etc. can be used as well. Fig. 12 shows the result at Tsimshatsui Centre where two adjustments based on contract capacity (CA) and unequal floor population (UFPA) have been made. It appears that the result is not so satisfactory compared with Fig. 11 since our knowledge on the population distribution of the building is very limited.

7. CONCLUSIONS

In this paper, the four parameters proposed by Beebe in identifying up-peak and down-peak traffic conditions have been verified and commented with suggested improvement. The two bunching coefficients suggested by Al-Sharif have been studied and suggestions for improvement have been made. Finally, enhancements have been proposed for the traditional inverse S-P method suggested by Al-Sharif to bring the probable number of passengers closer to the real values.

8. ACKNOWLEDGEMENTS

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