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Improvements to the Up Peak Round Trip Time Calculation

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ABSTRACT

Most lift designs are based on up peak calculations. The up peak is not always the most appropriate choice of peak period for the analysis. Nevertheless, the up peak calculation is important as an industry standard benchmark calculation, and a good starting point for assessing the handling capacity of a lift system. Improvements to the "standard" up peak calculation have been proposed. These include: (a) Introduction of formulae for the calculation of flight times. These formulae can be used for any travel distance and lift dynamics. (b) Formulation of adjustments made for lifts which do not reach rated speed in a single floor jump. (c) Introduction of an express zone term into the Round Trip Time equation.

LIST OF SYMBOLS

a	acceleration (m/s^2)
CC	car (rated) capacity (persons)
CF	capacity factor (%)
d_f	average inter-floor height (m)
df_n	height floor n (m)
d_H	distance to reach reversal floor H excluding express zone (m)
d_X	total height of unserved floors in express zone (m)
H	average highest reversal floor
j	jerk (m/s^3)
L	number of lifts
N	number of floors above main terminal
P	average number of passengers
S	average number of stops
T	cycle time (s)
t_a	advanced door opening time (s)
t_c	door closing time (s)
$t_{fd}(d)$	flight time for travel distance d (s)
t_{f1}	single floor flight time (s)

t_l	passenger loading time per person (s)
t_o	door opening time (s)
t_p	average passenger transfer time (s)
t_u	passenger unloading time per person (s)
t_v	time to travel between two adjacent floors at rated speed (s)
t_s	time consumed when making a stop (s)
t_{start}	allowance for motor start delay (s)
P	average number of passengers in car
$\%POP$	5 minute up peak handling capacity (% population)
RTT	round trip time (s)
U_{eff}	effective building population (persons)
U_i	population of floor i (persons)
$UPPHC$	up peak handling capacity (persons/5 min)
$UPPINT$	average up peak interval (s)
v	contract (rated) speed (m/s)

INTRODUCTION

Most lift designs are based on up peak calculations. The up peak is not always the most appropriate choice of peak period for the analysis. Nevertheless, the up peak calculation is important as an industry standard benchmark calculation, and a good starting point for assessing the handling capacity of a lift system.

The up peak lift calculation is based on estimating the time taken for a lift to make a single "round trip" of the building. The calculation assumes people load the lift at the lowest floor, and get dropped off as the lift stops off at upper floors. The lift then expresses back to the ground floor (some designers include an allowance for additional stops made by the lift on its return journey). The Round Trip Time (RTT) is calculated for a single lift, so results for two of more lifts are extrapolated accordingly.

The up peak calculation has evolved over a number of years. Jones[1] determined results for the probable number of stops made by the elevator during its round trip. Schroeder[2] determined formulae for highest reversal floor. Barney and dos Santos[3] formalised the method with formulae that are now generally accepted by the Lift Industry. A summary of these formulae follow.

UP PEAK FORMULAE

The average number of passengers assumed to load into a car during up peak traffic is

$$P := \frac{CF}{100} \cdot CC \qquad (1)$$

The effective building population of the buildings is

$$U_{eff} := \sum_{i=1}^{N} U_i \tag{2}$$

The average highest reversal floor is

$$H := N - \sum_{j=1}^{N-1} \left(\sum_{i=1}^{j} \frac{U_i}{U_{eff}} \right)^P \tag{3}$$

The average number of stops made by the lift during its round trip is

$$S := N - \sum_{i=1}^{N} \left(1 - \frac{U_i}{U_{eff}} \right)^P \tag{4}$$

The average time taken for a single person to load or unload the lift is

$$t_p := \frac{t_l + t_u}{2} \tag{5}$$

The time taken for the lift to travel between two adjacent floors at rated speed is

$$t_v := \frac{d_f}{v} \tag{6}$$

The single floor flight time, t_{f1} is taken from Table 1 [3].

Contract Speed (m/s)	Acceleration (m/s^2)	Single Floor Flight Time, 3.3m floor height (s)
1.00	0.4-0.7	7.0
1.50	0.7-0.8	6.0
2.50	0.8-0.9	4.8
3.50	1.0	3.7-4.0
5.00	1.2-1.5	3.7-4.0

Table 1   Typical flight times

The cycle time is the time to travel a single floor, and open/close the doors

$$T := t_{f1} + t_c + t_o \tag{7}$$

So the delay or “time consumed” by making a single stop is

$$t_s := T - t_v \tag{8}$$

The RTT is the time taken for the travel to/from the highest reversal floor at contract speed, plus the delay for each stop, plus the time for the passengers to load/unload. Thus,

$$RTT := \left[2 \cdot H \cdot t_v + (S + 1) \cdot t_s + 2 \cdot P \cdot t_p \right] \tag{9}$$

Some designers add 5-10% to the RTT for "losses" associated with controller inefficiencies, passengers holding the doors, and so on.

The up peak interval is calculated by dividing the round trip time by the number of lifts.

$$UPPINT := \frac{RTT}{L} \tag{10}$$

The interval is the average time between successive lift arrivals at the main terminal floor. It is not the average waiting time, which Strakosch states is about 55 to 60% of the interval, dependant on the control system[4].

The up peak handling capacity is the number of passengers transported in a five minute period. This is calculated as

$$UPPHC := \frac{300 P \cdot L}{RTT} \tag{11}$$

The handling capacity, expressed as a percentage of the building population transported in five minutes is

$$\%POP := \frac{UPPHC100}{U_{eff}} \tag{12}$$

IMPROVEMENTS TO CALCULATION

Flight time calculation

Determining flight time from Table 1 is limited as the inter-floor heights are assumed to be 3.3 m, and only "standard" speeds and accelerations are considered. The author's research in ideal lift kinematics [5][6] has yielded general formulae to determine flight time for any travel distance and lift dynamics.

$$\textit{if} \quad d \geq \frac{a^2 \cdot v + v^2 \cdot j}{j \cdot a} \quad \textit{then} \quad t_{fd}(d) := \frac{d}{v} + \frac{a}{j} + \frac{v}{a} + t_{start} \tag{13}$$

if $\frac{2\cdot a^3}{j^2} \le d < \frac{a^2\cdot v + v^2\cdot j}{j\cdot a}$ *then* $t_{fd}(d) := \frac{a}{j} + \frac{\sqrt{a^3 + 4\cdot d\cdot j^2}}{\sqrt{a\cdot j}} + t_{start}$ (14)

if $d < \frac{2\cdot a^3}{j^2}$ *then* $t_{fd}(d) := \left(32\cdot\frac{d}{j}\right)^{\frac{1}{3}} + t_{start}$ (15)

These formulae are consistent with results provided by Molz [7], but are in a simpler form.

Applying the $t_{fd}(d)$ function, the single floor flight time is

$$t_{f1} := t_{fd}(d_f) \quad (16)$$

Lifts not reaching full speed in single floor jump and non-equal inter-floor heights

The conventional RTT equations assume that the lift reaches rated speed in the distance of a single floor jump; and that there are no irregularities in floor heights. This is not always the case, and CIBSE Guide D [8] proposes a procedure for making “corrections” to the conventional RTT formulae. The author has formulated these corrections as follows:

Determine the distance d_H to reach reversal floor H, which can be written as

$$d_H := \left(\sum_{i=0}^{floor(H)-1} df_i\right) + (H - floor(H))\cdot df_{floor(H)} \quad (17)$$

(floor(x) is a function which returns the greatest integer less than or equal to x)

The average distance between stops is then

$$\frac{d_H}{S}$$

and the flight time to travel this distance is

$$t_{fd}\left(\frac{d_H}{S}\right)$$

The difference between this and the assumed time can be substituted into an enhanced equation for t_s which becomes

$$t_s := \left(t_{fd}\left(\frac{d_H}{S}\right) - \frac{d_H}{S \cdot v}\right) + t_c + t_o - t_a \qquad (18)$$

Advanced door opening time (s) has also been included in this formulae. Some designers subtract the advanced door opening time from the door opening time, but it is clearer to identify it separately.

The $2 \cdot H \cdot t_v$ term in the RTT equation also needs to be revised to $2 \cdot \frac{d_H}{v}$ to take into account the new approach. The RTT equation now becomes

$$RTT := \left[2 \cdot \frac{d_H}{v} + (S + 1) \cdot t_s + 2 \cdot P \cdot t_p\right] \qquad (19)$$

Equations for UPPINT and UPPHC remain the same.

Express Zones

In high rise buildings lifts are often zoned to reduce passenger travel times and to save core space by not having all the lifts serving the upper floors of the building. An example of a zoned building is represented by the diagram in Figure 1.

18					●	●	●	●
17					●	●	●	●
16					●	●	●	●
15					●	●	●	●
14					●	●	●	●
13					●	●	●	●
12					●	●	●	●
11					●	●	●	●
10					●	●	●	●
9	●	●	●	●	❍	❍	❍	❍
8	●	●	●	●	❍	❍	❍	❍
7	●	●	●	●	❍	❍	❍	❍
6	●	●	●	●	❍	❍	❍	❍
5	●	●	●	●	❍	❍	❍	❍
4	●	●	●	●	❍	❍	❍	❍
3	●	●	●	●	❍	❍	❍	❍
2	●	●	●	●	❍	❍	❍	❍
1	●	●	●	●	❍	❍	❍	❍
Ground	●	●	●	●	●	●	●	●
Lift No	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*
	LOW RISE				*HIGH RISE*			

Key ● Lift serves floor ❍ Lift expresses past floor without stopping

Figure 1 Zoned building

This express zone can be taken into account by revising the RTT equation, (19) to

$$RTT := \left[2 \cdot \frac{d_H + d_X}{v} + (S+1) \cdot t_s + 2 \cdot P \cdot t_p \right] \qquad (20)$$

where d_X is the express zone; in this example, the sum of the floor heights of Levels 1 to 9. It is suggested that equation (20) is used in preference to equation (19) for all cases; if there is no express zone simply set d_x to 0.

DISCUSSION

Most lift designs are based on an up peak RTT calculation, which is an important industry standard benchmark. The up peak calculation has been developed over a number of years with contributions from several researchers.

With the improvements discussed in this paper, the up peak calculation can be applied for any combination of floor heights and lift dynamics, including buildings with express zones.

The calculation still has limitations, which include

- only up peak traffic is considered; this is often not the most onerous traffic flow in buildings
- in some instances up peak calculations are inappropriate, e.g. in shopping centres, car parks, airports or hospitals
- it is difficult to adjust the calculation to analyse up peaks for buildings with basements, car parks or more than one entrance floor.

To overcome these limitations, more advanced techniques such as the *General Analysis* [9][10] and *Simulation* [11] are required.

Computer software implementing all these analysis techniques is available from the author.

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BIOGRAPHICAL DETAILS

Richard Peters has a degree in Electrical Engineering and is a Doctor of Engineering. He pursues a broad range of professional interests with notable expertise in Software Development, Mathematical Modelling, Vertical Transportation, and Environmental Engineering. His research papers have been widely published.

Richard worked for ten years with international engineering consultants Ove Arup & Partners. In 1997, he set up his own company, Peters Research Ltd which provides software development and engineering consultancy. His traffic analysis and simulation software *Elevate*, is used world-wide by consultants, universities and lift companies.