CABA™ Continental Automated Buildings Association

Elevator Systems for Future Intelligent Buildings

Part 3: Dispatchers and Energy Conservation

A CABA WHITE PAPER

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The Continental Automated Buildings Association (CABA) is an international not-for-profit industry association, founded in 1988, and dedicated to the advancement of intelligent home and intelligent building technologies. The organization is supported by an international membership of over 370 organizations involved in the design, manufacture, installation and retailing of products relating to "Internet of Things, M2M, home automation and intelligent buildings". Public organizations, including utilities and government are also members. CABA's mandate includes providing its members with networking and market research opportunities. CABA also encourages the development of industry standards and protocols, and leads cross-industry initiatives. CABA's collaborative research scope evolved and expanded into the CABA Research Program, which is directed by the CABA Board of Directors. The CABA Research Program's scope includes white papers and multi-client market research in both the Intelligent Buildings and Connected Home sectors. www.caba.org

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The CABA Intelligent Buildings Council works to strengthen the large building automation industry through innovative technology-driven research projects. The Council was established in 2001 by CABA to specifically review opportunities, take strategic action and monitor initiatives that relate to integrated systems and automation in the large building sector. The Council's projects promote the next generation of intelligent building technologies and incorporate a holistic approach that optimizes building performance and savings. www.caba.org/ibc

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1. ABSTRACT

In Part 1 of this series, we reviewed elevators that serve super high-rise and wide buildings. In Part 2, we discussed remote monitoring and control of these elevators with open protocols, and emergency operation. This paper, Part 3, will examine dispatching and energy concerns. Dispatching may be the most important feature of an elevator system because a dispatcher assigns the appropriate elevator car to serve every landing call and then directs the loaded elevator car to all passenger destinations.

The adoption of open protocols for interoperability has been a goal of modern building automation. This should apply to vertical transport, which includes elevators, for operation and monitoring. The recent publication of BACnet objects for lifts and escalators should facilitate this goal..

The slogan, "In case of fire, don't use the elevators, use the stairs," is no longer valid for super high-rise buildings as it is impossible for occupants to walk down over a thousand steps through stairways for egress. In this paper we examine two most important features of an elevator system: passenger dispatching and energy efficiency.

2. PASSENGER DISPATCHING

Passenger dispatching refers to how the system assigns elevator cars to answer passenger calls from landings. The following descriptions were extracted from a comprehensive reference book on this topic (Barney et. al., 2016). A good dispatch algorithm (call a "dispatcher") can ensure the system provides acceptable service to most passengers (number of passengers handled within a fixed period of time, say five minutes during the peak) and average waiting time (time a passenger has to wait on average after initiating a call at a landing until boarding the elevator) Sometimes, we also consider average transit time (time from passenger boarding an elevator until the destination floor is reached) Usually, the transit time is less important because most passengers are not too sensitive to the time spent inside the elevator car provided that it regularly stops for passengers to exit.

2.1 Classical dispatcher

The most traditional dispatcher is called "collective control," which operates in one of three modes: non-directional, up-distributive-down-collective, and full-collective.

For "non-directional" one pushbutton is provided at each landing. This pushbutton is used by a passenger to register a hall call regardless of the intended direction of travel. However, when an elevator car arrives at that particular landing, the passenger may not enter it because of a wrong direction of travel.

For "up-distributive-down-collective" (also called "down collective") all landing calls are assumed to be down calls. Under this situation, a passenger who wants to go up has to take a down elevator to the ground floor and then change another elevator to travel upward. This type of control is popularly adopted in high-rise residential buildings.

For "full-collective" two separate pushbuttons are provided for each direction of travel. This is also called "directional collective control," which is also called "simplex control" for a single elevator, "duplex control" for two elevators in a group, or "triplex control" for three elevators in a group, and so on. Whenever more than one elevator is involved, it is called "group control". This is the simplest form of group control and is often used in office or commercial buildings.

2.2 Sectoring

Under "group control", some features could be implemented to enhance the performance in terms of handling capacity and average waiting time. Sectoring is one common algorithm. There are several classical ways of grouping landings or landing calls into sectors. As the name indicates, a building is divided into sectors, usually the number of which is equal to the number of elevators in the group. Then, one elevator is assigned to a sector, but there is no limitation to the number of sectors assigned to one elevator.

There are two types of sectoring: "static" and "dynamic".

With "static sectoring" a fixed combination of floors, usually contiguous, is assigned to a sector permanently. There are two types, namely common sectors and directional sectors. A common sector is a fixed sector that is defined for both up and down landing calls generated from landings belonging to that sector. A direction sector is a fixed sector that includes a number of floors belonging to a sector but for one direction only. That means the arrangement of sectors for up landing calls would be different from that of sectors for down landing calls.

With "dynamic sectoring" the number of sectors and the position and range of each sector depend on the instantaneous status, position, and direction of travel of the individual elevators. In other words, the arrangement of sectors is specified during normal operation, but not at the design stage. The boundary of such a dynamic sector is usually where an elevator car is present, either idle or stopping at a particular floor.

It should be noted that sectoring only applies to landing calls generated from floors above the main terminal, usually the ground floor. At the main terminal, passengers are allowed to board any car with doors opened and not yet fully loaded. And these passengers are allowed to register any car calls (floor selection by a passenger inside an elevator) to any floors at will.

2.3 Other features of group control

There are a number of other features that serve passenger demands well, such as:

a) Up-peak service – this is the most important service for office buildings in the morning on a work day; under up-peak mode, most elevators do not answer landing calls from floors above the main terminal; they answer car calls only. Once an elevator becomes vacant at an upper floor, it travels express down to the main terminal; sometimes during up-peak the building is temporarily zoned so that some elevators serve the low-rise, some mid-rise, and some high-rise;

b) Down-peak service – it is a general problem with collective control that the elevator usually serves the highest down landing calls first gathering passengers as it travels down, making passengers at lower landings unable to enter such fully-loaded cars; under the down-peak mode, some elevators are designated to serve mid-rise or low-rise down landing calls;
c) Load-bypass – when an elevator car is almost fully loaded, it does not service any further landing call on this way to car call destinations;
d) Heavy demand floors – special service is arranged to serve such floors by more elevators than normal;
e) Lobby and preferential floor – this normally involves parking one or more elevators at these important floors whenever allowable;
f) Parking policy – this applies to where an elevator is parked during a low traffic condition to provide better service once the traffic gets to medium or high;
g) Basement service – during up-peak and down-peak conditions, performance could deteriorate significantly if basement floors are served; so, under these conditions, some systems do not answer landing calls, but car calls only;
h) Car preference – only passengers inside the car can control it, not outsiders; for example, when an elevator is in firefighting mode or emergency service, car preference is executed, which is usually initiated by a special key;
i) Automatic shut down – this applies to old elevators with a generator set; for modern elevators using power electronic drives, the energy consumption is rather low if the elevator is not ready to serve; and
j) Energy saving – this will be dealt with later.

2.4 More advanced group control algorithms

A relatively newer algorithm, developed in the 1970, is called “estimated time of arrival” (ETA) traffic control. Unlike the traditional “collective control” system that can be implemented on relay based circuitry, ETA requires a computer. Elevators are allocated to landing calls based upon computed car journey times, i.e., how long it will take an elevator to arrive? Elevator data needs to be continuously collected and used to compute the time of arrival, such as total number of landing calls answered at each floor during the last minute, total time taken to answer these calls at each floor during the last minute, average landing call waiting time at each floor, and maximum landing call waiting time and the floor at which it occurred. Newly registered landing calls are allocated to the elevators committed to moving towards the call in the same direction as the call, and also for any uncommitted elevators. To decide the passenger transfer times a fixed time of three seconds for each stop for a landing call is assumed. For car calls, the estimated number of passengers in the elevator and the number of relevant car calls are considered. Another relatively new approach is called “stochastic control”, the discussion of which is beyond the scope of this article.

A successful implementation of the dynamic sectoring control during the up-peak period (the most difficult period to serve in a high-rise office building) for landing calls generated at the main terminal was the "channeling control" (US patent 4804069A) invented by Otis in the late 1980's. During up-peak conditions, each car is dispatched from the main entrance floor to an individual plurality of contiguous floors, defining a "sector". Sectors are contiguous. The number of sectors may be less than the number of cars. Floors that constitute a sector assigned exclusively to a car are displayed on an indicator at the lobby. Sectors and cars are selected for assignment in a cyclical or round-robin sequence. Then, passengers automatically board the relevant car going to their destination floors based on the displayed indications.

The modern approach of car dispatching relies on additional information from the passengers. In those old days, the system only knew the intended direction of travel of the passengers. If the number of passengers and the intended destination of travel of each are known, car dispatching could be more intelligent and efficient. This concept is called "hall call allocation" (HCA), or "destination group control" (DGC), which was suggested in the 1970's and first implemented in the 1990's by Schindler, called Miconic 10. Both HCA and DGC refer to the same concept with slightly different algorithms for up-peak and non-up-peak scenarios.

A digital keypad with floor numbers is used to replace the traditional up-down pushbuttons at each landing. The HCA controller can track every passenger from selection of floor number (called "registration") to destination. The advantage of HCA is that the "channeling control" function is intrinsically built in. For every landing call, every passenger needs to press the destination floor, and the name of the allocated car is displayed on top of the keypad. In this way, the passenger is directed to board a specific car. Therefore, the average waiting time is unavoidably lengthened. But by this method, the number of stops during a round trip during the up-peak period can be reduced, thus the round trip time as well. So, more passengers can be handled in the same period of time, the handling capacity boosted. A shorter queue is present at the entrance lobby. During the pure down-peak period, there is no advantage because there is usually only one destination floor, the ground lobby.

Each time a new landing call is registered, the computer allocates the call in turn to each of the elevators available and evaluates a cost function that considers passenger waiting time, passenger average journey time, or a combination of both. The allocation associated with the lowest cost is then adopted. Usually, the passenger average journey time is used to evaluate the cost during up-peak, but sometimes a penalty is added to the cost if the passenger average waiting time exceeds an acceptable maximum value. It is because by using journey time, calls terminating at the same floor tend to be allocated to the same elevator, thus reducing the number of stops in a round trip during up-peak. But then a passenger may need to wait for the second or even third arrival of a car to board it, thus lengthening the waiting time. Outside the up-peak period, the HCA system automatically switches back to using average waiting time for the cost function. Psychologically a shorter waiting time is more preferable for passengers than a shorter journey time.

It seems that HCA are the state-of-the-art of car dispatching algorithms. I would speculate that it would be the dominant control system eventually. Further advancement is mainly in the integration of the HCA system with more information technology features. Schindler's PORT™ system is briefly discussed here for illustration; other international manufacturers have similar offerings. The conventional 10-digital keypad has been replaced by a sophisticated touch-screen terminal to provide more user-friendly input and displays. Besides manual input by finger typing, the terminal can read an RFID card so that the usual destination floor of a particular passenger is known and the allocated car is shown immediately. With an RFID system, the location of each passenger can be traced to provide security measures.

The terminal can also assist emergency evacuation by providing visual information and evacuation instructions for anyone approaching any elevator group or lobby in the building during an emergency, such as a fire, earthquake, or and terrorist attack. If the RFID card of a disabled passenger is recognized, more space in the elevator and more time to arrive at the calling floor might be allocated. Audio input and announcement could be available to aid passengers with poor eye sight. A VIP passenger can also be appropriately accommodated.

In the future, it is expected that the elevator system could merge into the general information system of the intelligent building and further into the community, including the building. The elevator system could operate jointly with other transportation means such as a subway system, public buses, and the private vehicles of building occupants to facilitate an improved transportation network for those living or working in the building. This is an aspect of the "smart cities" concept.

3. ENERGY EFFICIENCY

Previously, the energy consumption of elevator systems did not receive much attention because it only accounted for a relatively small percentage of total energy consumption of a building. In fact, this statement is correct only for a commercial office building. According to the statistics of a government department in Hong Kong overseeing energy efficiency, the total consumption of an elevator system in a typical office building is less than 11% of the total (Yeung et al 2011). According to *Lift Report* by Asvestopoulos (2010), in Europe, energy consumption of elevators typically represented 3 to 8% of the total energy consumption of buildings, depending on the structure and usage of the building, the type, and number of elevators. This report published in 2012 estimated that there were close to 11 million elevators in operation worldwide, with a growth of over 0.6 million per year. Now, this figure should be close to 14 million. Although the energy consumption of elevator systems in commercial office buildings does not account for a high percentage, it is quite significant for residential buildings where lighting and vertical transportation systems are common building expenses, while heating, ventilating, and air-conditioning are paid by tenants in most residential buildings.

At present, there are energy codes specifically for elevators in Europe and Hong Kong. In Europe, VDI 4707 of Germany was first published in 2007. It classifies elevator performance into seven categories: "A" is the best and "G" is the worst. This classification is based on two measurements, namely "travel" and "stand-by". Then, a mathematical model is employed to analyze the measurement with reference to usage category, speed, rated load, and travel height to arrive at the classification. The "travel" demand is the total energy demand of the elevator during trips at specified trip cycles and with a defined load while the resultant specific demand value is given in mWh/m-kg. Four usage categories are defined, namely, "low", "medium or occasionally", "high or frequently," and "very high or very frequently". The actual procedures of measurement and analysis are detailed in BS EN ISO 25745. Clause 4.2.1 of ISO 25745-1 2012 stipulates the procedure to determine the main energy of running as follows:

a) Run the empty car to the bottom landing;
b) Start the energy measurement;
c) Start the terminal landings cycling test;
d) Stop the cycling operation after a minimum of 10 cycles;
e) Record the number of cycles and total energy consumed; and
f) Average consumption is obtained.

Section 4 of ISO 25745-2 further specifies making measurements in two ways, with one run between two terminal landings with two complete door cycles (termed a reference cycle), or with one run between two predetermined landings with two complete door cycles (termed a short cycle). In this ISO standard, six categories of usage are specified, versus four categories in VDI, i.e. "very low", "low", "medium", "high", "very high", and "extremely high" respectively. Based on the running energy of a reference and short cycles, and subsequent simulations and statistics, the total annual energy consumption of an elevator can be estimated.

In Hong Kong, the first energy code for elevators and escalators was published in 1999. With several versions of updating, the mandatory version was enforced in 2013, and revised in 2015 (EMSD 2015). I have been a member of the code committee since 1999 and am now the chair of the division on elevators and escalators. The code is now comprehensive covering electrical systems, HVAC, lighting, and elevators. In the code various parameters are used to govern whether an elevator is energy efficient or not, including rated power consumption in kW when an elevator is moving upward under rated speed and full load, electrical parameters such as total power factor (at least 0.85), total current harmonic distortion, decoration load, lighting power consumption, etc. In addition the air-conditioner, ventilating fan, and in-car lights must be turned off if the elevator has been idle for a certain period of time. During an off-peak condition at least one elevator within a group must be under a parking mode, not readily available to serve passengers. Also, an elevator with a rated speed of 3 m/s (600 fpm) and rated load at 1,000 kg (2,200 lbs.) must be equipped with regenerative braking. And every motor drive of an elevator has to be equipped with a metering device that can measure voltages, currents, total power factor, total harmonic distortion, energy consumption in kWh, power in kW, and maximum demand in kVA.

Readers are welcome to download a copy of the energy code from the official web site of EMSD, HKSAR Government (http://www.beeo.emsd.gov.hk/en/pee/BEC_2015.pdf). Please note that the 2018 version will soon be published various parameters will be further refined.

Codes around the world now emphasize the power consumption of the motor drive. About 14 years ago I proposed the concept of <J/kg-m> that accounts for the performance of the dispatcher. An intelligent supervisory control system could serve more people in one trip, which should be considered an element of energy efficiency even if the motor drive may not be the most energy efficient. The analogy is the consideration of artificial illumination in two rooms: LED lamps in Room A and CFL lamps in Room B. Though the hardware performs better in Room A, Room B is still considered more energy efficient if the lamps in Room B are only turned on when it is occupied while lamps in Room A are on 24/7. This is simply a matter of good housekeeping.

So, the benchmarking parameter <J/kg-m> measuring the amount of energy to convey the weight of one kg of a passenger to move one meter along the hoistway, irrespective of the moving direction, can reveal whether the system is energy efficient or not. Even if a motor drive consumes a bit more energy while it conveys many more passengers, it is still considered efficient. Another analogy is the comparison of energy efficiency between a big bus and a small taxi. This parameter, the lower the better, was included as an emerging good engineering practice in the technical guidelines of the energy code of Hong Kong (EMSD 2015.) Readers who want to know more about various energy codes and my benchmarking parameter may refer to (So 2014d; So 2014e.)

It is certain that by dispatching elevator cars more intelligently to serve passengers, it is possible to consume less energy to convey more passengers. Furthermore, it has been well known that a lightly loaded upward moving car and a highly loaded downward moving car consume less energy or even re-generate energy back to the power grid. For a highly loaded upward moving car, if the counterweight is heavier, less energy is consumed. A counterweight weight adjustment method was proposed to select the optimal counterweight, of course within a safe range, say between 40% to 55%, based on traffic statistics (So et al. 2012.) This optimal setting can save energy throughout a period of say two weeks, but cannot save energy trip by trip. Unfortunately, up to now, it is still impossible to vary the counterweight trip by trip. Otherwise, the energy consumed can be very much reduced. Some researchers are investigating the possibility of varying the counterweight trip by trip to achieve the optimal energy consumption.

Regarding motor drives, besides the feature of a high torque-to-size ratio, pmsm (permanent magnet synchronous machine) motors consume less energy compared to conventional induction motors in general when delivering the same mechanical power. However, as discussed in a previous article of this series, linear motors will become dominant when elevators need to travel both vertically and horizontally with many elevators traveling in one hoistway, like trains on a long rail line. In such circumstances, it may become meaningless to talk about pmsm or counterweight anymore. Attention would then shift to the energy performance of linear motors.

4. CONCLUSION

In this white paper, intelligent dispatchers and energy efficient elevators have been discussed. Intelligent dispatchers ensure high efficiency in transporting passengers and will benefit from artificial intelligence features. Energy efficiency is essential for sustainability and environmental protection.

I trust that readers of these three CABA Elevator White Papers will gain insight into how vertical transportation in super high-rise and wide intelligent buildings will evolve in six area: speed, dimensionality, online monitoring, control and maintenance, emergency egress, dispatching, and energy conservation. Without smart and automated vertical transportation systems, buildings cannot be smart and automated.

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