Chapter 6: Average Waiting Time (AWT), the misleading parameter

Summary: The AWT parameter of traditional UP PEAK “traffic calculations” for "collective selective" groups gives a misleading impression of the quality of elevator services because the AWT calculation method is unrealistic. Comparisons of 4-car and 6-car groups with large cars show that 6-car groups are particularly inefficient cost much more and deliver service qualities that are worse than those of 4-car groups. Graphs of the Waiting Time Bandwidth (WTB) can disclose the true quality of AWT's of any group, with <u>any group control</u> and for any traffic period.

The Average Waiting Time (AWT) calculation method

The essence of traditional UP PEAK “traffic calculations” for traditional groups is the determination of the average UP PEAK Round Trip Time (RTT) assuming DOWN traffic is NIL. The AWT for <u>UP going passengers</u> is then calculated in two steps:

1. The average Departure INTERVAL is assumed to be the average UP PEAK RTT divided by the number of cars in the group.
2. The AWT is assumed to be the average Departure INTERVAL divided by two, because a lucky person arrives at floor zero when a car has just opened its doors and an unlucky person arrives just after a car has closed its doors and must wait the entire Departure INTERVAL for the next car.

If departures are perfectly regular the AWT will indeed be the Departure INTERVAL divided by TWO. Unfortunately perfectly regular departures are most unlikely during UP PEAK traffic. The cars are full and all car movements are controlled by the random destinations of the passengers.

In this connection we must also consider the natural inclination of high speed cars to **“bunch”**. When a car makes a stop the “time cost” for deceleration, door movements, passenger movements and acceleration is at least 10 seconds and during this time another car can cover a long distance and stop at the same or a nearby floor.

Experienced elevator passengers will have noticed that the Departure INTERVALS and waiting times of “collective selective” elevators are rather irregular during UP PEAK traffic. This is only logical because **they are the result of chance**.

The formation of a perfect “bunch” of cars, i.e. all cars arriving and departing from the same floors at precisely the same time, is most unlikely too. Please note that in this case the Departure INTERVAL would equal the RTT, i.e. the AWT would be the RTT divided by 2. For a **4-car group** the following is valid:

- theoretical <u>minimum</u> AWT = average RTT divided by 8
- theoretical <u>maximum</u> AWT = average RTT divided by 2

Consequently the realistic AWT is more likely to be the RTT divided by 5, i.e. substantially longer than the theoretical minimum AWT of traditional traffic calculations.

Another negative AWT influence: After a long Departure INTERVAL the number of waiting passengers may exceed the number of passengers that the next departing car can accommodate. The surplus will have to wait for the next car. After a short Departure INTERVAL a car may not reach full load.

Even in case all Departure INTERVALS would be perfectly regular a **second condition** must be fulfilled as well: The arrival rate of passengers on floor zero may not exceed the 5 minute Distribution Capacity (DC5) of the group. The combination of irregular Departure INTERVALS and arrival rates that temporarily exceed the DC5 is a very common situation for groups of elevators. Consequently it is **highly unrealistic** that the average waiting time equals the theoretical minimum AWT as calculated on page 1.

During heavy DOWN PEAK or heavy simultaneous UP and DOWN traffic the DOWN going cars of "collective selective" elevators may reach full load after few stops. Waiting passengers on lower floors will be by-passed and consequently the INTERVAL that is valid for UP passengers is not valid for DOWN passengers. It is a characteristic of "collective selective" groups that during periods of heavy simultaneous UP and DOWN traffic the waiting times for DOWN passengers are longer than for UP passengers. This is a further reason for the word misleading in the heading of this chapter.

The relationship between theoretical and realistic AWT's can be investigated with the methods described in the Chapter 10: “Traffic simulation”. Most elevator companies have the ability to do traffic simulation but it seems that very little has been published concerning this topic.

In this book the AWT's of traditional groups that result from traffic calculations will often be qualified with the words “theoretical minimum” to remind readers that the real AWT is probably much longer.

Comparison of the AWT's of 4-car and 6-car groups of “collective selective” elevators

In the previous chapter we have used the Comparative Performance Table (CPT) below for selecting the number of upper floors that can be served by a 4-car group of "collective selective" elevators if the expected maximum arrival rate is 14 %. For this chapter this CPT has been extended to show the performance parameters for 6-car and 3-car (see Appendix) groups. Please note that **the average RTT is not influenced by the numbers of cars in a group.**

Number of upper floors served	Floor designation highest floor	Total zone population	Total travel in meters	Contract speed in m/sec.	Average car load in persons	Number of "selected floors"	Number of "probable stops"	Average RTT Low & High trip in seconds	Average Travel Time in the car inseconds	% of population distributed into building by 4 elevators in 5 min.	Average Time To Destination in seconds (= AWT + ATTC)	Average departure INTERVAL from floor zero	Theoretical minimum Average Waiting Time (AWT) in seconds	% of population distributed into building by 6 elevators in 5 min.	Average Time To Destination in seconds (= AWT + ATTC)	Average departure INTERVAL from floor zero	Theoretical minimum Average Waiting Time (AWT) in seconds
Nr flrs served	Top floor	Pop.	Trav.	Contr. speed	Car load	Sel. floors	Prob. stops	Av. RTT L & H	ATTC	DC5 4-cars	ATTD	Dep. INT	AWT	DC5 6-cars	ATTD	Dep. INT	AWT
Contract load: 1600 KG (20 persons)																Chap6dia1	
9	9	675	36	2.5	16	9	7.6	129.5	50.5	22.0	66.7	32.4	16.2	32.9	61.3	21.6	10.8
10	10	750	40	2.5	16	10	8.1	136.7	53.3	18.7	70.4	34.2	17.1	28.1	64.7	22.8	11.4
11	11	825	44	2.5	16	11	8.6	143.4	55.9	16.2	73.8	35.9	17.9	24.3	67.8	23.9	11.9
12	12	900	48	2.5	16	12	9.0	149.7	58.3	14.2	77.0	37.4	18.7	21.4	70.8	25.0	12.5
13	13	975	52	2.5	16	13	9.4	155.7	60.6	12.6	80.1	38.9	19.5	19.0	73.6	26.0	13.0
14	14	1050	56	2.5	16	14	9.7	161.5	62.7	11.3	82.9	40.4	20.2	17.0	76.2	26.9	13.5
15	15	1125	60	2.5	16	15	10.0	166.9	64.7	10.2	85.6	41.7	20.9	15.3	78.6	27.8	13.9
16	16	1200	64	2.5	16	16	10.3	172.2	66.5	9.3	88.0	43.1	21.5	13.9	80.8	28.7	14.3
17	17	1275	68	2.5	16	17	10.6	177.2	68.3	8.5	90.5	44.3	22.2	12.7	83.1	29.5	14.8
NB: Above CPT does not show columns for Cycle RTT and Cycle INTERVAL because these are irrelevant																	
for "collective selective" elevators. The Appendix to this chapter shows all details.																	

Each line of the above CPT represents a building with a specific number of upper floors and a population of 75 persons per floor. The CPT shows how the DC5 and other performance parameters change in relation to the number of upper floors served.
If we increase the number of cars of the group to **six the 6-car group can serve 4 additional floors provided we accept the lower DC5 of 13.9 %.**

The reduced efficiency of the 6-car group is demonstrated by the relation between the **increase in the number of cars of 50 %** and the **increase in the number of floors served of 33 %**. The parameters of both groups compare as follows:

	4-car group	**6-car group**
Control	Col. sel.	Col. sel.
Number of upper floors served	12	16
DC5	14.2 %	13.9 %
RTT	149.7 seconds	172.2 seconds
INTERVAL	37.4 seconds	28.7 seconds
Theoretical minimum AWT	18.7 seconds	14.3 seconds
Theoretical maximum AWT	74.9 seconds	86.1 seconds
ATTC	58.3 seconds	66.5 seconds
ATTD (theor. minimum)	77.0 seconds	80.8 seconds
ATTD (theor. maximum)	133.1 seconds	152.6 seconds

The above comparison shows that the **4.4 seconds reduction of the theoretical minimum AWT** entails a **realistic ATTC that is 8.2 seconds longer**. The quality of elevator service is reduced instead of improved as suggested by the shorter AWT. The 6-car group has a DC5 of 13.9 % and this implies that the theoretical AWT of 14.3 seconds is under-stated because the 6-car group is slightly under-elevatored in comparison with the 4-car group.

The following cost guesstimate gives an impression of the relative cost of the 4-car and 6-car groups. If we assume one elevator for 12 floors costs 100 and one elevator for 16 floors costs 115 the 4-car group costs 400 and the 6-car group 690. These costs divided by the number of floors served yield 33 and 43 as the relative cost on a per floor basis. **The capital cost per floor of the 6-car group will be at least 30 % higher**. The 6-car group also entails higher costs for energy, maintenance and the **additional building volume** required for the 6-car group. **A high price for a lower DC5, a longer ATTC and later arrival of passengers at their destinations!**

During light or medium UP and DOWN traffic the theoretical minimum Departure INTERVAL of the 6-car group will be shorter but its ATTD will be longer. In Chapter 17: “Module for moderate traffic conditions” the 4-car and 6-car groups of this example have been used to check the average RTT, Departure INTERVAL, AWT and ATTD for an assumed set of identical traffic conditions. This comparison confirms that the **6-car group does not improve service quality during moderate traffic conditions**.

The above comparisons clarify why the overwhelming majority of "collective selective" groups are 4-car groups. The remarkable congruence of groups in respect of contract load and number of cars is the logical result of the inefficiency of the "collective selective" group control system. Although the above logical explanation has been “hiding in the interdependencies” of elevator performance it is obvious that many building owners and planners have realized that 4-car groups are more economical.

It is regrettable that the substantially better service qualities of 6 car groups with small cars, as described in the previous chapter, have not received attention.

3-car groups

The Appendix to this chapter shows the CPT of page 2 with additional columns for a 3-car group. This group has a DC5 of 14 % when it serves 10 upper floors and an ATTD that is one second shorter than the ATTD of the 4-car group. From a service quality point of view it is an acceptable solution. The economics are pretty good as well. If one elevator of the 4-car group costs 100 one elevator of the 3-car group may cost about 92. Total cost of the groups would be 400 and 276 and per floor served 33 and 27.6, i.e. the 3-car group costs about 16 % less per floor. Maintenance and energy costs will be reduced as well and the elevators occupy less building volume.

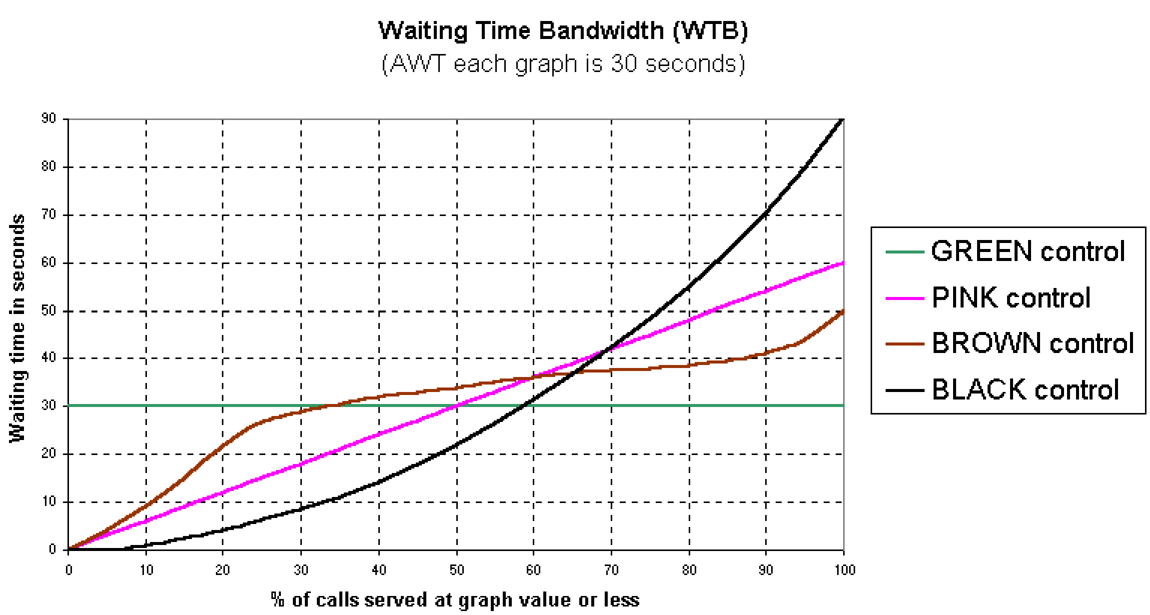
In spite of these economies 3-car groups are rare. The reason could be that a temporary loss of one car reduces transport capacities by one third. Also the symmetry of opposite cars enabled by 4-car groups will very often be an attractive planning option. The misleading AWT parameter could be a further explanation for the scarcity of 3-car groups.

Waiting Time Bandwidth (WTB)

This chapter proposes the Waiting Time Bandwidth (WTB) as a method to evaluate the quality of waiting times. The WTB discloses the **relative quality** of waiting times during a specific traffic period.

To asses the quality of AWT's during a **defined traffic period** the waiting time of each and every passenger must be recorded. This recording enables assessing the percentage of passengers that experienced waiting times of, for example, 5 seconds or less, 10 seconds or less, etc. The graph of these percentages forms the WTB and the longest waiting time defines the 100 % level of the **WTB graph**.

The diagram below shows **4 WTB graphs and each graph has an identical AWT of 30 seconds**. These artificial graphs show that the quality of waiting times may vary although the AWT of each graph is 30 seconds. The **shape** of each graph defines the relative quality of AWT's during a defined traffic period.



If we assume that the above WTB's result from simulation (see Chapter 10) of a specific group under identical traffic conditions but with different group control systems it is obvious that the GREEN control is the best control system. Reason: When the **best-possible** Average Waiting Time (AWT) is 30 seconds the most equitable solution is that all passengers wait equally long, i.e. 30 seconds. Consequently a straight horizontal WTB is the most desirable shape for any WTB. Its **level should be as low as possible**. Unfortunately the GREEN control is probably impossible, however, it is good to know the **ideal shape of WTB's**.

The PINK WTB is a straight line from 0 to 60 seconds. This is the performance that is suggested by an AWT of 30 seconds. A group of "collective selective" elevators can theoretically deliver this PINK WTB, however, a straight WTB is most unlikely to happen. Reason: Passengers who can use any car to go to random destinations will by chance often enjoy short waiting times. The BLACK WTB above shows that for a **specific Average Waiting Time** many short waiting times will cause many long waiting times as well. Consequently the WTB's of "collective selective" groups will probably have a **shape** that is similar to the BLACK WTB.

Optimizing AWT's with WTB know-how

"Intelligent destination" group controls will **avoid waiting times that are shorter than the best-possible or target AWT for prevailing traffic conditions**. This operation principle is a permanent feature of the artificial intelligence that controls and optimizes Average Waiting Times (AWT's) and Average Travel Times in the Car (ATTC's). How this can be done is described in Chapter 17: "Module for moderate traffic conditions". It is not possible to avoid short waiting times altogether because when a car stops and has a common destination with a waiting passenger this passenger will enjoy a short waiting time. However, **each time intelligent destination elevators avoid a waiting time that is shorter than the target waiting time by assigning this call to a NEXT car, other waiting passengers will be served earlier and the shape of the WTB improves**.

Waiting Time Bandwidth of "intelligent destination"

The BROWN WTB is probably typical for the **shape** of the WTB of groups with intelligent destination controls, but how much better the relative quality of waiting times of intelligent destination will be is a secret still to be unlocked. With **traffic simulation** it is possible to make **real WTB graphs** for any group control and any traffic conditions, i.e. **the exact comparison of group controls in respect of AWT qualities is possible.** When intelligent destination controls become available real data will replace the logic of this chapter.

Remarks

The above graphs demonstrate **that the shape of the WTB makes the relative quality of AWT's visible** for a specific traffic period. The value of the best-possible AWT in seconds depends on the prevailing traffic conditions during the period for which the WTB is valid. Intelligent destination groups will be able to deliver separate WTB's for any period for UP and for DOWN going passengers or for both.

A WTB that covers an entire day will be rather different to the WTB for 30 minutes of UP PEAK traffic and different again for 60 minutes of medium traffic.

Bandwidth graphs for other service qualities

The evaluation of service qualities with bandwidth graphs is desirable for all service qualities. Intelligent destination groups will be able to produce such graphs for Average Travel Times in the Car (ATTC's), Average Times To Destination (ATTD's) and average car loads as well.

Appendix: CPT for groups of "collective selective" elevators showing the relationship between the performance parameters of 3-car, 4-car and 6-car groups.

Chapter 6: Average Waiting Time (AWT), the misleading parameter

Appendix

Comparative Performance Table (CPT) for groups of "collective selective" elevators showing the relationship between the performance parameters of 3-car, 4-car and 6-car groups.

Number of upper floors served	Floor designation highest floor	Total zone population	Total travel in meters	Contract speed in m/sec.	Average car load in persons	Number of "selected floors"	Number of "probable stops"	Average RTT Low & High trip	Average Travel Time in the car	Average time for group to serve all floors once	% of population distributed into building by 3 elevators in 5 min.	Average Time To Destination in seconds (= AWT + ATTC)	Average departure INTERVAL from floor zero	Cycle INTERVAL: INTERVAL for AWT calculation	Theoretical minimum Average Waiting Time (AWT) in seconds	% of population distributed into building by 4 elevators in 5 min.	Average Time To Destination in seconds (= AWT + ATTC)	Average departure INTERVAL from floor zero	Cycle INTERVAL: INTERVAL for AWT calculation	Theoretical minimum Average Waiting Time (AWT) in seconds	% of population distributed into building by 6 elevators in 5 min.	Average Time To Destination in seconds (= AWT + ATTC)	Average departure INTERVAL from floor zero	Cycle INTERVAL: INTERVAL for AWT calculation	Theoretical minimum Average Waiting Time (AWT) in seconds
Nr flrs served	Top floor	Pop.	Trav.	Contr. speed	Car load	Sel. floors	Prob. stops	Av. RTT L & H	ATTC	Cycle RTT	DC5 3-cars	ATTD	Dep. INT	Cycle INT	AWT	DC5 4-cars	ATTD	Dep. INT	Cycle INT	AWT	DC5 6-cars	ATTD	Dep. INT	Cycle INT	AWT
Contract load: 1600 KG (20 persons)																									
9	9	675	36	2.5	16	9	7.6	129.5	50.5	129.5	16.5	72.1	43.2	43.2	21.6	22.0	66.7	32.4	32.4	16.2	32.9	61.3	21.6	21.6	10.8
10	10	750	40	2.5	16	10	8.1	136.7	53.3	136.7	14.0	76.1	45.6	45.6	22.8	18.7	70.4	34.2	34.2	17.1	28.1	64.7	22.8	22.8	11.4
11	11	825	44	2.5	16	11	8.6	143.4	55.9	143.4	12.2	79.8	47.8	47.8	23.9	16.2	73.8	35.8	35.8	17.9	24.3	67.8	23.9	23.9	11.9
12	12	900	48	2.5	16	12	9.0	149.7	58.3	149.7	10.7	83.3	49.9	49.9	25.0	14.2	77.0	37.4	37.4	18.7	21.4	70.8	25.0	25.0	12.5
13	13	975	52	2.5	16	13	9.4	155.7	60.6	155.7	9.5	86.6	51.9	51.9	26.0	12.6	80.1	38.9	38.9	19.5	19.0	73.6	26.0	26.0	13.0
14	14	1050	56	2.5	16	14	9.7	161.5	62.7	161.5	8.5	89.6	53.8	53.8	26.9	11.3	82.9	40.4	40.4	20.2	17.0	76.2	26.9	26.9	13.5
15	15	1125	60	2.5	16	15	10.0	166.9	64.7	166.9	7.7	92.5	55.6	55.6	27.8	10.2	85.6	41.7	41.7	20.9	15.3	78.6	27.8	27.8	13.9
16	16	1200	64	2.5	16	16	10.3	172.2	66.5	172.2	7.0	95.2	57.4	57.4	28.7	9.3	88.0	43.0	43.0	21.5	13.9	80.8	28.7	28.7	14.3
17	17	1275	68	2.5	16	17	10.6	177.2	68.3	177.2	6.4	97.8	59.1	59.1	29.5	8.5	90.5	44.3	44.3	22.2	12.7	83.1	29.5	29.5	14.8

Characteristics of elevators and building

Speed	>	see table	Distance 0 to lowest upper floor	4	meters
Acceleration and deceleration rates	1	m/s^2	Typical floor distance	4	meters
Jerk rate	1	m/s^3	Population	75	pers./floor
Door closing time	2.5	seconds	Car load in persons	>	see table
Door opening time	2	seconds	Traffic	>	UP PEAK
Time gain advanced door opening	0	seconds			
Time allowance car IN/OUT each pass.	2	seconds			

Chap6dia2