Modeling of Population Evacuation During Emergency Situations using Networks Petri

SHALALA JAFAROVA MEHDİ, MİRZAYEVA KONUL MİRZAJAN KİZİ, HUSEYNOVA LEYLA ILHAM KIZI
Faculty of Engeneer
Sumgayit State University, Sumgayit State Technical College
Sumgayit city, Baku Street 1, 43rd block, AZ5008
AZERBAİJAN

Abstract. This work addresses the issue of modeling population evacuation during emergency situations using networks. The research highlights the importance and relevance of accurately estimating evacuation time, as this parameter plays a decisive role in ensuring the safety of people within buildings during critical events. Evacuation conditions are highly uncertain because the distribution, movement, and density of the population inside any structure cannot be predicted precisely in advance. Therefore, developing a reliable modeling method is essential for supporting effective decision-making. To carry out the modeling, the internal structure of the building must first be represented using a Petri net (PN), which provides a formal framework for visualizing dynamic interactions, movement paths, and possible bottlenecks. Based on this representation, the operational flow chart of the evacuation management model is constructed. The study further describes the sequence of actions within the model, the logic of transitions, and the conditions under which evacuation routes are activated. Additionally, the corresponding software modules necessary for implementing the evacuation model are designed and developed. These modules support the simulation of various emergency scenarios, allow the adjustment of parameters such as population size and exit capacities, and help evaluate the impact of uncertainties on total evacuation time. The proposed approach provides a structured and analytical method for assessing evacuation processes and supports the development of more effective emergency response strategies.

Key-words: emergency situations, evacuation, Petri net, rescue team, flow chart, incident matrix

Received: May 16, 2025. Revised: August 28, 2025. Accepted: November 29, 2025. Published: April 29, 2026.

1 Introduction

The movement of people along predefined routes can be described as a discrete parallel process. Petri nets (PN) are considered highly effective for modeling such processes. The building structure is described using a fuzzy PN. Since estimating the evacuation time is considered the most critical factor, applying a fuzzy PN is deemed more appropriate among PN modifications. This is because the psychological stress and the movement of people into the corridors during an accident have a fuzzy nature. [1], [2]. (Figure 1.)

The main advantage of the algebraic modification of the fuzzy PN is its significant expansion possibilities for studying parallel, dynamically connected processes operating under conditions of uncertainty. [3], [4], [5].

2 Problem Formulation

The fuzzy algebra PN is described by the following five-tuple: [6]:

$$N = (P \cup F, T, A, V, \mu_0^R),$$

where, $P=\{p_1, p_2,\dots, p_n\}$ is a finite set of positions of type p;

$F=\{f_1, f_2,\dots, f_m\}$ is a finite set of positions of type f; $T=\{t_1, t_2,\dots, t_r\}$ is a finite set of transitions; A is a finite alphabet; μ_0^R is the initial marking of the positions.

$$V: [(P \cup F) \times T] \cup [T \times (P \cup F)] \rightarrow A*$$

and the description connects positions with transitions and transitions with positions;

$A*$-set of words; $\mu_0^R: F \cup P \rightarrow A * \times [0,1]^L$-

$A*$ is the initial marking of the positions of the words from the plurality, where $L = card(A^*)$; The number of arcs between positions and transitions is described as follows: if V $V(a, \epsilon)= \varepsilon$, ($\varepsilon$ is the empty word), then there is no arc between a and ϵ, $a \in P \cup F$, $\epsilon \in T$ or $a \in T$, $\epsilon \in P \cup F$; if $V(a, \epsilon)= s$, $s \in A*$, then there is an arc from a to ϵ, marked by the word s, $a \in P \cup F$, $\epsilon \in T$ və ya $a \in T$, $\epsilon \in P \cup F$.

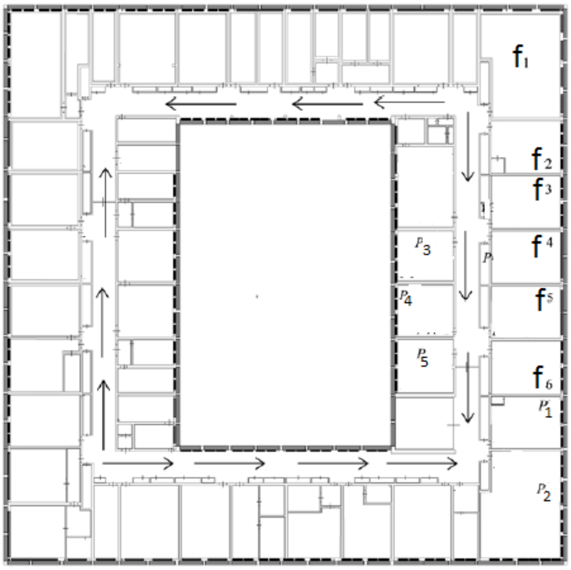

Fig. 1: Structural scheme of human movements inside the building.

Source: created by the authors.

The initial marking for all positions of the fuzzy algebra PS is described by the following tuple:

$$\mu_0^R(a) = \langle x_1 x_2 \ldots x_k, R(x_1)R(x_2)\ldots R(x_k)\rangle \quad (1)$$

For the marker μ, the transition t is allowed if $\mu(f_i)$ is a left-striking one for all positions of type f $f_i \in G^+(t), V(f_i, t)$ and is a $\tilde{\mu}(p_i)$ left-striking $p_i \in G^+(t), V(p_i, t)$ one for all positions of type p.

3 Problem Solution

To carry out the modeling, it is necessary to describe the building in the form of a PN. For this, it is necessary to take into account all the elements of the building, individual rooms and stairs. All this must be given by positions and arcs with transitions. (Figure 2)

As we know, any object or building has at least 3 or 9 floors and several entrances and exits. Naturally, during working hours, people are more often in the rooms. However, during evacuation, people leave the rooms and move towards the exit through the nearby corridors. In this network, there are two transport systems (TS) (one of these systems transfers rescued people, and the other receives and takes them away), two rescue teams (RT) - one rescues people and transfers them to the exit TS, and the other places people in the TS in safe facilities. [7], [8], [9].

The evacuation management model during an emergency situation is developed using the following procedure with a fuzzy algebraic PN:

The network positions and transitions are defined as follows (selection):

p_1 – information service (MX) reports the occurrence of an accident; p_2 – people are ready for rescue; p_3 – rescue vehicles are parked at the exit doors; p_4 – all lines of MX are free; p_5 – MX reception position is free; p_6 – MX exit position is free; p_7 – Rescue team (XQ) is free; p_8 – NS reception position is ready; p_9 – NS reception position is not full; p_{10} – XQ places people in the NS reception position; p_{11} – XQ sees off people in the NS; t_1 – information is given to the MX reception position; t_2 – information is given to the MX reception position; t_3 – Information about the occurrence of an accident is given; t_4 – Information about the occurrence of an accident is given; t_5 – XQ places people in the NS reception position; t_6 – Sending people and emptying all NS.

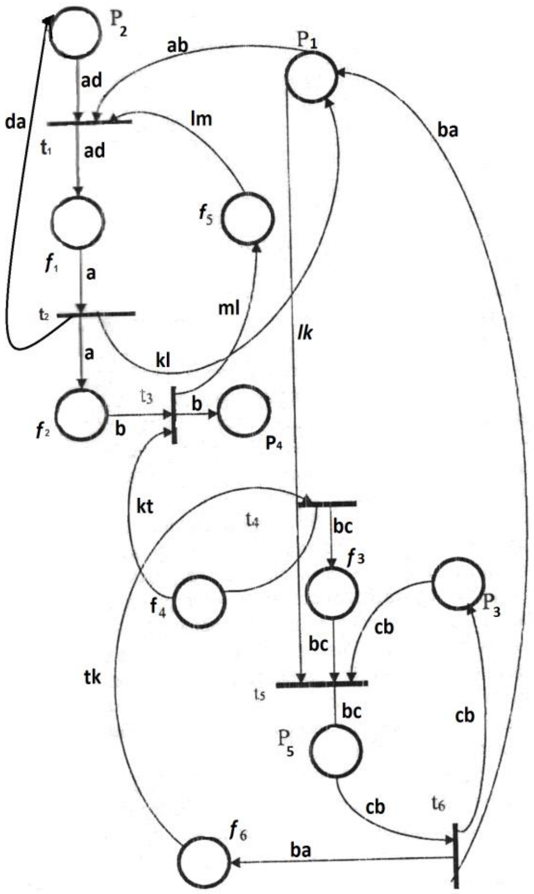

Fig. 2: Diagram of the operation of the evacuation management model.

Source: created by the authors.

$\mu_0 = \{ \langle \varepsilon; 0\rangle, \langle \varepsilon; 0\rangle, \langle \varepsilon; 0\rangle, \langle ad ; 0.001 \rangle, \langle da ; 0.01 \rangle, \langle ml ; 0.02\rangle, \langle bc ;0.03\rangle, \langle kt ;0.03\rangle, \langle cb ;0.02\rangle, \langle \varepsilon; 0\rangle, \langle \varepsilon ;0\rangle\}$ – is the starting marker of positions.

According to the graph-scheme of the operation of the management model, the transitions of the input and output incident matrix will take the following form, respectively:

	t_1	t_2	t_3	t_4	t_5	t_6
f_1	ε	a	ε	ε	ε	ε
f_2	ε	ε	b	ε	ε	ε
f_3	ε	ε	ε	ε	bc	ε
f_4	ε	ε	kt	ε	ε	ε
f_5	lm	ε	ε	ε	ε	ε
f_6	ε	ε	ε	tk	ε	ε
p_1	ab	ε	ε	ε	lk	ε
p_2	ab	ε	ε	ε	ε	ε
p_3	ε	ε	ε	ε	cb	ε
p_4	ε	ε	ε	ε	ε	ε
p_5	ε	ε	ε	ε	ε	cb

	f_1	f_2	f_3	f_4	f_5	f_6	p_1	p_2	p_3	p_4	p_5
t_1	ad	ε	ε	ε	ε	ε	ε	ε	ε	ε	ε
t_2	ε	a	ε	ε	ε	ε	ε	da	ε	ε	ε
t_3	ε	ε	ε	ε	ml	ε	ε	ε	ε	b	ε
t_4	ε	ε	bc	kt	ε	ε	ε	ε	ε	ε	ε
t_5	ε	ε	ε	ε	ε	ε	ε	ε	ε	ε	bc
t_6	ε	ε	ε	ε	ε	ε	ε	ε	cb	ε	ε

A fuzzy PN based on modern computing technologies, computer systems, and software tools has been developed for the implementation of discrete object modeling algorithms and models using modifications of the fuzzy PN. (1)

The functional diagram of the structure of the fuzzy PN modifications and the operation of the software modules is given in Figure 3.

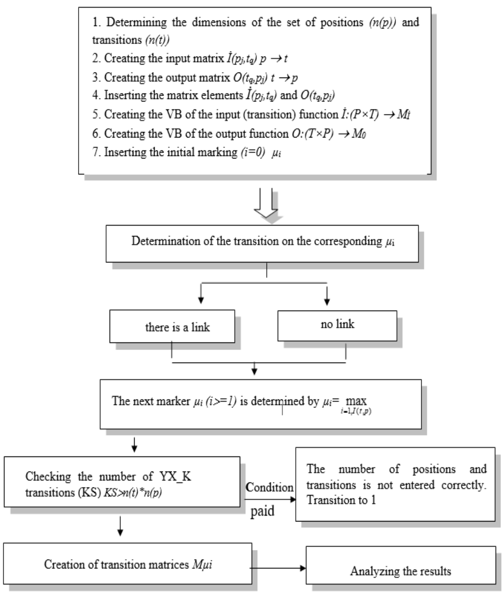

Fig. 3: Functional scheme of the program modules for obtaining the structure and operation of modifications of the fuzzy PN.

Source: created by the authors.

The C# environment ensures the effective operation of the program. It can open several windows on the screen at the same time, move the windows along the screen, partially or completely cover each other [10], [11], [12], [13].

The dialog monitor forms the function of an information-logical interface between the user's system modules and application program modules. The control program provides information-logical connections between the system modules and application modules in the process of the software operation.

The control program interprets the structural data of the network in the modeling process, modifies the structure in accordance with the control, and collects and processes the simulation results.

Service programs create conditions for input and output of data used in the modeling environment in a user-friendly and convenient format.

The application software for obtaining the structure, analysis and operation of modifications of the fuzzy PN consists of the following modules: formation of the network structure; creation of the input and output incidence matrices of the network; creation of a membership degree matrix for the implementation of transitions; creation of input and output membership degree matrices after the transition is implemented; analysis and formulation of results [14], [15].

The development of the software model is of fundamental importance in the development of a software system for modeling population evacuation by applying modifications of fuzzy logic.

4 Conclusion

A fuzzy PN, based on modern computing technologies, computer systems, and software tools, has been developed for implementing discrete object modeling algorithms using modifications of the fuzzy PN.

The application software for obtaining the structure, analysis, and operation of fuzzy PN modifications consists of the following modules:

1. Formation of the network structure.
2. Creation of the input and output incidence matrices of the network.
3. Creation of a membership degree matrix for the implementation of transitions.
4. Creation of input and output membership degree matrices after the transition is implemented.
5. Analysis and formulation of results.

The software model, written in the C# environment, allows for the implementation of discrete object modeling algorithms. The dialog monitor acts as an information-logical interface between the user's system modules and application program modules.

The developed application software consists of the following main program modules:

- A module for graphical representation of the network.
- A control program.
- A dialog.
- Modeling of discrete processes using fuzzy algebraic PN and fuzzy PN.

The algorithm for modeling population evacuation and the software's operation is structured such that data is stored in specially structured files. Working with the program modules requires a minimum user description. In text mode, the network's input, output, and structure are obtained using a developed algorithm. In graphical mode, the network's dynamics are shown by changes in the graphic cursor's location.

Ultimately, the user receives an image of the network, can work on it, and save the current image to external storage media if needed.

References:

[1] Barbera, R., Bruno, R., Fargetta, M., La Rocca, G.: The Catania Science Gateway Framework in the ReCaS Environment. // High Performance Scientific Computing Using Distributed Infrastructures, Italia, 2017, pp. 473-483. URL: https://doi.org/10.1142/9789814759717_0039

[2] Goldwasser S., Waisbard E.: Transformation of digital signature schemes into designated confirmer signature schemes. In: TCC 2004. LNCS, vol 2951. Springer, pp 77–100

[3] Umair, S. M. and Usman, R.: Automation of irrigation system using ANN based controller.// International Journal of Electrical & Computer Sciences IJECS-IJENS, vol. 10, pp. 41-47, 2010.

[4] Jensen K., Kristensen M.: Coloured Petri Nets: Modelling and Validation of Concurrent Systems. Berlin / Heidelberg: Springer, 2009. 382 p. 11. https://www.researchgate.net/publication/220690970_Coloured_Petri_Nets_Modelling_and_Validation_of_Concurrent_Systems

[5] Jafarian JH, Al-Shaer E, Duan Q.: Openflow random host mutation: transparent moving target defense using software defined networking. In: Proceedings of the first workshop on hot topics in software defined networks, Helsinki, 13 August 2012 , pp 127–132. https://doi.org/10.1145/2342441.2342467

[6] Kim, Y., Evans, R.: Software design for wireless sensor-based sitespecific irrigation// Computers and Electronics in Agriculture, vol. 66, no. 2, pp. 159–165, 2009. https://doi.org/10.1016/j.compag.2009.01.007.

[7] Al Ahmar, M. A.: Rule based expert system for selecting software development methodology // Journal of Theoretical and Applied Information Technology, scopus, pp. 143-148, 2005.

[8] Mammadov, J. F., Amiraslanov, B., Jafarova, Sh. M., Ibrahimova, E. J.: Designing the intelligent control system of mechanical assembly production machines and crane-manipulator // Proceedings of the 16th International Conference on Applications of Fuzzy Systems, Soft Computing and Artificial Intelligence Tools ICAFS, vol. 2, Ankara, Turkey, 2023, pp. 317-326. https://link.springer.com/chapter/10.1007/978-3-031-72506-7_42

[9] Fourati, M. A., Chebbi, W., Ayed, M. B., Kamoun, A.: Information and communication technologies for the improvement of the irrigation scheduling // International Journal of Sensor Networks, vol. 30, no. 2, pp. 69–82, 2019. https://doi.org/10.1504/IJSNET.2019.099469

[10] Saritas, N., Allahverdi, N., Sert, U.: A fuzzy approach for determination of prostate cancer // International Journal of Intelligent Systems and Applications in Engineering, vol. 1, issue 1, scopus, 2013, pp. 1-7.

[11] Javadi Kia, P., Tabatabaee Far, A., Omid, M., Alimardani, R., Naderloo, L.: Intelligent control based fuzzy logic for automation of greenhouse irrigation system and evaluation in relation to conventional systems // World Applied Sciences Journal, vol. 6, issue 1, scopus, 2009, pp. 16-23,

[12] Silva,. M..and Valette R.: Petri neta and flexible manufacturing. In: Lecture Not .. in Computer Science, Advance, in Petri nets 1989, Springer Verlag, Vol. 424. pp. 374-417.

[13] Amin, M., Shebl D. : Reasoning dynamic fuzzy systems based on adaptive fuzzy

higher order Petri nets. Inf Sci 286:2014, pp.161–172. DOI:10.1016/j.ins.2014.07.011

[14] Pan, HL, Jiang, WR, He HH.: The fault diagnosis model of flexible manufacturing system workflow based on adaptive weighted fuzzy Petri net. 2012, Adv Sci Lett 11(1):pp. 811–814

[15] Aura, T., Lilius, J.: Time processes for time Petri nets // 18th International Conference, ICATPN'97, Vol. 1248 of LNCS, Toulouse, France, June 23-27, France, 1997. DOI: https://doi.org/10.1007/3-540-63139-9

Contribution of individual authors in the creation of a scientific article (Ghostwriting Policy)

SHALALA JAFAROVA MEHDI- setting the topic and general guidance.
MİRZAYEVA KONUL MİRZAJAN KIZI- building a model on the topic.
HUSEYNOVA LEYLA ILHAM KIZI- conducting a computer experiment based on the developed model and obtaining the result.
The authors equally contributed in the present research, at all stages from the formulation of the problem to the final findings and solition.

Sources of Funding for Research Presented in a Scientific Article or Scientific Article Itself

No funding was received for conducting this study.

Conflict of interest

The authors have no conflicts of interest to declare that are relevant to the content of this article.