NEW CONCEPTS IN LIFT TRAFFIC ANALYSIS: THE INVERSE S-P (I-S-P) METHOD

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ABSTRACT

New methods for processing traffic patterns are discussed. The *I-S-P* method is introduced as a method for deriving the number of passengers using the lift from the number of car calls and lift movements. Applications of the method are given. The use of moving averages for filtering traffic patterns is outlined, with a method for deriving upper and lower bounds.

1.0 INTRODUCTION

Once a lift system has been installed, the need might arise for checking the performance of the lifts, or, if the lifts have been in service long enough, to refurbish the lift system.

In order to do this, the actual number of passengers using the lift system in different traffic conditions and the profiles of the traffic patterns have to be available. These could either be assessed or surveyed. Assessment techniques rely on using a percentage of the building population (Barney & Dos Santos 1985). This method expresses the expected worst five minute up-peak demand as a percentage of the building population, with different figures for different types of buildings. This assessment does not take into consideration changing work habits within the population and other factors. It also does not give the profile of the traffic against time throughout the day, which might be desirable in certain cases.

Manual surveys on the other hand (Beebe 1980, Barney & dos Santos 1985) give the size of the traffic and the profile against time, but are limited by the length of time for which human observers can conduct them. From a practical point of view, manual surveys are not usually conducted for more than 2 - 4 hours a day, and for 2 - 3 days per building. Another disadvantage is that manual surveys can only be conducted at one floor, (usually the main terminal), and thus do not take into consideration other heavy traffic floors (unless more human resources are employed). If a complete performance analysis is needed, at least one observer is needed on every floor and in every car (Beebe 1980).

With the advent of lift remote monitoring and self logging facilities in lift controllers, it would be desirable to be able to derive the actual particulars of passengers using the lift system from the logged data describing the lift activity, and thus be able to derive the various traffic patterns for various floors. If this is found to be possible, it would have the following advantages:

a- It would be possible to give the passenger loading profile throughout the whole day, and for any number of days, at no additional running cost.

b- It enables the derivation of patterns pertaining to specific floors in the main terminal group, showing in-going and out-going traffic as well. The terms in-going and out-going are used here in this context in place of up and down traffic, and are less misleading in cases when a heavy traffic floor exists above the main terminal, thus causing much confusion when interpreting the terms up and down. The term has been used by Siikonen (1991). In fact the extension of the concept of in-going traffic and out-going traffic to floors other than the main terminal, enriches the notion of "individual floor traffic", and allows the handling of special cases such as when no clear single main terminal floor exists.

Unfortunately, data directly related to the number of passengers using the lift system is not available to the remote lift monitoring system, and must be derived from other signals. Several methods exist and have been used to derive the number of passengers from the logged lift data, some of which are:

a- The load weighing device: In most cases these devices give the estimated weight in discrete steps (steps of 20%, 25% or even 50%) of full load, and thus only give a rough estimate of the number of passengers. The conversion process from absolute weights to passenger numbers assumes a fixed weight figure per passenger, which could vary widely, due to largely differing weights, different countries and other disturbances (e.g., passengers carrying objects, or pushing trolleys...etc).

b- Using Photocell signals: This method is used to identify the number of passengers leaving or entering the car (Siikonen, April 1991; Kaakinen & Roschier, March 1991). In cases where the lift responds to both a landing call and a car call, it is not clear how a single photocell could distinguish between in-going and out-going passengers, unless two displaced photocells are used and the two resulting signals are combined to derive the number of transferring passengers. Moreover, this system could give erroneous results if the door width is such that more than one passenger can board or alight at the same time.

c- Using a sensitive pad on the floor of the car, which identifies the number of passengers from the shape of the footprints (Haraguchi, March 1991).

d- Imaging systems, which use artificial intelligence techniques to identify the number of passengers.

Some of the above systems are rather expensive (c,d), and the other two (a,b) are not available on every system. It would be preferable to be able to derive the number of passengers, from the lift activity (car calls, landing calls, position...etc) and any other necessary signals.

2.0 THE INVERSE *S-P* METHOD (*I-S-P*)

In the design of lift systems, the traditional method has been based on calculating the RTT (round trip time), which relies on calculating the probable number of stops, S (Basset Jones, 1923) and the highest reversal floor, H (Schroeder, 1955).

The probable number of stops, S, is given as a function of the number of passengers boarding the car. It is proposed here that this method can be reversed, in order to find the probable number of passengers boarding from the knowledge of the number of stops. Although this will not give the precise number of passengers in EACH individual trip, it will approach the actual number of passengers boarding in a 5 minute period for a group of lifts. Although H could be logged and used as well in the derivation, actual logged data has shown much less correlation between H and P, as compared with the correlation between S and P (Al-Sharif, 1991a).

The work carried out here attempts to find a relation between the actual number of stops and the probable number of passengers boarding the car. The actual number of stops can be easily logged from any lift, provided certain precautions are taken in deriving the data.

Basset Jones derived a formula expressing the probable number of stops as a function of the passengers in the car (Basset Jones, 1923):

$$E(S) = N\left(1 - \left(\frac{N-1}{N}\right)^{P}\right) \qquad \dots (1)$$

where: $E(S)$ is the probable number of stops,
N is the number of floors served above the main terminal,
P is the number of passengers.

This formula assumes equal populations on all floors.

The above formula could be reversed to find the probable number of passengers as a function of the number of stops as follows (a full derivation can be found in Al-Sharif & Barney, 1991c):

$$E(P) = \left(\frac{\ln\left(\frac{N-S}{N}\right)}{\ln\left(\frac{N-1}{N}\right)}\right) \qquad \dots (2)$$

This result has been used by Basset Jones for expressing the probable number of passengers as a function of the number of stops, in order to calculate the variance in the number of stops.

The mathematical rigour of Equation (2) is discussed in (Al-Sharif & Barney, 1991c) and a table is produced. It gives the probable number of passengers against the number of stops and the floors served above the main terminal and assumes equal floor populations. This method of analysis will be denoted as the Inverse *S-P* method (*I-S-P*).

3.0 APPLICATION OF *I-S-P* METHOD

3.1 Surverys

In order to check the practical viability of the proposed *I-S-P* method, a two day manual survey was conducted in a building, in which a lift remote monitoring system was running. The remote monitoring system was set up to log the data from the lift system at the same time as the manual survey was conducted. A synchronisation procedure to the nearest second was conducted before starting the survey, in order to set the timing sources for the manual and the automatic survey to identical settings.

The manual survey recorded the in-going and out-going traffic from the lower ground floor. This floor becomes active at lunch time, due to the presence of the canteen at this floor. So the survey was conducted by one observer from this floor, who entered the observations in the tables against each minute marker, specifying the number of passengers boarding each up going lift and the number of passengers leaving each down going lift.

In parallel with the manual survey, the lift monitoring system was set up to log the lifts activity for the same period of time. This produced a raw text data file, which contained all the details of the calls and the journeys. Data concerning the number of stops for up traffic and down traffic was then extracted.

It is very convenient and common to classify a particular traffic pattern as a dominant up traffic, a dominant down traffic or an interfloor pattern. However, in most cases any traffic pattern is a mixture of all the above patterns and others in varying proportions. Thus the actual number of stops that a lift makes when going up in a dominantly up traffic situation might be augmented by stops caused by interfloor traffic. Thus, a way must be found which "filters" out the true number of stops caused by up traffic. The best method is to count the number of car calls registered, when the car leaves the incoming floor (the lower ground floor, LG, in this case). In a general case where more than one main terminal exists, (e.g, in a building with an entrance at the ground and several entrances at the basements serving the car parks), this number is taken as the number of car calls registered when the lift leaves the highest main terminal.

Thus, the resulting number will represent the number of stops in an up-traffic trip caused by pure up-traffic.

Following similar reasoning, a method has to be employed which would "filter" out down stops. In order to find the number of stops caused by down traffic heading to the outgoing floor, the lower ground floor (LG) in this case, the following rules were followed:

a - Each down landing call answered by a lift followed by a car call registration to the departure floors is considered as a stop generated by the down traffic destined to the floor.

b - Each down landing call answered by the lift, (after the car call to the relevant floor has been already registered on a previous stop), and if this is not followed by a car call registration to a floor OTHER than the relevant floor, this stop is also counted as a stop generated by the down traffic destined to the relevant floor.

c - Each down landing call answered by the lift which does not follow a or b above, is not considered as a valid stop generated by down traffic destined to the relevant floor.

Using these rules the number of stops for the down traffic can be calculated.

3.2 Actual traffic and Esimation Methods

Using all the previous gathered and derived data, it is possible to compare the actual and estimated up traffic. In the following plots, successive points are joined by lines to give a continuous impression. The actual traffic is a plot against time, in five minutes increments, of the actual traffic recorded during the manual survey. Three methods are examined: I-S-P, Bayesian and the best possible estimate.

The first estimate is the ***I-S-P* estimate**, which is based on the formula derived previously, which expresses the probable number of passengers as a function of the number of stops. Each trip of a lift is handled separately, and the expected number of passenger for each trip is found. Then the expected numbers of passengers are added for the whole group of lifts, in the five minute period. The summation is plotted against time as shown in Figure 1. Alternatively, the table could be used for finding the probable values of P, as a function of N and S.

It has to be taken into consideration that when using the formula or the table, the "effective" number of floors served above the main terminal has to be used. The term "effective" takes into consideration floors which are adjacent to the relevant floor, and which have a connecting flight of stairs in such a way, that passengers tend to use the stairs rather than the lifts. This reduces the number of effective floors served in the case under consideration from nine to seven. So the value of seven was used for N.

Another possible estimate is the **Bayesian estimate** which is based on a Bayesian equation (Al-Sharif & Barney, 1991c), and is plotted as well.

The effective number of floors served was also taken as seven in this case. The individual estimates for each trip for every lift were calculated based on this table, and then all the

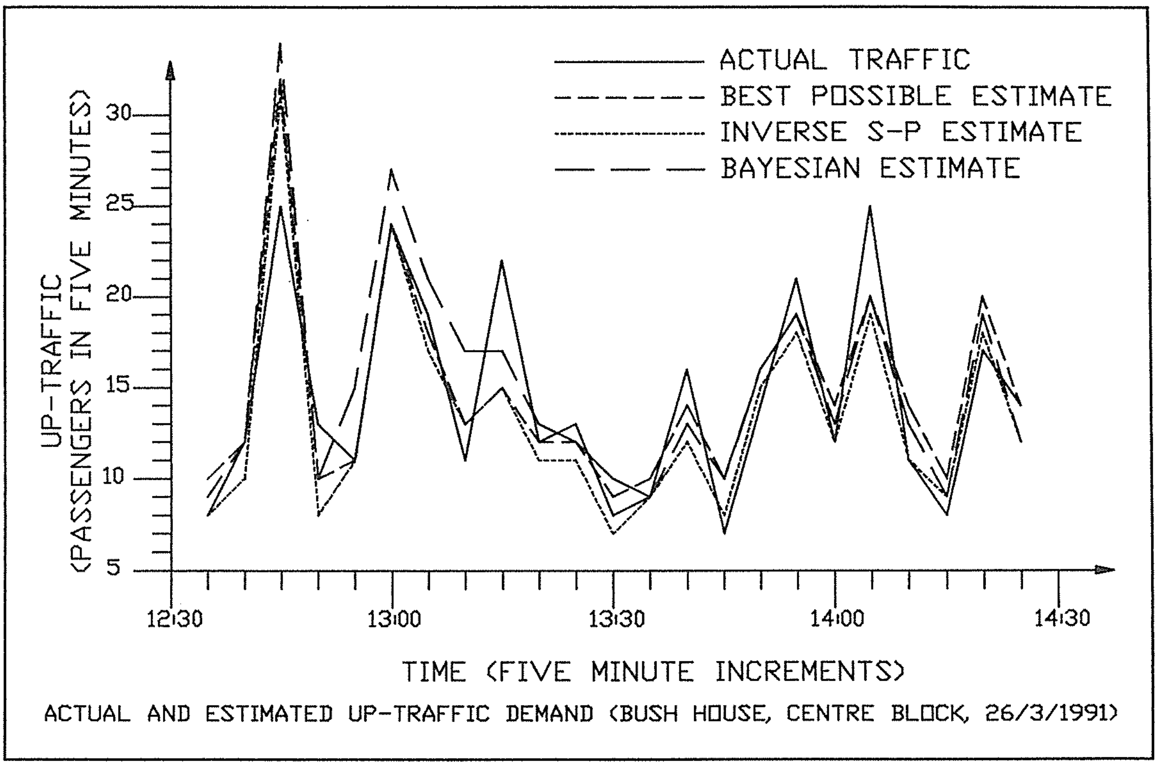

Figure 1: Up traffic estimates , 26/3/1991.

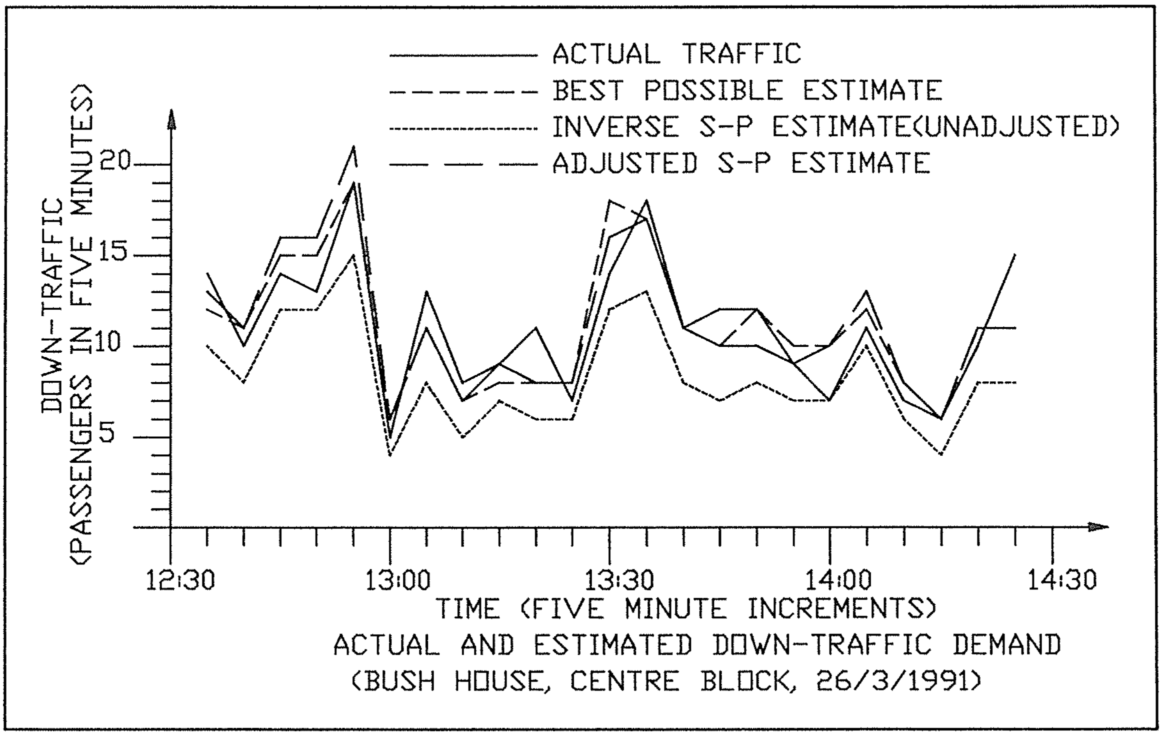

Figure 2: Down traffic estimates, 26/3/1991.

estimates for the different trips in the five minute periods for the whole group were then summed up and plotted, with successive points joined by straight lines.

The Bayesian estimate needs additional information, namely the probability distribution function (pdf) of S and the pdf of P. While the pdf of S was easily obtained from the automatically logged data (not shown here), the pdf of *P* (not shown here) was extracted from the manual survey conducted. This fact combined with the mathematical complexity of the computation, renders this method less attractive than the *I-S-P* method, although it is more rigorous from a mathematical point of view.

The **best possible estimate** is calculated using actual data from the lift system, which describes the actual number of passengers versus the number of stops, which is based on a derived table and not on a formula. Thus, it represents the best possible estimate in this case. Although this estimate cannot be obtained except by observation, it could be used as a comparison with other estimates. One possible criterion to use is the summation of the squares of the error in the number of passengers estimated.

The previous estimation techniques can be used in the same way to analyze down traffic with one difference. It has been shown, (Barney & dos Santos, 1985, pp 230; Al-Sharif, 1991b) that the probable number of stops in down peak are between 40% to 60% of the probable number of stops in the up peak case (different values applying to different control algorithms). Thus the *I-S-P* estimate has to be multiplied by an adjusting factor, which is the inverse of the above figure. The most suitable figure was found and the values adjusted accordingly. The plots show both adjusted and non-adjusted *I-S-P* estimates.

3.3 Results

Figure 1 shows the results of the up traffic plots for 26/3/1991. The results for 27/3/91 have not been shown here. It can be seen that best possible estimate represents the best performance. The Bayesian estimate does not offer any better performance than the *I-S-P* estimate. The summation of the square of the errors is used as a criterion for estimate performance, but results are not shown here.

The down traffic results are shown in Figure 2. The improvement in the adjusted *I-S-P* estimate is clear from the figure.

4.0 EXAMPLE OF AN APPLICATION OF *I-S-P*

As an application of the previous method, automatically gathered raw data was processed according to the *I-S-P* method. The raw data was available for the four consecutive days (2-5 April 1991). One of the results is shown in Figure 3 (the other results are shown in Al-Sharif & Barney, 1991c), where the numbers of up-travelling passengers in five minute intervals were plotted against time. The numbers do not include interfloor traffic or down traffic (Al-Sharif & Barney, 1991d).

Although a general pattern can be discerned from the data, the patterns do show a "disturbance component" superimposed on the general trend. This can be seen in the continuous oscillation of the pattern, at a frequency of one to three five-minute periods. This disturbance can be ascribed to the following factors:

a- Car Bunching: The lift control system plays a considerable role (Schroeder 1990; Al-Sharif & Barney, 1992a). This is due to the fact that these numbers do NOT represent numbers of up-travelling passengers arriving in each five minute period for service, but represent instead the numbers of up-travelling passengers actually boarding and using the lift system in each five minute period. Thus, despite the fact that the total numbers added will be the same, their assignment to various five minute periods will not necessarily be identical. The effect of car bunching in this context has a large impact on increasing this disturbance, producing the consecutive false peaks and troughs seen in the patterns.

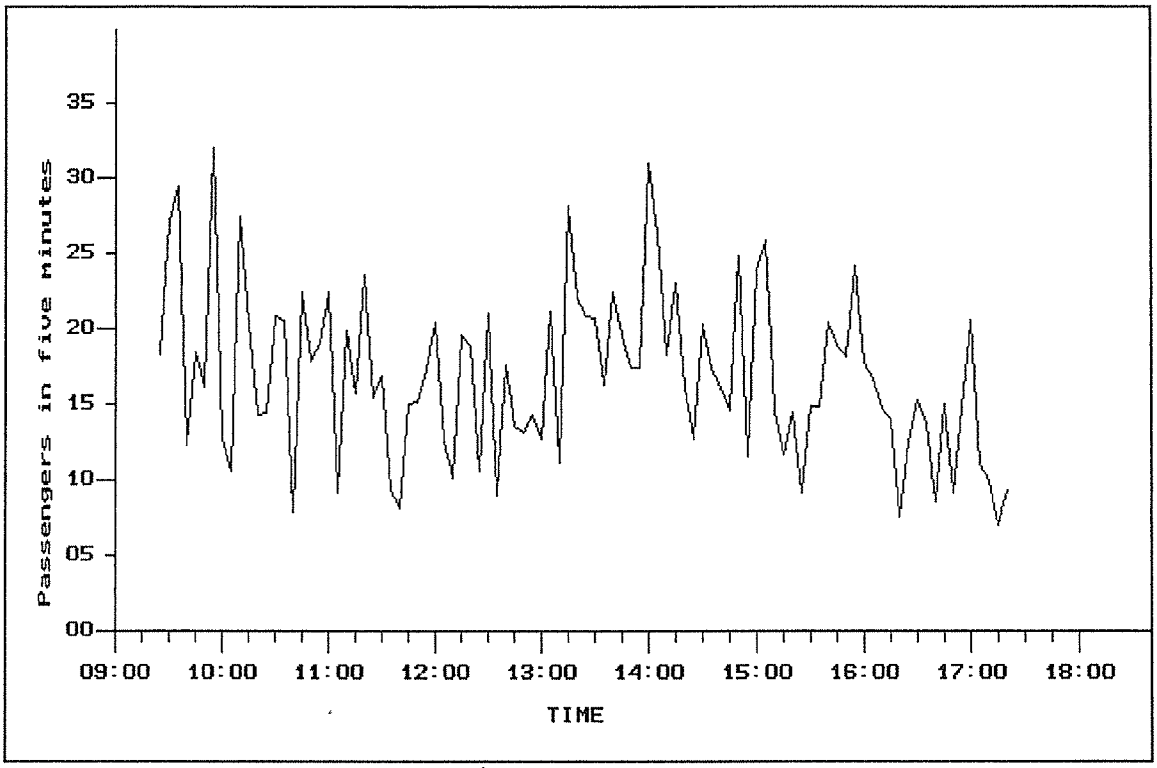

Figure 3: Traffic pattern on 2/4/1991, Bush House, Centre Block.

b- The randomness of the arrival of the passengers: The rate of arrival of passengers (or alternatively the mean time between passenger arrivals) is obviously a random variable. Moreover, the probability density function for this variable is not uniform (possibly Poisson distribution, see Alexandris, 1977). This randomness contributes to the disturbance in the patterns, although the size of this impact is thought to be of much less importance as compared with the first factor (car bunching).

c- "Boundary Journeys" and measurement error: Boundary Journeys are those journeys starting in one five minute period and ending in the following five minute period. The assignment of this journey to one of the five minute periods or the other introduces a measurement error, which in turn contributes to the pattern disturbances. The program used in this work assigns a boundary journey to the starting five minute period. It might be possible to assign half the number of boundary journey passengers to one five minute period, and the other half to the other period, although this option has not been investigated here.

Taking into consideration this disturbance in the resulting traffic patterns, and by intuitively discerning the patterns for the four consecutive days, the following results can be found:

a- There are three up-traffic peaks in the patterns, occurring at or around 9:30, 14:00 and 17:00.

b- The peak occurring at 14:00 is larger in size than the other two, amounting to 30 to 40 passengers per five minute period. This represents the worst five minute period.

These two results are helpful in the design or refurbishment of the lift systems. The same method with some adjustments can be used for down traffic (Al-Sharif & Barney, 1991c) or interfloor traffic.

5.0 THE USE OF MOVING AVERAGES FOR FILTERING TRAFFIC PATTERNS

Due to the oscillations in the previous patterns, a method is needed to filter out these disturbances. The filtering problem is a compromise by which enough filtering is applied to the pattern in order to take out the oscillatory component while not altering the general trend. The other criterion is that the resulting processed pattern must represent the trend and the size of the original pattern.

The centred moving average filtering technique is usually used in econometrics for "deseasonalising" a time series, thus taking out any seasonal variations. The resulting time series is usually called the trend, and shows how the variable is changing in the long term.

In an n based moving average, the centre quantity is replaced by the average of all the entries included in an n-wide window centred on the entry under question.

5.1 Finding the Suitable Period of the Moving Average

The first step in applying the method is to find the order of the moving average to be used, where the order is the number of the entries taken in calculating the average. The higher the order of the moving average, the more filtering is applied to the time series.

This is done by inspecting the consecutive "local" peaks in the time series, as seen in Figure 4. The order of the moving average can be taken as the average of all these numbers extracted from the shown time series. For the example under discussion, this has been found to be between four and five. Thus a five period moving average will be taken in the following calculations.

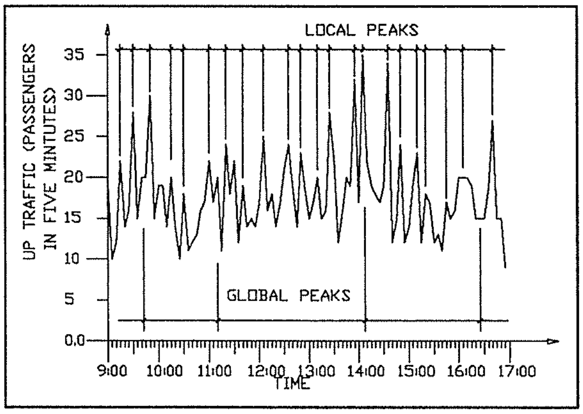

Figure 4: Up traffic 3/4/1991, Bush House, Centre Block.

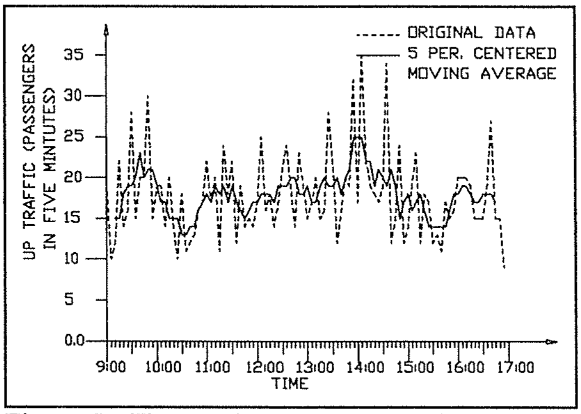

Figure 5: Five period centred moving average applied.

It can be seen from the figure that the distance between "global" or trend peaks in the time series is much more than 5 periods (nearly 24 periods). So, by keeping the period of the moving average higher than the disturbance period and lower than the trend period, it will be possible to filter out the disturbances while preserving the general trend in the time series.

5.2 Applying the Moving Average

Once the period of the moving average has been found, the *n* period moving average can be applied by replacing each entry by the average of the *n* entries surrounding the relevant entry.

Figure 5 shows the resulting five period centred moving average. The first two and the last two entries are lost, because five entries are needed for each resulting average, which is not the case for the first two and last two entries. This is a disadvantage if the number of entries is already small.

5.3 Upper and Lower Bounding Curves

Although the resulting centred moving average does reveal the general trend in the time series, it does not represent the actual size of the traffic. Thus, in order to be able to show the size as well as the shape of the traffic, the resulting average has to be adjusted by multiplying it by the appropriate adjustment factors. The resulting curves would be called Upper Bounding Curve (UBC) and Lower Bounding Curve (LBC).

An *ad hoc* technique for finding these two factors is described here, but any other suitable technique could be used. All the entries representing the unprocessed time series are divided by the moving average results giving factors between 0.5 to 2.0. Then the mean and the standard deviation of all of the resulting factors was calculated. The mean was found to be extremely near to 1.0 (confirming the correctness of the moving average results, that areas enclosed by the actual data above the moving average are equal to the areas below it).

The adjusting factors were then taken as the summation and the difference of the mean and the standard deviation. The moving average curve was multiplied by each of the adjusting factors, resulting in the Upper Bounding Curve and the Lower Bounding Curve. These are shown in Figure 6.

It can be seen that the two curves (UBC, LBC) nearly envelope the original time series, and that they show the shape as well as the size of the prevailing traffic.

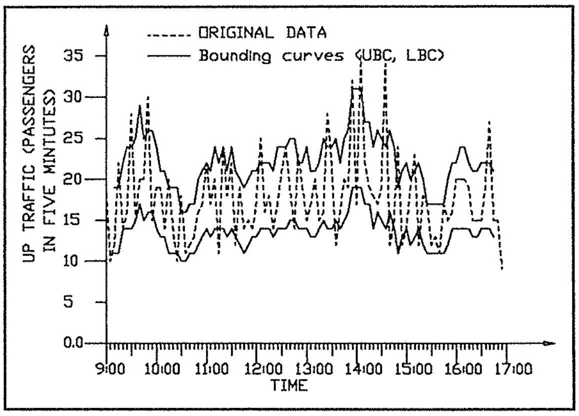

Figure 6: Upper and Lower Bounding Curves.

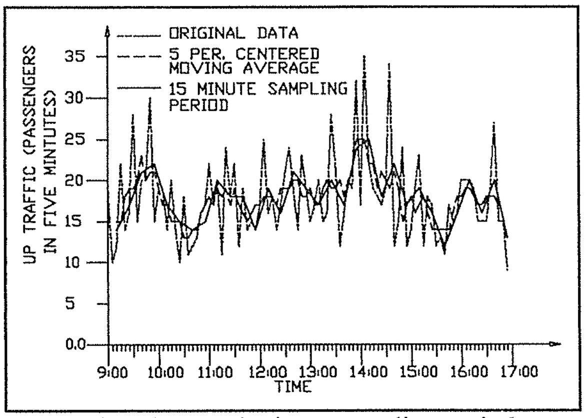

Figure 7: Using a 15 minute sampling period.

Some analysis techniques use the 15 minute period as a sampling period and as the basis for the analysis (EPTi analyzer software). This gives a curve of points at 15 minute intervals. An example is shown in Figure 7.

Beebe (Beebe 1980) has shown that varying the sampling period (using 10, 15, 20 or 25 minutes) can take out the disturbance in the time series, where he applied it to a time series representing the number of journeys. He proposes that a matching procedure be followed to find the most suitable sampling period for any building.

Applications of this method are discussed in (Al-Sharif & Barney, 1991e).

6.0 CONCLUSIONS

An inverse formula based on the relationship between *S* (number of stops) and P (number of passengers) can be inverted and used to derive the probable number of passengers from the lift activity. Several estimates can be derived (the *I-S-P* estimate, the Bayesian Estimate, the Best possible estimate), which represent a trade off between computational complexity and preciseness, and depend on the available data. The same method is applied to the down traffic with an adjusting factor.

The centred moving average is used to filter out disturbances in the derived traffic patterns, and statistical techniques are used to derive upper bounding and lower bounding curves.

The combination of the two methods, I-S-P estimation and the centered moving average filtering, can be very useful in lift monitoring software packages, for analysing the traffic patterns.

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