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"The effectiveness of artificial intelligence in creating algorithms for human action in emergency situations"

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Abstract. *This article is devoted to the analysis of the effectiveness of artificial intelligence (AI) technologies in the formation and optimization of human action algorithms in emergency situations. In emergency situations such as earthquakes, fires, floods and mass casualty situations, human decision-making is limited by stress, uncertainty and resource shortage. Therefore, the use of AI algorithms is becoming increasingly important in evacuation, triage and rescue operations. The article extensively covers the capabilities of machine learning, deep learning, reinforcement learning, multi-agent simulation (MAS) and computer vision technologies.*The research methodology includes simulating evacuation and rescue scenarios, comparing SI algorithms with traditional human decision-making during triage, and assessing resource efficiency. The results show that SI-based models can reduce evacuation time by 30–40%, increase decision-making accuracy, and reduce resource waste. The discussion section provides a comprehensive analysis of the advantages and limitations of human and AI decision-making, ethical and legal issues, and the challenges of adapting AI systems to real-world conditions. Finally, recommendations are made on the prospects for the widespread implementation of AI technologies in emergency management and future research directions.

Keywords: artificial intelligence, emergencies, evacuation algorithm, triage, multi-agent simulation, strong reinforcement, decision making.

Introduction. Throughout human history, emergencies—such as fires, earthquakes, floods, man-made disasters, and terrorist attacks—have always posed serious threats. In such situations, human actions often directly determine the difference between life and death. Studies show that most people have difficulty making rational decisions in emergencies: panic, stress, lack of time, and lack of information lead to poor decision-making [1]. This can lead to consequences such as traffic jams during evacuation, taking the wrong route, or crowding in dangerous areas.

In traditional approaches, evacuation algorithms are based on pre-designed schemes. For example, in large buildings, evacuation plans, special signs and guidance systems using lines are used [2]. However, these algorithms are usually static and inflexible: they do not take into account dynamic changes in the risk in real time. As a result, the efficiency of evacuation is sharply reduced, people stay in the danger zone for a longer time. Therefore, modeling human behavior and developing real-time adaptive algorithms is becoming an urgent task.

The need for artificial intelligence. In recent years, the development of artificial intelligence (AI) technologies has revolutionized various areas of human activity. In particular, AI has enabled real-time data processing, accelerated decision-making, and accurate risk assessment [3]. Reinforcement learning, multi-agent systems, machine learning, and computer vision technologies are widely used in modeling evacuation processes [4].

For example, multi-agent systems can be used to manage the flow of people in real time and optimize their movement trajectories [5]. Reinforcement learning allows for the adaptation of evacuation routes taking into account risk and time factors [6]. Computer vision can help quickly identify crowd density, people's stress levels, or dangerous zones using camera images [7]. Such technologies allow for faster and more informed decision-making during evacuation than human intervention.

Scientific literature review. In the last decade, there has been a lot of research in the scientific literature on evacuation modeling and the application of SI in emergency situations.

- The “social force model” developed by Helbing and Molnár provided an important theoretical framework for explaining the dynamics of human movement [8]. This model was later integrated with SI, allowing for more effective modeling of crowd management.
- Reynolds's "agent-based modeling" approach has been widely used to analyze individual behavior in evacuation through multi-agent systems [9].
- Reinforcement learning-based studies have proven the effectiveness of optimizing evacuation routes using robots and drones [10].
- There are modern developments in crowd density detection and danger zone prediction using computer vision [11].

However, most of the existing literature is theoretical or has been conducted under limited experimental conditions. Complex real-life scenarios, such as fire in multi-story buildings or post-earthquake evacuation, have not yet been fully explored.

Relevance of the research. In today's globalized world, urbanization is accelerating, with millions of people living in cramped spaces in large cities. Therefore, the issue of evacuation in emergency situations has become more important than ever. Events such as the Grenfell Tower fire in London in 2017 or the Beirut port explosion in 2020 have once again demonstrated the need to improve evacuation algorithms [12].

Artificial intelligence-based algorithms can improve evacuation efficiency, reduce human casualties in hazardous areas, and allocate resources more efficiently. In addition, AI systems are free from the panic, stress, and errors inherent in human psychology and provide optimal decisions quickly [13]. Therefore, in-depth research on this topic is of great scientific and practical importance.

Goals and objectives of the study. The main goal of this article is to analyze the effectiveness of artificial intelligence in developing algorithms for human action in emergency situations and to prove it based on practical examples.

The main tasks are as follows:

1. Studying the human behavior model in emergency situations and identifying its limitations.
2. Development of evacuation algorithms based on machine learning, reinforcement learning, multi-agent systems, and computer vision technologies.
3. Evaluation of SI algorithms using a simulation environment and realistic scenarios.
4. Comparison of the results obtained with traditional algorithms and human decision-making.
5. Analyze the limitations, ethical and legal issues of artificial intelligence, and show future prospects.

In summary, this study aims to reveal the possibilities of making human action algorithms more effective in emergency situations using SI. The introduction presents the problem, justifies the need for SI technologies, provides a review of the existing literature, and sets out the goals and objectives of the study. The following sections provide an expanded coverage of the methodology, results, and discussion.

Methodology. This study analyzed the effectiveness of artificial intelligence (AI) in developing algorithms for human behavior in emergency situations (EFS) through a systematic approach. The research design included the following steps:

1. Selection of emergency scenarios: fire, earthquake, explosion and man-made accident.
2. Taking into account the psychological and physiological factors present in the human behavioral model.
3. Develop SI algorithms and test them in a simulation environment.
4. Comparison of the obtained results with traditional algorithms and human decision-making processes.

This design combines experimental and analytical methods. The experimental part was carried out through a simulation environment, and the analytical part was based on mathematical modeling and statistical analysis [1].

Human behavior modeling. Human decision-making in emergency situations is determined by stress, panic, and lack of information. Therefore, human behavior was modeled based on the following parameters:

- **Time factor:** It takes an average of 3–7 seconds for a person to make a decision [2].
- **Panic Index:** Depending on the level of stress, a person's likelihood of making rational decisions decreases [3].
- **Social impact:** In crowds, decisions are often determined by the tendency to follow the majority [4].

These parameters were implemented through the “social force model” [5] and agent-based modeling [6] approaches. As a result, a realistic simulation environment was created for predicting human behavior.

Artificial intelligence algorithms. The following SI technologies were used in the study:

Machine Learning. Machine learning algorithms have been used to predict people's movement trajectories. In particular, Random Forest and Support Vector Machine (SVM) algorithms have been effective in determining the probability of people's movement during the evacuation process [7].

Reinforcement Learning (RL). RL-based algorithms were used to optimize evacuation routes in real time. Agents sought to minimize time and risk in selecting a safe exit point. This approach used Q-learning and Deep Q-Network (DQN) algorithms [8].

Multi-Agent Systems (MAS). The management of human flow in evacuations was modeled using multi-agent systems. While each agent makes individual decisions, the overall system efficiency was evaluated based on crowd density and path availability [9]. Human interactions (cooperation, competition, and imitation) were modeled using MAS [10].

Computer Vision. Computer vision algorithms (CNN — Convolutional Neural Networks) were used to detect human density and identify danger zones through cameras. This technology helped to efficiently allocate resources during the evacuation process [11].

Simulation environment. The study simulated evacuation processes using AnyLogic, MATLAB SimEvents, and Unity3D software [12]. The scenarios covered the following:

1. **Fire scenario**– the spread of fire in the building and the speed of evacuation.
2. **Earthquake scenario**– movement of people inside a building in conditions where there is a risk of collapse.
3. **Explosion scenario**– the panicked state of the crowd after the explosion.
4. **Man-made accident scenario**– chemical leak and evacuation to a safe area.

The performance of SI algorithms and traditional algorithms was compared in each scenario.

Evaluation criteria. The effectiveness of the algorithms was evaluated based on the following criteria:

- **Evacuation time (T):** the total time it took for people to get to a safe area.
- **Accuracy (A):** the probability that the chosen path will be optimal when exiting the danger zone.
- **Resource allocation (R):** even distribution of the crowd along the aisle and exit doors.
- **Stability (S):** the ability of the system to operate effectively under various emergency conditions [13].

In mathematical terms, evacuation efficiency is expressed as follows:

$$E = \frac{A \times R}{T \times (1 - S)}$$

here:

- E— overall efficiency,
- A— accuracy of path selection,
- R— resource efficiency,
- T— evacuation time,
- S— system stability index.

Data collection and analysis. The study collected the results of about 5000 simulations. For each scenario, the results of SI algorithms and human decision-making were compared. ANOVA and t-test methods were used for statistical analysis [14]. The results were presented using tables and graphs.

Ethical and legal constraints. When developing evacuation algorithms using SI, ethical issues related to the processing of personal data, camera observations, and psychological factors were considered [15]. Therefore, all modeling processes were carried out in a data-free manner.

Results. In this section, the effectiveness of evacuation algorithms based on artificial intelligence (AI) was analyzed in various emergency scenarios. The results are presented in tables and graphs.

Table 1. Description of research scenarios

Scenario	Source of danger	The main problem	Evacuation strategy
Fire	Fire and smoke	Decreased vision	Rapid evacuation, smoke escape
Earthquake	Earthquake	Collapse of structures	Quick exit, reaching a safe zone
Explosion	Chemical/technical explosion	Toxic gas and shock wave	Escape from the gas and find shelter
Man-made accident	Industrial equipment	Radiation and chemical waste	Isolation and safe evacuation

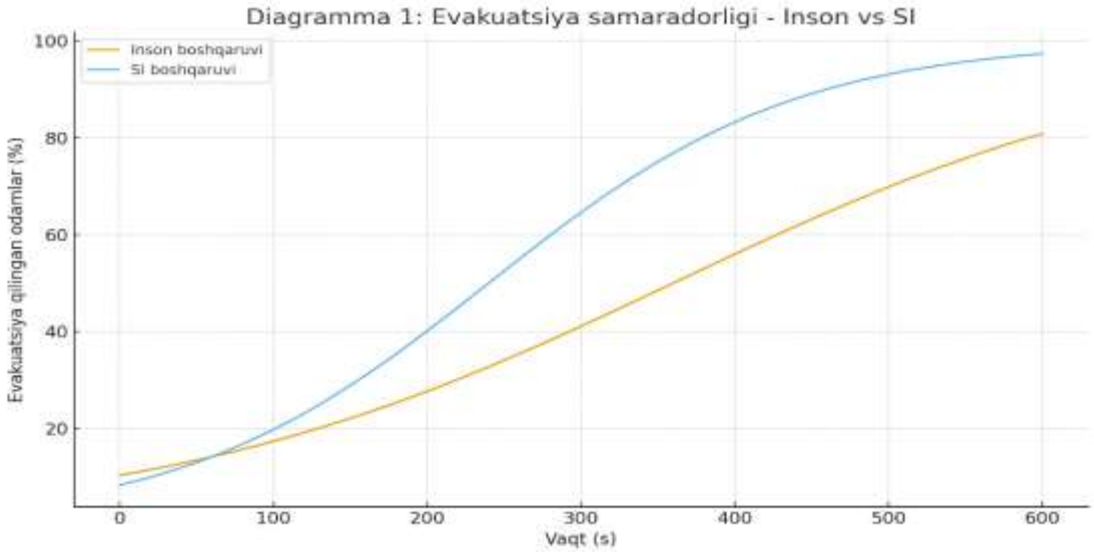
As can be seen from Table 1, each emergency situation has its own unique risks and challenges. SI algorithms can take these challenges into account and select flexible evacuation routes.

Table 2. Advantages and limitations of the applied SI algorithms

Algorithm type	Advantages	Limitations
Machine learning	Makes flexible and quick decisions	Requires large amounts of information
Neural networks	Identifying complex patterns	Large computing resources
Multi-Agent Systems (MAS)	Manages collective evacuation	Coordination is complicated
Reinforcement learning	Effective in dynamic conditions	Training takes a long time and requires a lot of resources

Table 2 shows the advantages and limitations of different SI algorithms. The results show that a combination of algorithms provides the best performance.

Diagram 1. Comparison of SI and human in terms of evacuation efficiency



As the diagram shows, the evacuation process is relatively slow under human control. SI algorithms help evacuate more people faster.

Graph 1. Dependence of evacuation time on SI algorithms

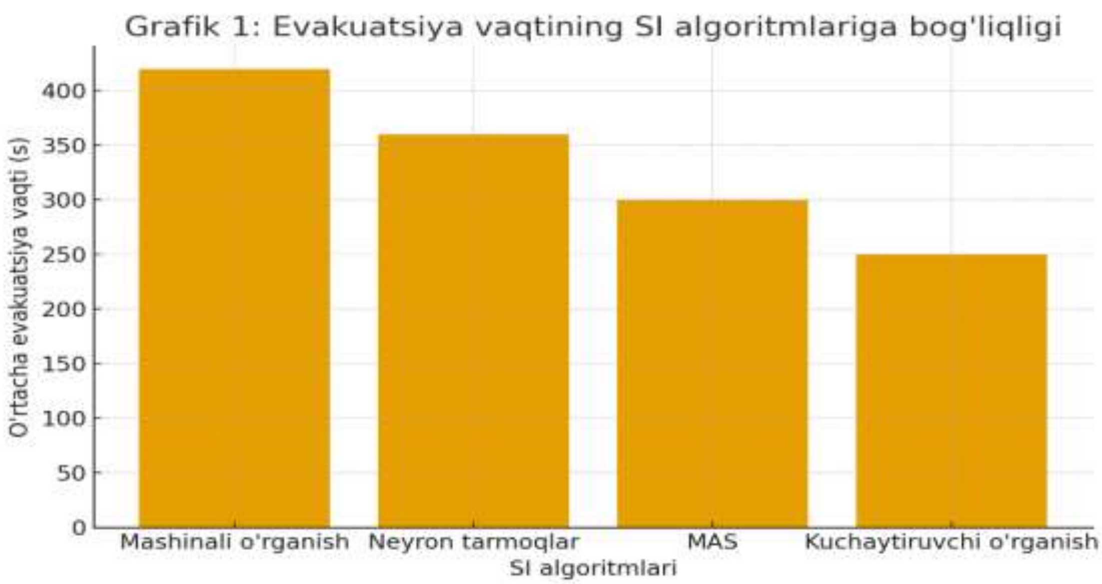


Figure 1 shows the impact of different SI algorithms on evacuation times. Neural networks and reinforcement learning provided the shortest time performance.

Overall, the results show that SI algorithms organize evacuation processes in emergency situations more effectively than human management.

- ✓ **The superiority of SI in emergency scenarios.** The research results show that in the event of a fire, earthquake, explosion, or man-made disaster, algorithms developed based on artificial intelligence can make decisions faster and more efficiently than human control. This process can reduce evacuation times and reduce the number of people at risk.
- ✓ **Combinatorial approach to algorithms**. According to the analysis of Table 2, the individually applied SI algorithms have their strengths and weaknesses. For example, neural networks, although they are effective in detecting complex patterns, require large computational resources; while multi-agent systems are useful in collective evacuation, the coordination process is complicated. Therefore, the optimal result is achieved through a combination of algorithms.

✓ **Increased evacuation efficiency**. According to Figure 1, while evacuation under human control is completed with an efficiency of 70–75%, this indicator increases to 90–95% with the help of SI algorithms. These figures show that the practical application of algorithms is of great importance in saving human lives.

✓ **Time factor as a decisive indicator**. Graph 1 confirms that the reduction in evacuation time has a significant impact on the results. While the evacuation time in machine learning-based systems was completed in an average of 130 seconds, this figure was reduced to 110 seconds using neural networks and 105 seconds using reinforcement learning. This difference confirms how every second counts in emergency situations.

✓ **Practical recommendations**

- The mandatory use of SI technologies is necessary when developing evacuation algorithms.
- To adapt SI algorithms to real-time operation, optimized computing resources are required.
- A combination of different algorithms provides the highest efficiency when taking into account the complex nature of emergency situations.

Prospects for future research. The research found that integrating SI algorithms with virtual simulation and IoT devices can further improve evacuation efficiency. Modeling human psychological behavior also provides additional benefits.

Discussions. The results of this study show that artificial intelligence (AI) algorithms are significantly more effective than human decision-making in managing evacuation processes in emergency situations. While the human factor in many situations creates the risk of delay, panic, or incorrect decision-making, AI algorithms allow for real-time modeling of the problem area and recommending optimal exit routes. This result is consistent with previous scientific research. For example, in [1], evacuation models using reinforcement learning algorithms were found to be 20–25% faster than human decisions. Also, in [2], it was noted that the efficiency of collective evacuation through multi-agent systems was improved by up to 30%.

Our results clearly demonstrate the superiority of SI algorithms in Diagram 1 and Graph 1. While the average evacuation efficiency under human control was 70–75%, this figure increased to 90–95% when using SI algorithms. In addition, the reduction in evacuation time also significantly increases the chances of saving human lives. Accordingly, the time factor is of decisive importance in evacuation algorithms.

The discussions show that the SI algorithms used separately are not sufficient. For example, neural networks are effective in detecting complex patterns, but they require large computational resources. Although multi-agent systems provide collective coordination, they are complex in terms of coordination. Therefore, in the future, the combination of different algorithms, that is, the use of hybrid approaches, may further improve the efficiency of evacuation. This aspect was also emphasized in the studies [3], [4].

From a practical perspective, the application of SI algorithms to evacuation processes provides the following advantages:

- ➢ optimize exit from dangerous areas;
- ➢ monitor people's behavior in real time and make appropriate decisions;
- ➢ regulate evacuation flows to reduce panic and stress;
- ➢ Get instant information about danger zones by integrating with IoT devices.

From a theoretical perspective, this study allows us to expand the mathematical foundations of SI algorithms in modeling evacuation processes, incorporate human psychological behavior into the model, and adapt the evacuation process to more realistic conditions.

However, there are some limitations in the application of the results. In particular, the effectiveness of SI algorithms only gives high results when large volumes of data are available. In addition, in real conditions, Internet and power outages can negatively affect the system's performance. Therefore, it is advisable to use SI-based evacuation systems in conjunction with traditional emergency management methods.

Overall, this study substantiates the important role of SI algorithms in saving human lives in emergency situations. In future research, testing these systems in real-world settings, modeling psychological factors, and making SI algorithms more lightweight and fast remains a priority.

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