BUNCHING IN LIFT SYSTEMS

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Abstract

Bunching increases passenger waiting time, but does not affect system handling capacity. This paper shows using a practical example, how bunching can increase passenger waiting time.

It is quite essential to be able to measure bunching quantitatively, in order to compare the performance of different systems, of different sizes. In order to do this, two measurement coefficients are presented and discussed: simulation based bunching factor, *bx*; and measurement based bunching coefficient, *BC2*. The advantages and disadvantages of both coefficients are outlined, along with methods for implementing them within software packages.

1.0 INTRODUCTION.

The ideal situation in lift traffic control is to keep the lifts in the group as far apart as possible, when they are circulating in up-peak. In fact, some of the early control algorithms control the lift system by dispatching the lifts from the main terminal at fixed intervals of time, in order to keep the lifts equally apart during their trips (Barney & Dos Santos, 1985, *pp* 37).

When the time interval between cars leaving the main terminal is not equal, bunching occurs and degrades the performance of the lift 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 (Schroeder, June 1990).

A typical case of bunching can be seen in lift systems when the lifts start following each other (or even frog-leaping), as they serve adjacent calls in the same direction. This has a detrimental effect on passenger waiting time. 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.

On the other hand, when no bunching exists, the *AWT* attains it minimum optimum value, which is equal to half the calculated up peak interval (*UPPINT*), namely $AWT = UPPINT/2$. This is based on the assumption that a uniformly distributed probability density function applies for the arrival rate of passengers. In fact, the design of lift systems relies on calculating the *RTT* (round trip time) and deriving the *AWT* from this based on an ideal assumption that $UPPINT = RTT/L$, where L is the number of lifts in the group.

Bunching affects waiting times, but will not usually affect handling capacity (Schroeder, June 1990).

2. THE EFFECT OF BUNCHING ON WAITING TIME.

As mentioned in the previous section, bunching in lifts systems increases waiting time, but does not affect handling capacity. This section aims to discuss an example of how irregular arrival of the lifts leads to an increase in waiting time.

Figure 1 shows a ideal case of regular arrivals of two lifts in a group, A and B. The round trip time of the system is 50 seconds, as shown by the consecutive arrivals of lift A (A and A'), and the interval between individual arrivals is 25 seconds.

Figure 2 shows a situation where bunching occurs, and lift B arrives 10 seconds after lift A.

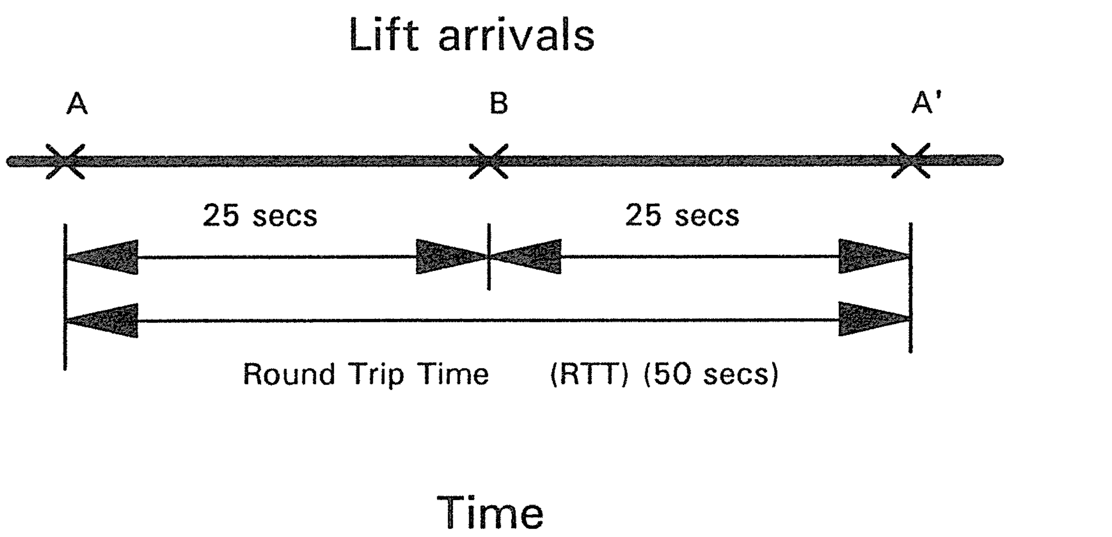

Figure 1: Regular arrival pattern of two lifts A and B.

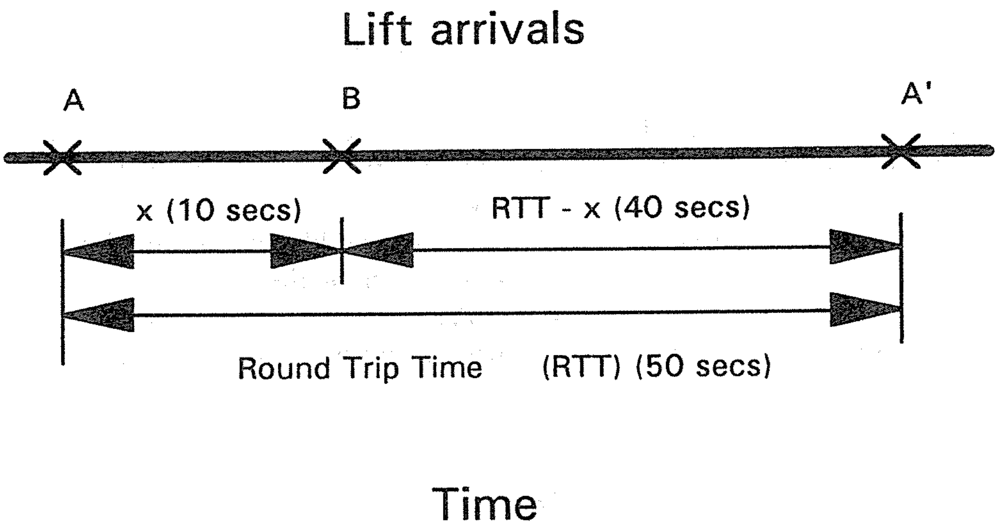

Figure 2: Irregular arrival pattern of two lifts A and B, and effect on waiting time.

The average waiting time can be calculated for both situations. For the purposes of this exercise, it can be assumed that a constant uniform passenger arrival rate exists, at a rate of one passenger per second. In the first case, the standard formula can just be used ($INT = RTT/2$), which gives $INT = 50/2 = 25$ seconds. Assuming a uniform arrival rate, the AWT is taken as $AWT = INT/2 = 12.5$.

In the bunching case, there are 10 x 1 = 10 passengers arriving during the first period [A-B], and having to wait between 0 and 10 seconds. In the second period [B-A'], it is expected that 40 x 1 = 40 passengers will arrive, having to wait between 0 and 40 seconds. Thus the average waiting time for each period will be half the maximum waiting time (assuming a uniform arrival rate). The total average waiting time is a weighted sum of both waiting times.

$$\frac{10}{50} \text{ x } 5 \text{ (sec)} + \frac{40}{50} \text{ x } 20 \text{ (sec)} = 17 \text{ (sec)}$$

This is also based on the assumption that car A is large enough to carry all 40 passengers, with none of them having to wait for car B.

If the case is considered where the cars have a limited capacity (say 25 passengers in this case), then only 25 passengers out of the 40 passengers will be able to board car A, while the other 15 passengers will have to wait for another 10 seconds. Thus,

$$\frac{10}{50} \text{ x } 5 \text{ (sec)} + \frac{25}{50} \text{ x } 20 \text{ (sec)} + \frac{15}{50} \text{ x } (20 + 10) \text{ (sec)} = 20 \text{ (sec)}$$

...which is three seconds more than the 17 seconds, which was based on the assumption of infinitely sized cars.

3.0 SIMULATION BASED BUNCHING FACTOR (*bx*).

Having shown the effect of bunching on waiting time in the previous section, this section attempts to outline a measurement coefficient for bunching, based on simulation. The next section develops a formula based coefficient.

Figure 3 shows a typical curve describing the relationship between the loading factor (some authors use the more generic term, "system utilisation", Barney & Dos Santos, 1985, *pp* 21), and an index of performance. The ratio of *AWT* to *INT* has been proposed as a measure of performance of the lift system (Barney & dos Santos, 1985, *pp*201). The loading factor is expressed as the ratio between the number of passengers and the rated capacity. The index of performance is taken as the ratio between the Average Waiting Time (*AWT*) and the Interval (*INT*), where division by the Interval is a method of normalising the measure of performance.

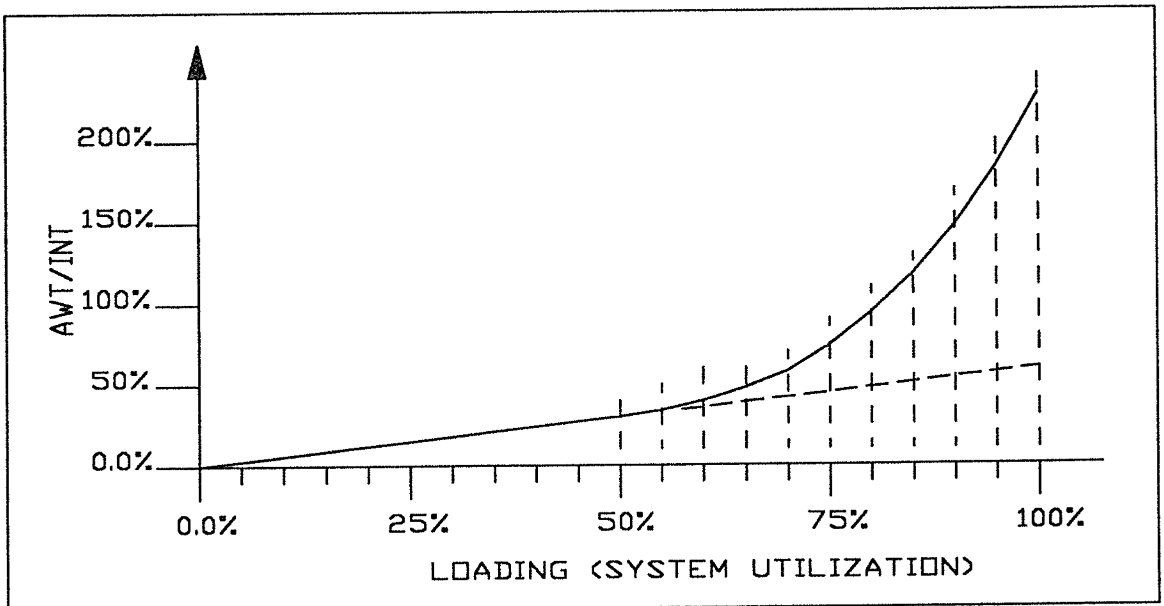

Figure 3: Relationship between System loading and *AWT/INT*, with a straight extrapolation of the linear part below 50% loading.

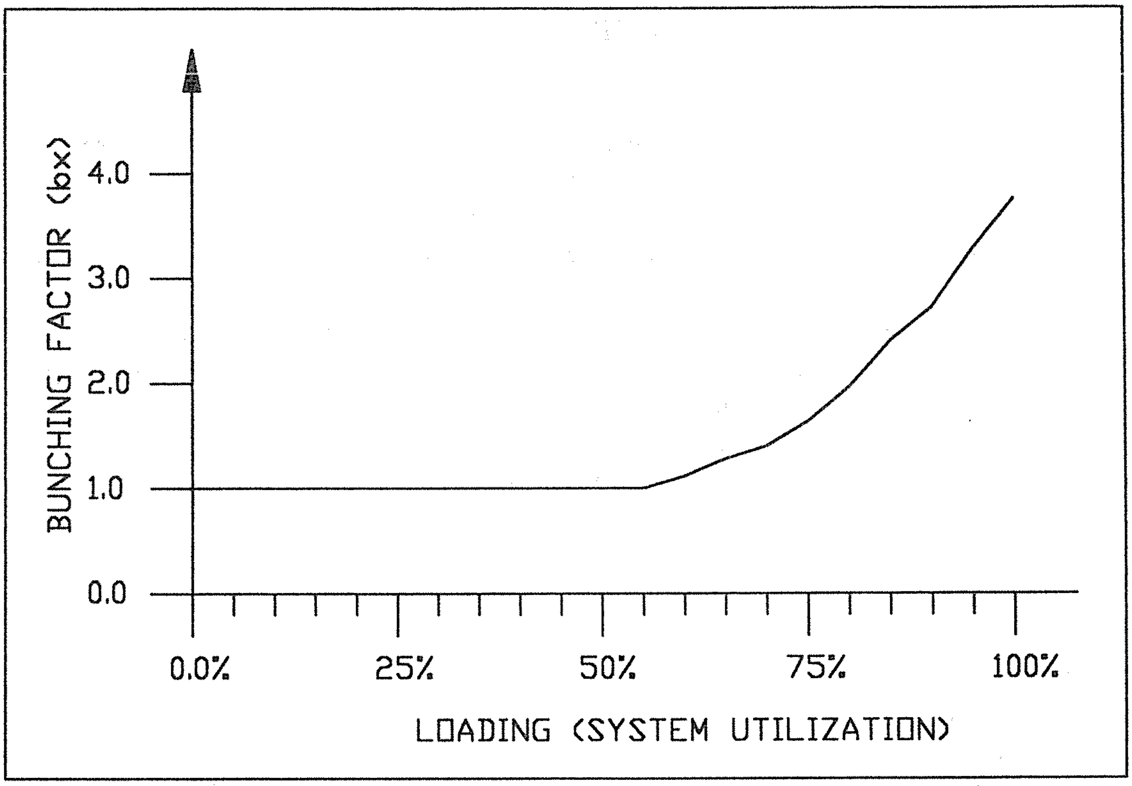

Figure 4: Corresponding Bunching Factor (*bx*) plotted against system loading.

The curve is linear in the region of loading 0% to 50%. As the system loading increases above 50%, the curve departs from linear behaviour, and increases rapidly. The linear relationship existing below 50% loading can be extrapolated as shown in Figure 3 by the dotted line. So it is possible to draw a straight line as a continuation of the linear relationship which exists at loads below 50%.

It has been proposed by Schroeder (June 1990), that the departure from this linear behaviour at loads of more than 50% is caused by the phenomenon of bunching in the lift system. Schroeder further proposes that the measure of bunching is the ratio between two quantities. The numerator is the actual *AWT* is at a certain system loading. The denominator is the value the *AWT* would have been if the linear relationship applied above 50% system loading. This is given the name Bunching Factor, *bx*. An example of this concept is shown in Figure 4, where these ratios have been taken from Figure 3, and the resulting ratios plotted as the Bunching Factor, *bx*, against system loading.

It is possible to investigate this point further by obtaining this performance/load curve for groups of lifts with lifts from one to eight, through simulation. Once the curves have been obtained through simulation, it would be possible to derive the bunching factor (*bx*) from these curves against system loading, in the same way that this have been done in Figure 4. Consequently, a three dimensional plot of the bunching factor (*bx*) against system loading and against the number of lifts in the group can be plotted.

This has actually been carried out by performing the simulations and plotting the curves. Then the bunching factor (*bx*) has been derived for system loading levels between 60% and 80% (80%, 77.3%, 74.6%, 72%, 69.3%, 66.6%, 64%). Figure 5 shows a three dimensional plot of the resulting bunching factor against system loading and the number of lifts in the group.

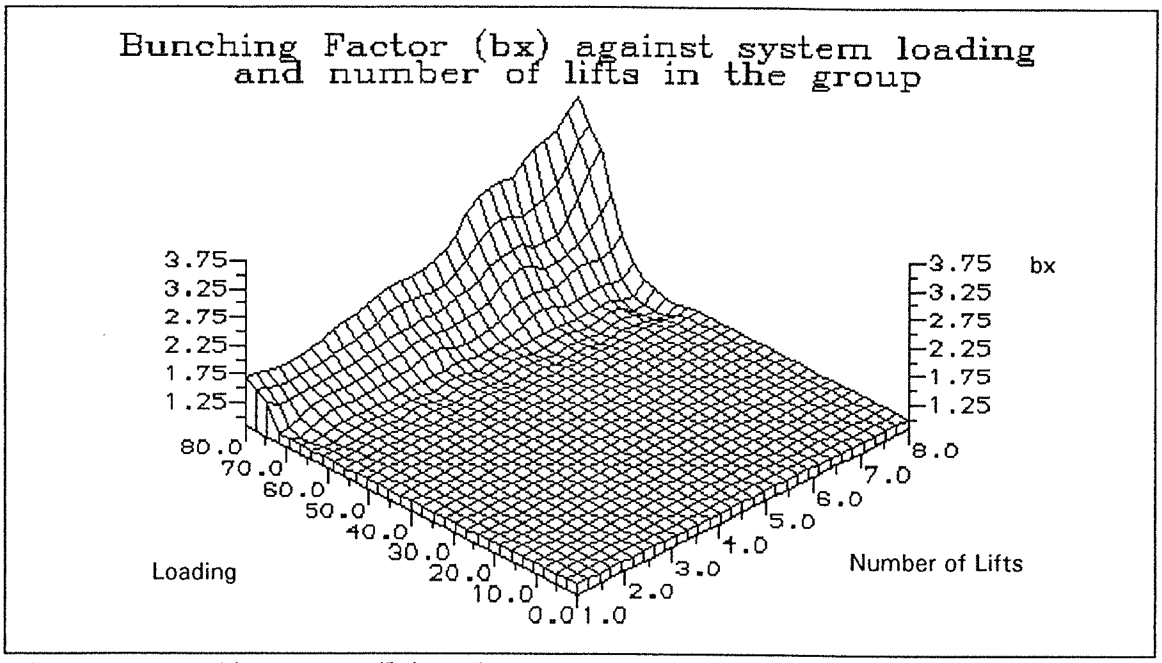

Figure 5: Bunching Factor (*bx*) against system loading and number of lifts in the group.

The following remarks are worth mentioning, regarding the plot:

a- *The bunching factor bx takes on values ranging from 1 to 3.75. The value of 1 corresponds to no bunching in the system.*

b- *As the number of lifts in the group increases, the bunching in the lifts system at the same loading level increases as well.*

c- *Bunching starts to be displayed at a system loading of around 65%, although it varies. Bunching starts to be displayed at smaller loading levels with increasing numbers of lifts in the group.*

d- *Bunching is displayed even with a single lift in the group. Intuitively, we would expect no bunching in the case of one lift in a group. This depends on the definition of bunching in the first place; it might be considered that variations from the calculated average Round Trip Time is a form of bunching even if only one lift exists in a group.*

One of the points raised by Schroeder as well is that the Bunching Factor will increase as the number of lifts increase; thus no bunching will occur with one lift in the group (*i.e.*, a Bunching Factor of 1.0 will prevail), and the Bunching Factor will increase until it achieves its maximum value with a group of eight lifts (Eight is the maximum number of lifts in one single group as specified by general practice).

So the Bunching Factor can be expressed as a function of two variables: System Loading and the Number of the lifts in the group.

Bunching Factor $(bx) = f(L, SL)$

...where

f is a function of the two variables,
L is the number of lifts in the group and
SL is the system loading expressed as a percentage of system capacity.

Schroeder (June 1990) has produced a curve similar to the curve in Figure 5, with the following two main differences:

a- *A factor of bunching of 1 has been plotted for a group of one lift.*
b- *Bunching starts at lower system loading levels (40% in the case of eight lifts, 60% in the case of two lifts).*

One drawback of this factor of bunching (*bx*) is that a single lift system would still follow the same relationship between *AWT/INT* and system loading. But bunching by definition cannot apply to a group with one lift.

4.0 FORMULA BASED BUNCHING COEFFICIENT (*BC*).

This section develops a formula based approach for measuring bunching. Consequently, bunching could be measured directly from the lift system behaviour, and satisfying certain requirements at the same time.

4.1 Basic Requirements of the Bunching Coefficient (*BC*).

The requirements to be satisfied by any bunching coefficient, can be summarised as follows:

a- *Normalisation: It has to be normalised, so that it is independent of the parameters of the system under consideration. This will enable it to be used as an additional measurement of performance between different systems.*
b- *Formula Based: It would be preferable if it could be measured instantaneously (on-line) from the lift behaviour, without having to compile large amounts of data for analysis.*
c- *Limited Range: It must have a defined range of values (e.g., 0.0 to 1.0, where 0.0 represents no bunching and 1.0 represent full bunching). Full Bunching implies that lifts are all moving together like one huge lift (with a capacity equal to the summation of all the capacities of the individual lifts in the group). No Bunching means that lifts are moving equally apart, or in more precise terms are leaving the main terminal at equal intervals (in the cases of up and down peak traffic conditions, where these intervals must be equal to round trip time divided by the number of lifts in the group, RTT/n), or reversing their direction of travel at equal intervals in the case of interfloor traffic or other traffic conditions.*

Due to the fact that we can define these two extremes of bunching in such a precise manner, it is reasonable to try to define the limits of the corresponding bunching coefficients at 0.0 and 1.0, and eventually find a mapping function or formula between them.
d- *It must produce a coefficient of bunching of zero for a group of one lift.*

4.2 Approach Used.

An intuitive concept to use for the formula, would be to define the ideal behaviour of the lift system under no bunching conditions, to calculate the amount of deviation from such ideal performance and then to use such a measure as an indication of the amount of bunching.

The ideal behaviour of a lift system under up peak traffic conditions and with no bunching, is that lifts depart from the main terminal at equal intervals, equal in value to the Up Peak Interval (*UPPINT*), which is calculated as the Round Trip Time divided by the number of lifts in the group (*RTT/L*).

If the time between lift number i departing and lift number i+1 is defined as $t_{i,i+1}$, then the difference between this time and the ideal time can be taken as the measure of how much bunching is prevailing in the system behaviour. Thus the quantity

$$\left(t_{i,i+1} - \frac{RTT}{L}\right)$$

...must be used in the formula. It is to be noted that positive and negative deviation from the ideal value are equally harmful (early arrival of a lift is as bad as late arrival). So, the absolute value of the above quantity has to be taken.

$$\left| \; t_{i,i+1} - \frac{RTT}{L} \; \right|$$

Taking the absolute value assigns equal costs to positive and negative deviations from the ideal value, based on the assumption that an equal cost is incurred in both cases.

One major drawback of using the absolute value of the difference, is that it gives equal weighting to small and large deviations of departure intervals from the ideal value (*RTT/L*). One way to penalise large deviations from RTT/L is to square the difference (this will also obviate the need for taking the absolute value, as the square of any quantity is always positive).

Summing up all deviations arising from all the lifts in the group, gives a representation of how the lifts in the group are deviating form a bunching free ideal performance.

The value of the sum of all of these deviations at full bunching is used as a normalising factor. As this is the maximum value that can be attained at full bunching, it is used for normalisation, by dividing the sum of absolute values of deviations by it.

This bunching coefficient would be called *BC2*, to indicate that is uses the square of the deviation. The full formula is shown in Al-Sharif & Barney (1992a). (The term $t_{L,1}$ denotes the time lapse between the FIRST departure of lift number L and the NEXT departure of lift number 1, and NOT the first departure of lift number 1. It is assumed that, within one *RTT*, all the lifts have returned to the main terminal.)

As can be verified, this formula satisfies all the criteria set out in section 4.1, as it lies between 0.0 and 1.0, it can be measured over one *RTT*, is independent of the lift system because it is normalised and it gives a bunching coefficient of 0.0 for a group of one lift (L=1).

Figures 6 is a three dimensional plot of the *BC2* for a group of three lifts, against two time intervals. The first time interval (Y axis) is the time lapse between the departure of the first lift in the group from the main terminal, $t_{1,2}$. The second interval

(X axis) is the time lapse between the departure of first lift in the group and the third lift from the main terminal, $t_{1,3}$. A *RTT* of 120 seconds, and an *INT* of 40 seconds are assumed.

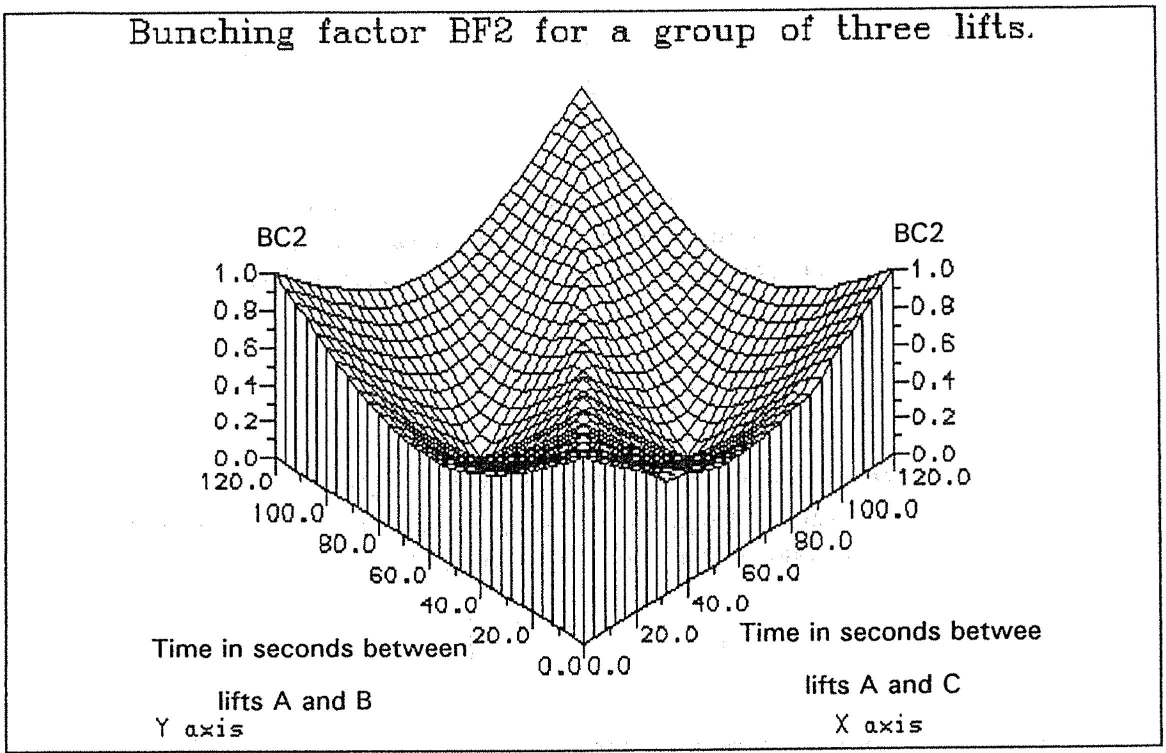

Figure 6: A plot of the bunching coefficient against the time intervals (in seconds) between lifts departing from main terminal. It is based on an assumption of a 120 second *RTT*, and an *INT* of 40 seconds.

It can be seen from Figure 6 that *BC2* attains the minimum values of 0.0 when X= 40 and Y = 80 or when X=80 and Y = 40 which is the case when equal intervals occur. On the other hand, *BC2* is 1.0 (full bunching), when X=0 and Y=0 or X=120 and Y=0 or X=0 and Y = 120 or X=120 and Y=120, which is shown by the value of 1.0 at the four corners of the plot. All these cases correspond to full bunching, as the lifts are all departing at the same time.

5.0 CONCLUSIONS.

Bunching in lift systems affects waiting time. A practical example has been shown, by which the effect of bunching in a group of two lifts has led to an increase in waiting time from 12.5 seconds to 20 seconds.

In order to measure bunching , two approaches have been used: simulation based and formula based.

The bunching factor *bx* can be extracted from simulation data, and is shown to increase with the increase in system loading and the number of lifts. It suffers from the disadvantage that is cannot be instantaneously measured from the lift system activity.

The second order bunching coefficient, *BC2*, is formula based and can be calculated from the measured values of the interval. This coefficient produces a value of 1 at full bunching (all cars moving as one huge car), and 0.0 at no-bunching (equal intervals between car arrivals at main terminal). The measurement of the bunching in this way can give an estimation of the quality of the performance, and can be carried out while the lift system is running.

The quantitative measurement of bunching in lift systems is useful in providing an objective comparison between lift system performance, regardless of any differences in system configuration.

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