Focus: Elevator Dispatching & Its Experts

Articles from ELEVATOR WORLD Magazine (in chronological order):

"Harmonized Elevator Dispatching and Passenger Interfaces"
– by Rick Barker, November 2018

"*More Than Math*"
– about Dr. Bruce Powell, December 2018

"*Fulfilling the Potential of DD DCS*"
– by Dr. Janne Sorsa, September 2019

"*At the Very Top*"
– about Dr. Marja-Liisa Siikonen, January 2020

Introduction by Rick Barker, December 2020

At JB&B I had the opportunity to follow George Strakosch, a published expert in elevator traffic from Otis, who had left JB&B for Elevator World Magazine. In a reversal of career paths, I left JB&B for Otis, where one my roles was to chair the "Otis Worldwide Dispatching & Elevatoring Steering Committee". This gave me the opportunity to work with one of the world's elevator dispatching experts, Dr. Bruce Powell. Later with our firm, knowing the basic merits and demerits of most dispatching techniques, I had some ideas we called "harmonized" dispatching, to improve upon destination dispatching, and a hybrid variation. This led to a chance to work with two other world dispatching experts, Dr. Marja-Liisa Siikonen and Dr. Janne Sorsa from Kone, who saw the benefits and led Kone's efforts to build this for one of our projects. After I published our ideas in Elevator World in late 2018 (placing these in the public domain), articles came out on these dispatching experts, and on the dispatching logic opportunities behind our harmonized platform.

Focus: Elevator/Lift Dispatching & People

ELEVATOR WORLD Magazine, November 2018

“***Harmonized Dispatching and Passenger Interfaces***”
– by Rick Barker

The Magazine of the International Building Transportation Industry

ELEVATOR WORLD

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Harmonized Elevator Dispatching and Passenger Interfaces

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Harmonized Elevator Dispatching and Passenger Interfaces

Improvements in traffic performance and user interfaces are shown in a case study on PNB 118, a 118-story building under construction in Kuala Lumpur.

by Rick Barker

Introduction and Credits

This article is based on an unpublished paper, "Intent of Specifications for Harmonized Dispatching — Groups of Passenger Elevators/Lifts for Office Buildings" by Barker Mohandas, LLC, and our prior project specifications covering such designs. Our designs as covered herein are now published for use without any restrictions from us. All designs by others that are referenced retain their exclusive rights.

This is also a case study on the designs as they are being built now by KONE under our specifications for the PNB 118 project in Kuala Lumpur. Some of our initial fixture sketches are shown, along with some in-progress project graphics by KONE. A key contributor to this article has been KONE's Dr. Janne Sorsa, who has also provided updated and expanded simulations initially provided by Dr. Marja-Liisa Siikonen. They have both been instrumental in taking the designs for the project forward.

It is also essential to recognize the foundational work of Dr. Joris Schröder and Dr. Paul Friedli in Schindler's Miconic 10® (M10) system, introduced in the early 1990s. This was the first commercially successful destination-dispatching system and, perhaps, the first major visible change in the automatic elevator. An excellent reference on "M10" is the article by Joris Schröder in the March 1990 edition of ELEVATOR WORLD.[1]

We have retained the Schindler techniques functionally at the main lobby for their benefits in handling and organizing incoming traffic and added some user improvements at that location (while we recognize that these improvements have likely already been built somewhere). However, in the cabs and at the office floors, things are different, yet also familiar in restoring and enhancing conventional elements in ways we believe improve known prior such techniques for office buildings.

Our goal was to bring predeveloped elements together in a way multiple elevator companies could build the designs, using a combination of dispatching techniques they had already developed underneath, overlayed with today's touchscreen displays and employing some contract engineering. The word "harmonized" then came to mind. Our motivation was to improve lunchtime traffic performance for double-deck elevators (primarily) and single-deck elevators (secondarily), and improve passenger interfaces for both.

This is not a detailed work on elevator dispatching or its smart algorithms, which decide which elevators in a group are to serve which calls. Statements made about the development of the logic are to the best of your author's knowledge. Experts in the field will likely know of various recent studies, including a major body of work by Janne Sorsa.[2] A small part of that work pertaining to double-deck elevators was partially inspired by our project designs.

Special credit is also extended to Dewhurst PLC, an independent U.K. provider of fixtures to the elevator/lift, keypad and rail industries, for its details of keypad buttons, arrows and car letter signs used in our original sketches. Also, the project graphics are in-progress screenshots by KONE that show industrial design thought extending beyond our sketches, which were only functional drawings.

Present Categories of Dispatching and Passenger Interfaces for Office Buildings

When developing the designs, we saw three general categories of dispatching and passenger interfaces for office buildings, including a hybrid version of the other two. At the risk of boring many readers (especially elevator-industry professionals), these are described as follows.

Conventional Dispatching and Passenger Interfaces

Most people are familiar with groups of elevators that use conventional up/down buttons at all floors, individual floor buttons in the cabs and an up/down hall arrival lantern at all entrances. Of course, at the terminal floors, such as the main lobby in an office building, there is a single "up" or "down" button and hall lantern signal. We generally categorize such systems as "conventional." (It should be noted that this term does not imply that today's dispatching is old fashioned, given its smart algorithms behind the scenes.)

Passengers press the up or down button at any floor for their direction (unless it is already pressed) as acknowledged by the familiar "call-registered" light. They then wait for an elevator to arrive as signaled by a hall lantern at the respective entrance, giving them enough notice to walk to the doors. As an aside, under U.S. building codes and standards, the traffic performance of conventional dispatching can be penalized by requirements for persons with disabilities. Without special operation, that for some reason is only allowed with destination dispatching under *ICC A117.1-2017 Accessible and Usable Buildings and Facilities*, the door dwell open time for all hall calls at all floors, including from all nondisabled persons, is to be based on a formula for the time for a disabled person to travel from the farthest hall station. This is a detailed benefit of destination dispatching and our harmonized designs.

After boarding the cab, the passengers press another button for their specific floor. For double-deck elevators with conventional dispatching, when the elevator is at its double-level main lobby, only the even-numbered floor buttons in the cab will be functional in the lower deck, and only the odd-numbered buttons will be functional in the upper deck (or vice versa, depending on building floor numbering). However, all in-cab buttons are always visible.

There is often a delay in the hall lantern signaling which elevator is ultimately assigned to the call. This allows the dispatching logic more time to optimize the final car assignment behind the scenes, considering many variables on traffic demands and the status of all elevators in the group, which continually change. This is a key point in this article.

To better understand the dispatching challenge of which elevator to assign to which hall call, consider a group of six single-deck elevators with eight hall calls. At that moment (and assuming conventional dispatching with delayed car assignments), there are about 6^8, or 1.7 million, possible car-to-call assignments. This is quite a combinatorial problem. Based on recent communications between your author and Dr. Bruce Powell, who is well known as a top elevator-dispatching expert, he noted that, in one sense, destination dispatching (where car assignments are made instantly at all floors) simplifies the problem by reducing such choices to six, while smart algorithms can make a nearly impossible optimization problem (such as 6^8) a task of manageable proportions (for conventional dispatching). Of course, smart algorithms are also used in standard destination-dispatching products to try to make the first and "instant" car assignment a good decision. Elevator dispatching experts, using the information available, can turn the problem into opportunities to reduce waiting times.

Destination Dispatching and Passenger Interfaces

Many people are now also familiar with destination dispatching found in newer office buildings, as reflected in Figures 1 and 2 (and, possibly, Figure 3 if the building has double-deck elevators). There are no floor buttons in the cabs accessible to passengers, and there are no signals at the elevator entrances — only static signs as to the car's designation (car A, B, C, etc.). Again, the March 1990 EW article[1] is an excellent reference.

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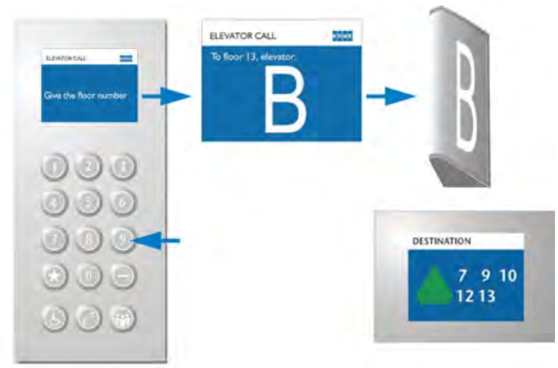

Figure 1: Keypad call stations at all floors (left), car designation sign at entrances (top right) and display inside the cabs (bottom right): similar systems are available from Otis; KONE; Mitsubishi Electric; thyssenkrupp; and, of course, Schindler, which introduced the technique. Graphic is from a KONE presentation on passenger interfaces for destination dispatching.

Figure 2: This graphic is from a Schindler brochure depicting how Miconic 10 helps organize queues at the main lobby. This can also have benefits in elevator lobby planning. Note that 24 people are shown in both cases. However, in principle, the up-peak traffic performance can reduce the total queue of passengers in the main lobby.

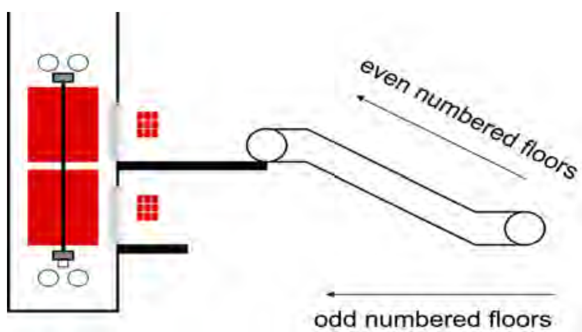

Figure 3: Boarding double-deck elevators by odd- versus even-numbered floors has become the standard circulation plan. This was developed by Otis along with the double-deck elevator. Graphic is from a Schindler presentation on boarding double-deck lifts at a double-level main lobby. Note the keypad call stations at both levels of the main lobby. Also, as a planning reference for the first modern double-deck systems, see "Planning Double Deck Elevator Systems" by W.H. Wuhrman and Paliath Mohandas.[4]

Car assignments are given "instantly" to each person at all floors (including at all office floors), typically at numeric keypad-type call stations in the elevator lobbies, where all passengers enter their destinations. After a person enters their destination, the car assigned to the call is displayed "instantly" at the station and only momentarily to allow for another person to place their call. Each person must (or should) enter their destination call this way. An exception is a group of people traveling to the same floor, such as the main lobby. No call acknowledgement or status signal is provided to the user after the car assignment is made. At the office floors, users wait at the entrance of the car assigned for as long as it takes for that specific elevator to arrive.

After a meeting when a group of passengers returning to different office floors arrives in an elevator lobby, where an elevator's doors are already open for a car headed in their direction, they cannot simply board the cab. Again, there are no floor buttons in the cab. Also, a passenger cannot change their floor destination in flight if their call was entered in error.

The primary traffic benefit tends to be at the main lobby, to improve handling capacity for incoming traffic. Note that the improvement in up-peak traffic performance at the main lobby can be significant with single-deck and very significant with double-deck elevators, which stop at two floors at a time when leaving the main lobby to handle incoming traffic. However, these improvements should not be used to reduce elevators, as standard destination dispatching can increase waiting times during the lunchtime peak. (An exception is using the dispatching for a group of shuttle elevators serving multiple residential sky lobbies in a supertall building as covered in "Sequel: Is 4,000 fpm (20 mps) Enough?" by your author with contributions from Sean Morris and George Wisner.[3])

In knowing passengers' destinations at the main lobby, cars can be assigned to groups of people by some commonality in their destinations, such as by floor zones or sectors, to reduce elevator stops and travel and, therefore, car round-trip time back to the main lobby. Note that techniques such as Otis Channeling® (invented by Joseph Bittar and Kandasamy Thangavelu) using dynamic sectoring or zoning also boosted up-peak performance at the main lobby. Individual floor buttons in a lobby actually date to the 1960s with the work of Leo Weiser Port in Australia. However, Schindler Miconic 10® was the first successful destination-dispatching system that also organized traffic queues at the main lobby, while boosting up-peak performance. There have been many patents since using floor destinations entered in an elevator lobby, even including a few Otis patents by your author (Frederick Barker) with coinventors such as Bittar and Powell.

A related benefit is that passenger queues are organized at the main lobby, where traffic is the heaviest. People tend to gather closer to the entrances of the cars assigned to them, which is a benefit for circulation planning. There are also some detailed benefits of destination dispatching:

- The call system can be integrated with identification cards used at security turnstiles at the main lobby. This can have circulation

benefits in reducing cross-traffic, along with some dispatching benefits.
- ♦ Keypad-type call stations can easily allow passcodes for special features for staff, etc.
- ♦ Entering a floor destination in the lobby also easily allows an elevator to be assigned to a floor served by fewer than all elevators in a group (when such planning is necessary).
- ♦ Similarly, with double-deck elevators, the upper deck of the elevator can easily be assigned to a destination that is the top terminal floor to hold hoistway "overhead" space.

Hybrid Dispatching and Passenger Interfaces

"Hybrid" dispatching and passenger interfaces are also offered by some manufacturers. For example, thyssenkrupp installed hybrid dispatching for a system we planned for the Great American Tower in Cincinnati, specified to reduce waiting times. Otis has also reported installing hybrid systems. The technique is also described in "The KONE Hybrid Destination Control Systems" by Johannes DeJong, which may be an unpublished work. For performance simulations, see "KONE Polaris Hybrid" by Marja-Liisa Siikonen, Janne Sorsa and Tuomas Susi.[5]

Hybrid dispatching is simply destination dispatching at the main lobby only (including numeric keypads and static car designation signs), conventional dispatching and passenger interfaces at the office floors (up/down buttons and hall lanterns) and conventional floor buttons inside the cabs. The in-cab buttons only become functional after leaving the main lobby and answering demands from the office floors, while the buttons are visible to passengers boarding the cabs at the main lobby. (If the in-cab buttons were functional at the main lobby, the key traffic performance benefit of the destination-dispatching element would be negated or, at least, significantly degraded.)

Hybrid systems are offered to retain the performance benefit of destination dispatching at the main lobby and overcome a performance issue at the office floors. By delaying car assignments at the office floors in a conventional way, better overall dispatching decisions to reduce long waits can be made. Like one's own decisions, when faced with many variables (yet maybe not enough information), an "instant" decision is not always the best. Despite current implementations of smart algorithms to fine tune reactive decisions, and methods to store and learn patterns to try to improve predictions, as the results of some simulations later herein will show, the process of assigning elevators instantly at the office floors does not tend to result in the best decisions for elevator waiting times.

Delayed Car Assignments, Waiting Times and Journey Times

The earlier example of a group of six elevators with eight hall calls was cited using conventional dispatching, at a moment when there is a huge number of possible car/call assignments. From when a hall call is placed to when the assigned car arrives, traffic demands and the status of the various elevators (calls assigned to each car, and each car's load, position, direction and door status) can change significantly. For such reasons, potential car assignments are recomputed many times a second.

As an aside, such frequent computations of each elevator's "e.t.a." to answer current and new demands might be credited to the New York City elevator companies Millar (acquired by Westinghouse Elevator, which was acquired by Schindler) and/or Computerized Elevator Control (acquired by thyssenkrupp). Similar techniques were also developed by others soon after the departure from relay-based logic to a computer on a chip. Otis computed each car's "Remaining Response Time" with bonus and penalty weighting factors. Later, some were adaptive. Fuzzy logic was added to fine-tune decision capabilities over 0/1 Boolean logic. Artificial neural networks then enabled pattern recognitions to further machine learning. There has also been extensive work in artificial intelligence in elevator dispatching by KONE with "Genetic Algorithms," Mitsubishi Electric with its "ΣAI-2200C" system and others. All are focused on improving elevator traffic performance. Those researching this will find that elevator dispatching behind the up and down buttons is hardly old fashioned.

In delaying car assignments at the office floors, the dispatching logic has more time to coordinate and compute potential assignments with new demands, and to seek opportunities to handle more calls productively — for example, opportunities to travel to a floor involving coincident demands from both the cab and lobby. Such strategies are very important for double-deck elevators, including to seek demands involving two contiguous floors that can be handled in one stop. On the other hand, when a car is assigned "instantly" to any passenger, there are no easy opportunities for car reassignments.

On that note, with standard destination dispatching, when a car assigned is being held up at another floor or becomes full unexpectedly (for example, not knowing how many people were waiting behind a call for a group of people bound for the same floor), or the car is taken out of group service, the passenger's call can be cancelled. It may also be quite some time before the passenger realizes this and that they need to place another call (then wait again for the new elevator assigned).

One can easily see the challenges of "instantly" assigning a double-deck elevator to a single call or instantly sending a single-deck elevator to run through a long express zone (compared to delaying car assignments at the office floors) to seek more opportunities to handle demands more productively. Elevator manufacturers take on these challenges when providing standard destination dispatching. Techniques to obtain destination information even earlier (for example, at decentralized locations for call stations, such as at the beginning of a corridor leading to an elevator lobby, to consider longer walking times in computations for car assignments) are interesting. Data storage of passenger traffic movements are also interesting, as is the question of what is done with the data to improve waits. Your author believes such techniques can also be useful within the framework of the harmonized designs covered in this article, toward future improvements.

In the details, some manufacturers now have the option of switching their dispatching algorithms to focus more on time to destination than waiting time, or vice versa. In your author's view, journey time seemed to be raised in importance with the introduction of destination dispatching. However, when stuck in automobile traffic, many of us prefer to take an alternate route to avoid waiting and keep moving, even if our trip takes a little longer.

Continued

Similarly, we favor waiting time as the more important criterion for elevators. In any case, as performance studies later herein will show, both waiting time and journey time can be improved.

Harmonized Dispatching and Passenger Interfaces

We prepared project specifications for the harmonized designs with the motivations of improving traffic performance over standard destination dispatching and user interfaces over all available techniques. These are best shown with some graphics and short descriptions (Figures 4-7), using our sketches from different projects. These are functional drawings only, not a particular industrial design. Also shown are KONE's implementations and enhancements via some renderings, which are in-progress screenshots for the PNB 118 project. Similarly, these are not actual fixture drawings, which would show all functions and visible work.

Main Lobby Level(s): Figures 4 and 5

At the main lobby, the basic functions are the same as initially put forward by Schindler, except with some improvements in passenger information (that have likely already been built somewhere) as follows:

1) To improve wayfinding at the hall stations to geographically orient the elevator lobby location of the car when assigning elevators (versus signals such "A>" provided with standard destination dispatching).
2) To annunciate calls assigned to the car at the elevator entrances for people who might forget their car assignment or second-guess themselves after a longer wait, and return to a hall station, causing cross-traffic and wasted calls (versus only a static car designation sign at the entrance and requiring users to wait for the car to arrive and open its doors to confirm the "next floors" being served).

KONE's implementation and enhancements for the hall stations at the main lobby are shown sequentially as follows. These are for a group of six double-deck elevators serving a high-rise local office zone for the project. Note that these stations could equally apply to a group of single-deck elevators.

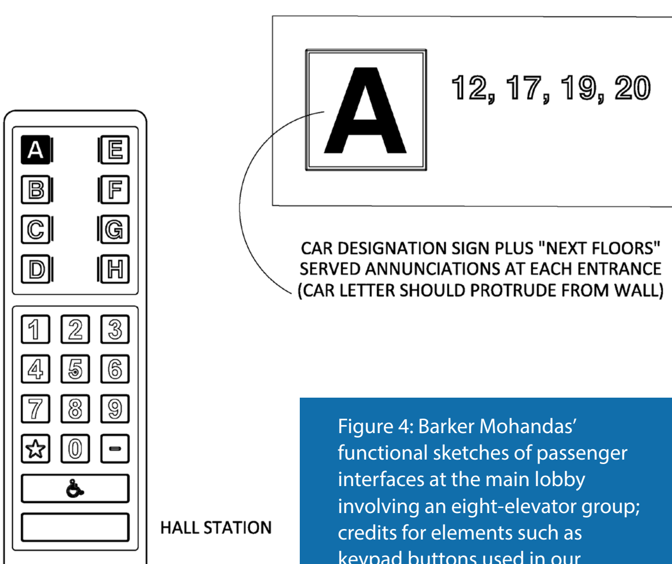

Figure 4: Barker Mohandas' functional sketches of passenger interfaces at the main lobby involving an eight-elevator group; credits for elements such as keypad buttons used in our sketches go to Dewhurst PLC.

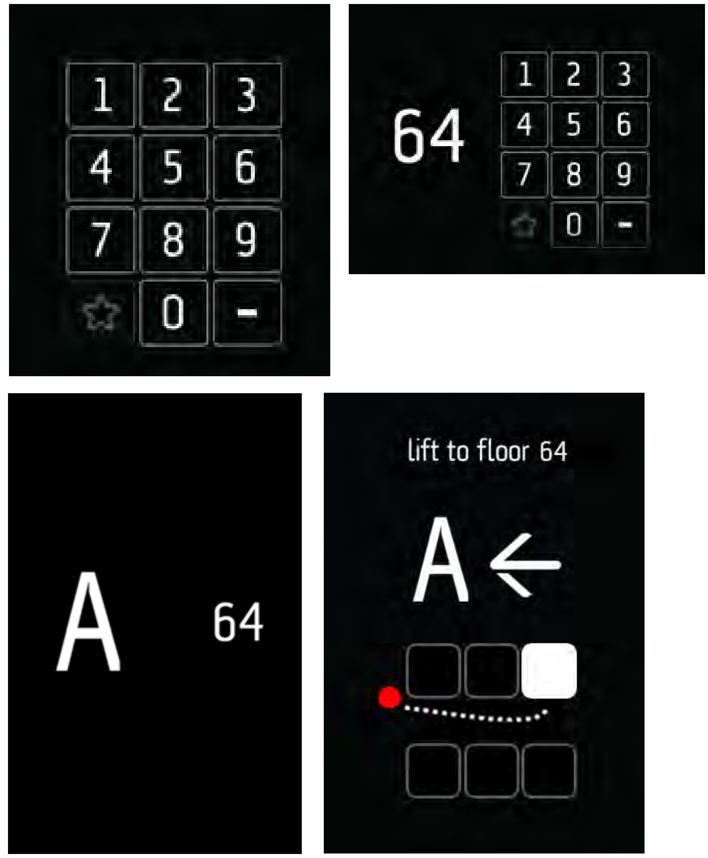

Figure 5: KONE's screenshots: (clockwise from top left) hall station touchscreen at the main lobby as seen by a person approaching the station; the screen acknowledges a destination call for floor 64 has been entered; the call is assigned to elevator "A," also showing its lobby location; display at the landing entrance for car "A" then annunciates "64" as a next floor served.

In Cabs (When Car Is at the Main Lobby): Figure 6

Inside the cab while at the main lobby, things "disappear" to resemble standard destination dispatching. Floor buttons, while present in the cabs, are not visible or functional for normal passenger operations. A valid criticism of "hybrid" dispatching is that visible yet inoperative floor buttons in the cab are confusing for passengers boarding at the main lobby. That same critique would apply to conventional dispatching for double-deck elevators, in which buttons are visible yet inoperative for odd- or even-numbered floors, depending on the deck. A touchscreen as part of a car operating panel can easily turn these floor displays off or on (Figure 6).

At Office Floors: Figures 7 and 8

The harmonized designs are more evident at the office floors. In the same way as standard destination dispatching, floor destinations are entered in advance at a hall station. Later in this article, we will see this is not the only means to enter calls at an office floor. However, as in conventional dispatching, a car may not be assigned instantly. Familiar up and down arrows, enhanced with

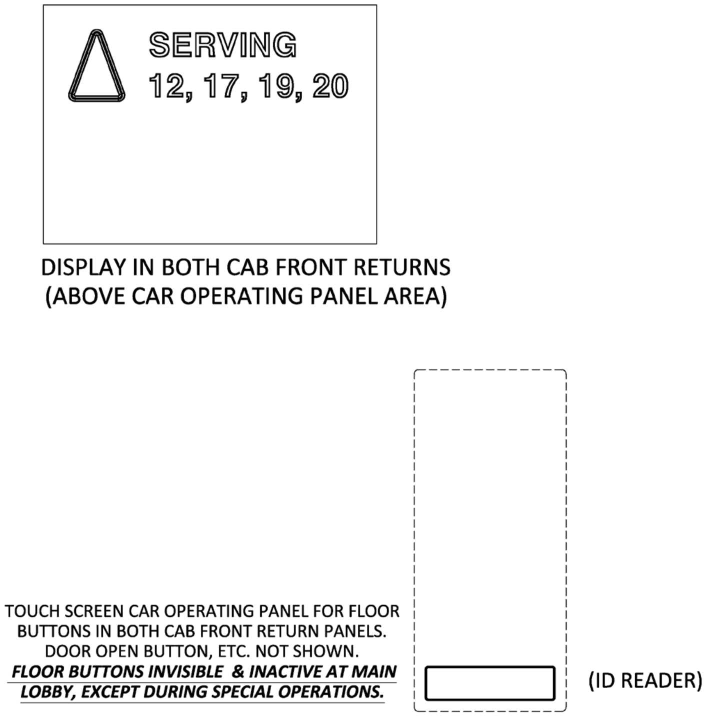

Figure 6: Barker Mohandas functional sketches of passenger interfaces in cabs when the elevator is parked at the main lobby: KONE's renderings for the project are essentially the same in function, so those are not shown; credits for elements such as keypad buttons used in our sketches go to Dewhurst.

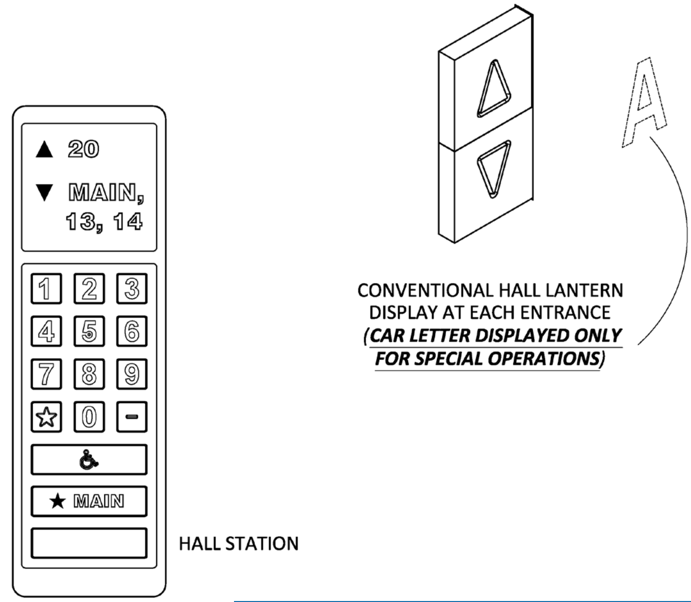

Figure 7: Barker Mohandas functional sketches of passenger interfaces at the office floors; credits for elements such as keypad buttons used in our sketches go to Dewhurst.

floor annunciations, acknowledge calls by floor and direction for both waiting and new passengers.

Conventional hall lanterns are used in a compatible electronic display design. Accordingly, during special operations only, the car designation can be shown when a car is assigned to an authorized user.

Figure 8 shows KONE's implementation and enhancements for the same group of six double-deck elevators described earlier (while fixtures for single-deck elevators would essentially be the same).

In Cabs (After Car Stops for First Demand From an Office Floor): Figure 9

When the car stops for its first demand from an office floor (for example, traveling down), things "appear" differently than standard destination dispatching. Floor buttons that were not visible in the cab when the car was at the main lobby appear and are operative. A person(s) just entering a lobby at an office floor, seeing the doors open for a car headed in their direction, can simply board it and enter their call(s).

During special operations, the floor buttons can be used at any location by building staff or first responders.

Initial Performance Simulations With Sample Group of Double-Deck Elevators

To check our traffic calculations for a certain group of double-deck local elevators during design of the vertical-transportation system for PNB 118, we obtained dispatching simulations for a lunchtime peak hour from some elevator manufacturers

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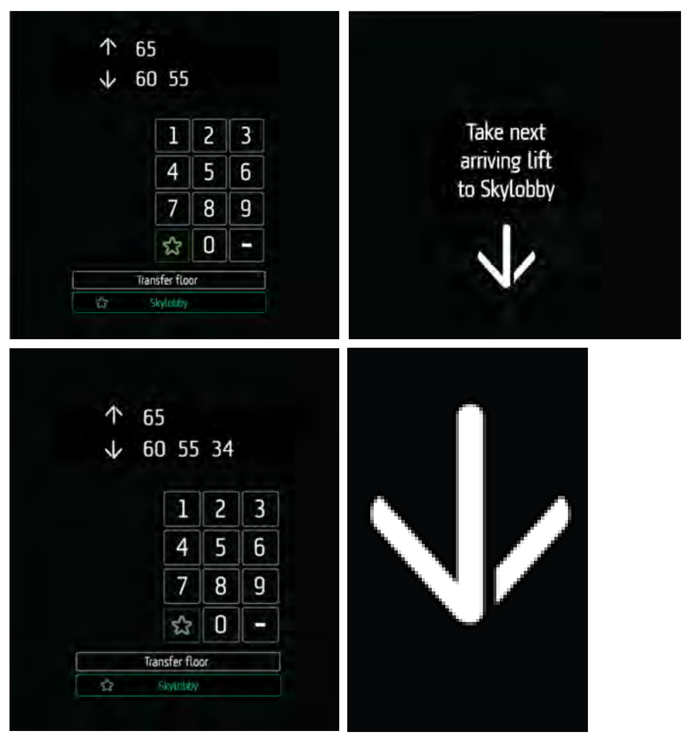

Figure 8: KONE's screenshots: (top left) a hall station as seen by a user approaching the station at an office floor (floor 63 in this example). The user wants to travel down to the "Skylobby" using a convenience destination button in the hall station. The sky lobby is two levels (floors 33 and 34). In an enhancement by KONE (top right), immediately after the sky-lobby call is placed, the user is asked to take the next down-traveling elevator. The touchscreen then continually annunciates the user's destination as an in-process call (bottom left) until the elevator arrives at the floor. When the final car assignment is made, a familiar hall lantern then signals over the landing entrance (bottom right). After the car arrives, the call for floor 34 is automatically transferred to the display inside the cab as a next floor being served (not shown).

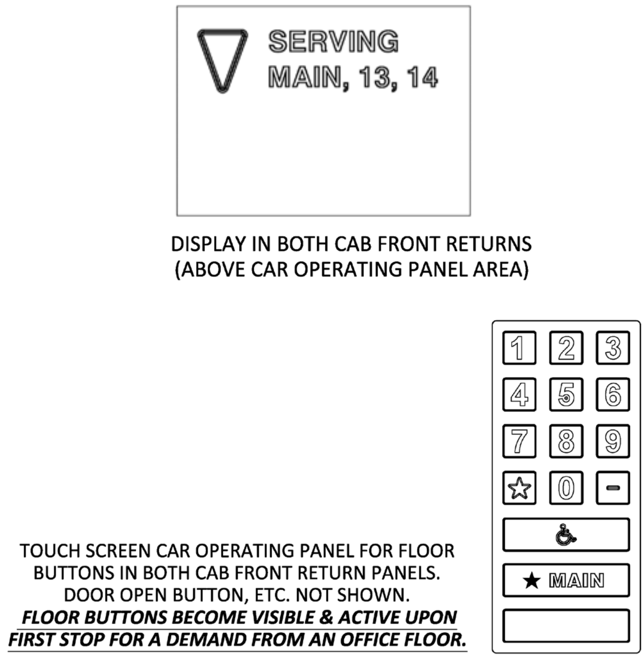

Figure 9: Functional sketches of passenger interfaces inside the cab when the car stops for its first demand from an office floor. KONE's renderings for the project are essentially the same in function, so those are not shown; credits for elements such as keypad buttons used in our sketches go to Dewhurst.

experienced with double-deck dispatching and the two basic types of dispatching needed for our harmonized designs. We did this to check long waits during lunchtime, comparing results using standard destination dispatching with instant car assignments at all floors, to results using hybrid dispatching with delayed car assignments only at the office floors. The harmonized approach would be represented closest by the latter, underneath.

The group of elevators involved has the following parameters (acceleration rate based on full up-running load):

- Group of six double-deck elevators, 1800+1800 kg (3968+3698 lb.) at 7 mps (1,378 fpm) with 1-mps^2 (3.3 fps^2) acceleration/deceleration
- Serving double-level main lobby, expressing by 16 office floors and serving 16 local office floors
- Total population served: approximately 2500, not uniformly distributed and weighted more to the top floors
- Intended for some large tenants occupying multiple office floors within this high-rise local zone

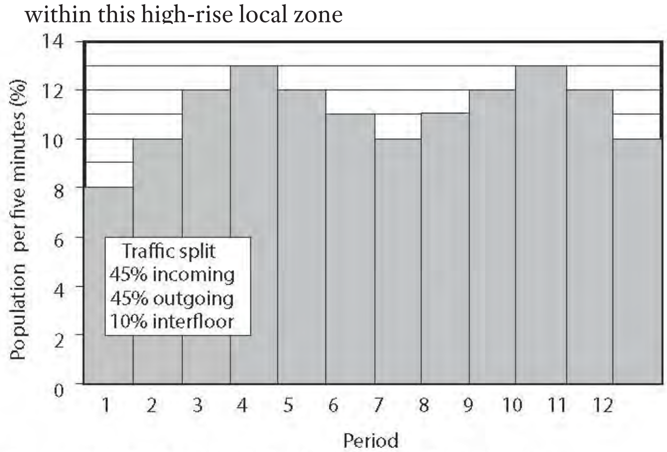

Figure 4.13 CIBSE modern office lunch peak traffic template

We asked the manufacturers to simulate performance using the lunchtime traffic pattern shown below in Figure 4.13 from *CIBSE Guide D: 2010 — Transportation Systems in Buildings*. This pattern was/is publicly available to all manufacturers and includes 10% interfloor traffic to cover many office buildings with larger tenants. (Revisions to this pattern in the 2015 edition of *CIBSE Guide D* are shown later in this article.)

Table 1 compares the results of the initial simulations provided and rechecked by project winner KONE. These are believed to be without extensive R&D in dispatching to take advantage of both knowing destinations in advance and delaying car assignments at the office floors. They reflect results for their hybrid dispatching, obtained using the KONE Building Traffic Simulator (BTS™).

Average Waiting Time (s.)	Average Time to Destination (s.)	% of Hall Calls Waiting > 90 s.
33.5	115	6.6%

Table 1a: Lunchtime peak hour, standard destination dispatching and instant car assignments (all floors)

Average Waiting Time (s.)	Average Time to Destination (s.)	% of Hall Calls Waiting > 90 s.
26.3	107	2.5%

Table 1b: Lunchtime peak hour, hybrid dispatching and delayed car assignments at office floors only

Note that the average wait during the lunchtime peak hour improved significantly, to well under 30 s. However, to quote a departed mentor of your author, William S. Lewis, P.E., partner, Jaros, Baum & Bolles, "The average person drowned in a river with an average depth of 6 in." We also like to look at long waits with elevators, not just an average. For office buildings, long waits (defined here as the percentage of calls waiting > 90 s.) should ideally be ≤ 1% of total calls. However, we have suggested 3% as a practical limit to avoid increasing the number of elevators.

With double-deck elevators, with two connected cabs, we expect some degradation in long waits during lunchtime, when traffic is both two-way and interfloor. We can see by simply delaying car assignments at the office floors, the minimum performance goals were achieved with double-deck elevators, *which were initially planned to reduce elevator core space by over 35% compared to single-deck elevators*.

This validated our planning, assuming at least hybrid dispatching was provided. Still, we felt there should be opportunities to improve performance further with the harmonized designs. Recent simulations for the same elevators, using the same lunchtime profile, *showed the average wait was reduced to 21 s., and the percentage of hall calls waiting > 90 s. was reduced to 1.9%*. These results help confirm that feeling. This lunchtime profile has since been revised and deserves updated simulations, which are covered in the next section.

Updated and Expanded Simulations

We asked KONE to provide dispatching simulations for the same group of six double-deck elevators to cover both the morning and lunchtime peak hours, with the updated traffic pattern for lunchtime in *CIBSE Guide D: 2015*. The 2015 patterns are shown below for both peak hours from Figures 4.11 and 4.12 in the guide.

The morning peak performance was never expected to be an issue in retaining destination dispatching at the main lobby, so those results are now shown more to complete the story. Similarly, we also show dispatching simulations for the lunchtime peak hour for a group of eight single-deck elevators.

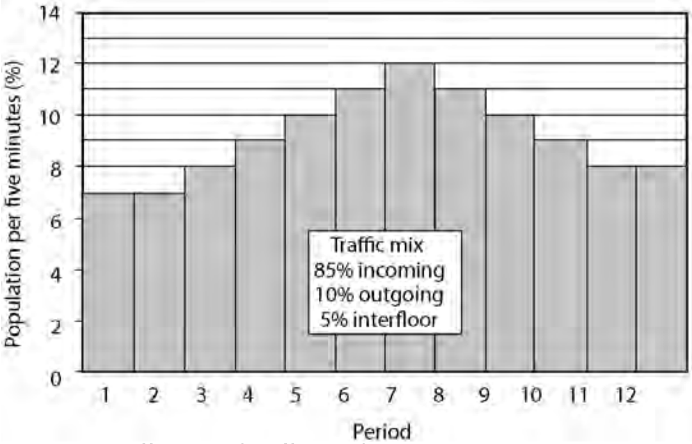

Figure 4.11 Office uppeak traffic templates

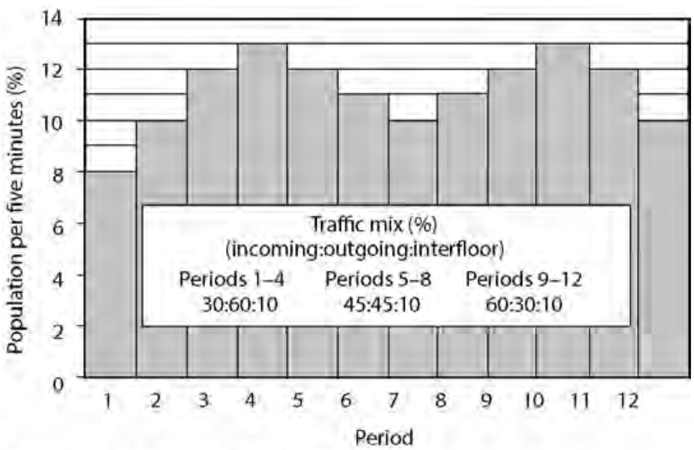

Figure 4.12 Office lunch peak traffic templates

Same Sample Group of Double-Deck Elevators

Tables 2-4 are updated and expanded simulations by the manufacturer for the same elevators described in the "Initial Performance Simulations With Sample Group of Double-Deck Elevators" section above. The results for the lunchtime peak hour are shown first, as these are more critical to examine. The impact of a detailed dispatching option is also examined for lunchtime, during which the manufacturer's algorithms can be switched to emphasize waiting time over journey time or vice versa. In Table 2, numbers not in parentheses are with more emphasis on waiting time, while the numbers in parentheses are with more emphasis on journey time.

Compared to the *CIBSE Guide D: 2010* pattern, the 2015 pattern for lunchtime contains more pronounced up-peak traffic at the end of the hour for passengers at the main lobby (sky lobby) returning from lunch. As a result, waiting times do not drop as much as in the aforementioned section, and if an option is selected to focus more on journey time, long waits are essentially at the 3% maximum target. Also, the manufacturer found a way to improve results using its standard "Double-Deck Destination Control System" in Table 2a.

Average Waiting Time (s.)	Average Time to Destination (s.)	% of Hall Calls Waiting > 90 s.
29 (33.2)	103 (98.6)	4.4% (5.8%)

Table 2a: Lunchtime peak hour, standard destination dispatching and instant car assignments (all floors)

Average Waiting Time (s.)	Average Time to Destination (s.)	% of Hall Calls Waiting > 90 s.
24 (26.8)	96.5 (90.2)	2.6% (3.1%)

Table 2b: Lunchtime peak hour, improved dispatching and delayed assignments at office floors only

Average Waiting Time (s.)	Average Time to Destination (s.)	% of Hall Calls Waiting > 90 s.
23.8	79.8	1.3%

Table 3a: Morning peak hour, standard destination dispatching and instant car assignments (all floors)

Average Waiting Time (s.)	Average Time to Destination (s.)	% of Hall Calls Waiting > 90 s.
20.1	76.3	1.1%

Table 3b: Morning peak hour, improved dispatching and delayed assignments at office floors only

The results, tested with different patterns and options, reaffirm our original planning for the harmonized dispatching and passenger interfaces. Also, both waiting and journey times are improved.

Sample Group of Single-Deck Elevators

Table 4 is made up of the manufacturer's simulations for an eight-car group of single-deck elevators for the same project. These have a travel from the sky lobby to the first office floor of 8.6 m (28.2 ft.), serve 18 office floors with heights of 4.3 m (14.1 ft) and 98 people per floor, and rated 1800 kg (3968 lb.) at 5 mps (984.3 fpm) with a full-load up acceleration of 1 mps^2 (3.3 fps^2) and have 1,200-mm (47.2-in.) openings with 1SCO doors.

Stops have been simplified compared to those planned. There is also an amenities level served by all eight cars, and fewer than all

Average Waiting Time (s.)	Average Time to Destination (s.)	% of Hall Calls Waiting > 90 s.
19	76.4	1.4

Table 4a: Lunchtime peak hour, standard destination dispatching and instant car assignments (all floors)

Average Waiting Time (s.)	Average Time to Destination (s.)	% of Hall Calls Waiting > 90 s.
16.3	74.3	0.3

Table 4b: Lunchtime peak hour, improved dispatching, delayed assignments at office floors only

cars serve a special stop both above and below the typical terminal floors, where we expect comparative improvements will be greater with the improved/harmonized approach to help handle these complications when making car assignments. However, even with the simplified stops, we can see the dispatching comes close to eliminating long waits for these single-deck elevators during lunchtime. The improvements in user interfaces are also provided for the more common single-deck elevators in our industry.

Continued

Improvements Summarized

This section summarizes some of the key improvements we see.

Buildability and Flexibility

The system should be buildable by any willing manufacturer who provides destination dispatching and conventional or hybrid dispatching, and suitable fixtures for the passenger interfaces. Advantages in using the touchscreens and displays for other purposes should also be evident: for example, during occupant evacuation modes at the office floors and various special operations.

Improved Traffic Performance

The improvements in traffic performance can be significant over standard destination dispatching and occur in all performance metrics studied. It is also believed that traffic performance can be improved in the future, where upgrades can also be provided onsite without changing fixture hardware.

Improvements for Users (Main Elevator Lobby)

Improvements in wayfinding for the assigned elevator and in information when standing at the assigned elevator are only incidental improvements over standard destination dispatching. And, as noted earlier, these have likely already been built somewhere.

Improvements for Users (Office Floors and in Cabs)

Improved passenger information restores and enhances conventional acknowledgements of passengers' calls and restores conventional in-car controls for passengers.

Conclusion

For office buildings, the harmonized dispatching and passenger interfaces offer improvements over both standard destination dispatching and hybrid systems, and serve as a platform for future performance improvements. These can be very important for double-deck elevators and beneficial for single-deck elevators.

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Rick Barker is a principal and cofounder of Barker Mohandas LLC, a vertical-transportation consulting firm founded in 2000. Barker has been director of Technical Services worldwide at Otis Elevator World HQ, where one of his roles was to chair the Otis "Worldwide Dispatching & Elevatoring Steering Committee." He has also been vertical transportation department head at Jaros Baum & Bolles (JB&B) Consulting Engineers, modernization manager for Delta Elevator in Boston (now Otis), and held various positions at Westinghouse Elevator (now Schindler). For more information on the firm and its projects, visit www.barkermohandas.com.

Focus: Elevator/Lift Dispatching & People

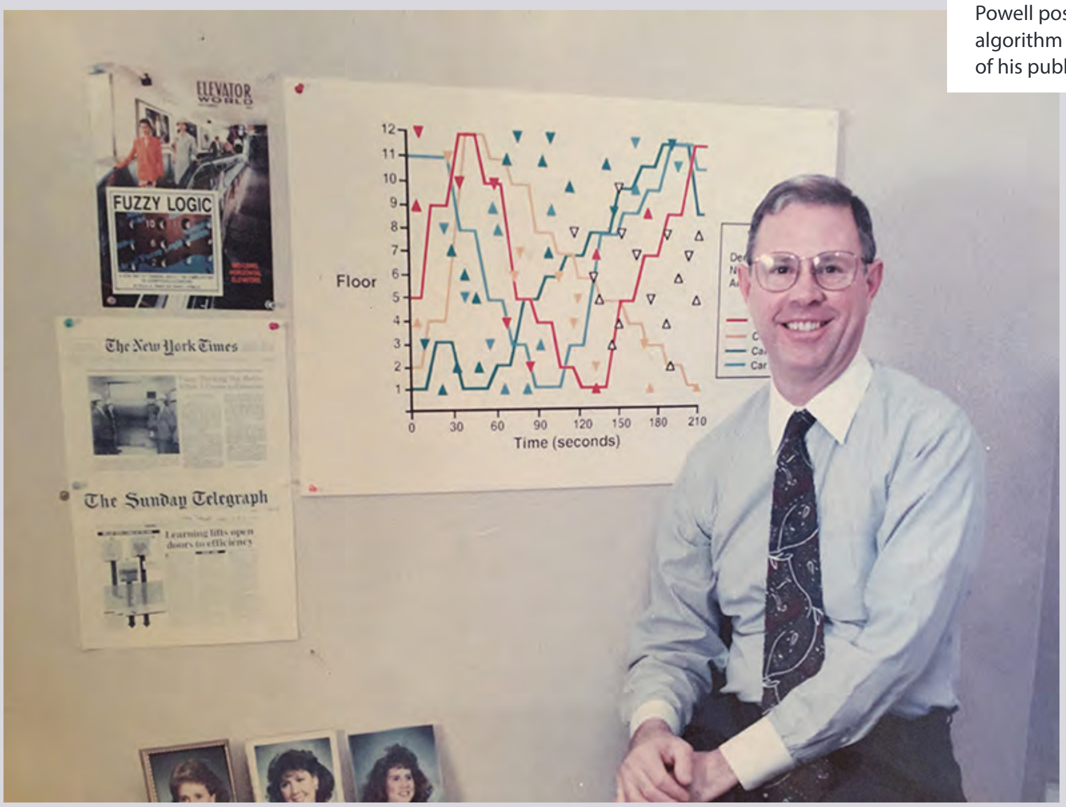
ELEVATOR WORLD Magazine, December 2018

"More Than Math"
– about Dr. Bruce Powell

Focus on Consultants

More Than Math

In this Industry Dialogue, Dr. Bruce Powell provides insight about himself, his illustrious career and the state of the VT industry today.



Powell poses with an algorithm chart and some of his published articles.

> ***I was fortunate enough to come along when the patent office expanded its scope from 'how to build a better mousetrap' to allowing novel mathematical algorithms that could be used to control things such as elevators.***

The present-day Powell, comfortable in his home office.

> *I would like to convince the segment of the industry that advises building owners, developers and architects that there is a world beyond the calculation of up-peak interval and handling capacity.*

by Kaija Wilkinson

Dr. Bruce Powell is a math nerd, sure, but with the clever, subtle-yet-blunt sense of humor of a right-brained comedian. He began his distinguished career at Westinghouse's R&D center in the 1960s, when computers were at least the size of refrigerators, New York City's (NYC) Twin Towers had not yet been built, and print newspapers were read daily in homes and offices. These days, Powell is "boss of himself" as principal of The Bruce Powell Co., Inc., a consultancy based in Canton, Connecticut. For the past 16 years, he has primarily served as principal traffic analysis consultant for thyssenkrupp on projects including One World Trade Center in NYC, the 80-story Federation Tower in Moscow served by a TWIN elevator system and major modernizations incorporating destination dispatch (DD), such as at One Wells Fargo Center in Charlotte.

Powell is well known throughout the "elevator world" as he continues to tackle each new project as if it is the most interesting and challenging of his career. He took the time to speak with ELEVATOR WORLD about his path to the industry, his personal life, how he used algorithms to help develop 37 patents, multiple publications and the people who have inspired and mentored him along the way. The former Otis Fellow shared fascinating insight about the future of new technology, the state of the consultancy industry today and the challenges that come with traffic analysis.

EW: Where were you born, where did you grow up, and at what point in your life did you decide on a career in the vertical-transportation (VT) industry?

BP: I was born and raised in Waterbury, Connecticut, but I am not sure that I ever fully grew up. I seriously doubt that anyone decides early in life to make a career in the VT industry. Like many college kids, I wrestled with the issue of what to do for a career. I thought about dentistry but lacked the prerequisite biology courses. Then, because church had been a big part of my youth, I considered the ministry but was discouraged by my Harvard MBA accountant father. That left pursuing further education in mathematics and computers. At that time (early 1960s), serious computers filled two conference rooms, and apples were for making pies and for winning favor from the teacher.

I went to graduate school in Cleveland at Case Institute of Technology (now Case Western Reserve University). Through a combination of good decisions and a lot of luck, I went down a path that led to a PhD in Operations Research and a position as a research mathematician at Westinghouse Electric Research

Continued

Powell, right, is presented the Otis Fellow award by his boss, the late John Kendall.

Laboratories in Pittsburgh. It was there that my skills in mathematical modeling and technical communication met with Westinghouse Elevator Co.'s need to develop a more solid technical approach to elevator design and more clever dispatching algorithms. After 21 years at Westinghouse, I joined Otis in their Advanced Research department, spending 13 years in Farmington, Connecticut.

Finally, leaving corporate America behind, I became "president of myself," working full time as an elevator consultant, mostly working with thyssenkrupp Elevator. It has been an interesting journey!

EW: You have been named an Otis Fellow and hold many patents. Of what professional accomplishment are you proudest?

BP: I have my name on 37 patents, and the rights of nearly all are owned by Otis. Of these patents, most are shared with other team members. I was fortunate enough to come along when the patent office expanded its scope from "how to build a better mousetrap" to allowing novel mathematical algorithms that could be used to control things such as elevators. Also noteworthy in my career are a number of citations of my work in public literature, namely, *The New York Times*, the *Wall Street Journal*, *CNN* and, of course, EW.

EW: To which professional organizations do you belong?

BP: Over the years, I have belonged to the Operations Research Society of America, The Institute of Management Sciences and the Society for Computer Simulation. I have also been active in presenting papers to the International Association of Elevator Engineers.

EW: If you could change one thing about our industry, what would it be?

BP: I would like to convince the segment of the industry that advises building owners, developers and architects that there is a world beyond the calculation of up-peak interval and handling capacity. This new world that I jumped into at Westinghouse in 1967 consists of dispatch algorithms with a solid mathematical foundation and a focus on estimating passenger waiting time (WT) and average time to destination (ATD). We don't have to bore our customers with mathematical details, but we must base our recommendations about good elevator configurations on computer-simulation models and input data gathered during traffic surveys at fully occupied buildings.

EW: Which colleagues in the industry inspire you and why? Did you have any mentors during your career you would like to mention?

BP: My career began at Westinghouse under Dr. Robert Hooke and Dr. Douglas Shaffer. These men were truly gentlemen and scholars. Bob Hooke fine-tuned my technical writing skills, and Doug Shaffer taught me the fundamentals of presenting technical information to non-technical people. Colleagues who have been quiet mentors, some without their knowledge, include John Kendall and Joe Walker, Otis; Rory Smith and Mark Schroeder, thyssenkrupp; Dr. Richard Peters, Peters Research Ltd.; consultant Rick Barker, Barker Mohandas LLC; and the Rev. William Paul.

EW: Which of your consultancy projects did you find most challenging/rewarding?

BP: The most challenging and rewarding consultancy project is the last one and the next one. Each job has little wrinkles that make it unique and challenging. Since I specialize in traffic analysis, which most often happens at the front end of the development of a building, my time spent on a particular project is short compared to that of design and construction engineers who might spend years with one major job. Over the years, I have worked on several hundred elevator projects, both small and large.

Another challenge involves convincing customers that the latest technological buzz ("fuzzy logic," "artificial intelligence," etc.) does not necessarily result in improved performance. You know what? The old timers really did know what they were doing.

EW: Was there any particular project or projects you worked on that really influenced you or changed your perception of this industry and its impact on society?

BP: I have been particularly interested in how slow the industry has been to embrace the control system we now call destination dispatch (DD). The fundamental concept of DD was invented nearly 60 years ago in Australia, several years before microprocessors were used to control elevators. Either for reasons of technical skepticism or product-strategy issues, the adoption of DD had been slow. Only in this century has DD gained momentum to the present, where it is often now the default specification for high-end office buildings.

EW: On a related note, how do you feel about the future of new technologies such as TWIN and, more recently, MULTI? Are they really game changers? Why or why not?

BP: Like DD, the concept of two elevators running independently in a single shaft is not new. Patents related to this technology were issued as far back as 1907. A working system as documented in *Scientific American* was installed by Westinghouse

> ***"Another challenge involves convincing customers that the latest technological buzz ('fuzzy logic,' 'artificial intelligence,' etc.) does not necessarily result in improved performance."***

in its East Pittsburgh manufacturing plant in 1931. So, it has taken more than 100 years to get to the place where elevators with two cars in hoistways are carrying passengers in office buildings in several European cities and will be doing the same very soon in major cities in the U.S. Are these technologies game changers? We will see.

EW: What is the biggest professional challenge you face currently, and how are you addressing it?

BP: Above, I referenced convincing recipients of my work that there is more to good traffic analysis than Round Trip Time and Interval calculations. A customer might come to me determined to use DD in, say, his five-story hotel. I struggle to convince him that DD may not be a good fit. I use publicly available simulation software, as well as a clear and concise presentation, to argue the pros and cons.

EW: What does your professional future hold? Do you have plans to retire anytime soon?

BP: I am well past the age when I am eligible to receive full Social Security benefits. Nearly all my contemporaries have retired, so I suppose that I should follow them soon.

EW: You have worked all over North America and the world. Which cities do you feel are most advanced and receptive to new VT technology?

BP: Europe has a substantial number of TWIN elevator systems operating today. The West Coast of the U.S. seems to have adopted DD more readily than other parts of the U.S., although that is changing. The Japanese elevator companies seem to have adopted advanced control algorithms more readily, although this is difficult to verify. After all, "It's only software!"

EW: Describe the state of the consulting industry today. Are there plenty of qualified, motivated candidates? Why or why not?

BP: Back in the "good old days," the fact that elevator suppliers were very reluctant to release technical information led to the growth of the elevator consulting industry. Looking for a change of scenery, many salespeople, as well as engineers, became consultants.

There is no uniform set of qualifications or certification, so anyone who so chooses can hang a shingle. This leads to nonuniformity in qualifications, but I suppose that this is just like almost every other profession. In the last couple of years, lift consultants have been extremely busy. There seems to be more work than people available to provide technically solid consulting.

EW: What advice would you give to someone considering getting into the elevator industry today?

BP: Think about being a dentist or a minister first. If that doesn't work, then try what I did. But, seriously, as silly as it

Continued

sounds, a person cannot be an effective consultant without knowing the key aspects of the product. This can most practically be obtained by working for an elevator supplier.

The two attributes that I would look for in a person who wishes to be a consultant are, first, a keen interest in technical mathematical details and, second, a passion for clear and concise written and oral communication (not necessarily in that order).

EW: Is there a particular project you admire that you'd like to tour or pick the brains of those responsible for it?

BP: I admire the Eiffel Tower in Paris for its technical achievements and staggering beauty. Considering that it was completed in 1889, the elevators that travel diagonally up the legs and the duo-lift passenger cars that travel to the upper platform some 906 ft. from the ground are impressive. The copies of communications I have seen between Gustav Eiffel and Otis are fascinating.

EW: Tell me about your family.

BP: Marlene and I have been married for 54 years. We raised three daughters to be fans of Pittsburgh Steelers football and Pirates baseball. We encouraged them to cultivate solid values, which included a high regard for technical education, as well as the importance of placing the needs of others first. Over the years, 11 grandchildren filled our home at Christmas and our hearts with joy, as well as trepidation. Now, we spend almost every summer at our camp in the lower Adirondacks in New York and the rest of the year in our home in the northwest hills of Connecticut.

EW: What do you like to do in your free time?

BP: My wife and I have found a great deal of enjoyment and satisfaction singing sacred classical music, as well as contemporary Christian music, in our local Congregational church.

I operate a small powerboat on fresh water, dragging grandchildren around on water skis and tubes. I fancy myself a once-reasonable golfer. My wife and I snow ski, mostly in the western U.S. Finally, in spite of my wife's overabundance of caution, I often use my chainsaw in the woods.

EW: What's the last book you read that was not elevator related?

BP: Spending a career with my nose in technical literature, I am not a fast reader. That said, I have enjoyed the work of Mitch Albom, specifically, *Tuesdays with Morrie* and *The First Phone Call from Heaven*.

EW: Where did you go on your last vacation, and what is your favorite vacation spot?

BP: Since 2002, my wife and I have taken at least one international trip per year. We have been to countless places, favorites among these being Paris, London, Ireland, Machu Picchu, and the Galapagos Islands. Our most recent trip was to Iceland. Some people call this "spending our kids' inheritance."

EW: Looking back now, is there anything you would have done differently, professionally speaking?

BP: I would like to have had more time allocated to going back into a newly constructed and fully occupied building for which I recommended the elevator configuration to see how things worked out. Also, I would like to learn how things would have worked out for Dr. Bruce Powell the dentist or the Rev. Bruce Powell the minister.

Focus: Elevator/Lift Dispatching & People

ELEVATOR WORLD Magazine, September 2019

"Fulfilling the Potential of DD DCS"
– by Dr. Janne Sorsa

Note: A note was sent to EW on the Editor's introductory note for this article on a double-deck destination-control system, that technically, Janne Sorsa's article was based on the concepts for harmonized dispatching and passenger interfaces by Rick Barker of Barker Mohandas LLC, not vice versa, while a published correction was unnecessary.

Fulfilling the Potential of DD DCS

The double-deck destination-control system (DD DCS) combines two well-known approaches to boost morning up-peak traffic in office buildings and save building core space.

by Dr. Janne Sorsa

This article describes the technical principles of elevator dispatching, on which Rick Barker's article "Harmonized Elevator Dispatching and Passenger Interfaces" (ELEVATOR WORLD, November 2018) is based. . . . Editor

Double-deck elevators with DCSes are used in tall buildings to reduce core space occupied by elevators. However, DCS lunch traffic performance still limits potential space savings, which is largely due to the immediate assignment of passenger calls to elevators and decks. This article introduces two optimization methods for an elevator group control system to solve this challenge. First, uncertain near-future passenger arrivals are modeled by scenarios, which then define the optimal elevator routes robustly. Second, the re-optimization of call assignments gives maximum flexibility for the control to react to new passenger arrivals.

Introduction

The DD DCS combines two well-known approaches to boost morning up-peak traffic in office buildings and save building core space.[6] A double-deck elevator consists of two attached elevator cars. This doubles car capacity per elevator shaft. In addition, the dual lobby enforces the even/odd split, where passengers are distributed to the lower and upper decks based on their destination floors.[5] In a DCS, passengers give their destination floors using numeric keypads in the lobbies. Based on the additional information, the DCS can gather passengers traveling to the same destinations in the same elevators, which reduces elevator stops and increases up-peak handling capacity.[13] On the other hand, both the double-deck elevators and DCS do not yet perform optimally during mixed lunch traffic.[15 & 16]

For the DD DCS, lunch traffic is challenging for several reasons:

1) Traffic: Lunch traffic does not provide as many opportunities to group passengers into the elevators as up-peak traffic does, since typically less than half of the traffic is incoming. Interfloor traffic between the upper floors breaks the even/odd split, which is an efficient strategy for incoming and outgoing traffic.
2) Signalization instant: The current de facto standard DCS assigns an elevator to each call and signals it immediately after a call has been registered. This assignment cannot be changed later. At the time the call is finally served, the assignment may no longer be optimal due to changes in system state.
3) Passenger behavior: The DCS assumes that each passenger gives exactly one call. Passengers, however, often travel in socially connected groups to the same destinations.[11] Typically, only one passenger in a group gives the call, while the others tailgate into the elevator. Individual passengers have also been observed to register several calls in rapid succession in the hope of getting an elevator faster or with more space.

Traffic conditions cannot be altered. However, the bilevel optimization model (in the following section) maximizes the efficiency of elevator routes independent of the overall objective, which minimizes, e.g., passenger waiting times. The signalization instantly determines the assignment policy under which the elevator group control system (EGCS) operates. The current DD DCS is based on

Continued

immediate assignment policy (IA), to which both the serving elevator and deck are immediately fixed. To reduce the risk of current assignments becoming suboptimal in the near future, the EGCS can optimize elevator routes in a robust manner by predicting new passenger arrivals and estimating the number of passengers of a call ("Predicting Passenger Arrivals With Risk Scenarios" section).

An alternative way of reducing the effects of future system states is to postpone the instant when the serving elevator or deck is finally fixed. The DD DCS allows the delayed deck assignment policy (DDA): the serving elevator is still immediately signaled, as is customary, but the EGCS can reoptimize the serving deck until the last moment. The delayed elevator assignment policy (DEA) allows reoptimization of both the serving elevator and deck. The DEA has also been considered for single-deck elevators.[9] In the "Genetic Algorithm for Real-Time Optimization" section, a real-time genetic algorithm is introduced to solve the bilevel model under DDA and DEA, while the advantages of these techniques are demonstrated by simulations in the "Simulation Results" section.

Bilevel Model of Double-Deck Elevator Dispatching

The main task of the EGCS is to dispatch an elevator to serve each passenger call. Mathematical methods to make the dispatching decision have been researched widely, especially for conventional control.[4] One approach is to frequently solve a snapshot optimization problem, called the "elevator dispatching problem" (EDP).[20] The solution to the EDP defines the route of each elevator belonging to elevator group E to serve the set of passenger calls V. The elevators are dispatched to the first calls of their routes. In the DCS, passenger calls pair a landing and car call. Therefore, set V can be further divided into landing and car calls, formally denoted by S and T.

The double-deck elevator dispatching problem (DD-EDP) assigns an elevator and a deck to each passenger call and determines their serving order.[18] This problem can be formulated as a single-level optimization model, where all decisions are simultaneously considered globally. In a bilevel optimization model, the elevator assignments are decided by an upper-level problem, while the deck assignments and the ordering are decided by separate lower-level problems for each elevator.

The single-level model has a disadvantage in that it may produce inefficient elevator routes when minimizing passenger waiting times. An example of such a situation is shown in Figure 1 (left), where a passenger inside the lower deck is traveling toward F3, and another is waiting for transportation from F3 to F7. The numbers beside the arcs show the combined stop and flight times between the corresponding start and end floors of the flight, as well as the elevator arrival time on the end floor (in parentheses). In this example, the problem is to decide whether the lower or upper deck picks up the waiting passenger on F3. Clearly, the upper-deck solution shown in the middle minimizes waiting times, since it takes only 4.8 s for the upper deck to reach F3, compared to the 6.8 s it takes the lower deck. However, the upper-deck solution contains a stop, during which the lower deck serves the car call on F3, and the upper deck stops on F4. As a result, the route time in the upper-deck solution is about 8 s longer than in the lower-deck solution (32.5 versus 24.7 s). The lower-deck solution also minimizes journey times: 6.8 s for the passenger to F3 and 24.7 s for the passenger to F7.

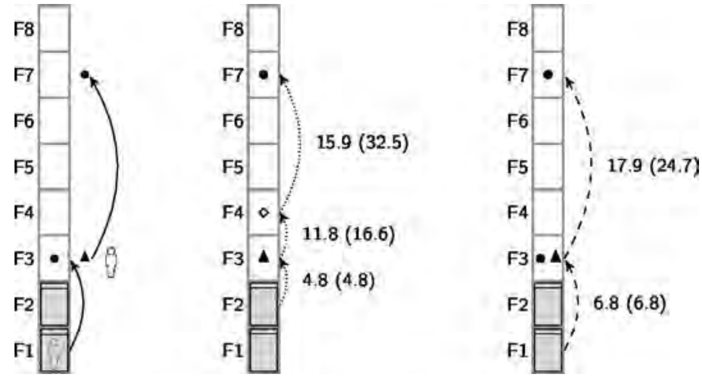


Figure 1: An example of a double-deck elevator route: a circle represents a car call, a triangle represents a landing call, and a diamond represents a stop with no calls to serve.

This observation leads to the decomposition of the single-level model to two levels, where the upper level optimizes passenger service quality, and the set of lower-level problems optimizes the route of each elevator separately. The bilevel model considers two assignment variables. In the upper-level problem, passenger calls $i \in V$ are assigned to elevators $e \in E$ by binary decision variables $x_{e,i}$. In the lower-level problem of elevator e, calls $i \in V_e$ are assigned to deck $d \in \{1,2\}$ by binary decision variables $y_{e,d,I}$, $V_e = \{i \in V | x_{e,i} = 1\}$. In addition, the lower-level problem determines the order in which the calls are visited using binary arc variables $z_{e,d,i,j}$, where call $i \in V_e$ precedes call $j \in V_e$ if $z_{e,d,i,j} = 1$. The key variable for objective functions is elevator/deck arrival time to a call floor, $t_{e,d,i}$, which defines passenger waiting and journey times, as well as the total elevator route time. Each call is associated with call time y_i elapsed since its registration and demand D_i, as well as the number of passengers, which is positive for landing calls and negative for car calls.

The bilevel optimization model follows (see your author's 2017 article, "Optimization Models and Numerical Algorithms for an Elevator Group Control System,"[18] for details):

$$\min f(x, R^*(x)) = \sum_{e \in E} \sum_{d \in \{1,2\}} \sum_{i \in S_e} \sum_{j \in V_e} (y_i + t_{e,d,i}) z_{e,d,i,j} D_i \quad (1)$$

subject to

$$\sum_{e \in E} x_{ei} = 1, x_{e,i} \in \{0,1\}, \forall i \in V \quad (2)$$

and

$$R_e^*(x_e) \in \arg \min_{R_e(x_e)} t_{e,d,N_e} \quad (3)$$

where $R^*(x)$ is the set of optimal elevator routes, $R^*(x) = (R_e^*(x_e))$, that minimizes the route time t_{e,d,N_e} for each elevator e with the given assignments $x_e = (x_{e,i})$. The objective function (Eq. 1) minimizes the total passenger waiting time. It is straightforward to modify it to minimize passenger journey times by changing the innermost summations to consider car calls T_e instead of landing calls S_e. Demand D_i typically corresponds to one passenger. The demand might also be a larger number, which is either an input or

Continued

an estimated passenger group size. Eq. 2 ensures each call is assigned to exactly one elevator.

The lower-level problem in Eq. 3 defines the route of an elevator as the sequence of locations to be visited. Elevator/deck arrival times are accumulated along the route by flight times between floors and stop times. The lower-level objective is to minimize route time, which corresponds to the arrival time for the last stop. In addition, the model keeps track of the number of passengers inside each deck. As a result, a feasible solution satisfies the capacity constraint. Furthermore, the basic rules of elevator operation are followed.[3]

Predicting Passenger Arrivals With Risk Scenarios

The DCS, under the IA, requires two kinds of predictions about passengers: the number of passengers and new arrivals. Individual passenger arrivals can be modeled as a Poisson process with rate λ persons per 5 min.[1] Modern elevators can accurately count boarding and alighting passengers and learn the arrival rates on each floor for the 15-min periods of a day.[14] Passenger batch arrivals can be modeled as a compound Poisson process, where they arrive at lobbies in batches or bursts of demand.[11] Batch sizes cannot be directly observed from the passenger counts but can be estimated for each one-directional elevator trip.[12] If batch sizes follow a geometric distribution with the mean batch size of β, the process is known as a geometric Poisson or Pólya-Aeppli process with λ/β arriving batches per 5 min.[10]

The robust DD-EDP considers multiple scenarios with different passenger demands.[19] A scenario *s* is defined by risk levels $\alpha_{sk}\alpha_{sk}$, which are used to predict demand $D_k D_k$ and arrival time $T_k T_k$ of a new passenger on floor *k*. The demand is drawn from the inverse distribution function of discrete random variables F^{-1} for probability α:

$$F^{-1}(\alpha) = \inf\ \{n \in \mathbb{N} | F(n) \geq \alpha\} \quad (4)$$

where *F* denotes the cumulative distribution function for *n* events.

The demand on call floor *k* consists of the initial demand at the time of registering the call and the demand increasing with time,

$$D_k^\alpha = F_G^{-1}(\alpha; 1/\beta) + F_{GP}^{-1}\left(\alpha; \left(\gamma_k + t_{e,d,k}\right)\lambda/\beta\,, 1/\beta\right) \quad (5)$$

where *G* and *GP* stand for the geometric and the geometric Poisson distribution, respectively. The parameter of the geometric distribution is $1/\beta$, while the geometric Poisson distribution is parameterized by the expected number of batch arrivals within time $\gamma_k + t_{e,d,k}$ (i.e., the time since the call was registered plus the remaining time until elevator arrival). The prediction can also be applied for the ordinary Poisson process with individual arrivals. Then, the initial demand F_G^{-1} equals one, and F_{GP}^{-1} reduces to the Poisson distribution with $\beta = 1$.

On floors without calls, a new passenger arrival may occur, at most, in time $\varepsilon_k + T_k$ with probability $1 - \alpha$, where ε_k denotes the time since the previous call was recorded on floor *k*. Since batch interarrival times follow an exponential distribution with parameter λ/β, time T_k can easily be solved from the distribution function.

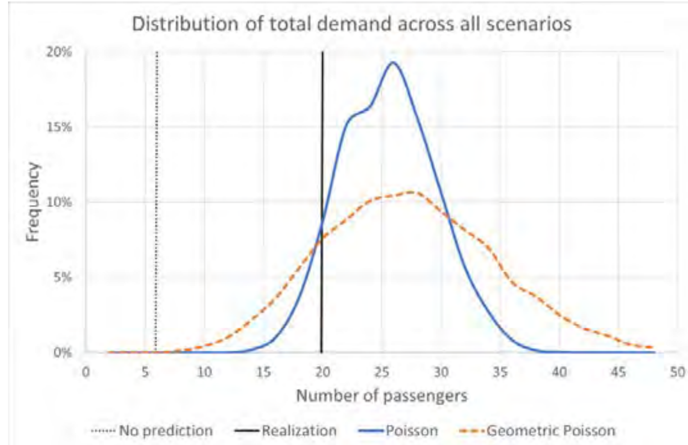


Figure 2: The number of passengers picked up along an elevator route

As an example, these prediction methods are tested on one single-deck elevator under the down-peak condition with the mean batch size of one-and-a-half persons.[19] Approximately 60,000 scenarios are generated by combining three risk levels for each floor. In each scenario, passengers are predicted with both the Poisson and the geometric Poisson process in an instance of the EDP. Figure 2 shows the distribution of the total demand carried along the elevator route across all scenarios. The figure also has two constant lines, which correspond to the demand without predictions and the realized demand in a simulation.

Clearly, the solution to the snapshot EDP has a risk of becoming suboptimal, since the realized passenger demand is much higher than assumed without predictions. The estimation with the geometric Poisson process results in wider distributions than the Poisson estimates. This guarantees the robustness of the solution. Furthermore, the realized values remain within the range only when assuming the geometric Poisson process. This indicates a batch arrival process should be used in passenger prediction.

Genetic Algorithm for Real-Time Optimization

A genetic algorithm is an optimization method that mimics naturally occurring evolution.[7] The algorithm manipulates the population of chromosomes over generations by genetic operators such as crossover and mutation. A chromosome defines a candidate solution to an optimization problem at hand, where each gene of a chromosome determines the value of one decision variable. The fitness of a chromosome corresponds to the objective function of the optimization problem, which is usually minimized.

A genetic algorithm has already been applied to single-deck elevator dispatching and the real-time optimization of an EGCS, which was later extended to double-deck elevators.[15, 17 & 20] The algorithm sets up a gene for each passenger call. The possible values of a gene are the range of elevator car indices, which uniquely map all elevator/deck combinations to an index. Thus, a chromosome assigns both an elevator and a deck to a passenger call, which makes it a single-level model.

The bilevel DD-EDP problem only assigns an elevator to a passenger call on the upper level. The genetic algorithm is slightly modified to solve the bilevel model: a gene value represents an

Continued

Assignment policy	Single-level DD-EDP	Bilevel DD-EDP
Immediate Assignment (IA)	$(2E)^{n_1}$	E^{n_1}
Delayed Deck Assignment (DDA)	$(2E)^{n_1}2^{n_2}$	E^{n_1}
Delayed Elevator Assignment (DEA)	$(2E)^{n_1+n_2}$	$E^{n_1+n_2}$

Table 1: The theoretical maximum numbers of feasible solutions in the double-deck elevator dispatching problem of a group of *E* elevators

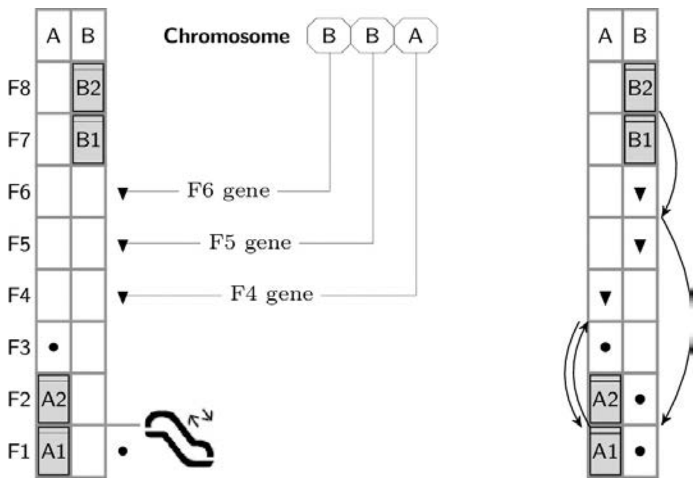


Figure 3: The genetic algorithm for the bilevel DD-EDP

elevator index. Thus, a chromosome corresponds to a solution to the upper-level problem. Figure 3 describes the principle through an example, where deck A1 has a passenger traveling to F3, and three passengers on floors F4, F5 and F6 are waiting to be picked up and transported to the main lobby. The task is to assign an elevator and a deck to these three passenger calls. The outgoing passengers can be served by both decks and transported to the lower or the upper lobby level according to the optimal solution. From the upper lobby, the passengers can use the escalator to travel to the ground-floor exit. The chromosome shown on the left side of the figure assigns the call on F4 to elevator A, and the calls on F5 and F6 to elevator B. The optimal deck assignments and elevator routes for this upper-level assignment are shown on the right side of the figure. Thus, the optimal solution takes advantage of coincident calls on F3 and F4 (simultaneous delivery and pickup), as well as on F5 and F6 (two simultaneous pickups).

The earlier single-level model allows poor deck assignments in the search space of the genetic algorithm. For example, deck A1 could serve floor F4; deck B1, floor F6; and deck B2, floor F5, which would maximize noncoincident stops, as well as passenger waiting and journey times. Poor candidate solutions are eventually discarded by the genetic algorithm, but they first need to be evaluated. This, on the other hand, wastes scarce computational resources of an EGCS. The bilevel model discards such irrelevant deck assignments from the highest level of optimization, which eases the search of the global optimum. Naturally, the bilevel model also needs to consider these poor deck assignments, but they are delegated to the less-complex lower-level problems, do not disturb the high-level optimization and can be handled by efficient heuristics.[18]

The assignment policy determines the moment when the serving elevator and/or deck of a passenger call must finally be fixed. In other words, a passenger call can be reassigned to another elevator and/or deck until fixed; e.g., at the deceleration point. This, on the other hand, is in direct relationship with the size of the search space in the genetic algorithm: the search space grows exponentially with respect to the number of newly registered calls n_1 and the number of calls waiting for pickup n_2 (Table 1). Usually, n_1 is small (either one or two), but n_2 may be large.

The most remarkable observation of the table is that the bilevel model has the same size of search space for both the IA and DDA. This means that the DDA does not increase the (high-level) computational complexity from the IA with the bilevel model. In the earlier single-level model, the search space grows exponentially with respect to n_2, which increases the required computational effort of the DDA beyond the practical limit of an EGCS. The high-level complexity of the bilevel model does not depend on the number of decks, which makes this approach efficient also for multideck elevators and other multicar systems.

As an example, consider a large-scale instance in which 32 passenger calls are waiting for pickup. A group of five double-deck elevators serves all floors. One call is newly registered, while 31 are waiting for pickup. Thus, when applying the bilevel model to this problem, the number of feasible solutions equals five for the IA and DDA but $5^{32} > 10^{22}$ for the DEA. Even if the evaluation of one solution took 1 μs, the evaluation of all feasible solutions would take 108 years in the case of the DEA. The genetic algorithm, however, evaluates only about 3,000 candidate solutions before converging to the likely optimum in less than 100 ms, which is fast enough for real-time optimization.[18] The fast convergence of the genetic algorithm is demonstrated in Figure 4, which shows the evolution of population fitness throughout the generations. In the initial population, the minimum (best), maximum and average fitness values are all high. However, they drop sharply within approximately 15 generations to such a level

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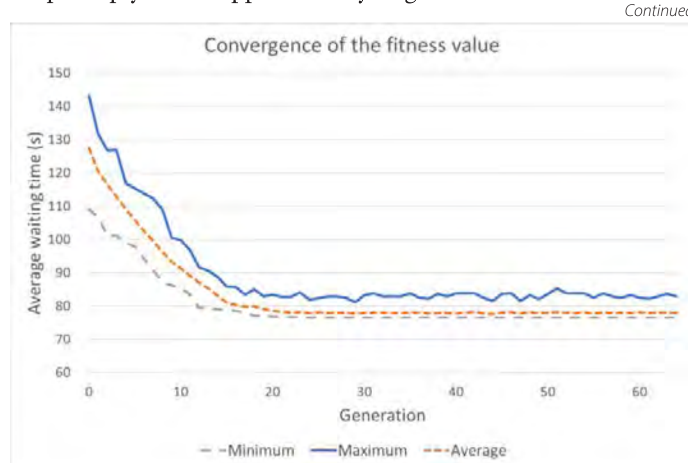

Figure 4: Convergence of the genetic algorithm shown by the minimum, maximum and average fitness values of each generation

that large improvements are not found anymore. The best solution is found during the 24th generation, while the algorithm continues to search for better solutions until the 64th generation.

Simulation Results

A case study of an office building with 18 upper floors and two entrance floors is conducted to demonstrate the effect of the assignment policies on passenger service quality. Each floor has a population of 100. Floor-to-floor distances are equal at 4.15 m. A double-deck elevator group with five identical elevators with a rated speed of 4 m/s, an acceleration of 1 m/s^2 and a jerk of 1.6 m/s^3 serves all floors of the building. The end floors are only served by one deck: the bottom floor by the lower deck and the top floor by the upper deck. Each deck has capacity for 17 passengers. Door opening and closing times are 1.4 and 3.1 s, respectively, while no door preopening is used. In addition, there is a start delay of 0.7 s and door closing delay of 0.9 s; i.e., the delay after passenger clearance before door closing.

Lunch traffic consisting of 40% incoming, 40% outgoing and 20% interfloor traffic is simulated using the KONE Building Traffic Simulator (BTS™).[21] In these simulations, the objective function of the DD-EDP minimizes the journey times of incoming passengers and the waiting times of other passengers. A series of simulations is run with increasing passenger demands from 4% to 15% of the population per 5 min.[8] Each passenger demand is simulated for 120 min, after which the simulation is reset for the next demand. The first 15 and last 5 min are discarded from the results. Average passenger waiting and transit time, as well as time to destination, are shown for each arrival rate in Figures 5-7.[2] In this study, the results of the immediate assignment (IA) represent the first double-deck destination control.[17]

The delayed assignment policies significantly improve passenger service quality, as can be expected. Average waiting times with the DDA are up to 5 s shorter than with the IA. On average, the improvement is about 10% but up to 15% under the most intense passenger demand. The DEA, on the other hand, shows a dramatic reduction of up to 15 s, or 30%, in average waiting time.

Figure 5: Average waiting time for all assignment policies

The delayed assignment policies also reduce passenger transit times. Somewhat surprisingly, the shortest transit times are observed with the DDA, as the averages are up to 5 s or 5-7% shorter than with the IA. In this respect, the DEA does not improve on the IA, except for the low passenger demands. The good performance of the DDA can be attributed to the reduced number of stops, since the origins and destinations of interfloor passengers can be better optimized among the other stops of elevator routes. On the other hand, the DEA seems to weigh waiting times more when it has the chance to reassign elevators optimally.

The improvements by delayed assignment policies in times to destinations combine the observations about waiting and transit times. With the DDA, average transit times are up to 8 s, or 7-8%, shorter than with the IA, which is the result of reductions in both waiting and transit times. The improvement provided by the DEA in average time to destination can be attributed to the improvement in average waiting time. The reduction is up to 15 s but varies between 10% and 15% for different passenger demands. As a result, the DDA and the DEA are rather close to each other (within 5 s), with respect to average time to destination. However, the DEA clearly provides the best service quality.

Figure 6: Average transit time for all assignment policies

Figure 7: Average time to destination for all assignment policies

The significance of the above results is clear if they are contrasted with elevator planning. Typically, passenger demand of 11% or 12% of the population per 5 min is assumed as the required handling capacity for lunch traffic. For such a high demand, passenger waiting time is usually the determining design parameter for the DD DCS. Typically, an average of less than 40 s is required. As shown in Figure 5, the average waiting time with the IA is slightly greater than 40 s with 11% and 12% demand.

Continued

With these demands, the DDA pushes the average waiting time to a satisfactory level, while the DEA can provide good service quality. Thus, the proposed elevator group should be rejected with the IA but is acceptable for the DDA and DEA. Another approach is to look for the maximum passenger demand that the elevator group can handle satisfactorily. Based on Figure 5, the DEA can handle at least 15% (and, probably, 16%) of the population per 5 min. This indicates the DEA can handle at least 30% more population than the IA or DDA.

Conclusion

This paper introduced advanced mathematical models and algorithms for an elevator group control system, which ultimately aims to solve the lunch traffic challenge and fulfill the potential of the DD DCS. The described methods enable higher occupancies in buildings, reasonable passenger service quality in the case an elevator is out of service or further reductions in the number of elevators.

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Dr. Janne Sorsa is head of People Flow Planning in KONE Major Projects in Finland. He obtained the degree of D.Sc. (Tech.) in applied mathematics in 2017 from the Aalto University School of Science in Finland. He has developed optimization models and numerical algorithms for elevator group control systems. His research interests include all aspects of modeling traffic flow in buildings, including transport planning, simulation, behavior, human factors and evacuation.

Focus: Elevator/Lift Dispatching & People

ELEVATOR WORLD Magazine, January 2020

"At the Very Top"
– about Dr. Marja-Liisa Siikonen

At the Very Top

Marja-Liisa Siikonen, one of Finland's most notable female inventors, has earned industrywide respect.

by Kaija Wilkinson

Among Finland's top women inventors, with more than 200 international patents to her name, Marja-Liisa Siikonen (**MLS**) has come a long way since growing up as a farmer's daughter in Seinäjoki, Finland, a village approximately 400 km north of Helsinki. Following her brother to Helsinki University of Technology (HUT, now Aalto University), Siikonen earned a master's degree in Technical Physics; her thesis was on radiation heat transfer in a loss-of-coolant accident at a specific type of nuclear power plant. Originally interested in natural sciences, Siikonen's vertical-transportation (VT) career began in 1984 when KONE hired her as a design engineer.


Siikonen

Once she determined VT as her career path, Siikonen pursued a PhD in Applied Mathematics at HUT; her thesis was on planning and control of elevators serving high-rise buildings.

> *It is rewarding to see that [KONE's] people-flow teams and experts continue the work I initiated.*

Rick Barker, principal at VT consultancy Barker Mohandas, LLC, says Siikonen is "at the very top of her profession," as she knows how to determine VT system size, speed and more with a precision admired industrywide. If not for her, Barker says, VT systems such as the one serving the supertall PNB 118 in Kuala Lumpur (EW, November 2018) that uses harmonized dispatch – built by KONE and collaborated on by Dr. Janne Sorsa – may not have become a reality. As she approaches full retirement, Siikonen is hardly idle, as she chairs a subgroup in the International Organization for Standardization (ISO) committee on a new standard on elevator/lift system planning and is writing a book.

Siikonen is not all work, though. She sings in a choir, and enjoys vacations with family, outdoor sports and reading for pleasure. She took the time to talk with your author (**KW**) about her background, career, personal life, work on international code committees, advice for young people considering VT careers and what her future holds.

KW: When and how did your KONE career begin?

MLS: After earning my MSc, I started work at Nokia Corp. on a scale operating room simulator used to train nuclear power plant operators. After some time, Nokia sold its nuclear power plant simulator department. My husband saw a newspaper ad for an elevator traffic specialist at KONE. My colleague from the university worked at KONE, and recommended the company to me. I started in the R&D department, where my initial work involved coding a software-based lift traffic simulator to test group control systems. The first software-based control systems were launched about the same time.

KW: What roles have you held at KONE and what did they entail?

MLS: In the beginning I worked as a design engineer, then as a project manager in R&D. At that time, KONE launched the Traffic Master System (TMS) microcomputer elevator controller piloted in the Humana Building in Louisville, Kentucky. TMS used mathematical methods such as artificial intelligence and fuzzy logic in call allocation. In 1995, I moved to KONE's High Rise Center, later, Major Projects as a manager and, later, director of Traffic Planning. In 2008, I returned to R&D as director of People Flow Planning, but continued simultaneously working in Major Projects. In 2018, I retired from my main role but continued working on some projects, such as on the ISO Technical Committee (ISO/TC) 178 Working Group (WG) 6, Subgroup (SG) 5.

KW: When did you become involved in chairing the ISO Committee for the new standard and what does it involve? What progress has been made, and what is the goal?

MLS: In my work planning buildings' VT systems, I often encountered the question of whether there are standard recommendations for how to select buildings' elevators. The answer was that guidelines and handbooks about the matter – but no standards – exist. There is ISO 4190-6:1984, however, for residential buildings.

In 2013, participants in an ISO/TC 178 plenary meeting in NYC decided to update the ISO 4190-6:1984 standard. ISO/TC 178 WG 6 nominated me as a convener of SG 5, to do the update. With 17 experts, SG 5 gathered for the first time in spring 2014. The goal of the update was to extend the existing standard to buildings other than residential. In addition to selection of elevators for residential buildings, elevators for hotels and office buildings are included in the new document. In selecting the elevators for buildings, calculation and/or simulation methods can be used that cover all types of controls, including destination dispatch. According to the new draft, ISO/DIS 8100-32, selection of a rated load can be based on

Siikonen speaks at a CTBUH conference in Kuala Lumpur.

(l-r) Dr. Gina Barney, Siikonen, Dr. Bruce Powell and Dr. Richard Peters at KONE's headquarters in Finland during a 2005 meeting

passenger mass or passenger mass and area. This new document is set to go to final voting this month to become a standard.

KW: What can you tell me about your upcoming book?

MLS: The work is ongoing. The subject is "People Flow in Buildings," and it should be ready within a year or so.

KW: Rick Barker says your faith in the harmonized dispatching system for PNB 118 was key to making it a reality. Can you tell me about that?

MLS: Rick, Janne Sorsa and I discussed the harmonized dispatching principle a few years ago. The current de facto, standard destination-control system fixes each passenger call to a specific car and shows the car identifier on the passenger terminal immediately after call registration. The harmonized dispatching system differs from the current system on upper/office floors, where the serving car is indicated by a lantern when the car is about to stop on the call floor.

[Dr. Sorsa] developed this kind of call allocation principle in KONE's building traffic simulator. Simulation results showed that harmonized dispatching is more efficient than the current standard. For the [PNB 118] project in Malaysia, Barker Mohandas specified the harmonized dispatching with double-deck elevators. KONE was the only elevator supplier to bid the system and received the order.

KW: Tell me about your work on Occupant Evacuation Operations (OEO) elevators.

MLS: After 9/11 in 2001, I started to emphasize that people should not only get around fast in tall buildings, but also get rapidly and safely out of buildings during emergencies. I was surprised to discover that the number of floors and population does not affect the number of staircases in tall buildings. Elevator groups, on the other hand, are planned according to population and number of floors to guarantee certain handling capacity and constant building ingress/egress and evacuation times. For instance, in a building with 100 floors, during evacuation two staircases become crowded, and occupant evacuation can last two hours or more. With immediate elevator evacuation, where all elevators evacuate straight to the ground floor, the evacuation time is 20-30 min.

In 2004, we had a Council on Tall Buildings and Urban Habitat (CTBUH) taskforce meeting in NYC. Out of that, CTBUH published an emergency evacuation elevator systems guideline. EN 81-72 had already specified protected firefighters' elevators, which provided the basis for the document and further development. I participated in many conferences discussing elevator evacuation modes and algorithms. Now, we see development of OEO elevators in the International Building Code and National Fire Protection Association NFPA 5000® code, and in ASME A17.1. EN 81-76 concerning evacuation of disabled persons using lifts in low and midrise buildings was published, as well as the technical specification ISO/TS 24744 on the requirements for lifts used to assist in evacuation. The work continues.

"After 9/11 in 2001, I started to emphasize that people should not only get around fast in tall buildings, but also get rapidly and safely out of buildings during emergencies."

KW: Of what accomplishments are you most proud?

MLS: I was pleased to be nominated as the alumna of the year by the School of Science at Aalto University in 2015, and the person of the year by the Finnish CERN Society in 2016. I am an inventor in more than 200 international patents of which KONE is the proprietor.

Furthermore, I am proud of the people-flow planning culture established at KONE. It is rewarding to see that people-flow teams and the trained traffic experts continue the work I initiated.

KW: Do you have any mentors who made a big difference in your career along the way?

MLS: I am grateful to many people at KONE, including Nils-Robert Roschier, who hired me, Risto Kontturi and Johannes de Jong, who have encouraged my work along the way. I learned elevator traffic background from world-famous traffic experts. I even had the pleasure of meeting Dr. George Strakosch and Dr. John Fruin.

The biggest turning point in my career probably came when I started working in Major Projects to help design the VT

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I learned elevator traffic background from world-famous traffic experts.

systems serving high-rise buildings in locations such as Mecca and London. I enjoyed being part of a design team where I could help shape VT solutions for those tall buildings.

KW: What advice would offer to a young person considering a VT career?

MLS: Elevator planning for tall buildings is interesting, but demanding, work. You have to be dedicated and exact in your work, which can be laborious and repetitive. On the upside, you have the opportunity to travel to project meetings where you get to know interesting people such as building owners, dealers, famous architects and consultants. You will see the concrete results of your planning in real buildings, and are always on the edge of the latest designs. Most important to becoming good at whatever you do, however, is to first complete your studies in your specialized, chosen field.

KW: Tell me about your family.

MLS: My family consists of a husband and a son, and was recently extended by a lovely daughter-in-law. My husband, Timo, is a professor emeritus at Aalto University, but continues work in a private company. My son works as a postgraduate student in the Helsinki Institute of Physics co-operating with the (European Council for Nuclear Research).

KW: What do you like to do in your spare time?

MLS: I have many interests. Orienteering [a competitive sport in which participants find their way to various controls across rough country with the aid of a map and compass][1] has followed me from my youth. I sing in a choir as a mezzo-soprano, and work as a historian for my husband's family. In the summertime, we spend a lot of time in our lake house.

KW: What do you read for pleasure?

MLS: I like classical and historical novels. During the past 20 years, I have also enjoyed reading detective stories, mostly by women authors such as Liza Marklund, Anne Holt, Patricia Cornwell and Agatha Christie. Recently, I finished [lead singer of The Who] Roger Daltrey's autobiography.

KW: Where do you see yourself in five years?

MLS: I imagine spending more time with my family. I am also considering doing some consultancy work for tall building projects.

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