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Control of a Multimodal Transportation System using Fuzzy Logic

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Abstract— This paper proposes a control approach using Fuzzy Logic for analysis and control of a multimodal transportation system. More precisely, the study focuses on the improvement of users' service in terms of minimizing their waiting times in the exchange platforms of passengers. Many studies have been developed in the literature for such problematic, and many control tools are proposed. In this paper we focus on the use of fuzzy logic technique to control the system during its evolution in order to minimize the arrival gap of connected transportation means at the exchange points of passengers. An example of illustration is worked out and the obtained results are reported.

Index Terms— Fuzzy logic; Analysis; Modeling; Control; Hybrid system; Multimodal Systems; Transportation Systems.

1 Introduction

Multimodal transportation is a major component of contemporary economics in the world. It has to face with two challenges: a society that expects always more mobility and a public opinion that cannot bear any more chronic delays and the poor quality of the performance of some services. Indeed, the flexibility of individual transportation modes grew for some years whereas the public transport supply is not sometimes up to the demand. This partially explains the rise of urban traffic involving more pollution and risks of accidents. The development of multimodal transport is an alternative solution to reduce these risks. However, the behavior of this transportation mode is often extremely complex. The diversity of its transport means and the increasing number of vehicles and platforms using for passengers exchange is a direct consequence for the generation of several related issues, for example, congestion, management of connections, allocation of vehicles, traffic management, etc.

Multimodal transportation systems include continuous and discrete events simultaneously represented respectively by continuous flows of passengers and discrete quantities of transport vehicles (e.g. bus, train, taxi).

Considering these two behaviors, we aim, through this contribution offer a better service to users and best management of passenger flows during their travels. In this context, a control approach based on fuzzy logic is developed.

The remainder of this paper is structured as follows. Section 2 presents the related work and gives an overview of developed researches in the field. Then the description of the studied system is given in Section 3. Section 4 gives a description of the model control by fuzzy logic tool, and exposes the obtained results. Conclusion and future work are given in Section 5.

2 Related Work

In the field of multimodal transportation systems, several approaches have been used for modeling, simulation and evaluation. In [1] Zidi proposes an assistant decision system for multimodal transportation networks named SARR to assist the developers in their exploitation management tasks in the cases of complex and simultaneous disturbances. The author has proposed two approaches. The first one, named ACFRS (Ant Colony Algorithm for the spatial Reconfiguration, is based on ant colony for the spatial reconfiguration. The second one is developed for rescheduling and called ACFRH (Ant Colony for the Hourly Regulation).

DSS, for Decision Support System, is a developed system enabling to provide a decision support for regulators [2]. Also, multimodal transportation has an important role in achieving the objectives of national and international logistics. Thus this mode is focusing on freight rather than people [3].

Transportation systems are mainly considered as a subclass of discrete event systems (DES). As proposed by Nait-Sidi-Moh in [4], a class of discrete Petri nets, called timed event graphs (TEG), was used to model and evaluate the behavior of a public transportation system. By combining TEG with (max, +) algebra, a control approach and minimization study of both passengers waiting times and number of used vehicles on a public transportation network are proposed. A Hybrid Petri net model was developed by Mahi and al. in [5] for a light controlled intersection. In [6] a, Júlvez and al. have used HPN for traffic modeling and controlling. The study aims to validate the design of new railway station and evaluate the existing stations for safety and security purposes.

For the control issues, fuzzy logic techniques have been applied for various areas including transportation systems. Among these studies, Wei et al. have proposed in [7] a fuzzy logic adaptive traffic signal controller for an isolated four-approach intersection with through and lest-turning movements. Another approach based on fuzzy logic as a very promising mathematical approach for modeling of complex traffic and transportation pro-

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cesses is proposed in [8]. Through this study, the authors showed the importance of fuzzy logic systems as universal approximators in solving traffic and transportation problems.

The primary goal of our contribution through this paper is the use of fuzzy logic in order to bring some solutions to the problems encountered in the management of passengers in their moving by minimizing their waiting times in the exchange points (connection stops).

3 SYSTEM DESCRIPTION

A configuration of an exchange platform of a multimodal transportation system is given in Fig.1. The system contains two transportation modes (bus and train) which are connected by a connection station enabling the exchange of passengers. Each public transportation mode is assigned to a transportation line and makes a circuit from its departure station to its arrival station (called also terminus) while serving other lines of the same mode or those of other transportation modes via connection stations or exchange platforms.

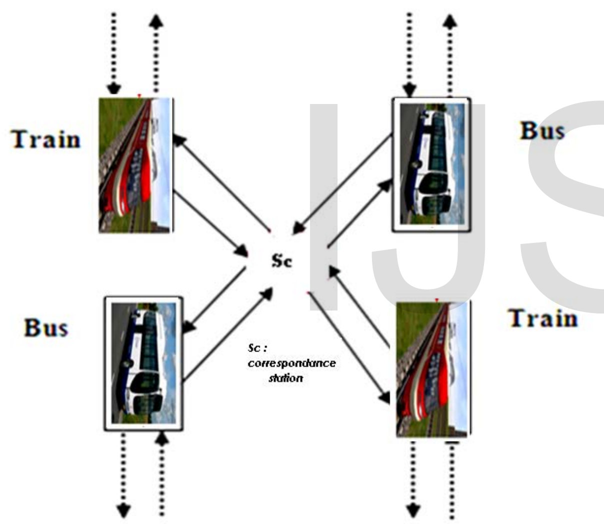

Fig. 1. Bimodal transportation system (Bus, Train).

For the considered configuration in the paper, all other sample stops without connections are not considered on the network. We mainly focus on the management of connections in a simplified network with two transportation modes in order to show the feasibility of our approach. We study the evolution of passenger flows transiting from one transportation mode to the second one.

The proposed approach and developed models can used for more complete configurations with several exchange platforms.

4 SYSTEM CONTROL USING FUZZY LOGIC

As underlined previously, a fuzzy logic model is developed to control the passenger flows into the exchange platform of the system. It is worth noting that fuzzy logic is logic based on approximate reasoning and can be expressed linguistically to capture the inherent vagueness of human mind. Thus, it can be applied to the areas which involve human decision making (such as supervision, monitoring, planning, scheduling, etc.) in different domains.

Fig.2 illustrates our fuzzy logic approach in order to control the waiting times in the platform of passengers exchange. We assume that this platform is composed of two areas called S_1 for the bus and S_2 for the train.

As given in Fig.2, the fuzzy logic controller uses two input parameters: delays of transportation means (bus and train) and percentage of passenger flows. As example, we consider
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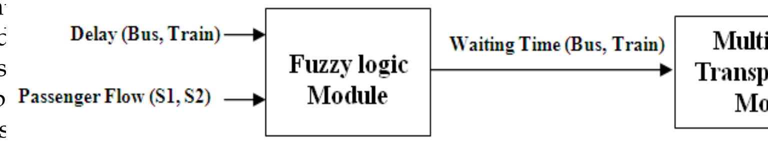

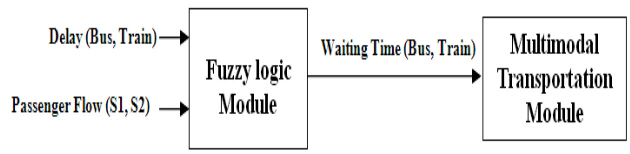

Fig. 2. Control diagram of multimodal trasportation system

The Multimodal Transportation module takes as input the computed waiting times for both bus and train from the fuzzy logic module and. As output, the multimodal transportation module gives the waiting times of passengers aiming to make the connection from bus to train or inversely in the exchange platform (areas S_1 and S_2).

The parameters of the fuzzy logic model are given in Table 1. For this first case, when considering only the bus delay, the simulation results for the three fuzzy variables (Short, Average, Great) are given in Fig.3. We note that the x-axis represents the bus delay which varies between 0 minutes and 12 minutes, the short delay of bus between 0 minutes and 3 minutes, the average delay varies between 1 minute and 7 minutes, and the large delay varies between 5 minutes and 12 minutes. The y-axis represents the degree of membership of each fuzzy variable.

In the same way, Fig.4 represents the evolution of passenger flow for each fuzzy variable. Where the short passengers flow varies between 0% and 40%, the average flow is between 20% and 80% and the great passengers flow is between 60% and 100%.

According to the bus delay and percentage of passenger flow, the waiting time of the bus as calculated by the fuzzy logic module and the evolution of this waiting times for the three fuzzy variables are given by the curves of Fig.5.

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The fuzzy inference evaluates the control rules stored in the fuzzy rule base.
Deffuzzification is a process to convert the fuzzy output values of fuzzy inference to real values. In our case we use centroid method to process to the defuzzification of the output varible (waiting time of bus) in the area S1. This method is mostly used because of the powerful performances it provides.

The principle of fuzzy rule is to express the knowledge with the conditional statements if - then (-else). For example:
IF Delay of bus is small AND Passengers flow in area S1 is average THEN Waiting time of bus is average.
In the same way, when considering train delay and passengers flow as input parameters, we obtain the waiting time of train in the area S2 as output Table 2 .Where the structure of model for Bus and Train are shown in Fig.6 and Fig.10. The obtained results are given in what follows.

TABLE 1

FUZZY LOGIC MODULE INPUT AND OUTPUT WITH DELAY OF BUS

put and output	Linguistic Variables
delay of bus (input 1)	short (SDB)
	average (ADB)
	long (LDB)
passengers flow area s_1(input 2)	small (SPFS1)
	average (APFS1)
	great (GPFS1)
waiting time of bus (output)	short (SWTB)
	average (AWTB)
	maximum (MWTB)

TABLE 2

FUZZY LOGIC MODULE INPUT AND OUTPUT WITH DELAY OF TRAIN

Input and output	Linguistic Variables
delay of train (input 1)	short (SDT)
	average(ADT)
	long(LDT)
passengers flow area s_2 (input 2)	small (SPFS2)
	average(APFS2)
	great(GPFS2)
waiting time of train (output)	short (SWTT)
	average (AWTT)
	maximum (MWTT)

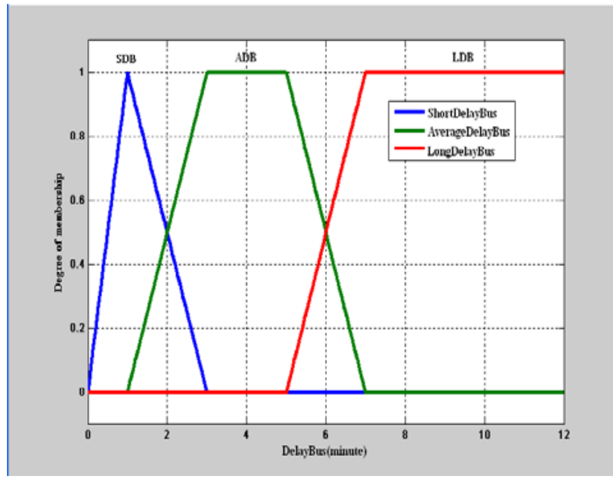

Fig. 3. Delay of Bus

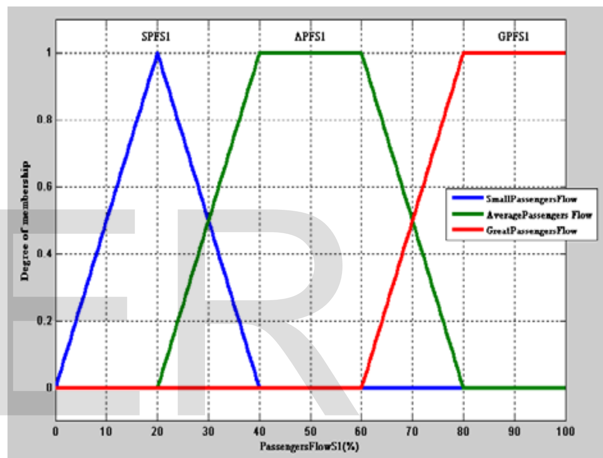

Fig. 4. Passengers Flow of Station 1

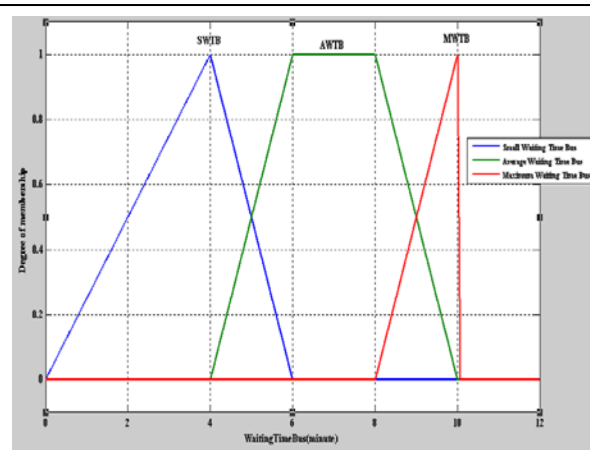

Fig. 5. Waiting Time of Bus

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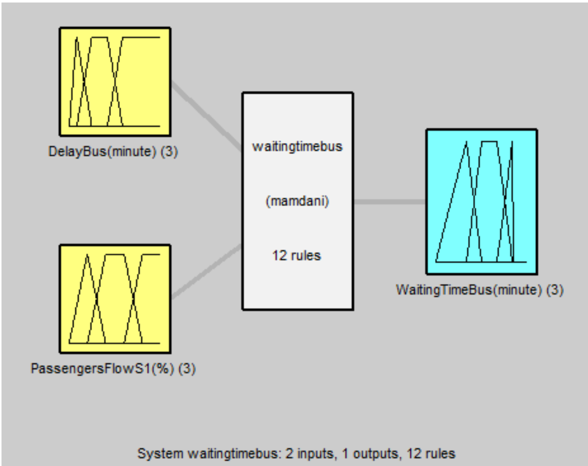

Fig. 6. The whole design structure of bus.

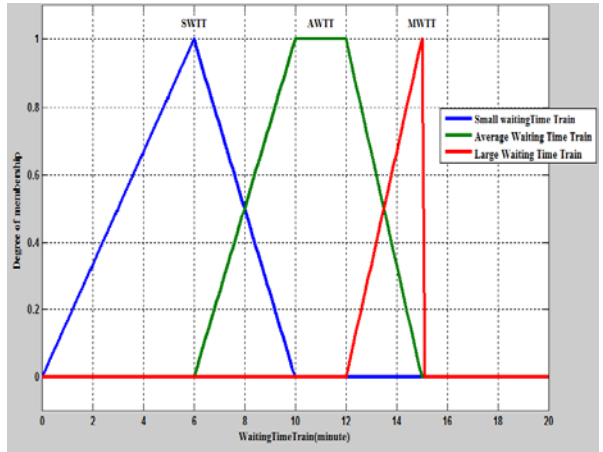

Fig. 9. Waiting Time of Train.

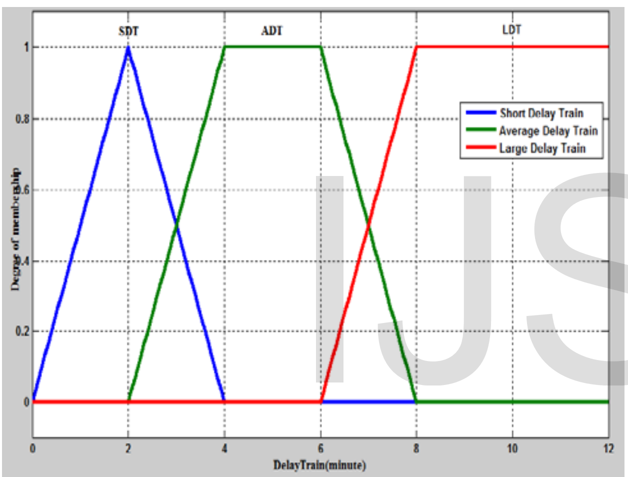

Fig. 7. Delay of Train

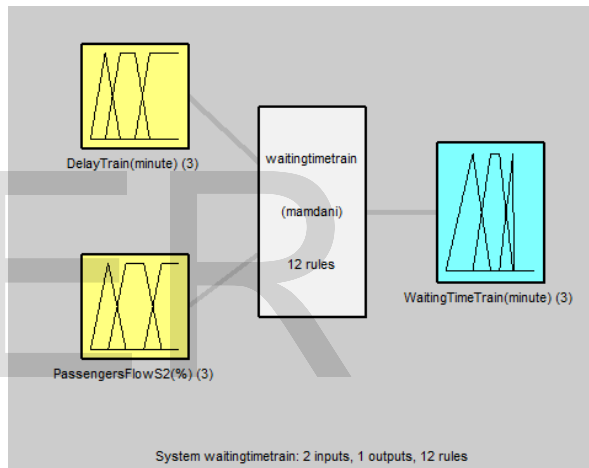

Fig. 10. The whole design structure of train.

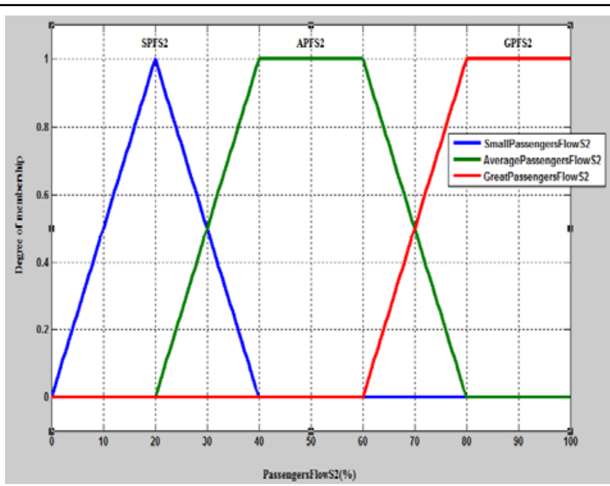

Fig. 8. Passengers Flow in the area S_2

5 Analysis and Discussions

This section gives some analysis and discussions about obtained results using fuzzy logic controller and evaluate the impact of the input variables on the system evolution. The following tables show the values of the waiting time of each transportation mode in its area in the platform for the cases related to passenger flows: Small, Average and Great.

TABLE 3

CASE 1 ; (BUS DELAY = 0 MINUTE, TRAIN DELAY= 0 MINUTE)

Waiting time	*Case 1* *Small*	*Case 2* *Average*	*Case 3* *Great*
of bus in area s_1	$5 \le \tau \le 6$	$\tau = 7$	$\tau = 8$
of train in area s_2	$\tau = 8$	$8 \le \tau \le 11$	$11 \le \tau \le 15$

TABLE 4

CASE 2: SHORT DELAY (BUS DELAY= 2 MINUTES, TRAIN DELAY= 1 MINUTE)

Waiting time	*Case 1* *Small*	*Case 2* *Average*	*Case 3* *Great*
of bus in area s_1	$5 \le \tau \le 6$	$\tau = 7$	$\tau = 8$
of train in area s_2	$\tau = 8$	$8 \le \tau \le 11$	$11 \le \tau \le 15$

TABLE 5

CASE 3: AVERAGE DELAY (BUS DELAY= 6 MINUTES, TRAIN DELAY= 5 MINUTE)

Waiting time	*Case 1* *Small*	*Case 2* *Average*	*Case 3* *Great*
of bus in area s_1	$6 \le \tau \le 8$	$\tau = 6$	$6 \le \tau \le 10$
of train area s_2	$8 \le \tau \le 11$	$\tau = 11$	$11 \le \tau \le 15$

TABLE 6

CASE 3: AVERAGE DELAY (BUS DELAY= 6 MINUTES, TRAIN DELAY= 5 MINUTE)

Waiting time	*Case 1* *Small*	*Case 2* *Average*	*Case 3* *Great*
of bus in area s_1	$6 \le \tau \le 8$	$\tau = 6$	$6 \le \tau \le 10$
of train area s_2	$8 \le \tau \le 11$	$\tau = 11$	$11 \le \tau \le 15$

In Table 3, we report the waiting times of bus and train in the exchange platform when the delays of bus and train equal to zero in their respective areas S_1 and S_2. For a small passengers flow, the value of the bus waiting time is ranges between 5 minutes and 6 minutes; for an average passengers flow the bus waiting time equals to 7 minutes; and for a great passengers flow the bus waiting time equals to 8 minutes. In the same way, the train waiting times for the three cases are given in the second line of Table 3.

Hereafter, we report the obtained results for other values of bus delays and train delays in Table 4, Table 5 and Table 6. Obtained results for all studied cases show that when the passengers flow becomes great, transportation means take longer in order to exchange the passengers. Then their waiting times in the exchange platform become large.

6 Conclusion and Future Work

In this paper we proposed a control study of a multimodal transportation system using fuzzy logic in order to give an optimal management and improvement of passenger service in terms of minimization of their waiting times in the exchange platform of the system. Through this approach, the waiting times of transportation means are calculated according to their delays and flows of passengers and this for different scenarios. The proposed control approach is validated through an example of illustration. Obtained results and conducted simulations proved the system feasibility in the practice. As perspectives of this research work, we plan to extend the proposed approaches for more generalized multimodal networks with more connection stops and platforms of passengers' exchanges.

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