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The Evolution of Elevator Control Systems in Society

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Abstract

Although elevators have been referred to since antiquity, with one of the first occurrences being to one made by Archimedes in 263 BC, a number of important innovations and cultural shifts have made it into something we rarely think about today. In this paper I will cover the technological innovations which have led to elevators' current societal niche, current trends in elevator and elevator control system design as well as what the future may hold.

How Passenger Elevators Came to be

Although elevators have been referred to since antiquity, with one of the first occurrences being to one made by Archimedes in 263 BC, a number of important innovations and cultural shifts have made it into something we rarely think about today.

The biggest time period for innovation in elevators came about during the late industrial revolution when massively increased demand for raw materials led to shaft mines getting progressively deeper, and thus miners needed ways to enter and leave the mines with the material in a way that was safe, quick, and flexible. Steam power was applied to elevators in the early-mid 1800's and in 1953, an improved safety mechanism was invented by Elisha Graves Otis allowing elevators to be safely used by people.

With dramatically increasing land value in cities like New York and Chicago, and the development of stronger steel, there was an engineering-enabled market pressure to build taller in order to maximize available space and rent income. Elevators were installed in larger buildings in order to make the upper floors livable as before the introduction of elevators, buildings rarely built higher than 5 stories.

Manual Control Systems

The primary control mechanism for early elevator cars was via a rheostat. This allowed the operator to not only control the direction of motion for the car, allowing them to move users up and down the building, but also it's speed so that the car can move quickly between floors but still align the car with the floor level for best user comfort.

In order to provide for users not on the same floor as the elevator car was resting an elevator operator would move the elevator to where the user was located and take them to their destination without the user touching the controls as there were additional safety hazards and the public was likely not completely comfortable with the technology at first.

Manual vs. Automated Control

This process was eventually automated. One of the major motivating factors for the automation of this system was regularly striking elevator operators, causing the life in the building to a standstill until whatever disagreement which started it was resolved. This was resulting from the fact that tall-buildings, and thus elevators, were most often found in expensive cities, making the cost of labor also high. So there was pressure to make a system which had fewer total man-hours involved with its operation.

An additional problem resolved by automation was the human operators' inability to quickly and precisely stop the elevator at the right height, especially when their view was obstructed by riders. This increased precision allowed automated elevator systems to stop at the exact same height as the destination floor, making the user more comfortable with stepping in and out of what was essentially a box suspended by a cable within a shaft of a building, and even increased accessibility as handicapped people would struggle with the gaps and height differences.

Additionally with the elevator operator developing a good idea of who goes where in the building, they can develop an intimate knowledge of the users and their social lives, for example if the Smiths live on floor 5 and the Robinsons live on floor 10, and Mr. Smith and Mrs. Robinson regularly go to floors 5 and 10 but not their partners, this information could potentially be held against the residents. Thus having an elevator operator is a needless invasion of privacy which could be another motivating factor for the decline of manual elevator control.

Early systems had a number of downsides, one of the largest was that the automated systems could be expensive to install and maintain, with the more complex vacuum tubes and mechanical systems breaking more often than completely analog/manual systems of the past. However with the invention of the transistor and other technological improvements, the system came to require very little maintenance, and thus this was no longer as serious of an issue.

Another issue is that these systems didn't have the insights that a human operator would have in an emergency situation, and with many modern things like elevator phones not being invented or commonplace yet, an automated elevator was notably less safe. Although the mechanical system generally caught the most relevant fear (falling instead of controlled descent/assent). In the event of a fire, or some other issue, things weren't as clear.

Additionally, because the automated system does not know the identity of the riders, it's unable to enforce security or block off access to particular floors. This could result in safety or liability issues. Some elevator systems have an id system which resolves this but this is very uncommon, and more often than not people have to take the closest floor to their destination and then switch to stairs with a key-ed entry to the secure area. And although this works, it's not ideal, especially for things like events. Which would be much easier to manage with a human operator.

Early automated elevators were likely less effective than manually controlled elevators, with the system not moving or accelerating as quickly and the algorithm lacking some optimizations which took time to recognize and implement. Poor effectiveness generally shows up in the form of increased average wait times for the riders, lower throughput elevator and/or carrying capacity.

Standard Elevator Algorithm and Terminology and Control Modes

The standard elevator algorithm works as follows:

> Upon receiving a request, move in the direction of the request, picking up any requests moving the same direction as the target, continue moving in that same direction processing requests until there are none, at that point idle moving the machine or start processing requests in the opposite direction.
>
> Although this algorithm has found uses outside the world of elevators, it's a bit simpler than modern elevator algorithms which are more complex and can take into account more data to improve efficiency. Which will be covered later.

In order to optimize throughput, an optimal algorithm must follow human behavior patterns, in order to reduce wait times. A notable pair of manual elevator modes for doing so are called "up peak" and "down peak" control modes. Which best align with when a large number of users are entering and leaving the building respectively.

In an office building the "up peak" control mode could align with the morning start time for many employees, and thus the majority of the building's elevator cars would be stationed in the ground floor and filled to capacity before dispatching to the requested floors. Versus a "down peak" could be fitting for a hotel when it's known that there is a midday weekend event which many guests would be attending.

Beyond Standard Elevator Algorithm

There are a number of factors to take into account when optimizing a real-world elevator algorithm. Because the scheduling challenge is NP-hard there of course isn't a simple solution, but there are a number of heuristic approaches to optimize elevator scheduling while taking into account the number of requests serviced with respect to the capacity of the car and other live operational data. For example (1).

Many elevator manufacturers closely guard their algorithms as trade secrets, and modern elevator algorithms can be very complex and optimized for a wide variety of situations.

Manual Learning vs. Automated/Machine Learning

In addition to manually designed algorithms, machine learning has been applied to this problem with promising results (3). The studies in question used machine learning models trained on historical data in order to optimize time efficiency. For example Swedish researchers applied a live-updated model to identify the up-peak pattern and saw a 12.5% improvement in performance (2).

In order to appropriately compare manual learning with machine learning we have to go back to the days of manual control. Eventually the operator may learn the riders for a particular building: what floors they use, what times they use the elevator, etc. in addition to when things are busy (times, days of the week, direction, etc.) and use this data in order to increase throughput. Although, I was unable to find a system which learns rider identities in order to increase throughput, many systems do track usage times in order to search for patterns, and this is a common goal for machine learning algorithms, thus they can provide an even better increase in effectiveness, despite using less input data, as machines tend to be better at recognizing patterns when compared to humans.

Another benefit of applying machine learning to an elevator control system is that it allows the algorithm to become bespoke to the building it's installed in versus being developed as a general, one-size-fits-all solution by the manufacturer. This allows elevators in societies with behavior unlike those of the manufacturer, for example as a result of religious practices or local traditions.

Beyond Elevators

Ultimately, elevators represent an ideal candidate for the application of machine learning. The problem is highly statistical and involves recognizing and acting on patterns in data and importantly getting the problem incorrect does not have dangerous repercussions such as death, harm, or property damage. In the worst case scenario, the algorithm could cause the rider to wait longer before arriving at their destination or take a car that's over-capacity. Whereas a driverless car could very easily become responsible for multiple instances of vehicular manslaughter.

It's clear that although current machine learning technologies are super valuable and present enormous potential, they are ultimately only statistical models and we as a society need to weigh their applicability to a given problem as there are many for which these types of solutions simply aren't a good fit.

Looking Forward

Additional sensor data such as security cameras with computer vision (or more likely, scales) which can estimate the current load and number of people at each request could be factored into a heuristic algorithm in order to improve efficiency. It's also possible to utilize a machine learning approach, which could potentially even grow its training set with real world usage data at the location it's installed in, providing a bespoke algorithm. However it remains to be seen if these technologies will ever be worth the added installation cost especially compared to simply adding more elevators.

One notable area of development is that of elevator systems for super-tall buildings (6), which have taken some unique design approaches, which change more about the elevators than just the control system. Some use a "Destination Dispatch System" (DDS) which asks the riders which floors they'd like to go to before the elevator arrives to pick them up or even some systems which have different elevators operating between limited subsections of floors, thus making the user take a different route depending on their destination. However these innovations have only been implemented for a very small subset of buildings and it's unlikely that they will become widespread soon due to the increased cost of input mechanisms on each floor along with these systems not being relevant for the vast majority of buildings with fewer than 20 floors or only a single elevator.

In addition to just optimizing throughput of humans, there are a number of other less-explored priorities, such as reducing energy consumption. While modern elevators, especially those in tall buildings, include regenerative braking systems and more efficient components, this goal could likely be incorporated into the algorithm in order to reduce movement which is not valuable enough to warrant the energy costs. This also could reduce wear and tear on the system.

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