DESIGN OF AN ELEVATOR GROUP CONTROLLER USING TYPE-2 FUZZY LOGIC

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The elevator group control systems are the control systems that manage systematically two or more elevators in order to efficiently transport the passengers. In the elevator group control system, the area-weight which determines the load biases of elevators is a control parameter closely related to the system performance. This paper proposes a type-2 fuzzy model to determine the area-weight. The proposed method uses a two-stage fuzzy inference model which is built by the study of expert knowledge. A software has been developed to simulate the traffic flow of three elevator cars in a 15-floor building. The software simulates the movements of the cars as found in practical elevator systems. This simulation software was used to facilitate the evaluation of the proposed Type 2 Fuzzy System strategy. The software allows simulation of different passenger's traffic situations. The Type 2 Fuzzy Logic System is compared with Type 1 Fuzzy System. The simulation results show that the Type 2 Fuzzy Logic Controller has better performance in the case of heavy traffic conditions. Type-2 Fuzzy Logic Controller reduced the average waiting time by 7 – 20 % and the long wait probability by 11 – 30 %.

Index Terms –Area weight, Average Waiting Time, Interval Type 2 Fuzzy System, Long Wait Probability, Karnik-Mendel algorithms

I. INTRODUCTION

Buildings with thirty floors or more are now a common sight in many cities around the world. So the demand for more efficient vertical transportation is rapidly increasing. The installation of multiple elevator is one of the nice solutions to cope with these trends. The elevator group control system, as shown in **Figure** 1, is a control system that manages systematically three or more elevators in a group to increase the service for passengers and reduces the cost such as power consumption.

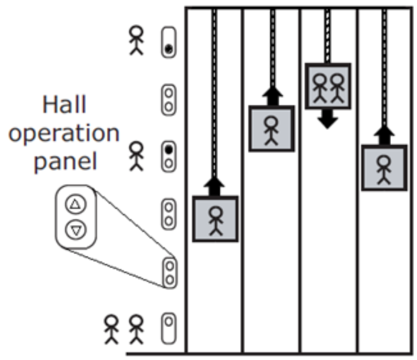

Figure 1. Elevator Group Control Problem

Most of the elevator group control systems have used the *hall call assignment method* which assigns elevators in response to a passenger's call. In this case, the elevator group control system considers the current situation of a building to select the most appropriate elevator.The hall call assignment method assigns a new *hall call* to the elevator having the smallest *evaluation function* value among all the elevators. The *area-weight* is a parameter which affects the evaluation-function value of the elevators in the area close to the hall call.

There have been many researches in this area utilizing numerous approaches in designing the most effective elevator supervisory controller. Various strategy based on fuzzy logic system have been studied to control the elevator group. C. B. Kim [1] proposed a fuzzy model to determine the area-weight. In another work, C.B. Kim proposed a control strategy generation method and fuzzy elevator group control system (FEGCS) in [2]. The control strategy of FEGCS is made using the classification of the passenger traffic and system manager's requirements, and the hall calls are assigned to suitable elevators by generated control strategy. In [3], R. Gudwin introduced a fuzzy group supervisory controller with context adaptation to accommodate different traffic patterns.

This paper explores the use of Type 2 Fuzzy system, which is well known for its powerful in handling an uncertainties [4], to determine the area-weight parameter. Although there are a lot of work on type 2

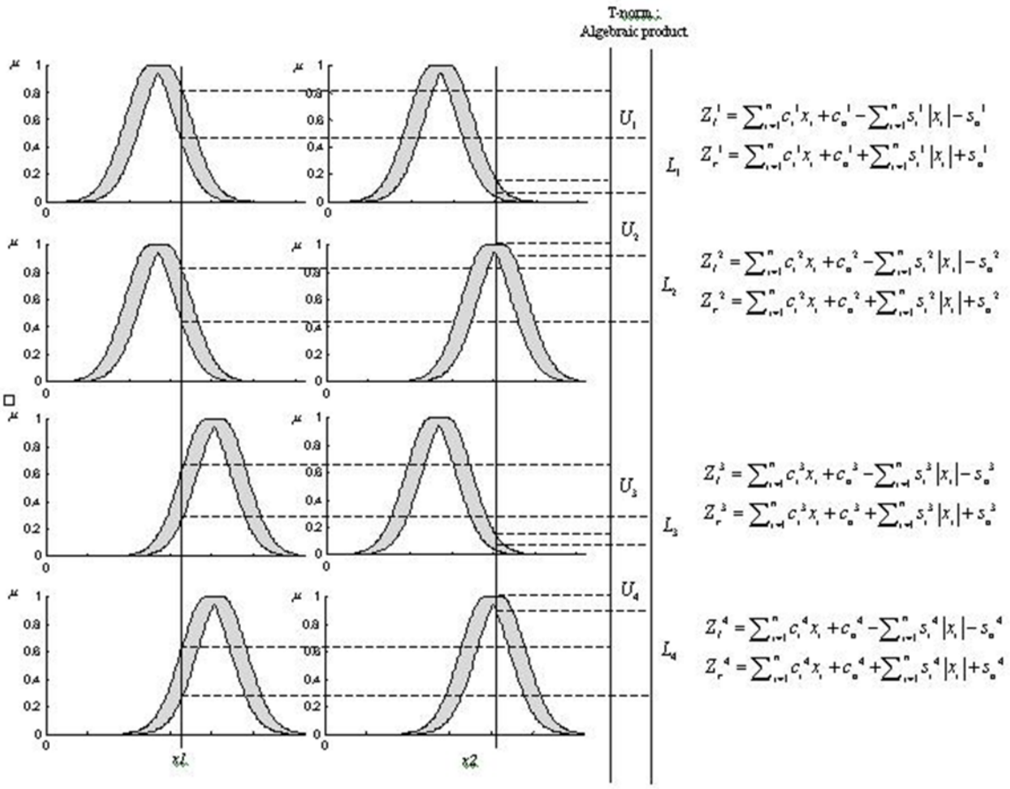

Figure 2. Interval type 2 TSK Fuzzy System Structure

Fuzzy as discussed in [5] – [7], as far as the author concerns, there is no work on development of type-2 Fuzzy is suitable for elevator group control. Contribution of this paper is to propose type-2 fuzzy algorithm suitable for elevator group control and compare the performance between the interval type 2 Fuzzy and type 1 Fuzzy.

The paper is arranged as follows. Type-2 Fuzzy structure is provided in Section II. In Section III we describe the elevator group control system and the area-weight of the control system. Fuzzy model to determine the area-weight is presented in Section IV. Its performance is analyzed through the simulation in Section V. In Section VI, we conclude with conclusion.

II. TYPE-2 FUZZY STRUCTURE

Type-2 fuzzy sets were originally presented by Zadeh in 1975. The new concepts were introduced by Mendel and Liang allowing the characterization of a type-2 fuzzy set with a superior membership function and an inferior membership function; these two functions can be represented each one by a type-1 fuzzy set membership function. The interval between these two functions represent the footprint of uncertainty (FOU), which is used to characterize a type-2 fuzzy set. Type-2 fuzzy sets allow us to handle linguistic uncertainties, as typified by the adage "words can mean different things to different people".

For type-2 TSK models, there are three possible structure [11]:

1. Antecedents are type-2 fuzzy sets, and consequents are type-1 fuzzy sets. This is the most general case and we call it Model I.
2. Antecedents are type-2 fuzzy sets, and consequents are crisp number. This is special case or Model I and we call it model II.
3. Antecedents are type-1 Fuzzy sets and consequents are type-1 fuzzy sets. This is another special case of Model I and we call it Model III.

We use Model I to design interval type-2 TSK Fuzzy system in this paper. A schematic diagram of the proposed T2TSK structure is shown in **Figure** 2., which is organized into *i* input variables and *m* rules.

Rule Base

In a first-order type-2 TSK Model I with a rule base of *m* rules and *n* input variables, is denoted as

$$\textbf{IF } x_1 \textit{ is } \mu_1{}^b(x_1) \textbf{ AND} \dots \textbf{ AND } x_a \textit{ is } \mu_a{}^b(x_a)$$
$$\textbf{THEN } Z \text{ is } p_1{}^b x_1 + p_2{}^b x_2 + \dots + p_a{}^b x_a + p_0{}^b \qquad (1)$$

where $b \in [0, m]$ and $a \in [0, n]$. The consequent parameter $p_1{}^b, p_2{}^b, \dots, p_a{}^b, p_0{}^b$, which are type-1 fuzzy sets, has interval, is denoted as

$$p_a{}^b = [c_a{}^b - s_a{}^b, c_a{}^b + s_a{}^b] \qquad (2)$$

The membership grades $\mu_1{}^b(x_1), \mu_2{}^b(x_2), \dots, \mu_a{}^b(x_a)$ are interval sets to, which denoted as

$$\mu_a{}^b = \left[\underline{\mu}_a^b, \overline{\mu}_a^b\right] \qquad (3)$$

Where $\underline{\mu}_a^b$ is lower membership function and $\overline{\mu}_a^b$ is upper membership function. These rules let us simultaneously account for uncertainty about antecedent membership functions and consequent parameter values.

Fuzzification

This process is transforming the crisp input to a type-II fuzzy variable. The primary membership functions for each antecedent are interval type-2 fuzzy systems described by Gaussian primary membership function with uncertain means, denoted as

$$\mu_a^b(x_a) = \exp\left[-\frac{1}{2}\left(\frac{x_a - m_a^b}{\sigma_a^b}\right)^2\right] \tag{4}$$

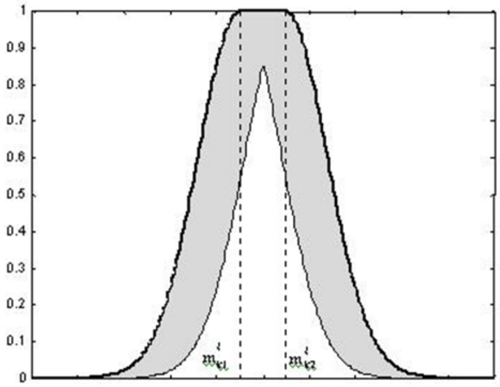

Figure 3. Gaussian interval type-2 fuzzy membership function with uncertain means

where $m_a^b \in [m_{a1}^b, m_{a2}^b]$ is the uncertain mean, with $a = (1,...,n)$ is the number of antecedent, $b = (1,...,m)$ is the number of rules and σ_a^b is the standard deviation.

There are two kinds of type-2 sets. First is a gaussian type-2 fuzzy set, which the membership grade of every domain point is a Gaussian type-1 set contained in [0,1]. Second is an interval type-2 fuzzy set which the membership grade of every domain point is a crisp set whose domian is some interval contained in [0,1]. **Figure 3.** shows gaussian interval type-2 fuzzy membership function with uncertain means

The upper membership function is defind as

$$\bar{\mu}_a^b(x_a) = \begin{cases} N(m_{a1}^b, \sigma_a^b, x_a), & x_a < m_{a1}^b \\ 1, & m_{a1}^b \le x_a \le m_{a2}^b \\ N(m_{a1}^b, \sigma_a^b, x_a), & x_a > m_{a2}^b \end{cases} \tag{5}$$

where

$$N(m_{a1}^b, \sigma_a^b, x_a) = \exp\left[-\frac{1}{2}\left(\frac{x_a - m_a^b}{\sigma_a^b}\right)^2\right] \tag{6}$$

And lower membership function is defind as

$$\underline{\mu}_a^b(x_a) = \begin{cases} N(m_{a2}^b, \sigma_a^b, x_a), & x_a \le \frac{m_{a1}^b + m_{a2}^b}{2} \\ N(m_{a2}^b, \sigma_a^b, x_a) & x_a > \frac{m_{a1}^b + m_{a2}^b}{2} \end{cases} \tag{7}$$

Fuzzy Inference System

Fuzzy inference mechanism applies the fuzzy reasoning on the rules in the rule base in order to derive a mathematically reasonable output or conclusion which represents the problem conditions best. Fuzzy inferences in antecedent using algebraic product, is denoted as

$$\underline{W}^b = \underline{\mu}_1^b(x_1) \times \underline{\mu}_2^b(x_2) \times ... \times \underline{\mu}_n^b(x_n) \tag{8}$$

and

$$\overline{W}^b = \bar{\mu}_1^b(x_1) \times \bar{\mu}_2^b(x_2) \times ... \times \bar{\mu}_n^b(x_n) \tag{9}$$

Figure 4. shows Fuzzy inference illustrative example of the simplified case with two input variable.

The interval value of the consequent Z^b is $Z^b = [Z_l^b, Z_r^b]$, where

$$\begin{aligned} Z_l^b &= \sum_{i=1}^n c_i^b x_i + c_0^b - \sum_{i=1}^n s_i^b |x_i| - s_0^b \\ Z_r^b &= \sum_{i=1}^n c_i^b x_i + c_0^b + \sum_{i=1}^n s_i^b |x_i| + s_0^b \end{aligned} \tag{10}$$

and Z_l^b and Z_r^b denote the lower and upper values of consequent output for b th rule. c_i^b denotes the center (mean) of Z^b and s_i^b denotes the spread of Z^b.

Type Reduction

The Karnik-Mendel algorithms is used for determining c_l and c_r. This process takes the type-2 output set and convert it to a type -1 set. The five steps for determining c_r : [12]

1. Initialize θ_r^b by setting:

$$\theta_r^b = \frac{1}{2}\left[\underline{W}^b + \overline{W}^b\right] \quad b = 1, \dots, n \tag{11}$$

and then compute

$$c' = \frac{\sum_{b=1}^{m} \theta_r^b Z_r^b}{\sum_{b=1}^{m} \theta_r^b} \tag{12}$$

2. Find $k_r \ (1 \le k_r \le N-1)$ such that

$$Z_r^{k_r} \le c' \le Z_r^{k_r+1} \tag{13}$$

3. Set :

$$\theta_r^b = \begin{cases} \underline{W}^b & b \le k_r \\ \overline{W}^b & b \ge k_r + 1 \end{cases} \tag{14}$$

And compute :

$$c'' = \frac{\sum_{b=1}^{k} Z_r^b \underline{W}^b + \sum_{b=k+1}^{m} Z_r^b \overline{W}^b}{\sum_{b=1}^{k} \underline{W}^b + \sum_{b=k+1}^{m} \overline{W}^b} \tag{15}$$

4. Check if $c'' = c'$. If yes, stop and set $c'' = c_r$. If no, go to step [5]
5. Set $c' = c''$ and go to step [2]

For determining c_l, same as previouse procedur, except in step 3, set

$$\theta_l^b = \begin{cases} \underline{W}^b & b \le k_l \\ \overline{W}^b & b \ge k_l + 1 \end{cases} \tag{16}$$

so that :

$$c'' = \frac{\sum_{b=1}^{k} Z_l^b \underline{W}^b + \sum_{b=k+1}^{m} Z_l^b \overline{W}^b}{\sum_{b=1}^{k} \underline{W}^b + \sum_{b=k+1}^{m} \overline{W}^b} \tag{17}$$

Defuzzification

Since the resultant type-reduced output is an interval type-1 fuzzy set, the output of fuzzy can be easily calculate using the

$$y = \frac{c_l + c_r}{2} \tag{18}$$

average of its lower and upper bounds :

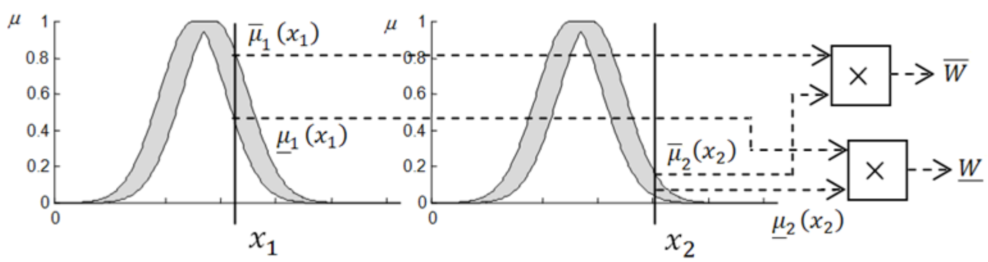

Figure 4. Illustrative example of inference mechanism using algebraic product

III. ELEVATOR GROUP CONTROL SYSTEM

The Elevator Group Control System

In the elevator group control system, there are two types of calls. The *hall call* is given through buttons on the hall of the building, and the *car call* is given in the elevator by the passengers. An elevator group control system has a pair of hall call buttons on each floor, one for *up hall call* and the other for *down hall call*. If a passenger presses a hall call button, an elevator is selected by the group control system for the passenger.

The most important task of an elevator group control system is selecting a suitable elevator for each passenger's hall call (up, down). The selection is made in order to provide service to every floor in a building, to minimize the time spent by passengers waiting for service, to minimize the time spent by passengers to move from one floor to another, to serve as many passengers as possible in a given time and to minimize the power consumption. The selection method is called the *hall call assignment method*. In this method, an *evaluation function* is used to achieve the above multiple objectives. The function is evaluated for each elevator and the elevator with the smallest function value is selected. Let $\emptyset(k)$ be the evaluating function for the k-th elevator, then this function is represented with the following formula :

$$\emptyset(k) = T_{AVR}(k) - \alpha . T_{\alpha}(k) + T_{E}(k) \quad (19)$$

When a new hall call is given on floor *h*, the function value is evaluated for the k-th elevator where *k* = 1, 2, , *n*. In the above formula, $T_{AVR}(k)$ is the estimated arrival time of the k-th elevator (the waiting time of the passenger when we assign the k-th elevator for the new hall call). $T_{AVR}(k)$ is calculated by the following formula.

$$T_{AVR}(k) = \sum_{stop} T_{stop}(k) + \sum_{drive} T_{drive}(k) \quad (20)$$

In the above formula, we divide the path of the elevator into *stop* and *drive*. *Stop* means floors where hall calls and car calls are assigned. *Drive* means floors where there are no calls near the floor. So if an elevator is distant from a hall call or it is moving opposite to the direction of the hall call, the probability of that elevator being assigned to the hall call decreases.

$T_{\alpha}(k)$ is called the *area value* and α the *area weight*, where $T_{\alpha}(k)$ is higher when the generated hall call is nearer to the floors where k-th elevator is going to stop. The value of $T_{\alpha}(k)$ is subtracted to adjust the usage of energy saving effect and α represents the extent of the adjustment.

$T_{E}(k)$ is the elevator's status value. This value is added to prevent selecting the k-th elevator if there exists a special kind of call (VIP call) or the elevator is not running.

The Area-Weight

If elevator k is going to floor n, the *area* of elevator k for floor n is defined. When a hall call happens in this area, our fundamental strategy is to select k elevator for the call. The area represents the range of floors which can be served easily by that elevator. The area-weight is the value to increase the assignment probability for an elevator which is going toward the floor where a hall call was generated.

In general, the area is defined in the form of a trapezoidal as shown in **Figure 5**. The area value $T_\alpha(k)$ is defined for the floors where a call (hall and car) has happened.

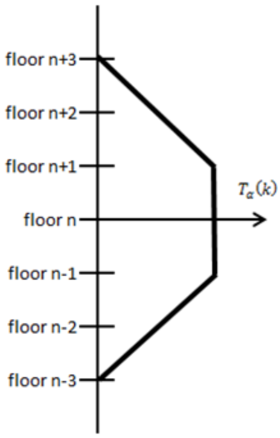

Figure 5. Example of the area value

We can see that $T_\alpha(k)$ is a fixed value and $T_{AVR}(k)$ are estimated values. However, the value α is calculated whenever a call is generated. Therefore the determination of the value α is important in the hall call assignment method.

If the value α is big, the possibility that the elevator close to the relevant floor can be selected is increased. Consequently, the transportation load may be assigned to a specific elevator which is in the area. Furthermore, the average waiting time increases and the total running frequency of elevator decreases. Therefore the power consumption is reduced. If α is small, the average waiting time decreases and the running frequency increases.

The predefined area-weight is usually used and it is defined according to the traffic modes classified by the passenger's traffic pattern. In this study, we use the fuzzy approach to model the uncertain situation of the system and to determine the area-weight.

IV. A TYPE-2 FUZZY MODEL TO DETERMINE THE AREA-WEIGHT

The type-2 fuzzy model is used to determine the area-weight. Fuzzy knowledge is generally formulated in the form of rules.

Fuzzy Rules

We classify the facts related with the determination of area-weight into two groups. The first group includes the up-going and down-going traffic amount named as pre-area fuzzy. The second group includes the average waiting time, long wait probability and power consumption named as area fuzzy.

The passenger's traffic varies from hour to hour and we can see that it is classified into some basic patterns.

- up-peak pattern
  This pattern is the case of which the up-going traffic is very large but the down-going traffic is very small.
- down-peak pattern
  In this pattern, the down-going traffic is much more than the up-going traffic
- normal pattern
  The case of which both up-going and down-going traffic are approximately equal.

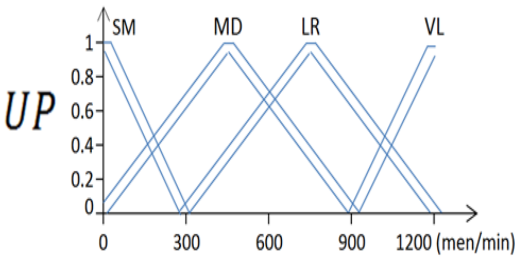

Figure 6. Membership Function of Up-Peak Traffic

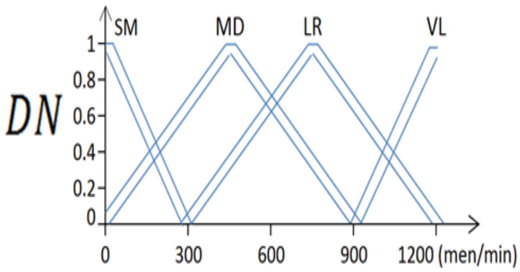

Figure 7. Membership Function of Down-Peak Traffic

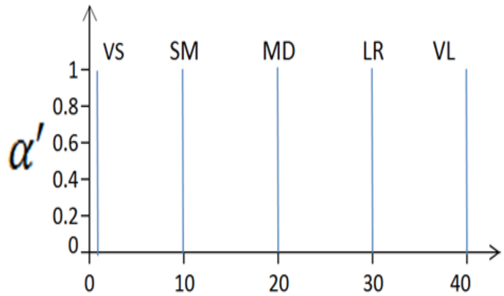

Figure 10. Membership Function of Area Weight

The membership functions of the variables for the pre-area fuzzy rules are given in **Figure 6 – Figure 8.** Because there are only two input variables in this case, the complete rule base can be documented in matrix form, as shows in **Table 1**. Each combination of a column and a row describes a certain TRAFIC situation. The conclusion is given by the term at the intersection of the column and row.

Let AWT be the average waiting time, PC be the power consumption and LWP be the long wait probability. We introduce an adjustment value k which represents the influence of the second group factors. This adjustment value will be added to the area-weight α' and give new area-weight α (that is, $\alpha = \alpha' + k$). The membership functions of the variables for the pre-area fuzzy rules are given in **Figure 9 – Figure 12.** Then we can represent fuzzy rules as **Table 2.**

Table 1. Pre-Area Fuzzy Rule

		Up Peak Traffic			
		SM	**MD**	**LR**	**VL**
Down Peak Traffic	**SM**	MD	LR	VS	VS
	MD	SM	MD	LR	VS
	LR	SM	SM	MD	LR
	VL	VS	SM	SM	MD

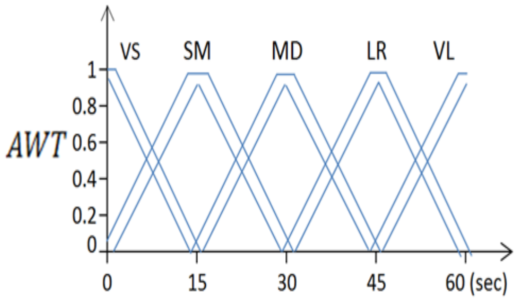

Figure 9. Membership Function of Average Waiting Time

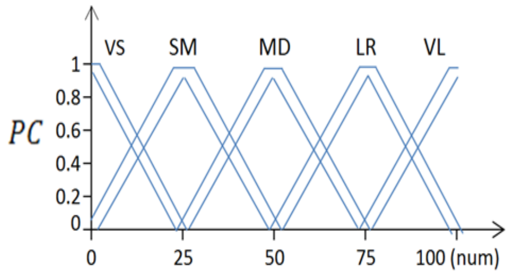

Figure 10. Membership Function of Power Consumption

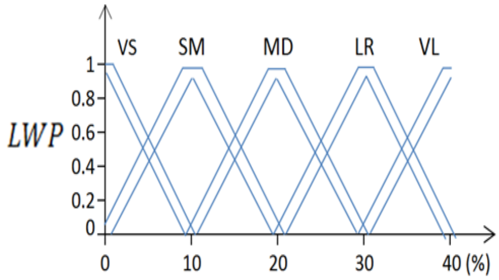

Figure 11. Membership Function of Long Wait Probability

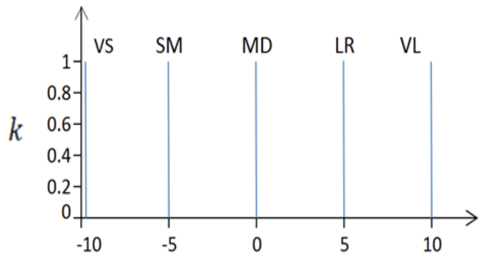

Figure 12. Membership Function of *k*

Table 2. Area Fuzzy Rules

Inference Rules	Weight
If AWT is VL Then *k* is NL	1
If AWT is LR Then *k* is NM	1
If AWT is MD Then *k* is PM	1
If AWT is SM Then *k* is PL	1
If AWT is MD Then *k* is ZE	1
If PC is VL Then *k* is PL	1
If PC is LR Then *k* is PM	1
If PC is MD Then *k* is NM	1
If PC is SM Then *k* is NL	1
If PC is MD Then *k* is ZE	1
If LPW is VL Then *k* is NL	1
If LPW is LR Then *k* is NM	1
If LPW is MD Then *k* is PM	1
If LPW is SM Then *k* is PL	1
If LPW is SM Then *k* is ZE	1

Fuzzy Model

We propose a fuzzy model to determine the area-weight through a two step fuzzy inference. Two step inference mechanism improves the system's stability from external accidents and reduces the complexity of the system. **Figure 13** shows the two step fuzzy inference mechanism.

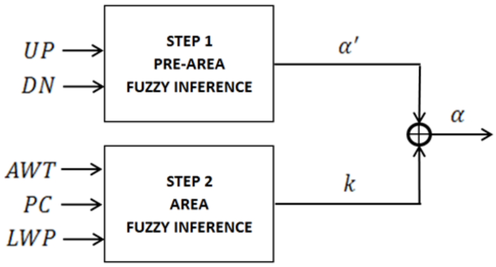

Figure 13. The Fuzzy model to determine the area-weight

In step 1 of the fuzzy inference engine, the predetermined area-weight (α') is calculated using the up-going (UP) and down -going (DN) traffic. In step 2, the adjustment value k is determined through the fuzzy inference mechanism using the average waiting time (AWT), the long wait probability (LWP) and the power consumption values (PC). This value is added to the predetermined area-weight.

V. SIMULATION RESULTS AND DISCUSSION

Performance of Type 2 Fuzzy Controller is investigated using simulation studies. The developed controller was compared with Type-1 Fuzzy Controller. The condition of simulation are shown in the **Table 3**. According to the traffic pattern, the simulation situation is divided into several periods such as before lunch time (12:00 – 12:40), after lunch time (12:40 – 13:20) and common time (13:20 – 15:00). The evaluation criteria is the means of the average waiting time (AWT), power consumptions (PC) and average long wait probabilities (LWP). In the simulation, the number of elevator runs is interpreted as the power consumption for that elevator. The average waiting time is measured in seconds and the long wait probability is in percent (%).

The **Figure 14** and **Figure 15** below show the traffic profile for down-peak traffic and up-peak traffic. The simulation results represented by these evaluation criteria are shown in **Table 4**.

Table 3 The Condition of Simulation

Number of floors	15
Number of elevators	3
Elevator capacity	20 man
Simulation time	12:00 – 15:00
Time to open the door	1 seconds
Time to close the door	1 seconds
Time for each passenger to get in	1 seconds
Time the door remains open	2 seconds

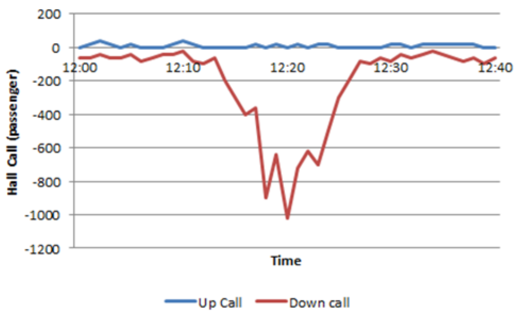

Figure 14. Profile for down-peak traffic

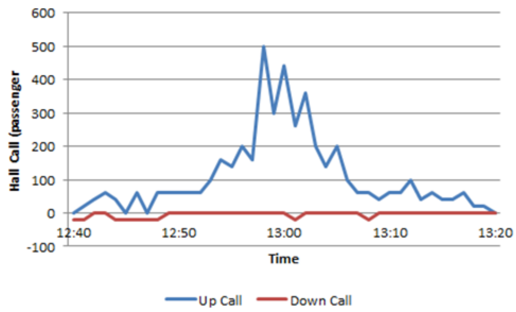

Figure 15. Profile for up-peak traffic

Table 4 The Simulation Results

		Type-1 Fuzzy	Type-2 Fuzzy	Improvement (%)
Before lunch	AWT	30.3	26.3	13.3
12:00 – 12:40	PC	48.0	52.8	-10
	LWP	7.7	6.1	20.5
After lunch	AWT	36.9	29.5	20
12:40 – 13:20	PC	46.0	52	-13
	LWP	12.9	10.3	20
Common time	AWT	32.7	34.9	-6.7
13:20 – 15:00	PC	51	48.6	4.7
	LWP	10.2	10.7	-4.7
Total	AWT	33.3	30.2	9.2
12:00 – 15:00	PC	48.3	51.1	-5.8
	LWP	10.3	9.0	12.0

As shown in **Table 4**, in the case of normal traffic results of type-1 fuzzy logic is better than type-2 fuzzy logic. But in the case of heavy traffic (before and after lunch time), results of type-2 fuzzy logic shows a decrease in the average waiting time and long wait probability but the power consumption is increased a litte. The comparison in the total period from 12:00 to 15:00 shows that the average waiting time is improved by 9.2 % and the long wait probability by 12.0 %.

We have simulated several times using other traffic data. By the simulation the average waiting time is improved by 7 – 20% and the long wait probability by 11 – 30 %.

VI. CONCLUSION

In this study the type-2 fuzzy was used to determine the area-weight which is one of the most important parameters of the hall call assignment method in the elevator group control system. To analyze the performance of the system, we simulated the proposed system and a conventional system. We could see that our system improved the system performance by 4 – 20% compared with the type-1 fuzzy controller.

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