A brief review on vertical transportation research and open issues

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Abstract Vertical transportation refers to the movements of people in buildings. High-rise buildings have emerged as a common construction nowadays. In such buildings, the vertical transportation is extremely difficult to manage, specially, when the people arrive at the same time at specific floors wanting to travel to other floors. To solve such situations, the installation of elevator group control systems (EGCS) is a usual practice. EGCS are used to manage multiple elevators in a building to efficiently transport passengers. EGCSs need to meet the demands by assigning an elevator to each landing call while optimizing several criteria. This paper reviews the most relevant contributions in vertical transportation industry.

Keywords: Vertical transportation, EGCS, landing call, optimization

1 Introduction

In the late years, the rapid growth of the building industry and associated technologies has been demanding parallel growth in the field of vertical transportation. The progressive price increase in the city urban centres has produced an intensive ground exploitation with increasing prices of the ground. This has resulted in the construction of tall buildings. To manage with the vertical transportation system of such buildings, the installation of synchronized elevator groups has become a usual

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practice. In addition, the multiple criteria arising make the problem particularly difficult. Traditionally, the main objective has been the minimisation of the passengers' waiting time to take a lift. Also, other significant performance criteria are the necessary limitation of the maximum waiting times and the queue sizes of persons waiting for the lift. However, new efficiency criteria are emerging, such as the energy consumption. This criterion is supported by cost and sustainability reasons. In fact, despite of an increasingly environmentally aware society, also a more rationale consumption of energy will lead to the reduction of the costs of the electronic devices, as well as the reduction of the energetic invoice at the same time. This paper addresses a quick review of the state of the art that should be enhanced by other recent readings such as Fernandez and Cortés (2015).

The rest of the paper follows with the definition of an EGCS and a proposed taxonomy for the problem. Subsequently, the next sections focus on the proposed problems in the taxonomy, such as data capture, traffic pattern recognition, self-tuning, car-landing call allocation and dynamic sectorization techniques. After that the paper highlights the main conclusions and further research in its final section.

2 Elevator Group Control System Definition and Taxonomies

An EGCS mainly consists of hall call buttons situated on every floor, car call buttons inside each cabin and a group controller. The functionality of an EGCS is to manage multiple lifts in a building in order to efficiently transport passengers. The primary task an EGCS needs to solve efficiently is the landing call assignation problem: this problem appears when a passenger wants to travel from one floor to another and so presses the landing call button at a floor, generating what is called in the argot a landing call. The duty of the EGCS is to satisfy all the demands by assigning a lift to each landing call (call made at a floor) in a way that some criteria are optimized. These criteria can be service oriented, such as average waiting time or long waiting call percentages or energy consumption.

Vertical transportation has an inherent significant amount of uncertainty due to the lack of information regarding the floors that the passengers wants to visit previously they have got into the elevator. In addition, the quantity of passengers behind a landing call is not usually known. It has to be noted that there exists certain systems such as preselection of destination or image capture that are integrated in certain transportation systems although they are not generally implemented. But even for these cases, the system has to deal with possible future calls too. As a result, partial mathematical approaches are very complicated. Moreover, the time lapse in reaching the solution to the dispatching problem has to be minimal: in this sense, a compromise exists between the quality of the solution that a dispatching algorithm can offer and the time that it needs to achieve it. All this kind of inherent uncertainty often requires the careful analysis by means of simulation techniques making use of specific simulation software such as ELEVATE® or by any other proprietary or specifically adapted simulation software (Cortés et al. 2006).

The tasks of an EGCS can be divided into two different categories: primary tasks, those that improve either the quality of service or the quantity of service, and secondary tasks, those that help to improve the performance of the EGCS while executing a primary task (Figure 1 depicts such taxonomy).

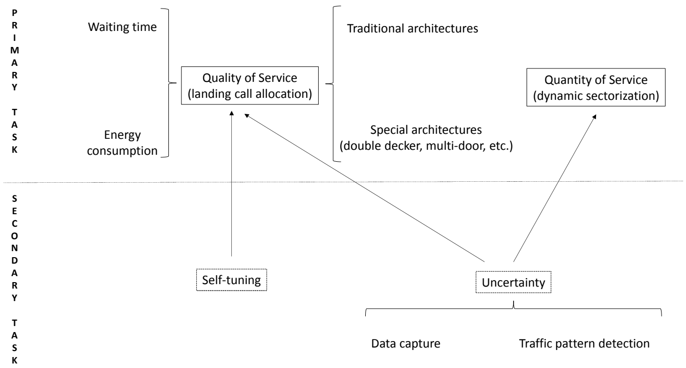

Fig. 1 Taxonomy of the tasks performed by an EGCS

3 Data Capture

The data capture layer integrates the information from the environment. This data capture layer can be divided into two different sub-layers: the software sub-layer and the hardware sub-layer. The hardware sub-layer comprises every physical device that belongs to the system. It includes the landing call panels that can consist of only two different buttons (for indicating the future travel direction) or can consist of numerical panels (in order to indicate the floor destination, in which case numerical panels placed inside the cabins are not necessary). The EGCS needs also to track the elevator position at all times and that is accomplished by placing height sensors on every deck. Large vertical transport systems track the demand and the passenger flows as well by employing technology, such as scales placed in the lifts' decks, so the number of passengers inside can be estimated. The more complex EGCSs can use more advanced technology, such as radar systems or camera-based detectors, to exactly anticipate the incoming passenger demand. The software sub-layer executes algorithms to transform the sensor information into orders to the system movement and is the core of the system.

4 Traffic Pattern

Traffic patterns represent the demand and behaviour of passengers wanting to use a lift to travel from their origin to their destination. Depending on the specific form of the traffic pattern, different behaviours are usually characterised. Figure 3 illustrates a typical traffic pattern in an office building. It shows the number of up and down landing calls that are registered during the working day. Normally, at the start of the day there is a larger than average number of up landing calls. These are due to the building's workers arriving to start work. This stage is called uppeak traffic. Later in the day there is the opposite phenomenon, and a larger than average number of down landing calls takes place. This corresponds to the building's population wanting to go home after the working day. This traffic pattern is called downpeak. In the middle of the day there are two joint phenomena, due to the appearance of up and down peaks. This period has been called midday or lunchpeak traffic. Finally, the rest of the day can be characterised for a constant low demand (usually around 4% of the total population) in both directions. This period has been called the interfloor traffic.

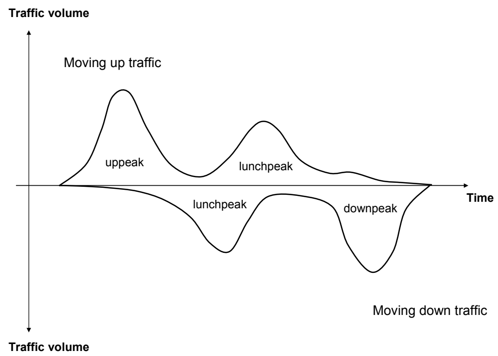

Fig. 3 Traffic pattern in an office building

The correct determination of the period of traffic pattern being experienced by the building is a key factor, because most of the calculations to estimate the passengers' average waiting time, the round trip time and other performance measurements, depend on the identification of the corresponding peak period. In fact, traffic pattern detection is one of the most important and less studied features of vertical transportation, which is a key issue to design a robust system able to efficiently attend to passenger demands. Statistical approaches have been used to forecast the traffic demand (Luo et al. 2005). Also the use of neural networks as predictive devices of the traffic has been provided (Imrak and Barney 1998). However, Fuzzy logic arises as a technology especially suited to detecting traffic pattern recognition due to its own definition and the nature of the detection problem (Cortés et al. 2012; Utgoff and Connell 2012).

5 Self-Tuning in EGCs

Several parameters need to be auto-calibrated in the EGCS. Consequently, captured data from the environment and processed into the algorithms require a self-tuning approach. So, Jamaludin et al., 2010 have addressed the relevance of the issue in vertical transportation. Cortés et al. (2012) have shown the relevance of self-tuning during the pattern detection problem. Additionally, the EGCS can also periodically calibrate the dispatching algorithm to optimize its performance: this optimization can be achieved in real time, in parallel, or through successive simulations carried out during the night employing data contained in a database. Liu and Liu (2007) have shown the relevance of self-tuning in dispatching algorithms.

6 Landing Call Allocation Algorithms: the dispatching problem

The situation arises when a passenger wants to travel from a floor to other different floor in a building. The passenger makes a hall call of an elevator by pressing a landing call button installed at the floor and located near the cars of the elevator group. After that, the elevator controller receives the call and identifies which one of the elevators in the elevator group is most suitable to serve the person having issued the call. This phenomenon is also called "dispatching". It is the task of the dispatcher to monitor the hall and car calls and to control the movements of the elevators to ensure that the passengers are collected promptly and transported rapidly to their destinations. So, the problem to be solved is to select for each hall call an elevator that will minimize a preselected cost function.

Traditionally, the performance of a group of elevators is assessed analysing the passenger Average Waiting Time (AWT) that is defined as the actual time a prospective passenger waits after registering a hall call (or entering the waiting queue if a call has already been registered) until the responding elevator doors begin to open. However, recently, other type of criteria and approaches are gaining interest. This is the case of energy optimization criteria (Fernández et al. 2103; Hasan et al. 2012; Lyu et al. 2010; Tyni and Ylinen 2006).

As the dispatching problem is NP-hard, most of the effective approaches have been based on artificial intelligence (genetic algorithms, fuzzy logic, neural networks, etc.). Genetic algorithms have been widely used providing good and valuable results (Cortés et al., 2004; Hirasawa et al., 2008; Bolat et al., 2010; Chen et al. 2012). Also, other soft computing techniques such as particle swarm optimization have been also applied (Bolat et al., 2013), as well as tabu search approaches (Bolat and Cortés, 2011) although have attracted less attention than genetic algorithms. Also combinatorial searching techniques have been successfully tested as the MV10 system proposed by Utgoff and Connell (2012) or Cortés et al (2013). Lastly, control systems based on fuzzy logic are being enthusiastically tried recently (Rashid et al., 2011; Cortés et al., 2012; Fernández et al. 2014), as well as the implementation of distributed artificial intelligence approaches based on mutliagent systems (Ogoshi et al. 2003; Muñoz et al. 2008; Wang et al. 2007).

Recently, special architectures are being considered in order to improve the efficiency of specific buildings. This is the case of double-deck systems and multi-door elevators (Sorsa et al. 2003; Hirasawa et al. 2008). A double-decker system consists of two cabins that are joined and travel together along the same shaft. In fact, a double-decker is an elevator with two cars attached together, one on top of the other. This system allows passengers on two consecutive floors to use the elevator simultaneously. The main advantage of double-decker systems is the room reduction in the core of the building. From a service perspective, the under-use of one deck at the expense of the other has to be avoided, implying the promotion of the elevators to attend to adjacent landing calls so that the number of stops is minimized. Multi-door elevator systems can serve various buildings at the same time. This special elevator architecture possesses several doors (although the most common are two doors, a rear door and a front door) giving access to each building that is protected by special codes. This system can also be combined with double-deck shafts in order to improve the transport capacity.

7 Dynamic Sectorization

Dynamic sectorization focus on the quantity of passengers being transported in spite of the quality of service given to individuals. This approach tries to maximize the handling capacity of a vertical transport installation during severe uppeak traffic patterns is to divide the building into a number of zones, equal to the number of elevators, in such a way that each zone can only be attended to by the elevator that is already assigned to it. Therefore, the approach is recommended for uppeak situations and not for other cases. The basic idea is to minimize the Round Trip Time. That is to maximize the number of rounds given to the elevators. Sectorization methods have been traditionally divided into two different groups depending on whether the boundaries of the zones are fixed or flexible, being static or dynamic sectorization, respectively. While static sectorization produces a poorer behaviour, dynamic sectorization performs better as it is able to adapt to the changes in the traffic flow, and, unlike the static, the performance of dynamic sectorization can be improved by means of artificial intelligence algorithms (Xu et al. 2004; Li et al. 2007; Li et al. 2007b).

8 Conclusions

The revision of the vertical transportation state of the art shows that one of the main research lines remains being the optimization of the dispatching problem. It has to be noted that most of the presented approaches are iterative and therefore they can take very much time of computation. The calibration and election of the parameters turns into a critical issue in these cases. They must be selected attending not so much to the algorithm accuracy but to the available time of trip of the elevator between different events, that is the time necessary to allocate a hall call. In real cases, an alternative can be stopping the algorithm previously to reach the next event, which would occur after a known time interval. However, the most relevant challenge relates to the link between the Internet of Things and the EGCS. The possibilities of ubiquitous computing at the car together with the capability of integrating ambient intelligence in the vertical transport system is turning into a challenging open issue. This ambient intelligence will lead to greater user-friendliness; more efficient services support, user-empowerment, and support for human interactions. The construction of a real ambient intelligence will need of ubiquitous computing, ubiquitous communication and intelligent user interfaces, such as embedded algorithms for traffic pattern recognition or devices for vision or pattern recognition for lift group control and monitoring among others. Following this line, relevant topics to be incorporated in a next future such as distributed artificial intelligence, vision or pattern recognition for lift group control and monitoring, human-machine interfaces, ubiquitous computing, ubiquitous communication, and embedded systems should try to attract the important research that is being carried out to the vertical transportation world.

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