Simulation of passenger movement dynamics in a vehicle

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Abstract. Support The article deals with the problem of modeling the movement of passengers in the interior of a vehicle using the example of an airport bus. Such modeling will allow automating the process of optimizing the layout of the salon, provide comfortable conditions for passengers and improve the fullness of the salon. When modeling the dynamics of passenger movement, the paradigm of agent-oriented programming, based on the modeling of social intelligence, was used. A class of extremely simplified discrete models - cellular automata - was used here. Developed methods that take into account the behavior of large groups of people were also used. To implement the developed methodology, the version of airport buses used in the 50s and 60s of the last century - a truck with a passenger semi-trailer - was taken as an example.

1 Introduction

The layout of buses is determined by their purpose and overall length. Buses up to 9 m long are designed, as a rule, on the basis of the chassis of trucks or cars or with the use of their units, which practically determines the layout of such buses (with the front engine). Buses with a length of 9 m or more can have different layout solutions depending on the purpose and operating conditions. For city shuttle buses, the choice of the layout of the engine and transmission is the most difficult, since in this case the layout must ensure the fullness of the salon, convenience, safety and speed of entry and passage and the exit of passengers, as well as the movement of passengers in the salon during boarding and disembarking.

The requirements of the standards for the interior and layout of the interior of city shuttle buses are basically the same as for high-capacity buses, but there are some differences [1,2] concerning the number and location of doors, as well as the dimensions of the aisles.

When designing the cabin, the problem of occupancy and the movement of passengers in the cabin was not taken into account and researched.

With the emergence of new design technologies, which contain components of automation and algorithmization of the process of creating new samples of technology, it became possible to model work processes involving the product being created and, accordingly, to reduce the number of design iterations even at the stage of conceptualization (creating the prerequisites) of the project. This will reduce the cost of time, intellectual, financial and other resources.

In the case of the layout of the bus interior, it is possible to predict various options for the placement of the engine, seats, wheel wells, and doors and to evaluate the interior's occupancy (static characteristic) and the ease of filling it (dynamic characteristic).

In works [3,4] , the impact of the design features of the interior layout of the bus and passenger ship on the evacuation process is considered. These research results are compared with the time of reaching the maximum permissible values of dangerous fire factors, determined by the results of modeling the dynamics of fire development in a vehicle.

The article [5] considers a new approach to determining the real dimensions of passenger planes with a comprehensive account of their commercial potential. It is proposed to use the concept of reduced passenger capacity as a denominator when calculating the technical and economic efficiency of aircraft, as well as when positioning aircraft families in terms of size relative to each other.

Works [6-8] consider the problem of scientific and methodological support for the analysis and selection of a rational layout scheme of small-sized vehicles according to various parameters, including the useful volume of the salon and its layout at the stages of design and planning. As a result, there is a wide choice of combinations of the location of units and passengers in the body space, which may differ from the generally accepted designs of cars.

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The article [9] presents the results of experimental studies of one of the important indicators for city bus transportation - the filling factor. A comparative analysis of this coefficient was performed on routes where large, small, and especially low-capacity buses are used at the same time. These are recommendations for ranges of changes in this coefficient for minibuses.

When solving problems of this class, multi-agent methods of intellectual optimization are used, simulating collective intelligence.

Multi-agent distributed artificial intelligence systems include multi-agent methods of intelligent optimization (collective intelligence methods, Swarm Intelligence). These methods have a bionic nature, that is, they are based on modeling the behavior of birds, animals, insects, etc., whose behavior is collective in nature, due to which the so-called collective intelligence is achieved.

In the implementation of these methods, the paradigm of agent-oriented programming, based on the modeling of social intelligence, is used, which includes: the method of ant colonies (Ant Colony Optimization, ACO) [10,11] , the method of bee colonies (Bee Colony Optimization, BCO) [12] , optimization using particle swarm optimization (PSO) [13-16] and other methods.

These methods are effectively used to solve various problems: ACO - for solving the traveling salesman problem, calendar planning problem, selection of informative features, clustering; BCO - for solving the problem of calendar planning, the traveling salesman problem, and the transport problem [17-19].

When simulating the fullness of the salon, it is advisable to use the developed methods that take into account the behavior of large groups of people. The behavior of a large group of people in a standard situation is easily predictable and well described in a probabilistic manner. The law of large numbers works here: even if one person for some reason decides to act non-trivially, his actions will not affect the group as a whole.

For mathematical modeling of crowd dynamics, it turned out to be possible to apply a class of extremely simplified discrete models - cellular automata [20-22].

One of the problems of a group of people, which occurs when moving, is the formation of traffic jams or "traffic jams" in the presence of some obstacles in the way of movement of such a group [23-26]. If for some reason such obstacles must necessarily be in the way of people, then it is advisable to predict in advance how much they will slow down the movement of people.

Articles [27,28] state that more complex crowd behavior can be modeled without a corresponding increase in the complexity of agents. It is possible to dynamically specify the behavior of the crowd in different parts of their space. An example is given for a city street and in a theater.

Therefore, the problem of the layout of vehicle cabins is partially and situationally developed. There is no single approach, methods and algorithms for the study of the fullness of passenger cabins, the assessment of the effectiveness of the completed layout of the vehicle, taking into account structural parameters, human factors, and mathematical methods of optimization.

Therefore, it is important to determine and create the basis for the layout of the vehicle as a whole, taking into account the human factor in the case of the layout of passenger cabins.

2 Presenting main material

Let's consider the model task of describing the dynamics of the movement of passengers in a vehicle. In the basic example, which will be the basis for further research with the increasing complexity of the layout environment of the vehicle, we will take the layout of airport buses as a basis.

Platform or airport buses are significantly different from traditional city transport. They are much wider than traditional models. The platform bus has a low landing and doors on both sides. Since there are practically no seats in it, passengers do not feel cramped or other inconveniences.

The simplest version of airport buses was the use of Skoda, Mercedes-Benz passenger semi-trailers in the 50s and 60s of the last century. They were also produced by various companies in the UK, Switzerland, Spain, France, and the USA (Fig. 1).

Fig. 1. Airport buses of the 50s and 60s of the last century: a - a Ford tractor unit with a passenger semi-trailer used at the Zurich airport; b - a Skoda truck with a semi-trailer based on a Skoda bus.

For the sake of simplicity, we will assume that the behavior of model agents is set on a rectangular grid, while in 1 modeling step, an agent occupying 1 cell can move no more than 1 cell.

The vehicle is a rectangular area of cells, where the entry and exit points of passengers are specified, all other points are equivalent (Fig. 2).

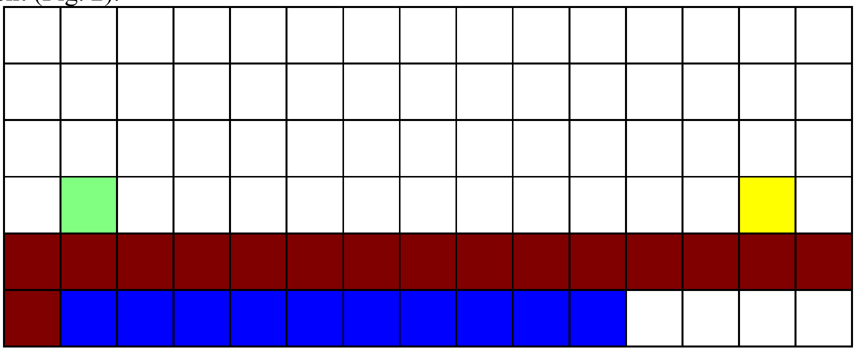


Fig.2. The model universe of the problem: above is an empty vehicle («bus»), the green cell is the entry point ("entrance door"), the yellow cell is the exit point ((«exit door»); below, under the dividing brown line, model agents are conventionally shown («passengers at the stop»).

To simulate the movement of agents, so-called stress models are used, in which behavior depends on various stress factors: interpersonal stressors (Interpersonal stressors) - efforts to avoid crowding [29,30], positional stressors (Positional stressors) - efforts to move to a given point [29,31] and a combined model that takes both factors into account.

Each agent moves to the point with the minimum value of the stressor, and in order to avoid collisions, the trajectory of movement is calculated using the so-called wave algorithm [32–34].

An interpersonal stressor $I_i$is given for each point with coordinates $p(x, y)$ model universe B in the form of

$$I_i(p) = \sum_{p' \in \omega} B\,(p - p') \tag{1}$$

where $p' \in \omega$ are all points belonging to some ω-circle of point p.

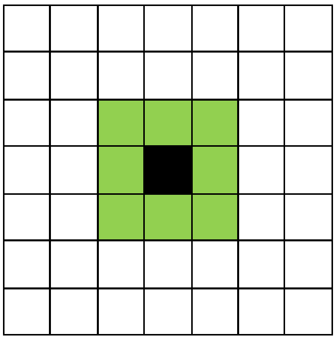


Fig. 3. Moore's circle (a set of eight cells on a square parquet that have a common vertex with this cell).

If the ω Moore neighborhood [4] (see Fig. 3) is considered as a -neighborhood, then equation (1) can be written in an explicit form:

$$I_i(x, y) = \ (B * u)_{x,y} \tag{2}$$

where the symbol $*$means the point, and the matrix $u = \begin{pmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{pmatrix}$ defines the point's neighborhood. Thus, in this case, the interpersonal stressor model represents the sum of neighbors around a point, and movement will go to points where the number of these neighbors is minimal.

The positional stressor is $I_p(p, p_0)$ set for the current point $p = p(x, y)$ and some («target») point p_0 as:

$$I_p(p, p_0) = const \cdot \|p - p_0\| \tag{3}$$

Without losing generality, we can assume that $const = 1$, and in this case it is appropriate to consider the L_1-norm.

Thus, the generalized stressor model considered in this article can be presented as:

$$I = \alpha I_i + \beta I_p \tag{4}$$

or

$$I(p) = \alpha \sum_{p' \in \omega} B\,(p - p') + \beta \|p - p_0\|_1 \tag{5}$$

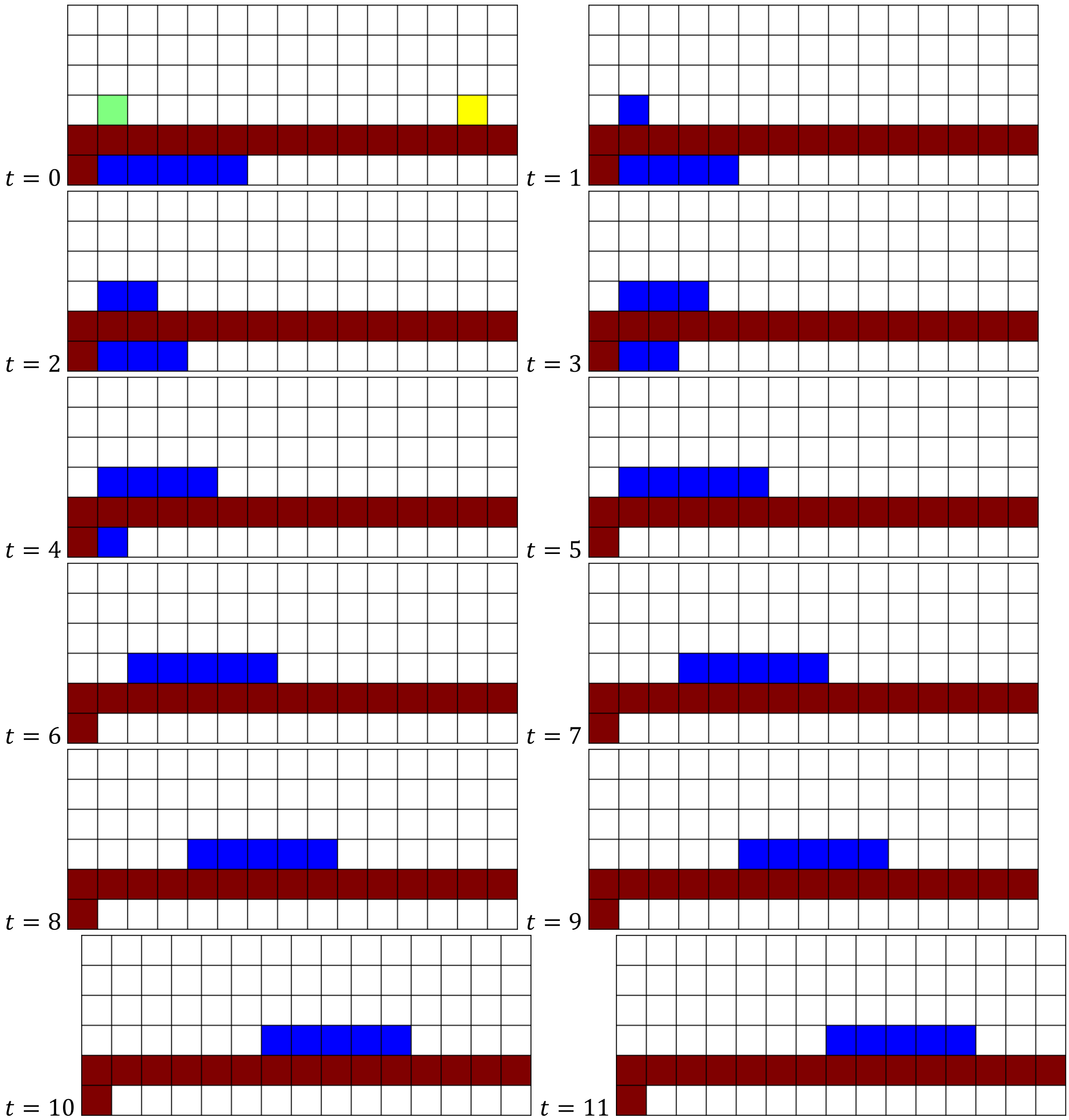
where α and β are some weighting coefficients, at the same time, we $\alpha = 0, \beta = 1$ get the interpersonal stressor $\alpha = 1, \beta = 0$ model for, the positional stressor model for, and the $\alpha = 1, \beta = 1$ combined model for . It is suggested to choose the exit point as the target point p_0.

In general, the modeling algorithm can be represented as a sequence of the following steps:

- initialization of the model universe B, setting the number of particles;
- until the maximum number of simulation steps is reached T:
    - if not all model agents are involved, add 1 agent to the entry point;
    - for each model agent located at a point p^a:
        - calculate the stressor matrix $I(p)$ according to formula (5) for each available point $p = p(x, y)$;
        - find a point $p' = \arg\min_p I(p)$;
        - with the help of a wave algorithm, build a trajectory of movement $w = w(p^a, p')$ and, if such a trajectory exists, move to the next point along this trajectory.

Note that the sequence of model agents at each step should be considered in a random order.

The results of modeling according to this algorithm are shown in Fig. 4.



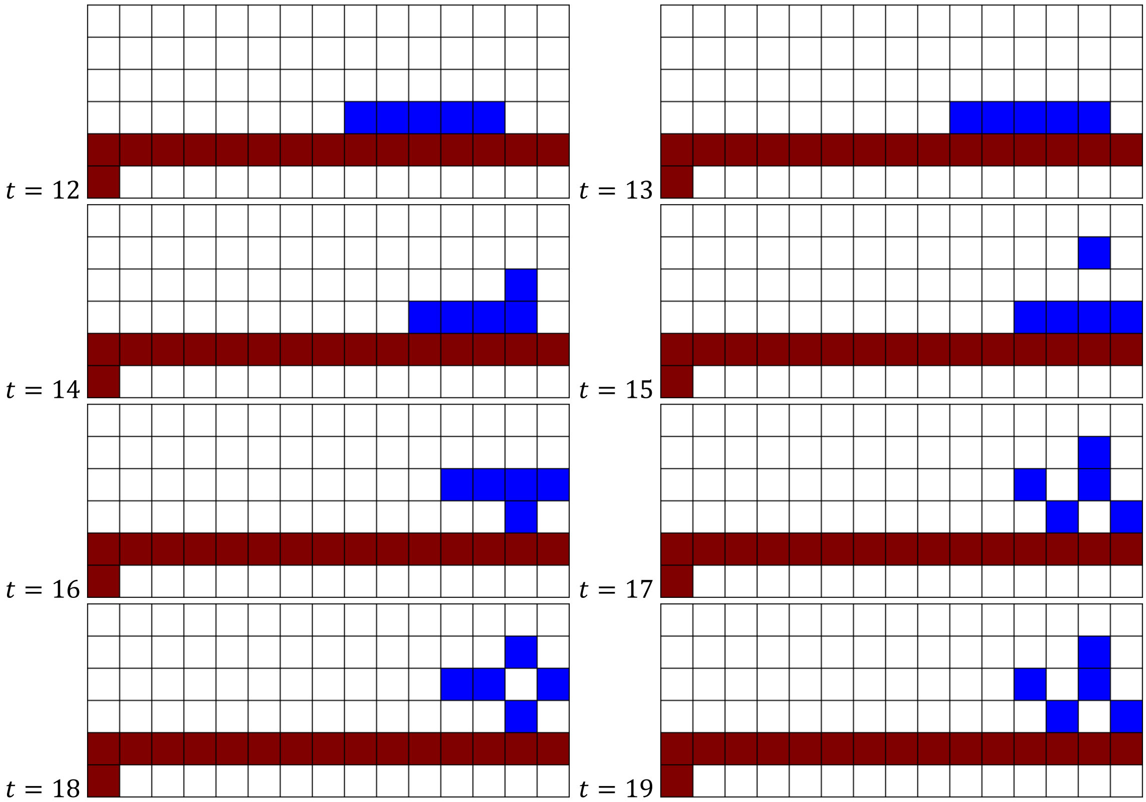
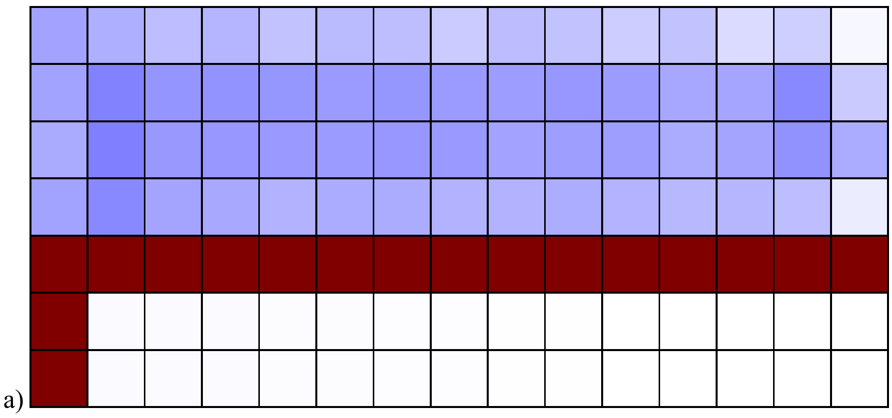


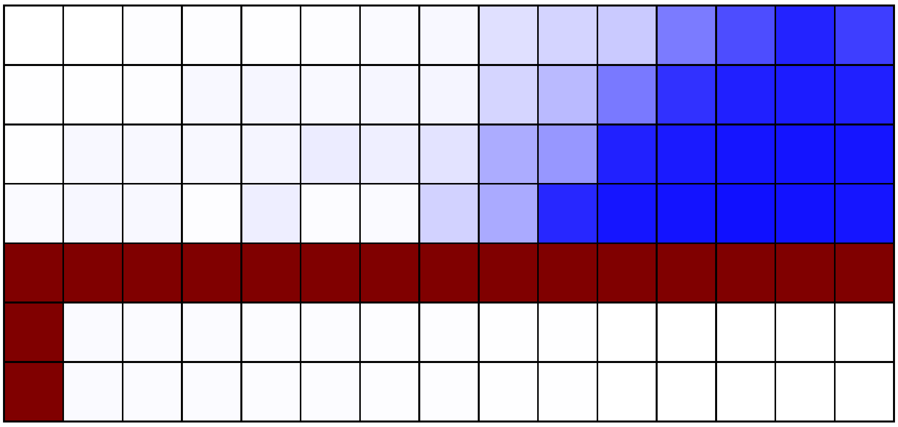
Fig. 4. Simulation results for 5 model agents.

Note that when analyzing the dynamics of the movement of a relatively large number of model agents (in this case, more than 10), we do not obtain a stationary configuration of agents, which is due to the fact that they "interfere" with each other and the permissible trajectories change at each step. This can be avoided (to obtain more realistic results consistent with practice) by introducing an additional condition that movement occurs only if the next step along the trajectory is guaranteed to reduce the value of stressors.

Thus, for the analysis of stationary configurations of motion dynamics, it is convenient to average the simulation results for a sufficiently large number of steps, as shown in Fig. 5.



b)



c)

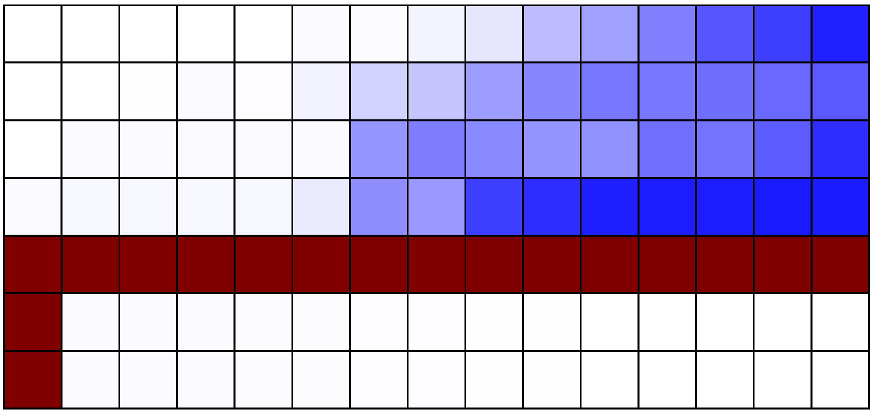


Fig. 5. Modeling results for 20 model agents averaged over $T = 1000$ steps for different behavior models: a - interpersonal stressors (Interpersonal stressors), $\alpha = 0, \beta = 1$; b - positional stressors (Positional stressors), $\alpha = 1, \beta = 0$; combined stressors, $\alpha = 1, \beta = 1$.

3 Conclusions

The following conclusions can be drawn on the basis of the conducted research:

1) the model , which takes into account interpersonal stressors, shows a statistically uniform distribution of model agents over time almost throughout the area, with the exception of the entry point (in which every agent must appear at the start of his story) and distant corner points (this effect had would disappear when the number of averaging steps increases);

2) the model, which takes into account only positional stressors, shows a compact distribution around the exit point;

3) the combined model, as expected, gives intermediate results - the distribution is grouped around the exit point, but is not compact enough compared to the model that takes into account only positional stressors.

As a direction of further research, it is advisable to supplement the model and conduct the following experiments:

1) add the asymmetry of the points of the vehicle (seats vs standing seats, seats near the window, etc.);
2) simulate the process of passenger exit;
3) simulate the effect of a positional stressor that maximizes the distance from the entry point.

Modeling the occupancy of passenger vehicles will make it possible to increase their efficiency.

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