CROWD EVACUATION USING MULTI-OBJECTIVE OPTIMIZATION AND TAKAGI-SUGENO FUZZY LOGIC SYSTEM

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Abstract: The increased frequency of events with massive numbers of attendants leads to crowd management issues. This paper proposes a system which prevents the occurrence of congestions on the evacuation routes, assuming that the number of persons per location, the sizes of the evacuation routes, and the density on each route are known. A Takagi-Sugeno fuzzy system computes the priorities for each evacuation route, based on its length and width and on the number of persons that are already on it. The allocation of the groups of people on the evacuation routes with the highest priorities is achieved through multi-objective optimization with genetic algorithms, in order to obtain a balanced evacuation of all locations, as quickly as possible. The dynamic of the number of people left in each location is displayed graphically and highlights the correct achievement of the proposed objectives.

Keywords: *crowd management, multi-objective optimization, fuzzy logic*

I. INTRODUCTION

In a world where large crowds can be gathered in a matter of hours via social media platforms (Facebook, Twitter), crowd management and control becomes more and more important. Crowd control techniques aim to prevent situations where panic and lack of judgment can cause a great deal of injured people, as well as damages [1].

There are a series of events where large crowds are expected, such as: musical festival, sport events, public demonstrations, street fairs, and religious gatherings. Estimating crowd behavior is fairly difficult, as it often implies exposing people to real dangerous situation [2]. Although every individual in the crowd is considered to be fundamentally good, the power of the crowd can do harm - no individual in the crowd wants someone to be crushed, but a crowd can crush a person [3].

Efforts are constantly being made towards ensuring safety and comfort for all individuals, when it comes to crowds.

A solution for modeling the crowd evacuation procedure, in the case of a fire disaster is presented in [4]. The system uses agent-based modeling to simulate crowd evacuation from a concert venue setting. The proposed solution allows high reconfiguration options (seat arrangement, stage, exits), as well as the possibility to take into account multiple fires with specific parameters (smoke dynamic).

A system for crowd evacuation in emergency situation based on dynamics model is proposed in [5]. The crowd's evacuation efficiency in a custom defined building can be analyzed. The impact caused by mass behavior, the structure of the building and the number of people inside is also evaluated.

Emerging trends in crowd evacuation include mobile sensing [6], robot guided evacuation [7] and cellular automata [8].

Computational intelligence techniques (fuzzy logic, genetic algorithms) have also been employed in developing evacuation strategies [9-10].

A hybrid intelligent system, consisting of fuzzy logic, operations research and decision support, that produces alternate decisions for the control of the huge crowd, gathered at a religious event, is described in [11].

This paper proposes a crowd evacuation solution that uses a Takagi-Sugeno fuzzy system and a multiobjective genetic algorithm that ensures the most rapid evacuation of all locations, without creating congestions. The novelty of the solution is given by the association between fuzzy logic and multiobjective optimization in solving the evacuation problem.

The paper is organized as follows: Section II describes the implementation details, Section is dedicated to presenting a series of results, while Section IV concludes the paper.

II. IMPLEMENTATION

The implementation of the proposed solution follows the diagram depicted in Figure 1.

Data initialization

The initial number of people in each location is stored in a matrix called *IGL* (*Index of Groups Locations*). A group is a number of people that can be dispatched (sent out) from a location, at a certain moment. The matrix has as many columns as locations. On the first row, the initial number of people for each location is stored. Then, as the evacuation procedure is applied, the matrix is populated with the remaining number of people, for each location.

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Compute route priorities

A Takagi-Sugeno fuzzy system computes the priorities of every evacuation route, as a function of the current density (the number of persons that are already using the evacuation route), length and width of the route. The structure of the fuzzy system is presented in Figure 2.

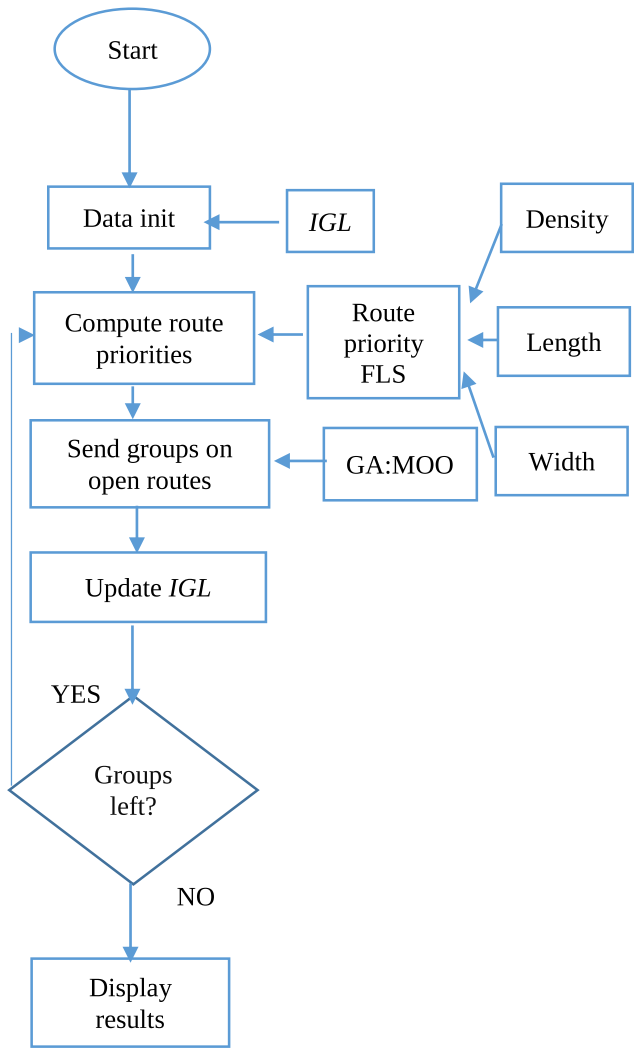

Figure 1. Block diagram of the proposed crowd evacuation system.

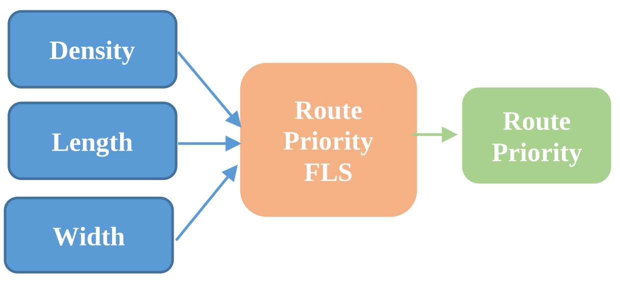

Figure 2. Structure of the fuzzy system for evaluating the priorities of the evacuation routes.

The domains of the input variables of the fuzzy logic system, *Density*, *Length* and *Width*, are covered with three membership functions, denoted *Small*, *Medium*, and *High*. The parameters are specified in Table 1.

Table 1. Parameters of the input variables for the fuzzy logic system

Params	**Input variable**		
	Density [people]	***Length [km]***	***Width [m]***
Domain	[0 100]	[4 8]	[6 15]
Small	[0 0 30]	[4 4 5.5]	[6 6 9]
Medium	[20 50 80]	[4.5 6 7.5]	[8 10 13]
High	[70 100 100]	[6 8 8]	[12 15 15]

The output variable of the fuzzy system, *RoutePriority*, has a universe of discourse between 0 and 10 and consists of 3 singleton fuzzy sets (*Low*, *Medium*, *High)*.

The inputs of the fuzzy logic system are stored in matrix, denoted *FLS_in*, which has three columns and a number of rows equal to the number of routes. The priorities for every evacuation route are stored in a vector, denoted *RP* (*RoutePriorities*). The length of the vector is equal to the number of currently available evacuation routes.

Send groups on open routes

The allocation of the groups to the available evacuation routes is performed using a multi-objective genetic algorithm optimization procedure. The objective function is the linear combination between two partial objective functions. These functions ensure the balanced evacuation of all locations, as quickly as possible.

The first partial objective function is the sum of the ratios between the number of persons in the group and the priority of the route.

The second partial objective function uses the standard deviation as a measure of avoiding to send multiple groups from the same location on the available routes, in the current iteration.

In each iteration, the algorithm provides an optimal solution of allocating the remaining groups. The solution is presented as a matrix, which contains:

- The index of the available evacuation route
- The location from where each group leaves, for each available route
- The priority of each open route
- The sizes of the groups that are to be sent on the available routes

Update IGL

The groups are to be moved according with the solution computed by the genetic algorithm. The number of remaining people in each location is updated in every iteration. The process stops when there are no more people left in any location.

The evacuation system was implemented using the Matlab integrated development environment. The Fuzzy Logic Toolbox was used for the implementation of the fuzzy system that computes the priority of the evacuation routes. The multi-objective optimization part exploits a series of facilities included in the Optimization Toolbox.

III. RESULTS

The results are provided both in the Matlab command line, as well as in Matlab figures, from which the evolution of the evacuation process can be observed.

For exemplification, a scenario involving six locations and four routes is presented. In this case, the *IGL* matrix has six columns. The initial number of people that are currently present in each location is stored on the first row. The following rows contain the number of people in each group:

IGL =

1563	1166	2211	1639	1865	623
200	400	250	600	330	100
450	220	821	439	245	123
913	246	560	450	250	400
0	300	240	150	450	0
0	0	340	0	590	0
0	0	0	0	0	0

The first column shows that there are 1563 people in the first location, divided into three groups, containing 200, 450 and 913 people.

For this particular case, the *FLS_in* matrix has three columns and four rows:

FLS_in =

17	6	8
65	8	10
84	7	7
25	5	9

The *RP* vector has four values, one for each route: *PR* = [10 5 0 9.16]. The indexes of the open (as in not blocked) routes are also stored in a vector, for further use: *idx_open_route* = [1 2 4]. Since the priority for the third route turns out to be 0, this means that this particular route is not available for use. Any route with a priority below 5 is considered closed (Figure 3).

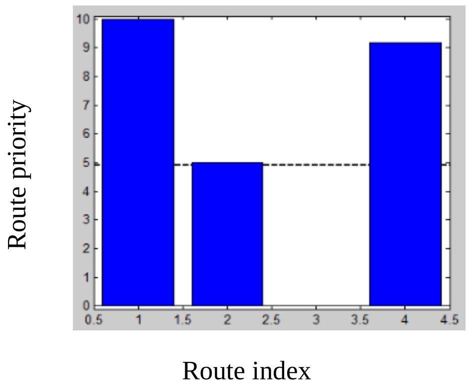

Figure 3. Route priorities, as computed from the fuzzy logic system.

The multiobjective optimization process returns a series of individuals located on the Pareto front. At the end of an iteration, the solution which provides the smallest values for both objective functions is adopted. This solution represents the indexes of the locations from which the next groups of people will leave. The solution is returned as a matrix of four lines:

Solution =

1.0000	2.0000	4.0000
1.0000	6.0000	3.0000
10.0000	5.0000	9.1667
200.0000	100.0000	250.0000

The first line represents the indexes of the open routes (information taken from *idx_open_route*); the second line contains the indexes of the locations from which to evacuate people; the third line represents the priorities of the open routes; the fourth line is the number of people to be evacuated from each location.

Table 2 presents the computed route priorities and the locations from which the groups will be evacuated, for all 12 iterations.

Table 2. Route priority and selected locations for each iteration.

	Route priority				Selected locations					
#	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**5**	**6**
1	10	5	0	9.1	1	0	1	0	0	1
2	0.5	5	0	0	0	0	0	0	0	1
3	0	5	5	0	0	0	0	0	1	0
4	0	5	5	5	0	1	0	0	1	1
5	0.5	5	0	10	0	1	0	0	1	0
6	0.5	5	6	0	1	1	0	0	0	0
7	10	0	7.3	10	0	1	0	1	1	0
8	10	0	5	10	0	0	1	1	1	0
9	0.5	5	5	10	1	0	1	0	0	1
10	0.5	0	0.3	5	0	0	0	0	0	1
11	0	0	7.5	5	0	0	0	0	1	0
12	10	5	0.3	5	0	1	0	0	1	1

Locations one and six are the first to be fully evacuated (the value 0, corresponding to 0 people left occurs on the fifth line of the matrix). Locations three and five are the last ones to be fully evacuated. A graphical representation of the evacuation process is depicted in Figure 4.

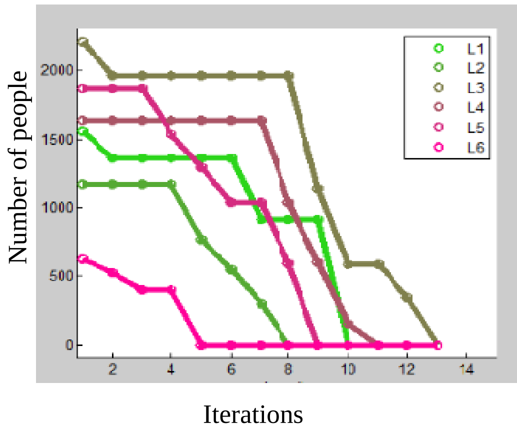

Figure 4. Evolution of the evacuation process.

Another way of visualizing the dynamics of the evacuation process is presented in Figure 5, which contains 4 subplot that evolve with each iteration. For the current iteration, the meaning of the plots is as follows:

- the top left figure shows the density for each of the four routes.
- the top right plot displays the computed priorities for each open route (routes 1, 3 and 4 are open)
- the bottom left plot gives us the locations from which the groups will leave – locations 6, 1 and 2
- the bottom right plot shows the total number of people in

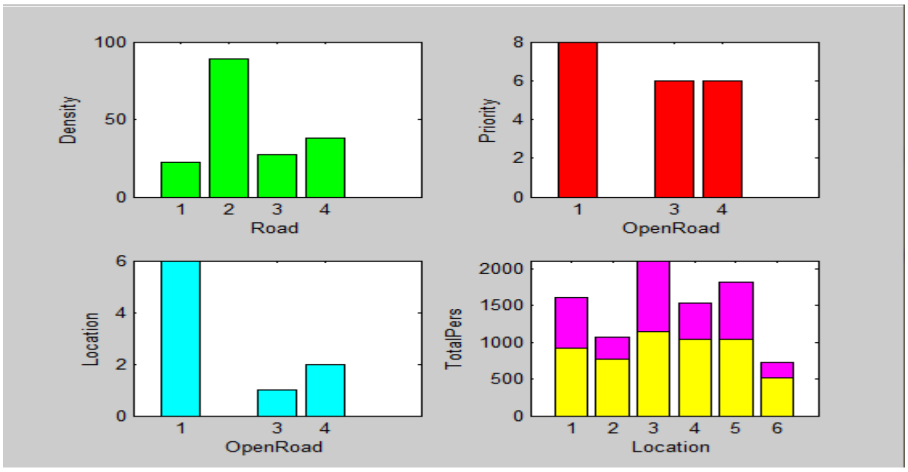

Figure 5. Route density, open road priority, location to move from and location evolution in a certain iteration.

each location (magenta bars) and the number of people left (yellow bars). The yellow bars decrease with every iteration.

IV. CONCLUSIONS

People safety is an important issue in the planning of events which are expected to gather large crowds. In order to avoid panic and congestion on the evacuation routes, crowd management strategies must be developed and applied. A possible solution is to use computational intelligence techniques.

The inputs of the crowd evacuation system are the number of locations, the number of people in every location and information about the evacuation routes. A Takagi-Sugeno fuzzy system computes the route priorities, based on the current density and the physical dimensions of the routes. Next, a multiobjective optimization process using genetic algorithms provides the locations from which the next groups of people should leave, so that the locations are cleared as soon as possible and that no congestion occurs.

The proposed solution provides numerical and graphical displays of results, for intermediate and final values, which help the user understand the evolution of the process. The system can be used for simulation purposes, to estimate evacuation times and congestion values. Real-time implementations are also possible; in this case, all the information about current route states and number of people left in every location are collected from video surveillance equipment.

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