"IS 2,000 FEET PER MINUTE ENOUGH?"

by Frederick Barker

Paper originally presented at: International Conference on High Technology Buildings, Council on Tall Buildings and Urban Habitat, São Paulo, Brazil, October 25-26, 1995.

Abstract

This paper suggests we build on our best present elevator technologies and techniques, including high-speed, double-deck elevators and skylobbies, to increase building net/gross efficiency if we desire to significantly extend building height in the near future. These technologies also include traffic design tools to compute possible elevator core solutions and then simulate advanced equipment options to minimize elevator quantities and duties. The importance of using the appropriate traffic criteria is stressed. The design challenges of super-speed, single-deck elevators and totally electric "ropeless" elevators are outlined. While practical concepts for more than one elevator per hoistway are recognized as a long-term goal, we believe we can find more conventional solutions for super-tall buildings by partnering our experience and technology.

Introduction

At the Fifth World Congress of the Council on Tall Buildings and Urban Habitat (CTBUH), Alfred McNeill and Doug Bennett touched on some of the most important current topics in elevators for tall buildings when they challenged – "Is 2,000 feet per minute enough?" – and – "We need new elevator technologies to get rid of all those cables."[1] In a paper from the proceedings of that Congress, James Fortune referred to our research at Otis and United Technologies on the physiological issues when descending from high altitudes at super-speed, and suggested some alternative elevatoring techniques for super-tall buildings that avoid super-speed.[2] In this paper, super-speed is considered to be that faster than 10 meters per second (~ 2000 feet per minute).

The core space consumed by an elevator system of adequate handling capacity has a fundamental impact on the economic feasibility of a tall building. Generally, building space efficiency decreases with building height, due primarily to vertical transportation. A system of high-speed, double-deck shuttle elevators to skylobbies and double-deck local elevators is the most efficient solution to the challenge yet to be introduced.* The Petronas Towers at the Kuala Lumpur City Center, now the world's tallest buildings under construction, will, according to our records, be the first tall building to use an all-double-deck skylobby system. The system will have much greater handling capacity and space utilization than super-speed, single-deck elevators, and the speeds and skylobby transfer involved will be easier on passengers' ears.

Super-speed elevators can create a "high-tech" impression if one ignores the related issues in a tall building (many of which are outlined herein). One could even ignore the merits of high-output elevator drives. For example, a high-speed elevator that can accelerate and decelerate its load more quickly to and from its full speed, and smoothly with servoed controls, can provide a run time matching slower-accelerating, super-speed elevators in a 70-story building. Acceleration can also be controlled to reduce the rate of increase in atmospheric pressure for the descent, or to conserve energy or maximize ride quality during off peak traffic periods. It all depends upon one's view of technology. In the final analysis, the technology of dispatching elevators more intelligently will minimize the need for rapid movements.

To find the optimal vertical transportation system for a tall building, we are becoming increasingly dependent upon computers in elevator traffic studies to search for possible system choices based on the building's projected floor populations, traffic patterns, and design criteria for the core(s). We can then simulate the selected system to see if one or more of our advanced dispatching and motion equipment options can reduce the quantities, rated loads, and/or speeds of the elevators. These design tools have taken the empirical art of "elevatoring" to a higher level, particularly when placed in the hands of experienced professionals. Of course, it is hard to replace experience when it comes to evaluating traffic criteria and circulation for a tall building.

Today our challenge is to apply the technology we have available. At the Council's Fifth World Congress, Mr. Cesar Pelli knowingly reminded us, "[a tall building] is a fundamental expression of the technology available at any one time."[3] We like this statement because it does not say we should make a quantum leap in elevator technology every time we do a tall building. In such buildings we must listen very carefully to our experience, Mother Nature,[4] the codes, and remember, vertical transportation is still a subsystem of the building.

Elevatoring Tall Buildings: An Historical Perspective

The handling capacity of an elevator system depends directly on the peak rate of people entering the building, plus the rate others are leaving and traveling inter-floor at the same time. Prior to our modern tall buildings, elevator system capacity was increased by simply planning more, larger, and/or faster elevators.

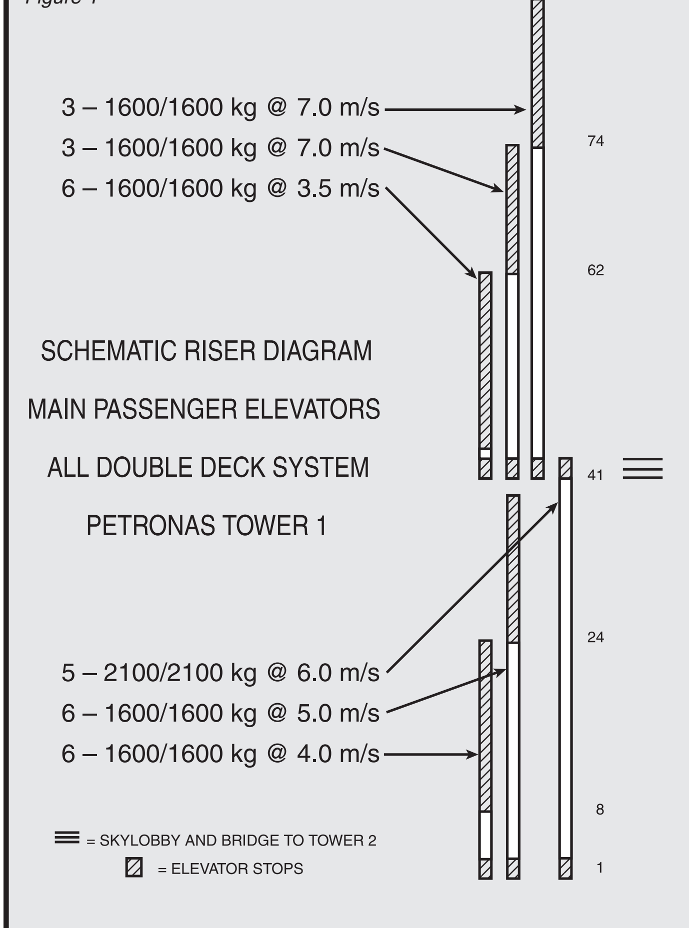
The challenge of reducing elevator core space in the tall buildings being contemplated in the mid-1960's brought forward the solutions of skylobbies and double-deck elevators that were envisioned 30 to 40 years earlier (when the Empire State Building began to make its mark). The system of high-speed shuttle elevators to skylobbies and stacked zones of local elevators helped to make New York's World Trade Center Towers possible. Boston's John Hancock Tower and Chicago's Amoco Building soon followed, as did New York's Citicorp, these buildings using double-deck elevators from the main lobby, without a sky-

****AUTHOR'S NOTE: When this paper was written, double-deck skylobby systems provided the most efficient traffic-handling approach for tall buildings. These systems have been surpassed by Otis Elevator Company's recently introduced Odyssey™ Integrated Building Transportation System. This new, innovative system offers comprehensive solutions for traffic handling in both tall and campus buildings.***

lobby. Sears Tower used essentially the same system as the World Trade Center Towers, except the elevators to the skylobbies were double deck (the local elevators were still single-deck).

Now, in the 1990's Kuala Lumpur's Petronas Towers will become the first tall buildings to combine the full merits of double-deck elevators and skylobbies. Both the main local elevators and the skylobby shuttle elevators will be double-deck for unprecedented handling capacity and space utilization. The net/gross efficiency of one of the Towers is readily conveyed below in Figure 1. The generic up-peak traffic performance of the system is sampled later in Table 1. Figure 2. compares double-deck and single-deck local elevatoring for another building.

Figure 1



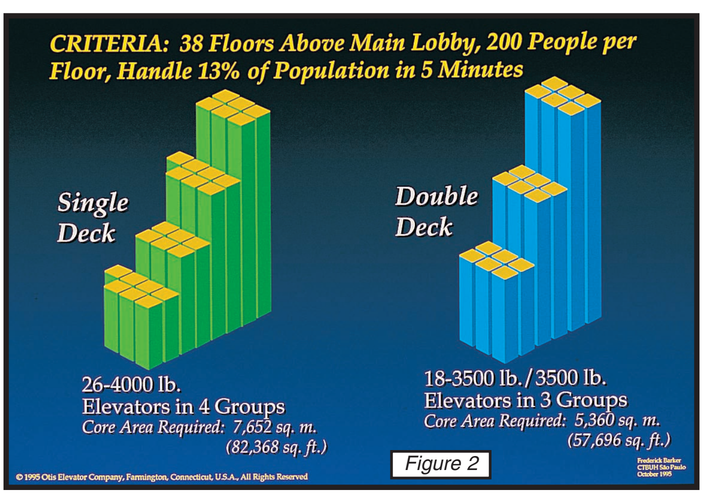


Figure 2

In 1983, a forum of leading building professionals seemed to agree that the core space consumed by elevators would hinder the construction of super-tall buildings.[5] While, with a second skylobby and a second group of shuttle elevators the system at Petronas could be extended efficiently for a building 550 meters high, these experts did raise a fundamental challenge. We believe the answer to that challenge, the next-generation elevator system which is applicable to a super-tall building, will continue to show that experience and technology make excellent partners.

Traditional Elevatoring Methods and Criteria

The "up-peak" traffic estimate is the most commonly used method of elevatoring office buildings. An elevator is assumed to make a probable number of stops going "up," based on a load in people and the number of upper floors served, and then express back to the main floor empty for another load of the same size. A "two-way peak" traffic estimate is then used for noontime traffic and for elevatoring hotel/residential spaces. The basic difference between the estimates is that the two-way method assumes the elevator will make a probable number of stops going "down" as well.

Handling capacity is the quantitative result of the estimates. It is expressed as the percentage of the population (or number of people) an elevator group can handle in five minutes while operating in the pure fashion assumed by the estimate (five minutes covering the very peak of most arrival rates). To determine handling capacity, the average interval or time between departures at the main floor is estimated and stated as the qualitative result. Service time, or another measure of the time a passenger may be in-transit, may also be stated.

Handling capacity and interval are inversely related. More people per elevator load will improve handling capacity, yet extend interval, and vice-versa. The goal is (or should be) to select an optimal passenger load which achieves the best balance between handling capacity and interval – handling capacity being the first criterion to satisfy – and that should correspond directly to the peak rates of arriving and counterflow traffic. Within usable limits, elevator speed, acceleration, and door opening speed will improve both handling capacity and interval.

Up-peak (the simplest and most widely used method), up-peak with N% counterflow (a more realistic method estimated like the two-way peak method), two-way peak, and down-peak are the full range of traditional traffic estimating methods developed at Otis Elevator Company many years ago. To allow roughly for counterflow traffic when using the now universal up-peak method for office buildings, one could seek to handle, for example, 12% of the population in five minutes if the projected morning peak arrival rate is 10% in five minutes, while another 2% will be traveling back to the main floor and interfloor.

It is very important to have an accurate estimate of the population and its distribution, arrival rate, and circulation. Handling capacity can be very expensive if too much (or too little) is planned. In many areas of North America and some areas of Europe, today's population densities at full occupancy, the adoption of flexible work hours, and/or delays in ground transportation may suggest the planning of fewer passenger elevators than in past urban office buildings. For similar reasons, the reverse may be true for service elevators and residential buildings. (For existing buildings in these areas, one of the advantages of computerized elevator traffic simulations mentioned earlier is to see if a passenger elevator(s) can be removed from service after the others in the building have been modernized.)

In certain "tiger economy" areas of Asia, many owners may find that norms for elevator system handling capacity previously

Continued ▶

considered acceptable can become below marginal with increases in their building's population, along with a need to modernize their elevators. Factors such as slow elevator floor-to-floor times, a lack of reserve cab space if one elevator in a group is out of service, and high machine room temperatures can exacerbate the situation. It is especially important in these areas to manufacture elevator systems that are highly reliable at higher ambient temperatures, to provide a commensurate process of maintenance and services, and to provide modernization solutions that make the most out of the quantity and duty of elevators available.

Sometimes, governmental regulations impact elevator performance. In the U.S. for the occasional person with a mobility impairment, the present guidelines suggest that the elevator doors be delayed at all times.[6] In Brazil, governmental standards, not market forces, suggest the minimum handling capacity of an elevator system, based on certain population criteria and the type of building.[7] In São Paulo, for example, if the suggested elevator system performance is overly conservative for a particular building's population and arrival rate, that building may be costly to build and inefficient. In these areas, professionals may need to communicate more with governmental officials.

Table 1. shows the results of generic up-peak traffic estimates for the double-deck local elevators below the skylobby for the building in Figure 1. While the projected floor populations have been omitted, one can see from the handling capacity in people that the percentages are likely better than 13% of the population in five minutes, which is excellent performance. The results also show that individual elevator motion performance can be estimated by using conventional estimating methods. (The results show the effect of adjusting the acceleration rate downward to 0.8 m/s^2 from 1.2 m/s^2.)

Group Serving Floors G/1, 8-23:		
6-1600/1600 kg @ 4.0 m/s	**@ 1.2 m/s^2**	**@ 0.8 m/s^2**
Handling capacity in five minutes	243 people	221 people
Interval	27.2 sec.	29.9 sec.
Group Serving Floors G/1, 24-37:		
6-1600/1600 kg @ 5.0 m/s	**@ 1.2 m/s^2**	**@ 0.8 m/s^2**
Handling capacity in five minutes	232 people	211 people
Interval	28.6 sec.	31.2 sec.

Table 1.

Table 1. assumes that the elevator drives are capable of 1.2 m/s^2, full load "up". This high performance may be reserved for full occupancy by simple adjustment, or even for peak traffic flows by automatic adjustment.

Unfortunately, little time can be devoted to methods to determine the service elevators, other than to make a few points on these important elevators:

- A rule of thumb has been to allow one service elevator for every 40,000 to 50,000 square meters of office space. In hotels, the number of service elevators is usually about half the number of guest elevators.
- Some code authorities allow service elevators to be used as firefighters' elevators considering their protected lobbies, larger size, and stops at all floors (or having a protect "skydock" transfer to a similar elevator).
- By providing more efficient passenger elevator systems, more thought can be devoted to service elevators. We should not ignore the importance of materials handling in today's office buildings with modular partitions, personal computer equipment, ongoing tenant fit-outs, food service, and aggressive construction schedules.

Effect of Equipment on Traditional Traffic Estimates

While traditional traffic estimating methods can account for the performance of an elevator drive or a door operator, they cannot measure the performance of a manufacturer's group dispatching system. Traditional traffic estimating methods can at best account for the elevators having automatic group operation with a "high-call reversal" feature, circa 1950's.

Office buildings should still be elevatored for the morning traffic rates, and then examined for noontime traffic (when waits are usually the longest). However, a now-established advancement in dispatching, called CHANNELING* operation, suggests that a bonus factor could be placed on handling capacity estimated using a traditional up-peak method. Of course, getting people into the building more efficiently is only half the battle. Accordingly, we recently developed Otis Fuzzy Logic, and its performance suggests that a relatively large discount factor could be placed on average interval (to determine average waits) estimated using the traditional two-way peak method. These are explained later by example in Table 2.

These performance factors can be determined using computer simulations of the actual dispatching algorithms, based on the specific building and population parameters. These simulations can show if an elevator(s) can be deleted – if the rated load and/or speed of a group(s) of elevators can be reduced – if marginal traffic performance can be rectified with advanced dispatching and/or high-performance elevator drives and door operators – and the effect of custom algorithms for a very special traffic situation.

Table 2. shows the use of these computerized design tools for a simple 30-floor high-rise office building (or perhaps 30 floors between skylobbies in a tall building). First, the possible elevator core solutions were computed based on the input parameters. Next, the basic traffic performance was estimated for the selected solution. Then, the actual performance was simulated, in this case by using one run with ELEVONIC* 411* RSR PLUS* operation from Otis Elevator Company – with and without CHANNELING* operation to improve morning handling capacity – and then with and without Otis Fuzzy Logic and Instant Car Assignment (ICA) to improve average waits at noontime.

On definitions, we use several measures for the quality of service because they help us balance the factors important to most passengers and, as we develop new dispatching algorithms, we want to be sure an improvement in one criterion does not lead to unacceptable performance in another:

Registration time is from when the first passenger in a lobby registers a call, to when the elevator slows down or opens its doors for that call, whichever occurs first. Waiting time is the weighted average for each passenger. (The second passenger, etc., joining the queue in the lobby usually waits less time.) Service time is the waiting time plus the time it takes the passengers to reach their respective destinations. Round trip time is from when an elevator leaves the main lobby, until that elevator leaves the main lobby again during a peak period.

Also, the following describes the advanced dispatching operations used in the simulations in Table 2:

The Otis ELEVONIC 411* RSR PLUS* patented dispatcher determines the best car to answer the call using a figure of merit called Relative System Response. The foundation is a*

Continued ▶

Sample Inputs:

Floors above main lobby:	29 floors
Population and distribution:	2100 people total 80 people/floor first 10 floors 75 people/floor next 10 floors 62 people/floor next 9 floors
Floor heights:	Main – 5.5 meters, typical – 3.7 meters
Core parameters:	1 to 6 groups of 4 to 8 elevators each, 1360 kg to 1800 kg capacity elevators
Time to open and close doors:	3.3 seconds
Acceleration/deceleration rate:	1.2 m/s^2
Peak-arrival rate:	11.5% of the population in 5 minutes
Counterflow traffic rate:	0.5% back to main lobby + 0.5% inter-floor
Interval between departures:	30 seconds or less, up-peak
Round trip time:	240 seconds or less, or 15 floors or less
Maximum load "up":	13 people if 1350 kg elevator 15 people if 1600 kg elevator 17 people if 1800 kg elevator
Load for two-way peak estimate:	8 people "up" + 8 people "down"
Decks:	Single deck solution
Transfer floors:	None

Sample Output:

Possible elevator core solutions meeting input criteria, listed by least-core and cost:

- Low-rise: 5 – 1350 kg @ 3.5 m/s, Floors 1-16
- High-rise: 5 – 1350 kg @ 5.0 m/s, Floors 1, 17-30

or

- Low-rise: 6 – 1350 kg @ 2.5 m/s, serving Floors 1-16
- High-rise: 5 – 1350 kg @ 5.0 m/s, serving Floors 1, 17-30

Estimated basic traffic performance, up-peak with counterflow, for first solution:

Low-rise:

Handling capacity:	11.7% up + 1% counterflow in 5 minutes
Interval:	28.4 sec.
Round trip time:	141.8 sec.

High-rise:

Handling capacity:	12.0% up + 1% counterflow in 5 minutes
Interval:	29.4 sec.
Round trip time:	147.1 sec.

Two hours of morning traffic simulated using base dispatcher, with and without Channeling* operation for low-rise group in first solution:

	With Channeling* Operation:	Without Channeling* Operation:
Avg. registration time:	13.7 sec.	11.4 sec.
Avg. waiting time:	14.7 sec.	38.0 sec.
Avg. service time:	53.3 sec.	101.2 sec.
Avg. round trip time:	81.3 sec.	122.9 sec.

Estimated basic traffic performance, two-way peak, for low-rise group in first solution:

Handling capacity:	6.4% up + 6.4% down in 5 minutes
Interval:	32.1 sec.
Round trip time:	160.3 sec.

Two hours of noontime traffic simulated using base dispatcher, with and without Otis Fuzzy Logic with ICA operation, for low-rise group in first solution:

	With Fuzzy Logic:	Without Fuzzy Logic:
Avg. registration time:	12.2 sec.	14.3 sec.
Avg. waiting time:	8.7 sec.	10.1 sec.
Avg. service time:	43.1 sec.	48.9 sec.
Avg. round trip time:	84.1 sec.	92.5 sec.

Table 2.

"IS 2,000 FEET PER MINUTE ENOUGH?" *Continued*

set of numerical bonuses and penalties. The algebraic sum of all applicable parameters comprise the RSR score, and with Boolean (crisp) logic, the car which has the lowest RSR score is assigned. Otis Channeling operation is a patented traffic management feature used during the morning up-peak traffic period. Channeling takes maximum advantage of coincident destinations by directing passengers at the main lobby with similar destinations into the same car. This is done by restricting the number of floors served on any trip to a small subset of the total number of floors. This reduces the number of stops for each round trip, which reduces round trip time (see Figure 3.). We are now also using Otis Fuzzy Logic to deal with unclear dispatching decisions, and evaluate additional information in a more natural way. (See Figure 4. and for more on Fuzzy Logic, the reader may refer to the paper by Bruce Powell and David Sirag, September 93/ ELEVATOR WORLD.)*

In Table 2., the technology available was used to maximize performance, not minimize equipment. Minimizing equipment could have been the next step.

The point is, quantitatively and qualitatively, the optimal elevatoring can be determined if the available technology is utilized. We are also continuously developing better dispatching systems which will take elevator intelligence to even higher levels. The following points are made on why intelligent elevator systems and when experience with pedestrian circulation in tall buildings should prevail:

- Intelligent dispatching technologies can minimize the quantities of elevators and their rated duties, and make elevators more convenient to use and understand. Wouldn't it be nice someday not to have to push any buttons at all?
- Intelligent dispatching presently has merit for all local elevators, which includes all passenger groups of elevators between the main and any skylobbies. Intelligent dispatching also has special merit for double-deck local elevators during complex two-way traffic conditions, and has been easier to implement today with the microprocessor.
- It is important that visitors to a building understand how they board double-deck elevators for "odd/even" floors as they approach a double main lobby. This is best handled architecturally and supplemented with signage. (The typical floor elevator lobbies require no special attention because they are used just like any other elevator system.) For skylobbies, circuitous transfer routes, several transfers, and poor signage should obviously be avoided.
- Most applications of the Port system,[8] where each passenger must enter their floor destination in advance, will cause congestion in a busy main lobby during peak times, especially in tall urban office buildings. During a peak time, elevators should be intelligent enough to handle a busy main lobby without passengers having to push any button most of the time, and forgiving enough for people who change their minds on their destination, or simply want to board the elevator that has its doors open. The real technology challenge is, how does the elevator dispatcher perform with the traffic data it has at hand?
- "Top-down" elevatoring schemes, where local elevators extend "down" from a skylobby while other local elevators extend "up", should only be applied when necessary. Traveling "down" to reach an upper floor in a tall building can confuse even regular passengers. The scheme saves the express zone of some local elevators, but the shuttle elevators must travel to a higher skylobby, which may counter the space saved by the locals. A space-saving double deck solution is also usually possible. The decision has come down to the type of space the scheme saves, if any.

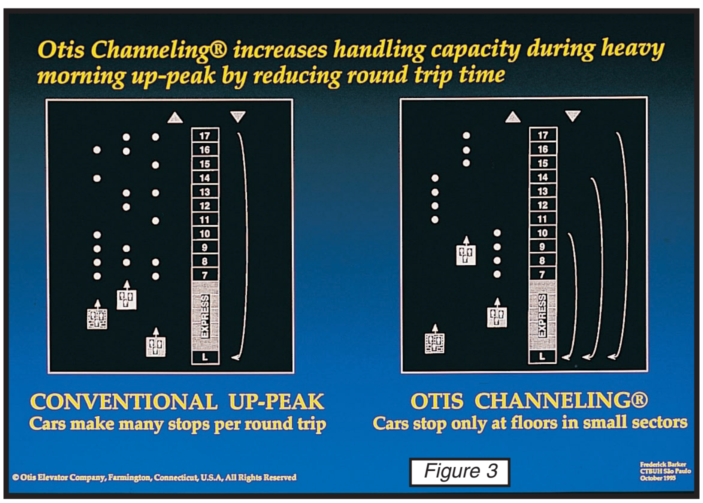


Figure 3

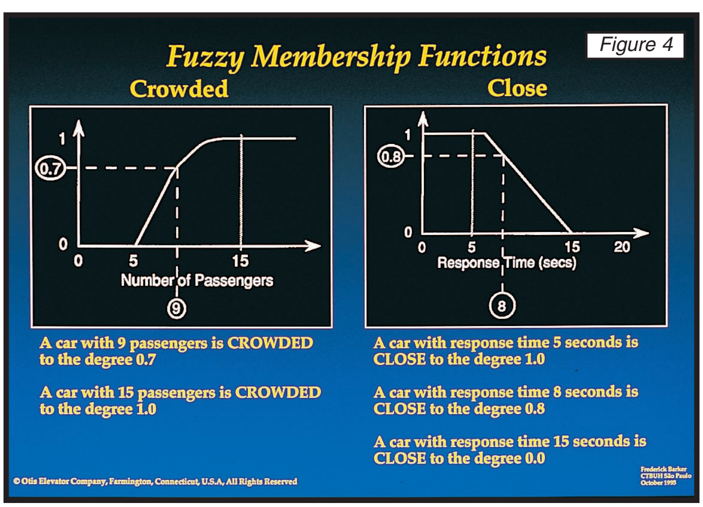


Figure 4

Skylobby Shuttle Elevators and Tall Building Issues

The basis of a skylobby is shuttle elevators. They typically have no more than two primary stops in a tall building due to the volume of traffic they must handle (an unusually slender building or tower section being exceptions). These elevators must provide maximum handling capacity, consume as little space as possible, and be extremely reliable. Additionally, their designs demand long-term experience with tall buildings. The following touch upon some of the related issues inherent in today's technology, most of which deserve a separate professional paper or reference:

- Traffic-wise, high-speed, double-deck shuttle elevators handle far greater numbers of people than super-speed, single-deck shuttle elevators. In the next section we will show that space would be required for at least 75% more single-deck shuttle elevators to provide handling capacity equal to the number of double-deck shuttle elevators required.
- Space-wise and traffic-wise, double-deck shuttle elevators (e.g., 2250/2250 kg) are also preferred to very large single-deck shuttle elevators of the same capacity (e.g., 4500 kg), based on experience at the World Trade Center. Passengers do not tend to fill very large footprint single-deck elevators efficiently, apparently for psychological reasons.
- During very long descents, super elevator speed can cause aural discomfort. A study we did with United Technologies Research Center indicates that if the differential ear pres-

Continued ▶

sure exceeds approximately 2000 Pa, a significant number of passengers will feel ear discomfort.[9] Based on that study, it is wise to keep the rated speed below 10 meters per second (~2000 feet per minute) for a direct descent of 100 floors.

- During a long descent after an elevator has been parked for an extended period, and the building has been swaying due to high winds, super speed can amplify traveling cable and compensation rope movements to problematic levels, even cause entanglement, if this equipment is near resonant with the movements of the building. When suggesting super speed for super-tall buildings, it is helpful to have demonstrated experience in dealing with building sway and high speed in 100-story buildings.
- Super speed increases pressure on hoistway walls, and may require that the walls be acoustically designed. The severity will depend upon how many elevators are in a common hoistway, the type of hoistway wall construction, the use of the surrounding spaces, the planning of relief vents (with smoke dampers), and the amount of counterflow air from normal or reverse stack effect. These design challenges cannot be overlooked.
- A study we did indicated that without countermeasures for noise reduction, intermittent increases in elevator cab interior noise were in the range of V^3 with velocity, and continuous noise was in the range of V^2 with velocity.[10] Variances to this will depend upon some of the situations described in the preceding paragraph. Super speed requires aerodynamic streamlining and other designs to reduce noise and air buffeting when passing the counterweight, other elevators, entrances, and steel members between elevators.
- Super speed requires special elevator equipment and testing for safety. For example, no code criteria is presently tabulated for certain aspects of elevator ropes, safeties, buffers, and governors for speeds higher than 2000 feet per minute (~10 meters per second) in the elevator safety code in the U.S.[11] The most history with tall buildings also exists in the U.S.

Shuttle Elevator Performance – Examples

This section will show with traffic estimate results that high-speed, double-deck shuttle elevators have much greater handling capacity than super-speed, single-deck shuttle elevators, and take much less space. This section will also show that higher acceleration performance can provide equal flight time performance to super-speed in most buildings, and that acceleration can be adjusted downward for the descent to minimize aural discomfort.

Let's assume 12.5% of a population of 5000 people must be transported to a skylobby 400 meters above the ground in five minutes. Let's also assume that there is space for one group of eight elevators (arranged four-facing-four to minimize boarding distance), that the interval between departures cannot exceed 30 seconds, and the differential ear pressure should not exceed 2000 Pa for the descent. Table 3. compares super-speed, single-deck shuttles to high-speed, double-deck shuttle elevators of the same platform footprint.

A prime requisite of an elevator system is to handle the traffic. In the example in Table 3., another six super-speed, single-deck elevators would actually be required to provide the same handling capacity as the double-deck shuttle elevators. Additionally, if the acceleration/deceleration rate were reduced to 0.8 m/s^2 in the super-speed example, another seven elevators actually would be required – almost twice the quantity of elevators! (Reducing the vertical acceleration rate obviously reduces the drive output requirements for torque.) It should also be noted that the interval between departures at the main floor is excellent in the double-deck example.

Quantity in group:	8	8
Decks:	Double deck	Single deck
Capacity:	2250/2250 kg	2250 kg
Load:	23/23 people "up" 0/0 people "down"	23 people "up" 0 people "down"
Full speed:	9 m/s	14 m/s
Accel./decel. rate:	1.2 m/s^2 "up" 0.7 m/s^2 "down"	1.2 m/s^2 "up" 1.2 m/s^2 "down"
Interval:	**22.0 seconds**	**18.4 seconds**
Handling capacity:	**12.7% in 5 minutes (636 people)**	**7.6% in five minutes (381 people)**
Differential ear pressure:	**1995 Pa "down"**	**2508 Pa "down"**

Table 3.

Let's assume the elevators in Table 3. only reach the upper skylobby and, with just two separate elevators, we want to turn around the maximum number of people to an observation deck at 550 meters above the ground to help generate revenues for the owner. (These elevators will be accessed below grade to separate the traffic from tenants and guests.) Table 4. again compares high-speed, double-deck with super-speed, single-deck, and the effect of changing the acceleration rate for the decent to minimize aural discomfort. In this example, we will assume nearly full loads in each deck for both the "up" and "down" directions, where passengers are queued in lines and assisted by attendants.

Quantity in group:	2	2
Decks:	Double deck	Single deck
Capacity:	2250/2250 kg	2250 kg
Load:	23/23 people "up" 23/23 people "down"	23 people "up" 23 people "down"
Full speed:	9 m/s	14 m/s
Accel./decel. rate:	1.2 m/s^2 "up" 0.2 m/s^2 "down"	1.2 m/s^2 "up" 1.2 m/s^2 "down"
Interval	**148.0 seconds**	**110.6 seconds**
Handling capacity:	**2245 people/hour**	**1507 people/hour**
Differential ear pressure:	**1986 Pa "down"**	**2966 Pa "down"**

Table 4.

In the double-deck examples in Table 3. and 4., we intentionally reduced the "down" direction acceleration/deceleration rate. In the single-deck examples in Tables 3. and 4., we intentionally ignored aural pressure going "down" to show single-deck shuttle elevators still fall short in handling capacity. (Obviously, even poorer performance would result if slower acceleration/deceleration rates were used going "down" in the single deck cases.)

From a different perspective, Figure 5. shows that at 70 stories, higher elevator acceleration performance could be a match in a race with super speed, if one perceives simple start-to-stop time for a single elevator to be most important.

In Tables 3. through 4. and Figure 5., the same generic traffic estimating method was used (including the times to open and close the doors, the passenger transfer time, and the inefficiency factor for passengers holding the doors open).

We are not suggesting control smoothness be sacrificed. Even at an acceleration rate of 1.2 m/s^2, the rate of change in the acceleration rate will not exceed 2.4 m/s^3, given the servoed motor controls in the ELEVONIC* 411* system. The acceleration rate and the rate of change in that rate (jerk) can also be adjusted to provide a profile of 0.6 m/s^2 at 0.6 m/s^3, respectively.

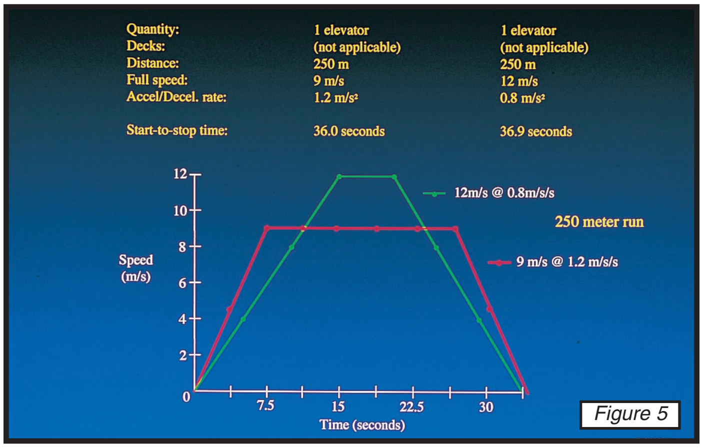


Figure 5

“Ropeless” Elevators?

With skylobbies, an all double-deck passenger elevator system could efficiently be expanded for a building 550 meters tall. Still, we are often asked rhetorical questions like, could a pair of elevators travel 1600 meters to the observation deck in the “mile-high” building Frank Lloyd Wright envisioned for Chicago?

We recognize that suspended elevators do have a rise limitation (albeit very high) due to the strength of the wire ropes and their ability to carry their own weight. Relatively speaking, “ropeless” elevators would minimize core space, maximize traffic handling and enable unlimited rise. However, we also recognize that “ropeless” elevators are not yet a cure-all, particularly in the arena of energy conservation.

The counterweight is still a thing of beauty in helping an elevator overcome gravity. Without a counterweight, elevator system energy consumption could increase by a factor of three to eight. Elevators now account for only four to eight percent of the energy consumed in an office building, and are near optimized with regenerative static drives and variable acceleration rates. Fully electric (non-counterweighted) elevators would counter the energy conservation strides being made in building lighting and mechanical systems. Such a trend could affect infrastructure during high mid-day demand periods, and might benefit from or even require localized power. (Localized power might be necessary for power emergencies. Now, when building evacuation is necessary, moving a full elevator “down” and an empty elevator “up” is the mode consuming the least energy, due to overbalance with the counterweight.)

A design goal of the fully electric (non-counterweighted) elevator will be to reduce its own dead weight to reduce the energy it consumes, without significantly reducing its load carrying capacity. Otherwise, this could have some diminishing returns. As we have demonstrated, making the elevator too small in carrying capacity will affect the volume of people it can transport. Adding more fully electric elevators would increase energy consumption.

“Ropeless” elevators will also pose some structural challenges. Assuming they are used to reduce the number of hoistways to extend building height (on the basis of building net/ gross efficiency), structural engineers will have to compensate for the loss of hoistway framing in the core, and depending upon how the car guidance and power transmission system allows for building compression and emergency safety/brake loads, loadings could increase in unusual ways. Another challenge will be to keep full height close-gap linear motors from being viewed as a significant property damage risk in areas of high seismicity. Otis Elevator has gained significant experience in these areas through research as a result of having installed and maintained the first commercial elevators with roped linear induction motor drives in Japan.

Conclusions

At Otis, we are headed down two paths at the same time. One is to develop practical systems to allow more than one elevator in a hoistway. The other builds upon our experience in 60 of the world’s 100 tallest buildings. Right now it appears that with the assistance of technology, we can reach much taller from the experience shoulders of our past. This is to the point where, if a super-tall building of, let us say, 1000 meters were to come along tomorrow, we would be ready.

We hope we have provided the members of the CTBUH with some thoughts that will be useful in their day-to-day designs. In response to the challenges introduced at the CTBUH’s Fifth World Congress, we believe we can keep all those cables a while longer, 2000 feet per minute can be enough, and from another perspective, additional speed is not the only answer. ❏

1. McNeill, A., 1995
A THEME ADDRESS: “THE BLEND OF INNOVATION AND TRADITION IN FUTURE CONSTRUCTION PRACTICES”, *Council on Tall Buildings and Urban Habitat, Fifth World Congress,* Amsterdam, Netherlands.
2. Fortune, J.W., 1995
MEGA HIGH-RISE ELEVATORS: THEY COULD BE HAZARDOUS TO YOUR HEALTH, *Proceedings of the Fifth World Congress, Council on Tall Buildings and Urban Habitat,* Amsterdam, Netherlands.
3. Pelli, C., 1995
A THEME ADDRESS: “COSMIC PILLARS”, *Council on Tall Buildings and Urban Habitat, Fifth World Congress,* Amsterdam, Netherlands
4. Credit for the “Mother Nature” analogy is given to William S. Lewis, formerly with Jaros Baum & Bolles Consulting Engineers and Otis Diversified Systems.
5. Engineering News-Record, 1983,
HOW TALL?, The McGraw-Hill Construction Weekly, New York, N.Y., November 1983, pp. 44-55.
6. U.S. Department of Justice, 1991
APPENDIX A TO PART 36 - STANDARDS FOR ACCESSIBLE DESIGN, ADA ACCESSIBILITY GUIDELINES FOR BUILDINGS AND FACILITIES, FEDERAL REGISTER, VOL. 56, NO. 144, July 26, 1995.
7. Norma Brasileira Registrada, 1983
ASSOCIACAO BRASILEIRA DE NORMAS TECHNICAS, CALCULO DO TRAFEGO NOS ELEVADORES, NBR5665, April 1983.
8. The Port System, designed by Mr. Leo Port, an Australian Engineer, was patented in the 1960’s and installed in two buildings in Sydney, Australia.
9. Basis was Internal Correspondence by J. Kendall, Otis Elevator Company, January 10, 1994, and an internal report by J.W. Fuller, J. Ruiz, and M. Kurisko of United Technologies Research Center entitled CONTROL OF PRESSURE COMFORT AND MOTION IN ULTRA-HIGH SPEED ELEVATORS, April 1992.
10. Based on a report by P.L. Lavrich of Untied Technologies Research Center, T. Derwinski of Otis Elevator Company, and W.M. Presz, Jr. of Western New England College entitled AERODYNAMIC NOISE AND VIBRATION SOURCES FOR HIGH-SPEED ELEVATOR CABS, presented at *Noise-Con 93 in Williamsburg, Virginia,* May 3-5, 1993.
11. ASME-A17.1, 1993
SAFETY CODE FOR ELEVATORS AND ESCALATORS, AMERICAN SOCIETY OF MECHANICAL ENGINEERS, New York.

*** CHANNELLING, ELEVONIC, 411 and RSR PLUS are registered trademarks of the Otis Elevator Company. Other trademarks and tradenames appearing herein are owned by their respective companies.**

The author believes all data and other information to be true and correct, but disclaims all warranties for data and information. The author acknowledges the material contributions to this paper from John Kendall, Bruce Powell, and Joseph Walker at the Otis Elevator Company and Jim Fuller, Ernie Gagnon, and Rich Peruggi of the United Technologies Research Center.

***Rick Barker** is Director, Technical Services at Otis Elevator World Headquarters in Farmington, Connecticut. He has been in the elevator industry since 1973, also with Jaros, Baum & Bolles Consulting Engineers, Delta Elevator (now a subsidiary of Otis Elevator), and Westinghouse Elevator. He is currently a member of the National Interest Review Committee of the A17 Elevator Safety Code and co-chairs the Vertical Transportation Committee of The Council on Tall Buildings and Urban Habitat. Rick’s other paper was on the topic of multi-purpose elevators for use during a fire (re-printed September 95/ELEVATOR WORLD).*