UPPEAK, DOWN PEAK & INTERFLOOR PERFORMANCE REVISITED

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Abstract
It is easy to calculate the round trip time, interval and handling capacity of a specified lift system. This does not, however, give an accurate idea of performance as represented by passenger waiting times, as these are greatly affected by car load and the probability distribution function of the passenger arrivals. This paper provides, with worked examples, a simple method of estimating average passenger waiting times for the three major traffic conditions.

1 TRAFFIC DESIGN

Lift systems are sized for the uppeak traffic pattern by using the following well known formula (Barney & Dos Santos, 1985-p22), in order to obtain the system round trip time (*RTT*), the interval (*INT*) and the 5-minute Handling Capacity (*HC*):

$$RTT = 2.H.tv + (S+1)ts + 2.P.tp \qquad \text{... (1)}$$

$$INT = RTT/L \qquad \text{... (2)}$$

$$HC = 300.P/INT \qquad \text{... (3)}$$

where:

H is the highest reversal floor
S is the average number of stops
P is the average number of passengers carried
t_v is the interfloor time
t_s is the stop time
t_p is the passenger transfer time
L is the number of lifts

The purpose of a traffic design is to match the passenger arrival rate (A_r, persons arriving/second) to the lift system handling capacity (*HC*, persons/5-minutes). Conventionally Equation (1) is solved for the uppeak traffic pattern with P equal to 80% of the rated capacity (*RC*) of the lift car.

Interlude 1
To be more accurate the 80% value should 80% of the actual (possible) capacity of the car (*AC*) [see Table A.1]. In this paper the actual capacity of the cars will be used.

Therefore if P is set to 80% of the actual capacity of the car then the number obtained from Equation (1) is the *UPPRTT* and the number obtained from Equation (2) will be the *UPPINT* and the number obtained from Equation (3) will be *UPPHC*

It is unlikely that during any uppeak 5-minute period that cars will fill precisely to an average of 80% of actual capacity of the car, so matching the uppeak design criterion. A wide range of average car loads will obtain, and with, them different intervals.

Example 1
Consider an example system equipped with 2,000 kg cars (RC=26 persons, AC=20 persons), which is designed to provide an *UPPHC* of 169 persons/5-minutes at an *UPPINT* of 28 s. As the passenger arrival rate (A_r) changes the average number of passengers (P) carried in the car changes also. The *INT* then changes so that the *HC* matches the arrival rate (A_r). Table 1 illustrates how, for a matching handling capacity to the arrival rate, the number of passengers in the car changes.

Table 1: Matching of passenger arrival rate (A_r) and lift system handling capacity (HC)

P	2	4	6	8	10	12	14	16	18
%AC	10	20	30	40	50	60	70	80	90
INT	11	15	18	20	23	25	27	28	30
HC/A_r	57	82	102	118	133	146	158	169	180

All figures are rounded

NOTE: At all times $P = A_r \times INT$. [eg: for P = 10 then 133/300 × 23 = 10]

2. ESTIMATION OF PASSENGER AVERAGE WAITING TIME DURING UP-PEAK

The designer having sized a lift system to meet the anticipated traffic demand, would then like to know the likely average passenger waiting times. Many lift companies give this figure as half the interval. Others using logged data, state that the system response time is the average passenger waiting time.

Interlude 2
System response time is the time between a passenger registering a call at a landing and the subsequent cancellation of that call by the traffic controller. These times are often inaccurate as some lift companies cancel the call registration as much as eight seconds before the lift actually starts to open its doors at a landing.

Passenger waiting time is the time an individual passenger waits at a floor before being able to board a lift. It is advisable to determine the average passenger waiting time for each car load of passengers in order to obtain statistically significant figures. Average passenger waiting time is not dependent solely on *UPPINT*, but is also affected by the average car load and the arrival probability distribution function.

Barney & Dos Santos (1985-p248) relate the average passenger waiting time (*AWT*) to the car load and interval as shown in Figure 1. In Figure 1 the average passenger waiting time (*AWT*) is normalised by dividing it by *INT* to give a performance figure against percentage car load as the independent variable. The solid line gives an average value and the dotted lines indicate the probable range of values. This latter aspect accounts for the possible range of building and lift system (including traffic controller) parameters, and passenger demands. Table 2 provides the graphical values of Figure 1 in tabular form.

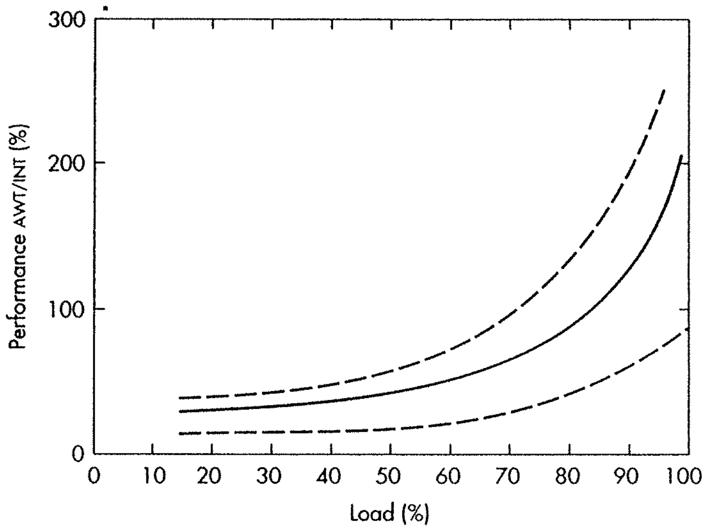


Figure 1: Uppeak performance
Percentage car load is the average car load as a percentage of car capacity.
AWT is the average passenger waiting time and *INT* is the average interval as the specified car load.

Table 2: Tabulation of uppeak performance as shown in Figure 1

Car load (%)	*AWT/INT* (%)	Car load (%)	*AWT/INT* (%)
30	0.32	75	0.74
40	0.35	80	0.85
50	0.40	85	1.01
60	0.50	90	1.30
70	0.65	95	1.65

For car loads from 50% to 80% the curve of Figure 1 can be approximated as:

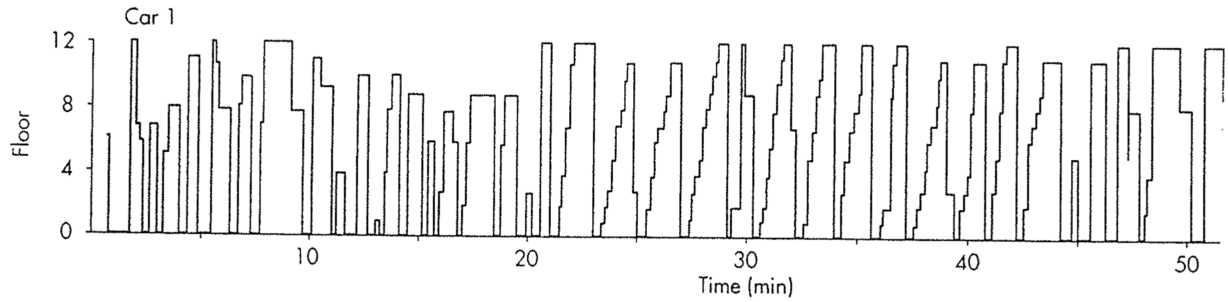
$$AWT = [0.4 + (1.8.P/AC - 0.77)^2]INT \qquad \text{... (4)}$$

For car loads less than 50% the average passenger waiting time (*AWT*) is given by:

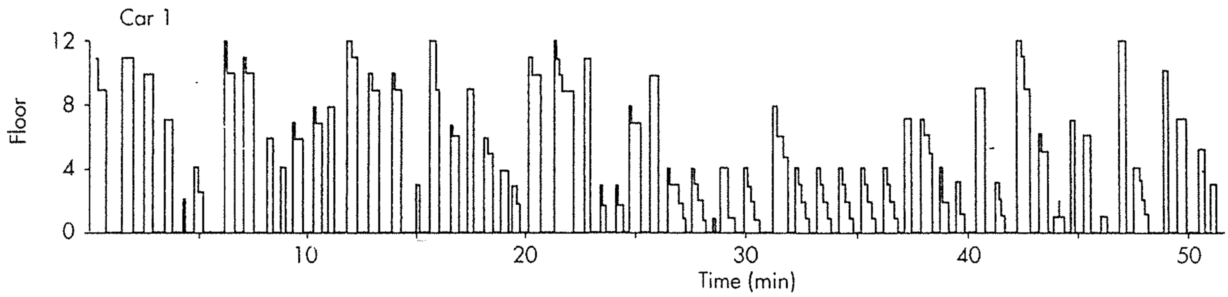
$$AWT = 0.4 \times INT$$

Car loads above 80% have not been considered in this paper.

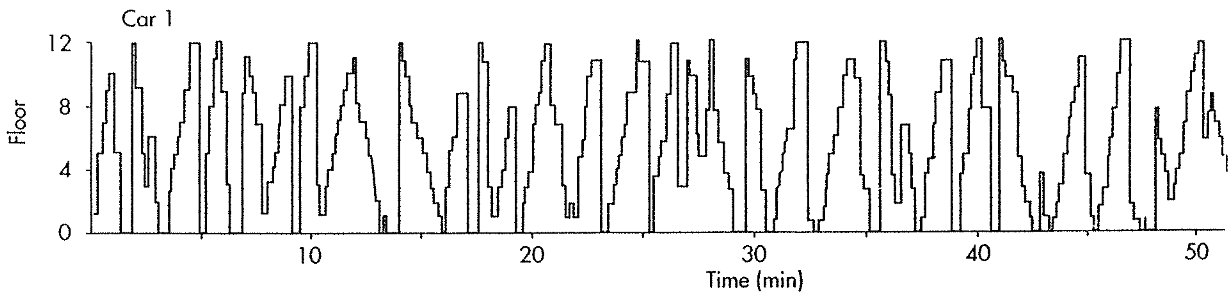
The uppeak traffic pattern is well defined but, in practice, it is rarely as simple as has been suggested. Often there will be some downward travel and interfloor traffic during the uppeak period and some designers attempt to include these in their calculations. However, with the wide range of possible assumptions no general benchmark condition can be defined. Therefore it is recommended that all uppeak calculations are carried out on the assumption that the uppeak is 'pure' and this may then be used as a benchmark to compare different designs and tenders.



(a) Uppeak



(b) Downpeak



(c) Interfloor

Figure 2: Traffic patterns

Example 2
Determine the average passenger waiting time for uppeak traffic condition for the following system:

N=16; CC=16; t_v=1.0 s; t_s=8.0 s; t_p=1.2 s; A_r=120; L=5.

where:

N is the number of floors above the main terminal
CC is the rated capacity

assuming P=12.8 and using Equations 1, 2 and 3 then:

RTT = 142.3 s
$UPPINT$ = 28.3 s
$UPPHC$ = 135.7 person/5-minutes

The latent handling capacity is larger than required and thus an iterative balance calculation will need to be made thus:

Table 3: Iterative balance calculation

Parameter	Trial 1	Trial 2
INT_1 (s)	25.0	24.2
P	10.0	9.7
H	15.0	15.0
S	7.6	7.4
RTT (s)	122.8	120.5
L	5	5
INT_2 (s)	24.6	24.1*
New $INT_1 = INT_1 - 2(INT_1 - INT_2)$		
New INT		24.2*
Car load (%)		61.0

* Further trials are unnecessary since the difference between INT_1 and INT_2 is less than 1%.

Thus the car load is 61% at an interval of 24.1 s. From Table 2 for 61% car load and using interpolation:

AWT/INT = 0.515

Therefore for an interval of 24.1 s the average passenger waiting time is:

AWT = 0.515 x 24.1 = 12.4 s.

3. OTHER TRAFFIC CONDITIONS

3.1 General

During uppeak traffic the pattern is as shown in Figure 2(a), although there may be some down peak and interfloor traffic to spoil this ideal pattern.

During down peak traffic there may also be some uppeak and interfloor activity to spoil the ideal pattern shown in Figure 2(b). It is possible to derive equations for down peak in the same way as for uppeak.

True interfloor activity will be completely random (ie: no obvious pattern of calls) and balanced so that no floor either gains or loses population over a period of several hours, see Figure 2(c). Again, equations can be developed, but they are of limited use due to the wide range of possibilities. Alexandris *et al* (1979) have derived complex formulae for the most general case of interfloor traffic with unequal floor demands and unequal floor populations.

Using the technique of discrete digital simulation to analyse a representative number of lift configurations equations can be derived empirically for the important traffic patterns (Barney & Dos Santos, 1977).

3.2 Down-peak traffic design

The pattern of car movements are characterised by the 'down staircase' pattern of floor stops shown in Figure 2(b). The cars stop less often than during the uppeak and the interval at the main terminal is smaller. Digital computer simulation confirms both these observations as shown in Figure 3.

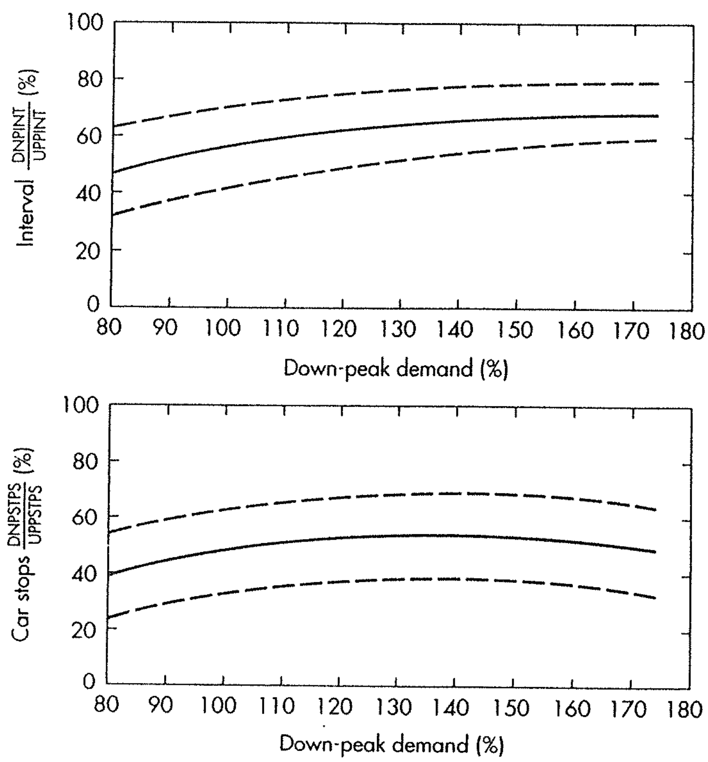


Figure 3: Down peak traffic design.
(a) Percentage interval (b) Percentage number of car stops

In Figure 3, the independent axis relates to the percentage down peak demand (D_d):

$$D_d = A_r/UPPHC \times 100 \qquad \dots (4)$$

where *UPPHC* is calculated for an 80% car loading and A_r is the passenger arrival rate in persons per five minutes.

Thus, when D_d is 150%, this is equivalent to one and a half times the uppeak demand, which is a typical down peak handling requirement.

The solid line on Figure 3(a) shows the average down peak interval (*DNPINT*) normalised by dividing it by *UPPINT* to give a percentage relationship. Figure 3(a) shows that the *DNPINT* is about 67% of the *UPPINT*, thus confirming the inherent extra handling capacity available in a given lift system during down peak.

The solid line on Figure 3(b) relates the average number of down peak stops (*DNPSTPS*) to up-peak stops (*UPPSTPS*) and indicates that the number of down peak stops are about 50% of the uppeak stops. This is because during down peak cars tend to load fully at a few floors only.

An indication of the quality of service during down peak is given in Figure 4. Here passenger average waiting time (*AWT*) is shown as a ratio of *UPPINT* against down peak demand.

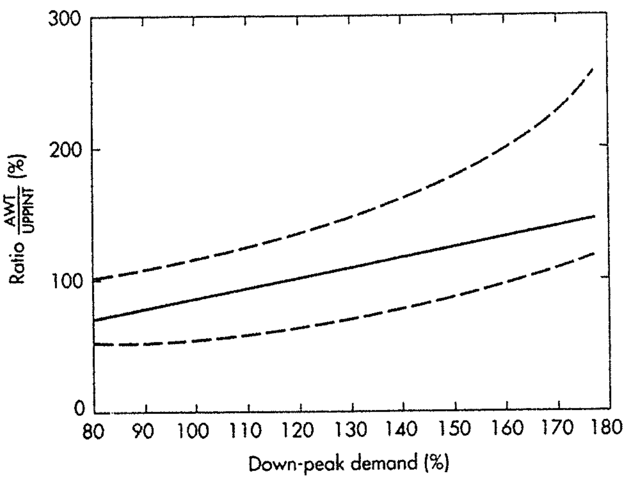


Figure 4: Down peak performance

The straight line is the average of many lift configurations and control systems and represents the relationship:

$$DNAWT = UPPINT \times 0.85 \times D_d/100 \qquad \dots (5)$$

where *DNAWT* is the down peak average passenger waiting time and D_d is the down peak demand.

The traffic controller has a greater influence during down peak than uppeak. Its effect can be seen in Figure 3(b) where the cars may be seen to be despatched to different levels of the building. This cycling of the cars ensures an even service at all floors. If all cars returned to the highest floor they would be filled by the time they reached the lower floors.

Example 3
Determine the down peak average passenger waiting time for the system described in Example 2 for a down peak arrival rate of 180 persons over 5-minutes.

Using Equation 4 then:

$$D_d = 180 \times 100/135.7 = 132.7\%$$

Then using Equation 5:

$$DNAWT = 28.3 \text{ x } 0.85 \text{ x } 132.7/100 = 31.9 \text{ s}$$

3.3 Interfloor traffic design

There is no discernible pattern of movement during interfloor traffic, see Figure 2(c). The concept of an interval has no meaning during interfloor traffic as round trips do not always pass through the main terminal. An indication of the quality of service is shown in Figure 5 in which the ratio *AWT/UPPINT* (expressed as a percentage) is plotted against interfloor demand D_I.

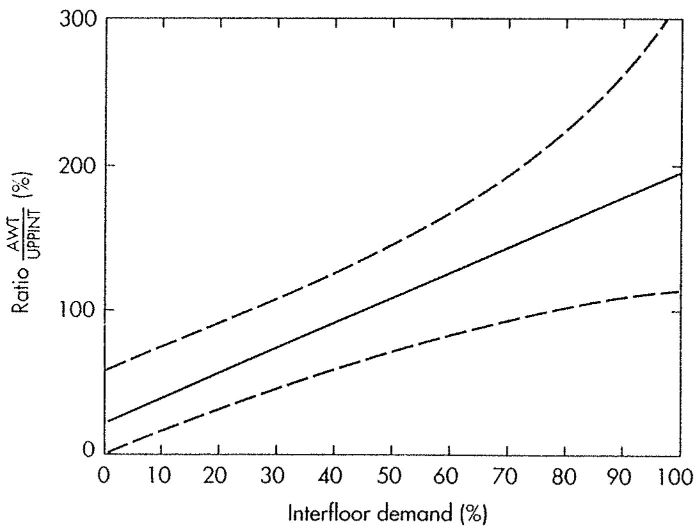


Figure 5: Interfloor performance

In Figure 5 the independent axis relates to the percentage interfloor demand (D_I), ie:

$$D_I = A_r \times 100/UPPHC \qquad \text{... (6)}$$

Bedford (1966), working with a fixed sectoring priority timed algorithm, suggests that 2.25 stops per car per minute is typical of the values for D_I expected for busy or heavily loaded systems. This is equivalent to about one half of the population of a building using the lifts in one hour with an average waiting time of about half that endured during the up-peak.

For design purposes, it is recommended that an average busy system should be considered as one in which one third of the building's population uses the lift system in one hour. Thus if 36% of a building's population used the lifts in one hour this would be equivalent to A_r of 3% of the building's population in every five minute period.

The broken lines indicate the probable range of values. A straight line can be fitted to the average of similar plots for many lift configurations and control systems, which has the relationship:

$$IFAWT = UPPINT(0.22 + 1.784D_I/100) \qquad ...(7)$$

where *IFAWT* is the interfloor passenger average waiting time.

The traffic controller has a considerable influence on interfloor traffic performance. At high demand levels the fixed sectoring systems perform less well than either dynamic sectoring or modern computer based algorithms. However, at interfloor demands below 30% the differences are only a few percent.

Example 4
Determine the interfloor average passenger waiting time for the system described in Example 2 for a interfloor arrival rate of 25 persons every 5-minutes.

From Equation 6:

$$D_I = A_r \times 100/UPPHC$$

$$D_I = 25 \text{ x } 100/135.7 = 18.4\%$$

Then using Equation 7:

$$IFAWT = 28.3(0.22 + 1.784 \text{ x } 18.4/100) = 15.5 \text{ s}$$

4. CONCLUSIONS

The procedures given above allow an estimate of uppeak, downpeak and interfloor average passenger waiting times to be obtained. Obviously the figures obtained are average values and specific lift installations may be at variance. Once a favoured system has been selected these values should be confirmed by simulation using a package such as PC-LSD.

5. REFERENCES

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Biographical details

Dr.G.C.Barney holds the degrees of B.Sc.(Dunelm), M.Sc.(Dunelm) and Ph.D.(Birm) and as a Chartered Engineer holds the professional qualifications of Fellow of the Institution of Electrical Engineers and Eur.-Ing. An energetic writer he has written, co-authored and edited some 100 books and papers the majority on the topic of lift systems. Currently his activities include: Chairman, Lerch, Bates & Associates Ltd.; Visiting Senior Lecturer, UMIST; English Editor, Elevatori; Chairman, IAEE Board of Executives and a member of the British Standards Institution, Technical Committee MHE/4.

APPENDIX

TABLE A.1: Actual passenger capacity for different rated loads

EN81 rated capacity (persons)	EN81 rated load (kg)	EN81 max area (m^2)	Actual area (-5%) (m^2)	Actual max persons ($0.2m^2$/per)	80% actual value (*P*)	Actual to rated load (%)
6	450	1.30	1.24	6.2	4.9	82
8	630	1.66	1.58	7.9	6.3	79
10	800	2.00	1.90	9.5	7.6	76
13	1000	2.40	2.28	11.4	9.1	70
16	1250	2.90	2.76	13.8	11.0	69
21	1600	3.56	3.37	16.9	13.5	64
26	2000	4.20	3.99	20.0	16.0	61
33	2500	5:00	4.75	23.8	19.0	58

[2216]