Lecture Notes on Data Engineering
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Sergii Babichev
Volodymyr Lytvynenko *Editors*

Lecture Notes in Data Engineering, Computational Intelligence, and Decision-Making, Volume 2

2024 International Scientific Conference "Intelligent Systems of Decision-Making and Problems of Computational Intelligence", Proceedings

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Preface

Data engineering, along with the collection, analysis, and processing of information, represents the forefront of modern computer science. Many contemporary domains generate vast amounts of data that need to be systematically stored, analyzed, and processed to derive meaningful insights about the studied processes or objects. The development of advanced information and computer technologies for data analysis and processing in fields like data mining and machine learning enhances the efficiency of information processing by reducing time and increasing accuracy.

The international scientific conference "Intellectual Decision-Making Systems and Problems of Computational Intelligence" is a prominent series held in Eastern Europe. This conference is crucial for the region as it addresses modern trends in artificial and computational intelligence, data mining, machine learning, and decision-making. The conference aims to showcase the latest research in these fields, focusing on their application to various scientific research problems.

The ISDMCI'2024 Conference, held in Jan Evangelista Purkyně University in Ústí nad Labem, Czech Republic, from June 19 to 23, 2024, continues the tradition of the highly successful ISDMCI series that began in 2006. Over the years, ISDMCI has attracted hundreds, and even thousands, of researchers and professionals dedicated to artificial intelligence and decision-making. This volume contains 16 meticulously selected papers from the third thematic section of the conference—**Data Engineering, Computational Intelligence and Inductive Modeling**:

- Inductive methods of hybrid systems modeling.
- Data engineering.
- Computational linguistics.
- Data mining.
- Multiagent systems.
- Neural networks and fuzzy systems.
- Evolutionary algorithm and artificial immune systems.
- Bayesian networks.
- Fractals and problems of synergetics.
- Images recognition, cluster analysis and classification models.

We hope that the broad range of topics related to artificial intelligence and decision-making covered in this proceedings volume will help readers understand the significance of computational intelligence, data mining, and machine learning as crucial elements of modern computer science.

June 2024

Oleh Mashkov
Yuri Krak
Sergii Babichev
Volodymyr Lytvynenko

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Contents

Determination of Fire Evacuation Parameters in Higher Education Institutions with Inclusive Groups Using Machine Learning Methods

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Abstract. The object of the study is evacuation parameters from institutions of higher education with inclusive education, in particular, speed, flow density and the proportion of participants using crutches and wheelchairs. The relevance of the work is confirmed by the rapid development of inclusive education in Ukraine and abroad. This requires adaptation of existing models for calculating the evacuation duration for use in educational institutions with inclusive education. A way to solve this problem is to present the speed of movement of people during evacuation as a function not only of the flow density, but also of the participants with reduced mobility percentage. In the work machine learning methods, in particular, a linear regression model and an artificial neural network are used to establish the relationship between movement speed, flow density, the proportion of participants using crutches and the proportion of participants moving in wheelchairs. It has been proven that the use of the obtained dependence makes it possible to increase the accuracy of calculating the duration of evacuation from educational institutions with inclusive education by 14%. This makes it possible to use an individual approach in standardizing fire safety requirements for evacuation routes and exits in higher education institutions with inclusive groups.

Keywords: machine learning · linear regression model · artificial neural network · emergency evacuation · evacuation speed · flow density

1 Introduction

In 2009, Ukraine ratified the UN Convention on the Rights of Persons with Disabilities. According to Article 24 of this Convention, all participating states are obliged to ensure the implementation of an inclusive model of education. Statistics show that over the past 10 years, the number of students with special educational needs in Ukraine has increased almost 15 times. As of September 1, 2023 more than 12,000 of them study in higher education institutions [9].

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The current legislation of Ukraine enshrines state guarantees for the formation of an accessible and safe educational space. The accessibility of the space is ensured by the creation of a barrier-free educational infrastructure, the provision of psychological-pedagogical and scientific support, and the preparation of adapted educational programs. Security is achieved through the development and control of compliance with legislative norms for educational infrastructure [22].

Fire protection is an important component of life safety. For each object, one of the criteria for assessing the level of fire safety is the value of individual fire risk. This is a complex indicator, the calculation of which involves taking into account several parameters. One of these parameters is the evacuation duration from the building in case of fire. The evacuation duration is calculated individually for each object, taking into account its volume-planning and structural solutions, as well as the number and mobility of the people staying in it. Legislative approaches to inclusive education in general and to issues of life safety in its implementation can differ significantly in different countries [19]. The standard [3], which is valid from 2020, is a guiding document that provides methods for calculating the evacuation duration in Ukraine. The analysis of this document shows that the existing methods do not allow taking into account the presence of students with special educational needs in evacuation flows and their influence on the speed of the flow. This especially applies to evacuation participants with musculoskeletal disorders, who use wheelchairs and supports (crutches) to move around. According to [18], their share in the study group can reach 10%. Another factor that cannot be taken into account in these methods is the need to carry out evacuation in groups under the supervision of teaching staff. These problems can be solved using machine learning.

1.1 Main Contribution

In this research, regression analysis was performed using two methods - linear regression and artificial neural network. Based on the results of the analysis, it was established that the speed of the flow depends not only on its density, but also on the proportion of participants who use wheelchairs and crutches during movement.

The obtained dependence was used in practice to calculate the duration of evacuation from the building according to the simplified analytical method standardized in many countries. Comparison of calculated data with experimental data showed that the results of this work make it possible to improve the simplified analytical method for calculating the duration of evacuation. The improved method can be used to calculate the duration of evacuation from institutions of higher education with inclusive groups, which, in turn, contributes to the rational implementation of a barrier-free environment and the regulation of the permissible number of students with special needs in each individual institution.

1.2 Problem Statement

Evacuation can be conditionally divided into two types: independent and organized. In all residential and most public buildings, in case of a fire, evacuation is independent. Each participant chooses a route to a safe place at his own discretion. For modeling such processes, the best option is to use software complexes created on the basis of individual models. Individual models make it possible to simulate the movement of each individual evacuation participant based on a predetermined dependence of his movement speed on the density of the human flow (number of people per unit area) or the distance to the nearest obstacle.

At such facilities as educational or healthcare institutions, the evacuation of people is organized. As it was said before, it is carried out under the control of scientific and pedagogical workers or medical personnel. Under such conditions, the evacuation participants cannot independently choose the route of movement, and their speed depends on the speed of those who move slower than them. To simulate such scenarios, it is advisable to use group models. Such models consider the flow as a whole, that is, they assume that each member of the evacuation moves at the same speed, which depends on the density of the flow.

When trying to simulate the evacuation process from an educational institution with inclusive education, where the educational groups include students who move in wheelchairs or use crutches, several problems arise. First, such a scenario is difficult to simulate with the help of individual models, because the speed of movement of participants who move independently will depend on the speed of movement of participants who use assistive devices. Secondly, in the process of movement within the group, scientific and pedagogical workers as well as the other students can help participants with reduced mobility, therefore it is incorrect to equate the speed of the flow with the speed of the slowest participant. Therefore, the use of the flow model will also not give the proper accuracy of the results.

One way to solve this problem is to use a flow model, where the speed of the flow can be represented not only as a function of density, but also of the participants with reduced mobility share in the flow. Therefore, as a research hypothesis, we assume that during evacuation from an educational institution with inclusive education, the speed of the flow will decrease both with an increase in the density of the flow and with an increase in the share of evacuation participants in wheelchairs and on crutches.

The purpose of the work is to use machine learning methods for determining the dependence of the human flow movement speed V on 3 parameters: density D, the share of participants using supports (crutches) $M3$ and the share of participants moving in wheelchairs $M4$. To achieve the goal, the following tasks must be solved:

- creating a dataset of speed measurements which can be used for training and testing the regression model;
- using regression algorithms for establishing the relationship between speed and the above-mentioned predictors (D, $M3$, $M4$);

– testing the obtained regression model by calculating the duration of evacuation in real conditions.

Since each study has its own conditions and limitations, it should be noted that, to ensure compliance with the requirements of current regulatory documents, the total share of evacuation participants with reduced mobility ($M3 + M4$) should not exceed 10%.

2 Literature Review

During the analysis of scientific sources, both works devoted to the issue of evacuation from educational institutions and studies related to the evacuation of persons with musculoskeletal problems were analyzed.

In [23], a flow evacuation model is presented, which includes participants in wheelchairs. The research concerned organized evacuation. At the same time, the percentage of participants with reduced mobility significantly exceeded the indicators of flows typical for educational institutions. Articles [7,21] are devoted to evacuation from inclusive educational institutions. However, they pay attention, first of all, to the organizational and pedagogical component - evacuation drills, the purpose of which is to reduce the duration of the process. Article [8] is devoted to the modeling of people with special needs evacuation processes. The models considered in the work are mainly behavioral and aimed at taking into account the impact evacuation participants' psychological state on the movement. In work [5], the main parameters of the evacuation flows were determined, which, like educational institutions with inclusive groups, included up to 10% of participants with reduced mobility. At the same time, organized evacuation was not considered, which does not make it possible to use such models in educational institutions with inclusive education. In [17], evacuation from school education institutions was considered, taking into account the influence of the participants' age on their movement speed. The work [4] is devoted to the simulation of oncoming flows, which included participants with reduced mobility. In educational institutions with inclusive education, in the process of evacuation during a fire, the movement of oncoming flows is unlikely. In [12], an analysis of regulatory documents in Ukraine was performed and the need to make changes which would allow adapting existing models for use in educational institutions with inclusive education was proved. The work [13] deals with the process of school-aged children evacuation. A partial flow case was considered, in which the percentage of participants in wheelchairs was 10%. Other flow configurations were not considered. Analysis of sources [11,14,15] proves the relevance of using machine learning methods to solve fire safety issues.

Therefore, based on the results of the analysis, it can be concluded that the processes of organized evacuation have been studied less than the processes of independent evacuation. The impact of the percentage of participants with reduced mobility on the speed of the flow during an organized evacuation requires special attention. The use of machine learning methods makes it possible to significantly improve existing calculation models and methods and adapt them for use in higher education institutions with inclusive groups.

3 Stepwise Procedure

The research was conducted in several stages. Materials and methods used in the implementation of each of the stages are presented in Table 1.

Table 1. Stages of the research

#	Stage of the work	Materials, Methods and Software used
1	Experimental Studies	Dynamic videorecording, Video surveillance, 3 wheelchairs, 3 pairs of crutches
2	Obtaining measurements dataset	Videoplayer, Microsoft Excel, OpenCV libraries, SORT algorithm
3	Regression Analysis	Python (Google Collaboratory) Pandas, NumPy, Scikit-learn, MathPlotLib, Seaborn Libraries
4	Approbation of the model	Simplified analytical method, Pathfinder software complex

The first stage involved conducting experimental studies, the purpose of which was the formation of a dataset, which was later used to train the regression model. During the experiment, the process of an organized evacuation in a higher education institution was reproduced. The experiment was conducted at Lviv State University of Life Safety with the involvement of students. In the process of movement, to ensure compliance with real conditions, the participants of the experiment helped the students who were moving on crutches and wheelchairs. The length of the evacuation route was 50 m, the width −3 m (Fig. 1).

In the process of conducting the experiment, dynamic video recording [10] was performed, which involved synchronous use of action cameras by some of the participants. Subsequently, the simultaneous viewing of several recordings in combination with the analysis of video surveillance cameras made it possible to determine the speed of movement of individual participants and the density of the flow. To simplify the calculation, special marks were placed on the path at a distance of 2 m from each other.

Fig. 1. Performing the experiment

Neural network analysis of CCTV recordings was also used, which involved recognition of participants and determination of their movement speed using OpenCV tools, the SORT algorithm and the Kalman filter [11].

The next step was the formation of a dataset in the form of a table. Each row of the table contained the following data: participant movement speed V, the density of the flow D, the percentage of participants who use crutches $M3$, the percentage of participants who move in wheelchairs $M4$. The final version of the dataset was saved in Microsoft Excel (.xlsx) file format.

Regression analysis was performed using the Python programming language in the Google Collaboratory environment [6] with the Pandas, NumPy, Scikit-learn, MathPlotLib, Seaborn [20] libraries.

At the final stage, the models obtained as a result of the training were used to improve the simplified analytical method for calculating the evacuation duration in case of fire [3]. The effectiveness of these models was tested in practice. The results of the evacuation duration for various scenarios were determined using an improved simplified analytical model, using the Pathfinder software complex and an experimental method. The obtained values were compared.

4 Experiment, Results and Discussion

4.1 Experiment

Conducting the experiment involved 3 repetitions of 10 different scenarios, in each of which the human flow configuration was different (Table 2).

Thus, based on the results of processing the video recordings obtained during the experiment, a dataset of 416 speed measurements was obtained (Fig. 2).

Table 2. Experimental scenarios

Scenario #	Total number of agents	Number of agents using crutches $M3$, (%)	Number of agents using wheelchairs $M3$, (%)	Number of measurements
1	30 (100%)	0 (0%)	0 (0%)	44
2	29 (96,67%)	1 (3,33%)	0 (0%)	46
3	28 (93,33%)	2 (6,67%)	0 (0%)	35
4	27 (90%)	3 (10%)	0 (0%)	37
5	29 (96,67%)	0 (0%)	1 (3,33%)	41
6	28 (93,33%)	0 (0%)	2 (6,67%)	39
7	27 (90%)	0 (0%)	3 (10%)	43
8	27 (90%)	1 (3,33%)	2 (6,67%)	43
9	27 (90%)	2 (6,67%)	1 (3,33%)	47
10	28 (93,33%)	1 (3,33%)	1 (3,33%)	41
Total				**416**

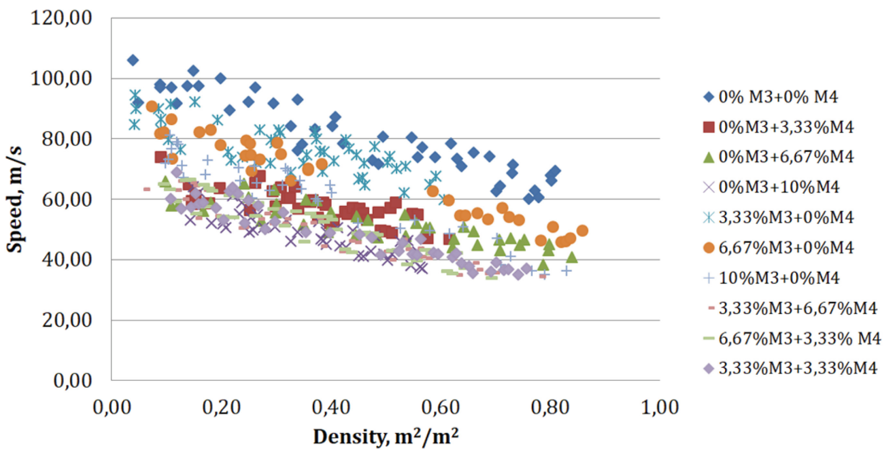

Fig. 2. Experimental results

It should be noted that in homogeneous flows, where each participant has a constant area of the horizontal projection, the unit of measurement is the number of persons per square meter. In this case, the flow is heterogeneous, so we define the density in m^2/m^2. When calculating, the area of the horizontal projection of participants using wheelchairs was taken as equal to 0.96 m^2/m^2, participants on 2 crutches -0.3 m^2/m^2, and the rest of the participants -0.125 m^2/m^2 [3].

4.2 Regression Analysis

First of all, the correlation between all parameters was determined and a heat map of correlations was constructed (Fig. 3).

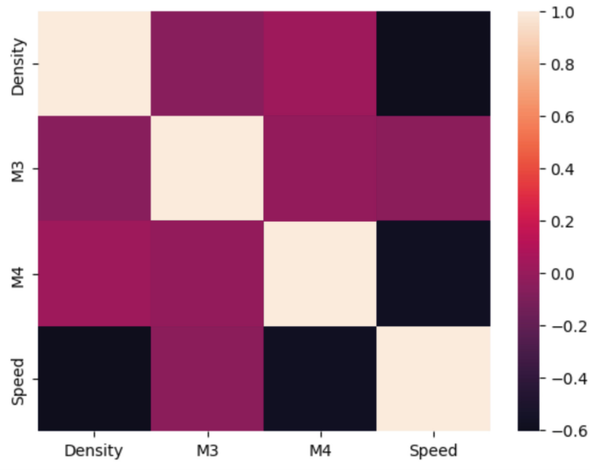

Fig. 3. Correlation heatmap

The values of the correlations between the components indicate that the flow density (−0.8) has the strongest influence on the change in the movement speed. An increase in density leads to a decrease in speed. An increase of the percentage of people moving in wheelchairs in the flow also causes a decrease in speed (−0.56). The presence of students using crutches reduces the speed not as significantly as the previous factors (−0.19).

The multicollinearity test showed that the correlations between the predictors are insignificant.

To establish the dependence of V on parameters D, $M3$, $M4$, a linear multivariate regression model was used [16]. The dataset formed at the previous stage of the research was divided into training and test samples in the ratio of 80% to 20%. The results of model training are shown in Table 3.

According to the results of the regression analysis, Eq. (1) was obtained:

$$V = 97,03 - 44,68 \cdot D - 1,89 \cdot M_3 - 3,36 \cdot M_4 \tag{1}$$

where V is the speed of flow, m/s; D – flow density, m^2/m^2; M_3 – percentage of participants using crutches (%); M_4 is the percentage of participants using wheelchairs (%).

Overall, the provided metrics indicate that the regression model has quite good forecasting quality. The R-squared for the test data is practically identical to the R-squared for the training data, indicating no overfitting of the model.

Table 3. Results of linear multifactor regression.

Training data r-squared	0.8199
Test data r-squared	0.8518
Intercept	97.0314
Mean absolute error (MAE)	5.3047
Mean squared error (MSE)	39.7764

The MAE and MSE are also acceptable; however, further improvement of the model could be considered depending on specific project requirements and goals. The results demonstrated by the model on the test sample are shown in Fig. 4.

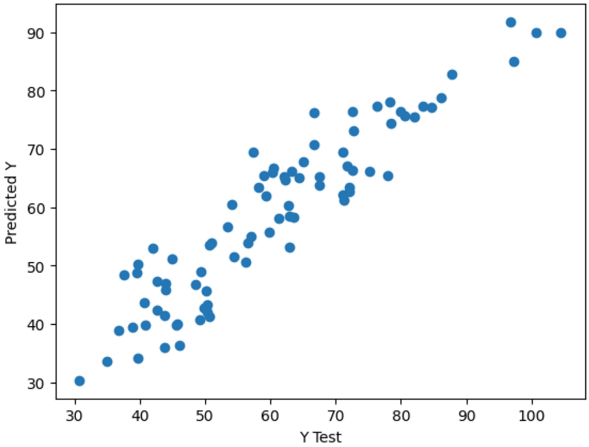

Fig. 4. Results of linear regression test sample values prediction

The second method involved the use of a fully connected neural network [20]. Initially, data normalization was performed using the .mean() and .std() methods.

The neural network architecture comprised 2 layers of neurons, with the initial layer comprising 144 neurons activated by the ReLU function. The output layer was a single neuron. A total of 721 parameters were trained. The dataset was split into training and testing sets at an 80:20 ratio. Adam optimizer was utilized, with Mean Square Error (MSE) serving as the performance metric. Additionally, Mean Absolute Error (MAE) was selected as a measure of accuracy. After 80 training epochs, the MSE reached a value of 14,69 on the training and 15,21 on the test samples. MAE reached a value of 3,16 on the training and 3,23 on the test samples (Fig. 5).

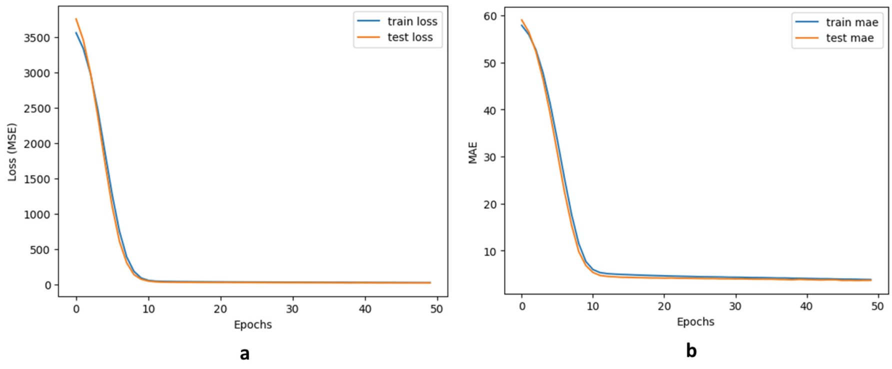

Fig. 5. MSE(a) and MAE(b) values reducing during model training

The results demonstrated by the neural network on the test sample are shown in Fig. 6.

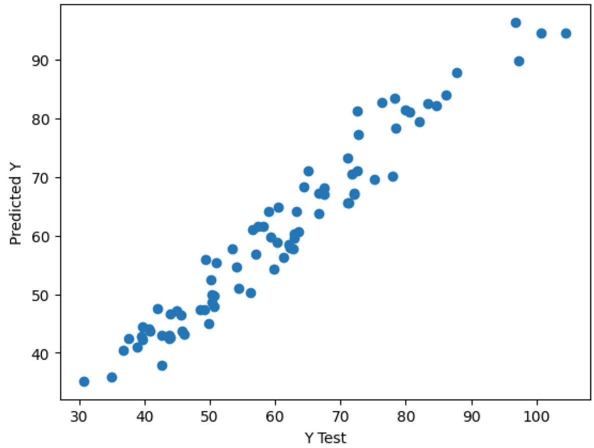

Fig. 6. Results of neural network test sample values prediction

The comparison of the main metrics shows the better accuracy of the work on the test sample of the neural network in comparison with the linear multiple regression model.

4.3 Computer Simulation

The effectiveness of evacuation duration calculations using the obtained models was tested in practice. For this, another series of experiments was conducted with the involvement of other participants. At the same time, on the experimental section of the path with a width of 3 m and a length of 50 m, a section with a length of 5 m was provided, on which the width was narrowed to 1.2 m. This made it possible to achieve different values of the flow density during the movement. The evacuation duration under each of the scenarios was determined in seconds. After that, the corresponding values were determined by calculation, using a standardized simplified analytical model [3], the Pathfinder software complex (Fig. 7), as well as improved simplified analytical models supplemented by dependence (1) and a model based on an artificial neural network (NN), respectively.

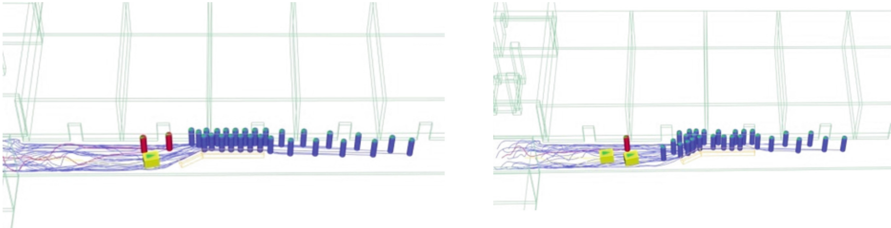

Fig. 7. Computer simulation of the evacuation process

The obtained results were summarized in Table 4. For each of the calculation methods used in the work, the deviation from the experimental results was determined in percent.

Table 4. Comparison of evacuation duration values (in seconds)

Scenario #	Experiment	Simplified analytical method [3]	Pathfinder software complex	Modified simplified analytical method (1)	Modified simplified analytical method (NN)
1	37	30 (−18,92%)	41 (10,81%)	31(−16,22%)	33 (−10,81%)
2	50	42 (−16,00%)	56,3 (12,60%)	44 (−12,00%)	45 (−10,00%)
3	52	42 (−19,23%)	58,2 (11,92%)	47 (−9,62%)	47 (−9,62%)
4	55	42 (−23,64%)	60,3 (9,64%)	48 (−12,73%)	49 (−10,91%)
5	58	50 (−13,79%)	65,9 (13,62%)	54 (−6,90%)	54 (−6,90%)
6	60	50 (−16,67%)	69,3 (15,50%)	55 (−8,33%)	56 (−6,67%)
7	63	50 (−20,73%)	71,1 (12,86%)	56 (−11,11%)	58 (−7,94%)
8	62	50 (−19,35%)	70,3 (13,39%)	56 (−9,68%)	57 (−8,06%)
9	60	50 (−16,67%)	66,7 (11,17%)	55 (−8,33%)	55 (−8,33%)
10	59	50 (−15,25%)	66,2 (12,20%)	54 (−8,47%)	54 (−8,47%)
Average deviation		−18,02%	12,37%	−10,34%	−8,77%

4.4 Discussion

Conducted studies and obtained results indicate that, in addition to the density of the flow, the percentage of students with reduced mobility also affects the speed of movement. Equation (1) shows that the presence of wheelchair users has twice as strong an effect on speed as compared to crutch users. When solving the regression problem, the artificial neural network demonstrated better accuracy metrics than linear multiple regression model. Thus, when performing practical calculations according to 10 scenarios using 4 models, the average value of the deviation from the experimental results was determined for each of the models. The standardized simplified analytical model showed an average deviation of 18.02%; the individual model (Pathfinder software complex) −12.37%; the improved simplified analytical model, in which the dependence (1) proposed in this paper was used to determine the input data −10.34%; the improved simplified analytical model in which the neural network trained in this work was used to determine the input data −8.77%. It is worth noting that since individual models do not allow setting the conditions under which other evacuation participants provide assistance to participants using crutches, the duration of evacuation calculated with the help of these models is longer than the one obtained experimentally. This fact proves the feasibility of using group models adapted by machine learning methods to calculate the duration of evacuation from institutions of higher education with inclusive education.

5 Conclusions

In the work, machine learning models have been used to establish a regression relationship between the movement speed of evacuation flows in higher education institutions with inclusive groups, the flow density, the share of students who use crutches and the share of students who move in wheelchairs.

In the course of the work, an experiment has been conducted, which have made it possible to obtain a dataset of 416 speed measurements and subsequently to form training and test samples for training regression models.

A linear multivariate regression model and an artificial neural network have been used to establish the relationship between the measurements, and it has been found that the model based on the neural network had demonstrated better accuracy.

The results of the work have been used for calculating evacuation duration in real institution with inclusive groups. It has been established that the use of an artificial neural network to determine the input data for calculation according to a simplified analytical model makes it possible to reduce the deviation of the calculated and the experimental value from 18.02% to 8.77%.

The obtained models make it possible to calculate the value of the mixed flow speed, taking into account not only the density, but also the percentage of participants with reduced mobility. Thus, machine learning tools make it possible to improve group models for calculating the evacuation duration and to adapt them for use in institutions of higher education with inclusive groups.

It is worth noting that, in addition to students with musculoskeletal problems, students with visual impairments can study in educational institutions with inclusive education. Visual impairment is a factor that also reduces mobility. Therefore, the goal of further research is to improve the proposed models, which would allow taking into account such an option when calculating the evacuation duration. Also, a promising and important task for further research is the extension of mobility groups standardized in current documents using clustering methods [1,2].

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