FUZZY ELEVATOR GROUP CONTROL SYSTEM USING TECHNOLOGY FOR INDUSTRIAL AUTOMATION

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Abstract.*Elevator groups are normally used in commercial buildings and their control can be carried out in different ways, for instance by using the nearest elevator for attending the hall calls or by using a selection process, which evaluates multiple criteria in order to compute the most suitable elevator. From this point of view, the main objective of this work is the analysis and application of fuzzy control techniques in order to define the attribution of elevator priorities for attending the hall calls. This work considers a DCS (Destination Control System), which provides the control system with an a-priori knowledge of the desired floor for each hall call. Also, it makes use of industrial automation architectures for implementing the elevator group control system (EGCS). The methodology applied in this work considers several stages, as follow: At the first stage, the background and the state of art regarding EGCS's was analyzed in order to extract the main advantages of each control strategy used nowadays for proposing an unified model based on fuzzy logic. Secondly, a fuzzy controller was developed. It uses as inputs the distance, the elevator load availability and the passenger waiting time and outputs the suitable value of each elevator for attending the hall call. In order to validate the performance of the elevator system, an elevator group simulator was developed. The elevator group dynamics wasimplemented using a PLC (Programmable Logic Controller) emulator and a hall call generation system. This is responsible forcreating a list of times when the hall calls are expected to occur based on probabilistic techniques. Additionally, an OPC (OLE for Process Control) client software was developed, which can be used for reading and feeding back all the dynamic information of the elevators. On the other hand, the client system includes the fuzzy controller and the data management routines, used for performing the simulation of the elevatortraffic. A case study with various passenger flows was used for simulation purposes and the achieved results were compared with the results reported in the literature, demonstrating a compatible performance of the proposed elevator control system.*

***Keywords**:* Elevators system,Control system, Fuzzy Logic, PLC

1. INTRODUCTION

Elevator group control systems (EGCS) have an important effect on the usefulness of high-rise modern buildings. EGCS are control systems that systematically manage a group of elevators in order to efficiently transport passengers. The elevator system has a dynamic discrete event behavior, in which the elevator assignment consists of a multi-objective problem that must be solved in real-time. The elevator scheduling problem is a *NP-hard* computational class and involves a stochastic process, considering uncertainness about the time instant at which a new hall-call button is pressed, about the number of passengers waiting in halls, among others (Beielstein*et al*., 2003).

Commonly, the elevator system performance is measured using several criteria, such as, service quality related to the waiting time of passengers, traffic throughput and energy consumption (Beielstein*et al*., 2003).

Conventional EGCS implementations are based on fuzzy logic, neural networks, genetic algorithms, Markov chains, among others (Kim *et al*., 1998), (Liu and Liu 2007), (Ikeda *et al*., 2008), (Nikovski and Brand, 2004). In a traditional elevator control system, up and down hall-call buttons are used. The latest elevator system has structural differences from conventional ones, such as Destination Control Systems (DCS), which allow the desired floor to be known before the user enter a car (Markon et al., 2008). Performance of elevator systems that use DCS is improved given that control strategies can be implemented by using the previous information about the number of passengers waiting for a car as well as the passengers' desired destinations. Such a control systems result in a more accurate destination assignment to the elevator cars, since the control system can group the passengers going to the same floor in the same car, thus reducing the waiting time and the number of stops during the travel (Sorsa et al., 2005).

Based on the experience reported by several authors in the literature, this paper proposes a Fuzzy Elevator Group Control System (FEGCS) that selects the most suitable elevator for attending a hall-call. We focus on the control strategy applied to commercial office buildings. The FEGCS receives as input parameters the information acquiredby the destination Data Input Hardware (DIH). Also, this paper describes a new architecture for an elevator system, using a PC for implementing the FEGCS, a Programmable Logic Controller (PLC) for performing the Local Control Systems (LCSs) and industrial instrumentation, such as a DeviceNet® industrial network and human-machine interfaces, such as PanelView® for implementing the input and output interface between the passengers and the FEGCS, implementing the so called DIH. This architecture allows the elevator system to benefits from the advantage proportioned by industrial automation, which is the highest safety and the possibility of integration with the other systems in modern office buildings.

The remainder of this paper is organized as follow. Section 2 briefly presents the related works covering fuzzy logic approaches for solving the scheduling elevator problem. Section 3 describes the elevator system architecture and its main components. Numerical results and analysis based on simulation experiments are reported in Section 4. Finally, Section 5 concludes the work.

2. RELATED WORKS

Many studies have been proposed in order to implement different control strategies for Elevator Group Control System (EGCS), improving the performance in different traffic situations. However, due to the non-linear and the stochastic behavior of the scheduling elevator problem, an analytic solution is difficult to be found; therefore, the most common strategies are based on probabilistic approaches such as Markov chains (Nikovski and Brand, 2004) and artificial intelligent techniques such as fuzzy logic (Kim *et al.*, 1998), neural networks (Liu and Liu, 2007) and genetic algorithms (Ikeda *et al*., 2008).

A method for generating the elevator control strategy, based on fuzzy logic, was proposed by Kim et al. (1998). The authors entitled such a method as Fuzzy Elevator Group Control System (FEGCS). It was based on the classification of traffic status along the day, using fuzzy rules and a dispatch manager for assigning hall-calls to suitable elevators. This strategy resulted in a dynamic behavior for the controller in such a way as to adapt its performance to the changing elevator demands found during a working day. The control strategy tries to minimize three quality service criteria, namely: (a) passenger average waiting time; (b) power consumption; and (c) rate of long waiting calls. A similar approach was adopted by Siikonen (1997), who proposed a FEGCS based on a forecasting method and a fuzzy system for traffic pattern recognition. Also, in this FEGCS the next floor to be visited by the car is calculated using a cost function, taking into account the current traffic situation in the building.

In general, approaches using DCS allow increasing the handling capacity in up-peak traffic situations. In previous works, the waiting time of passengers has been decreased, obtaining better performance than approaches using heuristic control rules (Tai et al., 2008).

Nowadays, the elevator system is expected to allow the implementation of complex algorithms for performing the dispatcher of the elevator cars in an efficient way, further to being sufficiently robust, reliable and secure in terms of hardware and software. In this context, the elevator control system implementation using Programmable Logic Controller (PLC) technologies could be an important advance in the development of reliable and easily maintainable elevator systems.Yang *et al.* (2008) describe an architecture involving only one low end PLC for implementing an elevator system with two elevator cars and nine floors; however, they do not consider the use of elevator group control strategy, thus limiting the scalability of the elevator system. Also, the authors (Yang *et al*., op. cit.) did not consider the use of DCS in their implementation. Therefore, it is expected that the performance of such an elevator control system is worse than that expected from a more elaborated one, mainly in heavy traffic situations. Architectures using PLC's and DCS's have been currently implemented by the ThyssenKrupp company (ThyssenKrupp, 1999), who proposes an architecture based on PLC's and a CAN bus network ensuring reliable connection of all components. Such architecture considers the use of one PLC for implementing the Local Control System (LCS) of each elevator. However, considering that the algorithms involved in the LCS's do not need complex computations, a simpler and cheaper solution, in terms of hardware, would be the implementation of as many as possible LCS's in the same PLC.

3. ELEVATOR SYSTEM ARCHITECTURE

The Elevator Group Control System (EGCS) manages systematically three or more elevators in a group to increase the service of passengers, reducing the waiting time and the power consumption. Most of the EGCS's makes use of a hall call assignment method for scheduling elevators in response to passenger's calls. In this case, the EGCS considers the current traffic situation of a building to select the most appropriate elevator (Kim *et al.*, 1995).

Figure 1 depicts the general architecture of the EGCS proposed in a previous work (Patiño-Forero, 2009). The input data of passengers are entered through a human-machine interface (HMI) based on a *PanelView*®, installed at each floor. These HMI's allow the destination control system (DCS) for an *a-priori* knowledge of the destination floor of the passenger that originated a hall call. A Programmable Logic Controler (PLC) integrates several local control systems (LCSs). Each LCS executes the speed control of one elevator, controls the door, computes the elevator position as well as verifies the available load capacity. The proposed elevator system has a *DeviceNet*® fieldbus network for connecting several industrial instrumentation, such as the AC drivers (each for one elevator), inductive sensors for elevator positioning, digital input/output data modules and the HMI interface (Patiño-Forero, 2009). The proposed ECGS also considers an Ethernet protocol for monitoring processes through a local network.

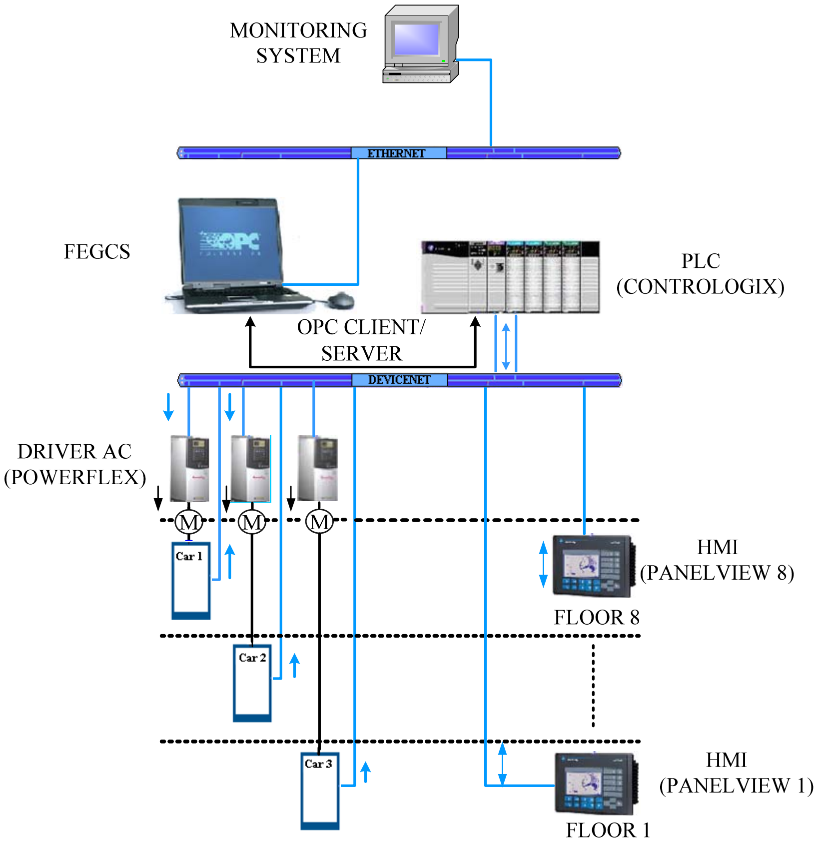


Figure 1 Elevator system (Patiño-Forero *et al.*, 2010)

In this work an elevator control system based on fuzzy logic control techniques has been proposed using software development tools from *Rockwell Automation*. One of the main contributions of this work is the development of a traffic simulation environment for elevator systems using the DCS technique and industrial automation instrumentation. The simulation environment allows the designers to carry out a comparative analysis of different techniques for elevator control. A case study of eight floors and three elevators was used for validating the proposed simulator.

4. THE FUZZY ELEVATOR GROUP CONTROL SYSTEM

Figure 2 shows the main algorithm of the elevator group control system developed in this work. The first stage receives the hall calls and estimates the input variables, waiting time, distance and load capacity of the system. This information is sent to the fuzzy system, which calculates a priority value for each elevator according to its current state. Thus, it is possible to select the elevator with the maximum suitable value for attending the hall call. At the second stage, a collective approach is applied for scheduling the selected elevator. At the third stage, a communication module based on OPC (OLE for Process Control) is implemented. The communication between the control system and the elevator group was developed as a client/server network.

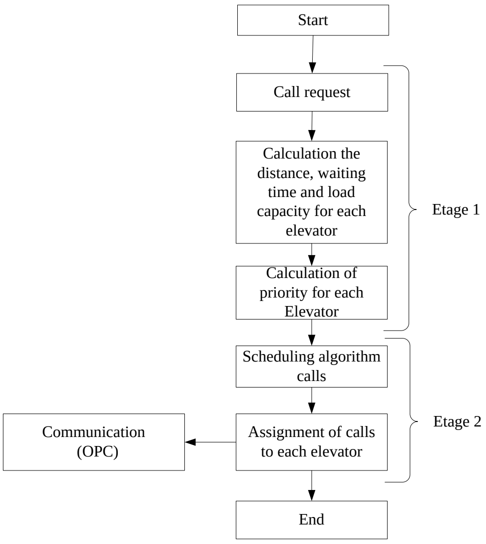


Figure 2 Elevator control system model

4.1 The simulator construction

In order to validate the proposed fuzzy elevator group control system, a simulation environment was developed. It constitutes a suitable software solution for testing the quality service of control techniques in different scenarios. The construction of the simulation environment was based on component diagrams of the elevator system taking into account several development tools, for instance the industrial automation tools and the programming language to be used. Figure 3 depicts the component diagram which explains in a general way all the basic elements of the simulator environment for an elevator group system.

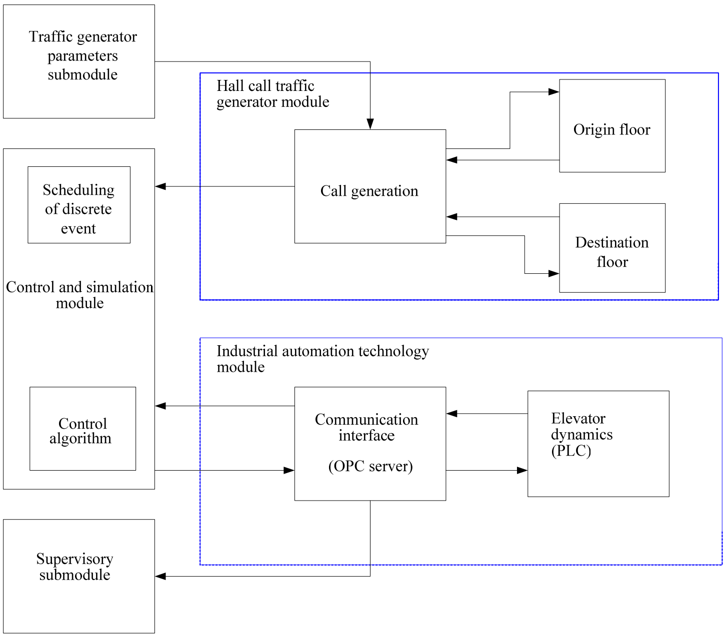


Figure 3 Components of the simulation system

The component diagram is composed of three main modules and two submodules. The first module, namely *hall call traffic generator*, was developed for creating the hall calls based on an exponential distribution function for passenger traffic generation. Additionally, this module applies different algorithms to generate the hall calls according to the desired traffic situation to be simulated. It is composed of three blocks, as follow: (1) hall call floor, (2) destination floor and (3) hall call generation. Notice that this module also requires several parametersettings which are defined by the user and sent through the *traffic generator parameters* submodule. Thus, the *hall call traffic generator* module can create the hall calls according to several building characteristics (or simulationparameters), such as number of floors, number of elevators, expected population, traffic situation, among others.

The *industrial automation technology* module was developed taking into account some industrial automation tools. This module is composed of two blocks, namely *communication interface* and *elevator dynamics.* The first one was developed for connecting components using the industrial standard OPC (OPC Foundation, 1996). The second one, implemented on a PLC emulator, allows different algorithms to emulate the elevator dynamics.

The *supervisory submodule* was designed as a graphics interface and allows the user to check the system behavior. This submodule runs on a host computer, which is connected to the *DeviceNet*®network through the OPC communication protocol, via the RSLinx® communication software.

Finally, the *control and simulation* module implements the general control of the elevator system. This module receives the hall call data and the current position of elevators (according to the current state of the elevator dynamics running on the PCL emulator) to compute the priority value of each elevator, using the fuzzy-based control algorithm (explained below). Once the priorities have been computed, this module dispatches the most suitable elevator to attend the hall call or performs a scheduling process if all the elevators are currently busy.

4.2 The elevator priority calculation

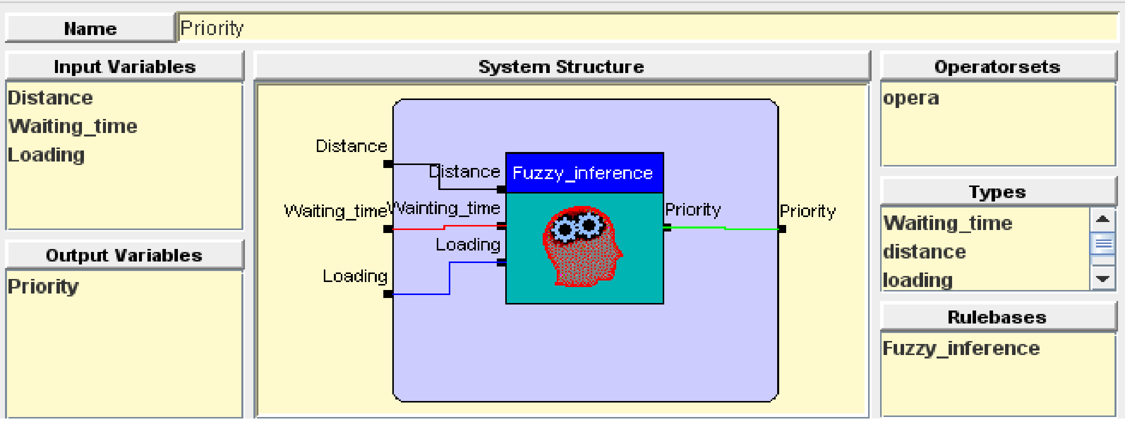
When a new hall-call is requested, a fuzzy system (Xfuzzy 3.0, 2003) is executed in order to compute the priority value of each elevator for attending this hall-call. This computation must be performed N times in order to find the most suitable elevator, where N is the number of elevators. Figure 4 shows the structure of the fuzzysystem that computes the priority value of one elevator.

The fuzzy system receives as input three important variables of the performance measurement of elevator systems, as follow:

a) Distance: it is the number of floors that the elevator must travel from its current position to the floor where the new hall-call occurred.
b) Loading car: The loading car is the current number of vacancies available in the car when it arrives at the floor where the hall-call was generated.
c) Waiting time: is the estimated time that the passengers must wait in the halls until the elevator arrives at the floor after the passenger inputs his desired destination to the system via the DIH. The estimated waiting time is computed using equation (1).

$$Waiting\ Time = (Number\ of\ \ stops) \times T_v + (Distance) \times T_s \qquad (1)$$

where, *Number of stops* stands for the number of stops the elevator car is scheduled to between its current position and the hall-call position; T_v stands for the sum of the door opening time and the door closing time; and T_s, for the travel time between two adjacent floors at the rated speed.



Name: Priority

Input Variables: Distance, Waiting_time, Loading

Output Variables: Priority

Operatorsets: opera

Types: Waiting_time, distance, loading

Rulebases: Fuzzy_inference

Figure 4. Fuzzy priority calculation

In order to develop a elevator control system that can be used for different traffic situations, commonly found in business buildings, we decided to classify the traffic situations in three groups: (1) *Up peak* (at the beginning of the working day), (2) *business time* (commercial time), and (3) *Down peak* (at the end of the working day). The membership functions and the inference database of the fuzzy controller were designed to define the elevator system behavior according to the traffic classification. Table 1 presents the inference rules proposed in this work. These inference rules store the specialist knowledge and establish a relationship between the input variables and the properties of the system outputs.

Table 1 Inference rules of the proposed Fuzzy controller

	Inference rules	Priority
R1	IF(Distance ==High & Waiting Time == High)	Low
R2	IF(Distance == High & Waiting Time == Low)	Medium
R3	IF(Distance == High & Waiting Time == Medium)	Low
R4	IF(Distance == Low & Waiting Time == High)	Medium
R5	IF(Distance == Low & Waiting Time == Low)	High
R6	IF(Distance == Low o & Waiting Time == Medium)	Medium
R7	IF(Distance == Medium & Waiting Time == Medium)	Medium
R8	IF(Distance == Medium & Waiting Time == High)	Low
R9	IF(Loading == Low & Waiting Time == High)	Low
R10	IF(Distance == Low & Loading == Low)	Low
R11	IF(Loading == Medium & Waiting Time == Low)	High

4.3 The sortingalgorithm

The passengers sorting algorithm is a control strategy of modern elevator architectures which make use of destination control systems (DCS). This algorithm checks the registers of the scheduling hall calls of each elevator and compares them with the new hall calls to be evaluated by the fuzzy control system. Thus, passengers with the same origin floor and same destination floor can be attended by the same elevator. Therefore, the new hall calls which were scheduled by the sorting algorithm do not need to be evaluated by the fuzzy control system. The sorting algorithm behavior is shown in Figure 5. It works as follows: A new hall call is requested by an user and the algorithm checks if the hall call has the same origin floor and destination floor than previous ones. In a negative case the hall call goes to the fuzzy control system, otherwise goes directly to the allocation block in order to define which elevator will be scheduled. Finally, the hall call is stored in the elevatorscheduling register.

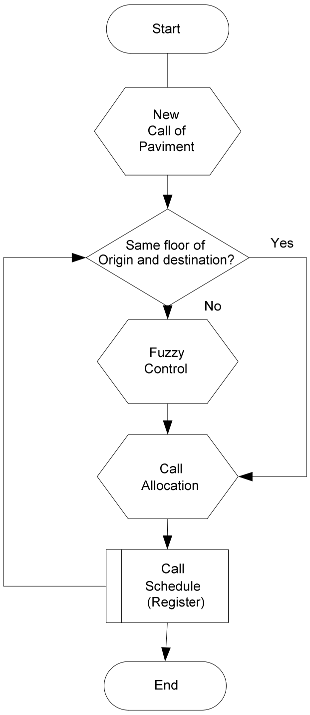


Figure 5 Sorting algorithm

5. EXPERIMENTAL RESULTS

A case study of an elevator system with destination control (DCS) was considered for simulation purposes. A business building with eight floors, three elevators and a population size of 430 passengers was used. All the simulations were carried out for an up-peak traffic situation. In order to quantitatively analyze the effect of the DCS and its respective sorting algorithm to the proposed fuzzy control system (Patiño-Forero, 2009) we have performed simulations using two different control approaches:

(a) Control system with sorting algorithm (CAO). It is based on the previous knowledge of the destination floor in which is applied the sorting algorithm for passengers with same origin and destination floors.

(b) Control system without sorting algorithm (SAO). It is based on the previous knowledge of the destination floor; however, all the hall calls pass through the fuzzy control system, i.e. no sorting algorithm which bypasses the fuzzy control system is used.

The simulation data provide the performance results, which were useful for comparison analysis between the two above explained approaches. In addition, qualitative comparisons with similar approaches in the literature were carried out.

The simulation environment allows to set some elevator parameters, such as load capacity, nominal speed, acceleration coefficient, floor distance and trip times (including the opening and closing door time, which obviously depends on the door size). We made use of the same parametersetting as reported in Markon et al. (Markon, 2006). Table 2 presents the parametersettings used in the simulations.

Table 2 Simulation parameters

Item	**Value**	**Units**
Nominal capacity	10	people
Nominal Speed	0,8	m/s
Acceleration/deceleration	0,7	m/s^2
Open/close door	2,0	s
transfer timeofpassengers	0,8	s
height of a floor	3,5	m

Hall waiting time and car waiting time curves for different passenger flows are commonly used as a criteria for measuring quality service of elevator systems (Siikonen, 2000). These curves allow designers to evaluate the performance of control techniques as well as the group elevator behavior. The *waiting time* is defined as the time interval from the moment a passenger requests a new hall call until he/she boards the assigned elevator. *Destination time* is defined as the total waiting time from the moment a passenger requests a new hall call until he/she leaves the car at the desired floor, i.e., (*waiting time* plus the *trip time*).

Figure 6 shows the performance results of the elevator control system without sorting algorithm (SAO) i.e., using directly the fuzzy control system. It can be observed the *waiting time* and the *destination time* for an up-peak traffic situation.

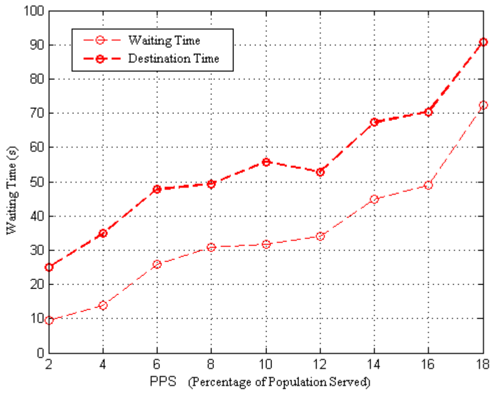


Figure 6. Performance of the SAO control system for an up-peak traffic situation

Figure 7 shows the performance results of the elevator control system with sorting algorithm (CAO). In a similar way, it can be observed the *waiting time* (the time which the passengers wait in halls) and the *destination time* (*waiting time* plus *trip time*) for an up-peak traffic situation.

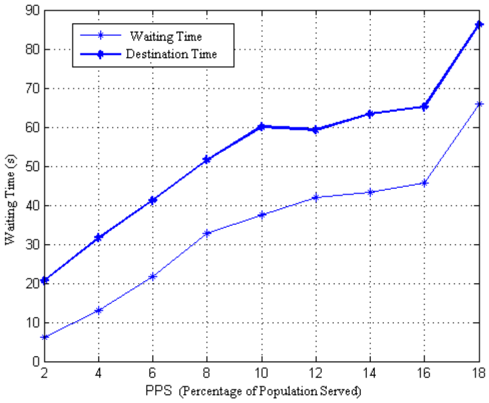


Figure 7. Performance of the CAO control system for an up-peak traffic situation

Figure 8 presents a *waiting time* comparison of the CAO and SAO control systems for an up-peak traffic situation. Notice that the curves are composed of nine different passenger flows, which can be divided in three groups, as follow: (a) small values of passenger flow (2,4,6), (b) medium values of passenger flow (8,10,12), and (c) large values of passenger flow (14,16,18). It can be observed that the control system with sorting algorithm (CAO) has a better performance than SAO approach for small and large regions of the passengers flow. However, for medium values, the control system without sorting algorithm (SAO) provides the shorter *waiting times*.

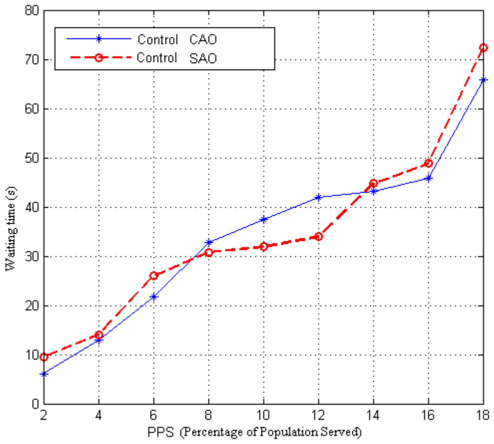


Figure 8. *Waiting time* comparison

Figure 8 presents a waiting time comparison between the control system without sorting algorithm (SAO) and the traditional model proposed by Siikonen (Siikonen, 2000), which uses a conventional collective control (*full collective*). The collective approach considers that all the elevators can attend all the floors. In an up-peak traffic situation, elevators arrive at the first floor with total load capacity, allowing the passenger to board any available car. It is important to take into account that the SAO control system used in this work makes use of the fuzzy controller, and then, all the elevators are not able to attend all the floors and, as a consequence, the passengers can not board any elevator, but the assigned elevator to attend its hall call. Therefore one can expect large *waiting times* of the SAO approach in comparison with a full collective technique, as shown in Figure 8.This figure also presents the waiting time results of the CAO approach used in this work and the modern control system with destination control proposed by Siikonen (Siikonen, 2000). Elevator systems with destination control (DCS) commonly present a higher transport capacity(amountof passengersthattheelevatorcancarryfromthefirst floortoupper floorsatatimeof5 minutes, Barney, 2003) than conventional systems. Figure 9 shows a increasingly monotone behavior in which the growth rate tends to a constant. Obviously, the passenger flow in Figure 9 are lower than the transport capacity of the system, but one can expect an accelerated growth on the waiting times as the flow increases. In the simulation process,such inference becomes evident at the passenger flow of 18%. It is important to take into account that the control system proposed by Siikonen (Siikonen, 2000) presents a slightly higher transport capacity than the case study simulated in this work, thus allowing the simulation to collect more samples and, as a consequence, the resulting waiting time curve presents a better behavior.

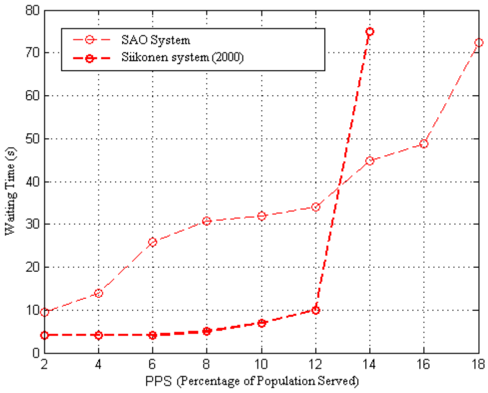


Figure 9 Waiting Time

6. CONCLUSIONS

This work proposes the implementation of control techniques for elevator group systems based on fuzzy logic and using industrial automation technologies. These techniques were developed to be implemented in a modern elevator architecture using destination control systems (DCS), allowing the performance of the control systems to be improved. The elevator system control techniques based on fuzzy logic revealed to be suitable for analyzing the effect of model architectures using DCSs, allowing new algorithms to be executed in order to decrease the waiting time and to increase the passengers comfort.Performance evaluation of proposed control techniques for elevator systems point out that the control system with sorting algorithm (CAO) achieves better results in terms of waiting time than the control system without sorting algorithm (SAO). It can be explained taking into account that the CAO system takes advantage of previous knowledge about passengers destination. Such information is available to the controller due to use of the Destination Control System (DCS) approach, which allows for improving the elevator occupation, thus reducing the number of stops during the trips. Additionally, the CAO and the SAO control systems achieved a behaviorsimilar to the systems reported in literature.

7. ACKNOWLEDGEMENTS

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