Mathematical Modeling and Research of Passenger Flows in Marine Passenger Port

Matematičko modeliranje i istraživanje protoka putnika u morskim putničkim lukama

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Summary

Modern passenger terminals are characterized by dynamic processes variability, diverse options consideration, taking into account the criteria of safety, reliability analysis and the continuous research of passenger processing. For any modern marine passenger terminal it is necessary to use the tool to simulate passenger flows. In this way it is possible to obtain the analytical information and use it for decision-making when solving the problem of the amount of personnel required for passenger services.in line with the original ship arrival schedule, to solve problems of forecasting groups at the terminal. Of particular relevance is the choice of the mathematical transport model and the practical conditions for the implementation of the model in the real terminal operation. In this article the analysis technique of simulation-based terminal services, provides a mathematical model of passenger movement inside the terminal. Also, the conditions of implementation of the transportation model during the operation of marine passenger terminal are examined. The object of the research is the marine Passenger Port of St. Petersburg "Marine Facade". The paper discusses advantages of using such systems and their introduction in the early stages of operation of the terminal. In addition, the conclusion about the effectiveness of such systems for the analysis of the correctness of internal space of the marine terminal. The study represents an example of analytical information used for the forecast of the terminal operations, the analysis of the workload and efficiency of the organization of the marine terminal.

KEY WORDS
transport processes
mathematical modeling
simulation
passenger flow simulation

Sažetak

Moderni su putnički terminali obilježeni dinamičnim I različitim procesima te mogućim opcijama, uzimajući u obzir kriterije sigurnosti, analizu pouzdanosti i neprestano istraživanje procesa putovanja. Za bilo koji moderni putnički terminal bitno je koristiti se sredstvima stimuliranja protoka putnika. Na ovaj način moguće je dobiti analitičku informaciju i koristiti se njome pri donošenju odluka za rješavanje problema o broju osoblja koje je potrebno za putničke usluge, u skladu s originalnim rasporedom dolaska broda, kako bi se riješio problem dočekivanja grupa na terminalu. Iznimno je važan izbor matematičkih transportnih modela i praktičnih uvjeta za implementaciju modela stvarnog stanja na terminalu. U ovom članku analiza tehnike simuliranja terminala omogućava matematički model gibanja putnika unutar terminala. Također se ispituju uvjeti implementacije transportnih modela tijekom upravljanja pomorskim putničkim terminalom. Predmet istraživanja je pomorski putnički terminal luke St. Petersburg "Marine Façade". Članak opisuje prednosti korištenja takvih sustava i njihov uvod u ranije faze upravljanja terminalom.Pritom se dodaje zaključak o djelotvornosti takvih sustava za analizu točnosti unutarnjeg prostora pomorskog terminala. Istraživanje predstavlja primjer analitičke informacije korištene za predviđanje operacija u terminalu, analizu opterećenja i djelotvornosti organizacije pomorskoga terminala.

KLJUČNE RIJEČI
transportni procesi
matematičko modeliranje
simulacija
simulacija protoka putnika

1. INTRODUCTION / *Uvod*

Passenger Port of Saint Petersburg is the first and the only specialized passenger port in the North-West Russia and also the largest in the Baltic region. The Port is located on the reclaimed territories of Vasilievsky Island. Port complex includes seven berths with a total length of 2,171.06 meters, three cruise terminals and one combined cruise-ferry terminal. Passenger port of Saint Petersburg can accommodate cruise ships of up to 340 meters in length. Passenger Port of Saint Petersburg "Marine Facade" PLC is an active participant of the global cruise market and appears regularly at international cruise industry events and exhibitions. The Port is a member of ASOP (Association of Commercial Seaports), CLIA (Cruise Lines International Association), IAPH (International Association of Ports and Harbors), Cruise Industry Members Association, Cruise Europe, and Association of Marine Tourism Enterprises.

The aim of this paper is to develop a practical research simulation tool to simulate and forecast passenger flows inside the terminal at the micro-level and forecasting work services of the „Passenger Port of St. Petersburg" Marine Façade "[1]. On the basis of a software system that offers the ability to create the conditions from which one can make a decision and improve the quality of work at the port. For example, the number of personnel required for passenger service in accordance with the arrivals schedule. In addition, it should be noted that such tool could be used for transportation object safety analysis simulating various emergency situations or finding possible passenger congestion points inside the terminal.

The passenger terminal infrastructure consists of four individual marine stations, which differ in type of cruise ship that can dock, and such parameters as the number of passport control counters. With a maximum occupancy in passenger port all berths work in parallel mode, while the load on them is different. It should also be noted that each berth has architectural features that affect the organization of passenger flows. Architectural features are important in the practical implementation of the simulation model in a software environment. Stats time „Passenger Port of St. Petersburg" Marine Façade "is shown in fig. 1.

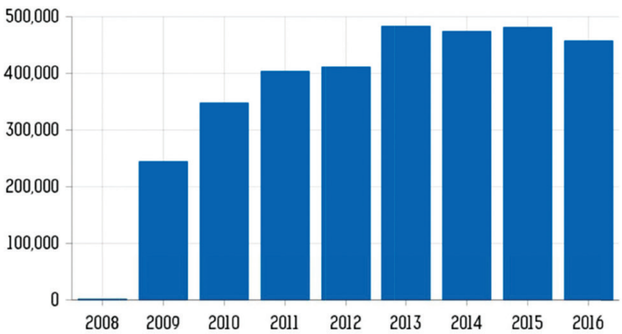

Figure 1. Number of cruise passengers 2008-2016.
Slika 1. Broj putnika na kružnim putovanjima

Main cruise lines in port Saint-Petersburg:

1. Carnival Corporation & plc. 1490606 pax. – **43.05%**
2. Royal Caribbean International and Celebrity Cruises. 559757 pax. – **16.17%**
3. Norwegian Cruise Line. 232144 pax. – **6.7%**
4. MSC Cruises S.A. 371391 pax. – **10.73%**
5. Other. 808560 pax. – **23.35%**

According to the source [1] the number of cruise ships, and number of passengers are increasing every year (in year 2016 these parameters were down by 2-3% as a result of the world economic situation). Respectively, load on the terminal services that handle passenger flows increases. When the load increases, the likelihood of failure in any process also increases. Failure may cause the entire processing circuit to delay as the passenger handling structure is realized by linear models.

2. METHODS OF ANALYSIS OF PASSENGER FLOWS INSIDE THE PASSENGER TERMINAL / *Metode analize protoka putnika unutar putničkog terminala*

One practical way to analyze the passenger flows of the terminal is an analysis based on the block diagram [3]. This method, using a set of vector operators, corresponding to each division involved in the passengers processing, provides a dependence of mutual influence of individual services in the whole chain of passenger processing. The resulting block diagram can be transformed to a graph view. On the formula Meisona basis [3] a link between any two nodes of the graph may be found, eliminating everything in between. But this method does not take into account the nature of the traffic flow. Each passenger has its own individual objective functions. We can say that every passenger will make its own motion pattern, which can be represented geometrically. The collection of individual movements forms a potential center of passenger concentration inside the terminal. For example, finding a point of passenger concentration can be calculated on the basis of fig. 2.

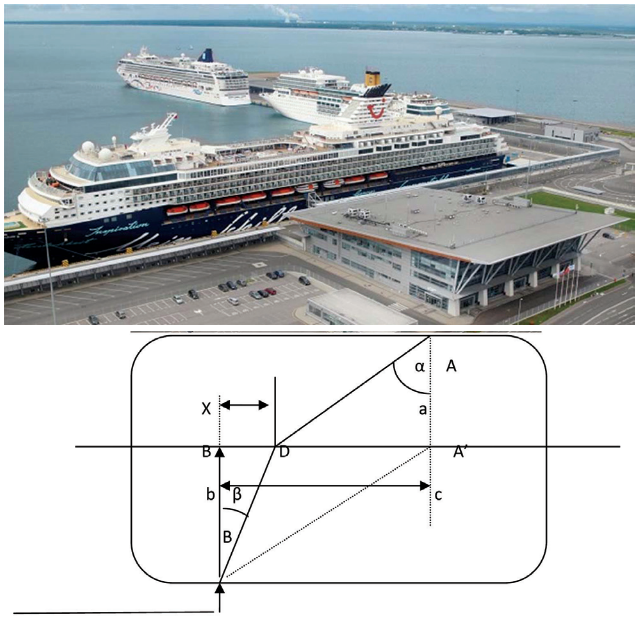

Figure 2 Moving passengers inside the terminal (top view)
Slika 2. Gibanje putnika unutar terminala (pogled odozgo)

Point B is the entrance to the passenger terminal, and the point A is the transition to a passenger vessel. According to fig. 2 distance DA' will be defined as (c-x). Then two ways of passenger movement are considered (L_1,L_2) (1)

$$L_1 = \sqrt{b^2 + x^2}; L_2 = \sqrt{a^2 + (c-x)^2}, \quad (1)$$

where L_1,L_2 - path length of the intervals BD and DA.

Parameters S1 and S2 represent movement efficiency inside the passenger terminal. Then the movement of a passenger from point B (the entrance to the terminal) to A (landing to cruise ship) is expressed in the following way (2)

$$y(x) = S_1\sqrt{b^2 + x^2} + S_2\sqrt{a^2 + (c-x)^2}, \quad (2)$$

To define a minimum resulting function, we find the first derivative and equate it to zero, from which we obtain the following ratio, which reflects the location of the point D. It is also possible to obtain and the transition to the small angle (fig. 2) (3).

$$\frac{x}{\sqrt{b^2+x^2}} / \frac{c-x}{\sqrt{a^2+(c-x)^2}} = \frac{S_2}{S_1}; \frac{\sin\beta}{\sin\alpha} = \frac{S_2}{S_1} \tag{3}$$

This method makes it possible to determine and predict the ′geometrical point of concentration with increasing complexity of passenger movement that takes place in practice; this method leads to a very large equation, which is quite time-consuming to calculate analytically. This method shows good results when assessing the small number of passengers. Modern conditions require prediction of any movement, not limited to certain passenger groups. The main problem that occurs when modeling (simulation) the passenger movement is the difficulty of recreating plausible behavior. Passenger moves only guided by its personal goals. The model must enable random passenger movements that may arise in random time. Analysis is to be performed on the transfer basis of all the passenger movement objectives in the terminal, but then the problem arises when modeling specific objectives for defined passengers.

In practice, the passenger transport simulation is based on different physical models. The classic approach involves representation of the passenger flow, such as a substance consisting of large objects within certain limits. This flow is characterized by a certain set of parameters. It is necessary to find a model that will be correct (on one side), but also it has to play close to real processes of passenger behavior. When selecting the model of the passenger terminal it is necessary to define a number of parameters such as the selection of a micro or macro level of the passenger terminal. Selected level will determine the number of passengers involved in the simulation process. At the micro level it is possible to describe a sequence of individual movements of individual passengers. In this case, it becomes possible to simulate some scenarios. At the macro level, you cannot select individual passenger. At this level, the objects of study are passenger flows, which can be structurally represented in the form of different graphs.

In the development of the simulation model it is necessary to lay the properties of deterministic or stochastic models. The deterministic model has all possible movements and passenger reactions determined. The stochastic model of the passenger may respond differently to the same situation. In fact, the passenger may be represented by some agent [5,6,7]. The individual behavior of each agent forms a global behavior of the simulated system.

Because each passenger is surrounded and affected by other passengers, The passenger is subject to the rules and the effects of the surrounding passengers and (it) is subject to the rules of the infrastructure of passenger terminal. Passenger decision is made depending on the magnitude of the resultant size of the sum of the forces acting on it. For example, if there is a queue at the front, the passenger can, if there is some time, move to some other goals, for example, a newsstand, and then return to the original purpose.

In the simulation process, you have to strive for „realism" of the model. A model with a high degree of accuracy will try to implement the flow movement as close to reality, making the choice of algorithms, path, etc. Model with a low degree of accuracy can be completely devoid of any intelligence. The

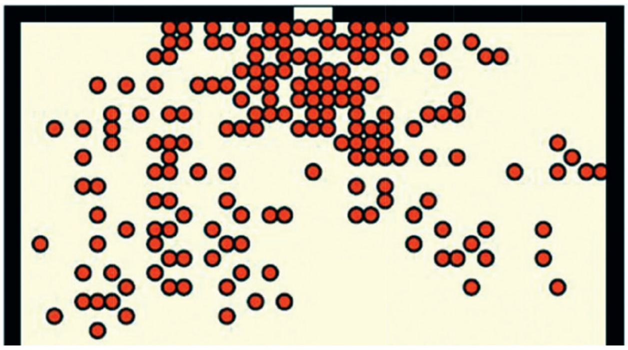

Figure 3 Move the passengers inside the terminal using a presentation based on cellular automata
Slika 3. Gibanje putnika unutar terminala koristeći prezentaciju temeljenu na celularnoj automatizaciji

first model leads to greater complexity, increase in the number of variables and response times, as it will be handled a large number of data. The model with a lower accuracy will be more easily implemented, it will work faster, but you must take into account the mistakes and errors.

Among the existing models of passengers flows different kinds can be identified such as a model of attracting forces, models using queuing theory to describe the movement of pedestrians using the probability functions, model „cellular automata", gas-kinetic model, the model of social forces [8,9,10,11,12] . These models are based on specific mathematical models of passenger flows. It is also necessary to point out the computational model, the use of which a large part of the one-time parameter is calculated on the basis of practical experiment data. It is neccessary to create a table depending on passenger traffic. In the future, these data will be used to describe the motion of foot traffic and may be entered as input data in simulation model.

For simulation purposes GOST 12.1.004-91 „Fire safety. General requirements „ can be used, which is based on the current method of submission of foot traffic in the same way as it is done in a gas-kinetic model. This GOST was designed in Russia. This Standard gives only a rough idea about the effectiveness of the configuration layout of buildings. GOST 12.1.004-91 has many disadvantages, such as:

- greater reliance on predefined variables (only the 3 options average density of human horizontal projection - adult, adult in winter clothes, teen);
- it does not take into account the fact that the human body can vary a lot ;
- low simulation accuracy (eg, decompression is not considered as passenger stream);
- the focus is only on fire safety.

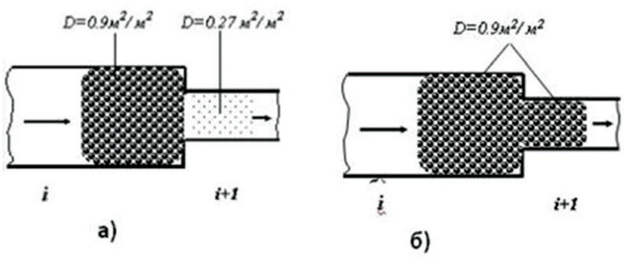

Figure 4 A graphical representation of different density of passenger traffic
Slika 4. Grafički prikaz različite gustoće putničkog prometa

3. PRACTICAL SIMULATION OF THE PASSENGER TERMINAL / *Praktična simulacija putničkoga terminala*

Global experience has proven the effectiveness of simulation in making competent decisions in the field of transport. It should be noted that each object has unique transport and flow characteristics of internal and external processes. There is no universal software system tool for simulation of transport processes that is both appropriate for the different transport facilities and different modes of transport

The 'traditional' design of marine passenger terminals is done with the following steps:

1. Simulation is usually used only in the last stages of the design;
2. The capacity of the terminal is calculated according to the empirical rules, that is, using a spreadsheet or using directories or regulatory sources;
3. The simulation produces only a limited number of scenarios;
4. Then, a simulation of the finished operational terminal project is run before putting it in service. Moreover, if defects and weak points are detected there is usually no time for making major changes in terminal.

The simulation model should be implemented in the early stages of project development [4,5,6,7] and used in main parallel project. After the completion of the terminal simulation model, taking into account the structural modifications, it should be transformed into a transport model. The transport model based on the simulation will help solving of the following tasks:

1. Calculation of the passenger terminal capacity;
2. The calculation of the required channel / service resources in accordance with the future demand for cruise ships;
3. Simulation of various terminal configuration options and assess their impact on passenger flows;
4. Simulatiing the behavior of passengers who use the shops and food outlets in services, in order to optimize the location of the trade areas;
5. Simulation of emergencies and analysis on the vulnerability of the transport facility.

Consider, for example, the analysis of the operating concept in terms of the maximum throughput. To determine the maximum capacity of the expansion of new cruise vessels on the ferry lines, or when the number of passengers continuously increases, we need to use simulation.

Analysis on the basis of performance simulation results in determination of:

1. The length of the queues at passenger's services;
2. The waiting time for passengers;
3. Analysis of passenger flows;
4. Using / practical capacity of the passenger marine terminal;
5. The effectiveness of the passenger's service;
6. The passenger capacity;
7. The total time of service processes of the passengers.

Thus, it turns out to achieve operational processes to ensure stability. As a result the analysis offers the opportunity to identify congested areas in passenger terminal.

When we are creating a simulation model for the most realistic reflection, one should focus on the key points. For close to reality simulation model calibration is required, in order to ensure the required accuracy of the results of the various analyzed areas of the passenger terminal

At the first stage the mathematical model has been chosen and the prescribed terminal operation algorithms for the precise description of the processes of the passenger terminal [12]. The basis unit of queuing systems and agent-based modeling methodology are chosen. A queuing system consists of several main elements: the incoming stream, turn to pass the checkpoint, the attendant device (metal detector and X-ray scanner), for the passage of all border control sectors serving device (metal detectors and introscopes) and the effluent. With each of them associated with a number of possible assumptions about the course of the service processes. To simulate the use libraries AnyLogic Pedestrian Library. The models created with the Pedestrian Library, passengers move continuously in response to different types of obstacles [9,10,11]. Passengers are modeled as interacting agents with complex behavior. For a quick description of the Pedestrian Library provides a high-level interface flows in the form of a block diagram. AnyLogic [13] allows you to perform a simulation, not only using the Pedestrian Library, but also on the basis of both discrete event and agent-based modeling. The disadvantage of the second method is the inability to create a three-dimensional realization.

In the second stage logistical chain passenger traffic in the port, realized in the form of a directed graph was constructed (fig. 5)

Following the development of the logistics chain of passenger movements it is necessary to develop the block diagram of the simulation model and the settings of the relationship between the elements that make up passenger processing system (Fig. 6).

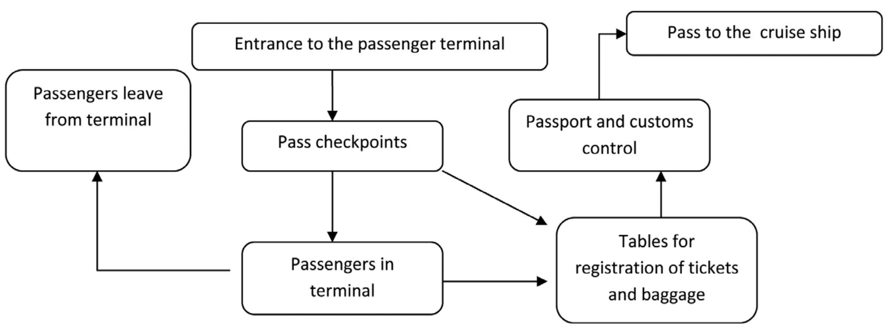

Figure 5 The logistical chain of movement of passengers in the port
Slika 5. Logistički lanac protoka putnika u luci

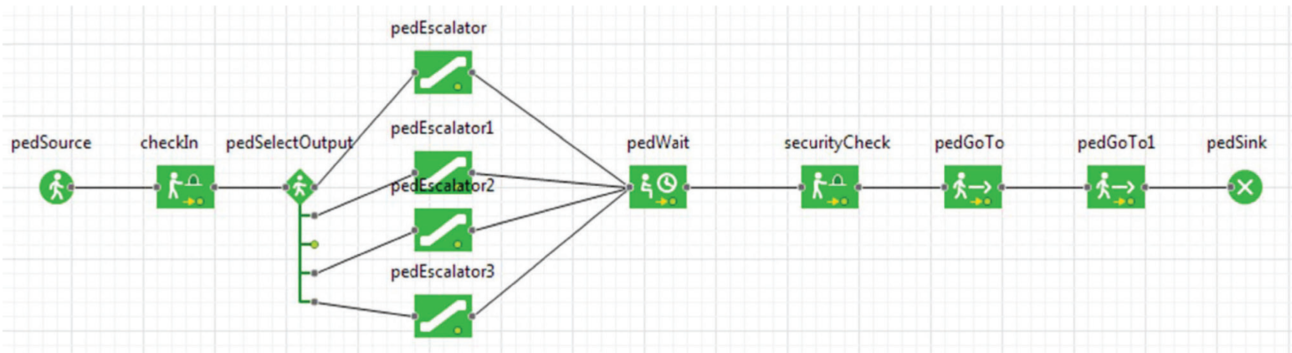

Figure 6 The logic simulation model (fragment)
Slika 6. Logični simulacijski model (fragment)

In the study of „Passenger Port of St. Petersburg" Marine Façade architecture" it was decided to reproduced by hand the architectural structure with proportions for simulation model. The next step was to build a transport model and perform simulation-based real schedule of cruise ships. (Fig. 7).

As a result of simulation we get a large amount of analytical information on passenger traffic. The intensity of passenger traffic over a certain period of time is shown in (Fig. 8) At each stage of the processing performed, passenger service time analysis was obtained and compared with the reference. For example, no more than three minutes is allocated to the passage of screening per passenger. When leaving, for a given interval of time, the system generates an informational message to the decision-maker. After the simulation, decision maker can analyze the possible failures in the processing of passenger operations.

On figure 8 red colors shows the number of passengers who entered to the terminal, yellow color shows the number of tourists entered the cruise ship, green color shows the number of people who came out of the terminal. Green graph shows the number of passengers on the 2nd floor in the passenger terminal. Purple graph shows the number of passengers on the 1st floor in the passenger terminal. The blue graph shows the number of passengers on the 2nd floor in the passenger terminal. Model is the dynamic model which performed in the simulation time.

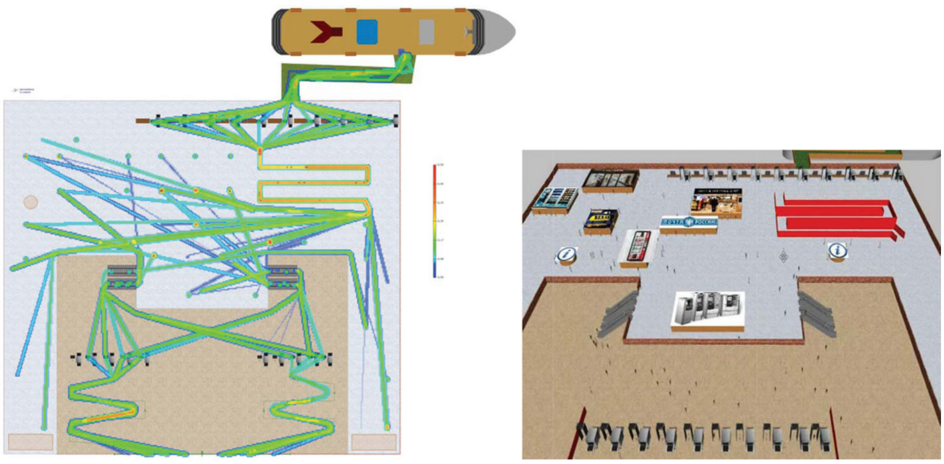

Figure 7 Simulation results passenger flows in the terminal
Slika 7. Rezultati gibanja putnika na terminal

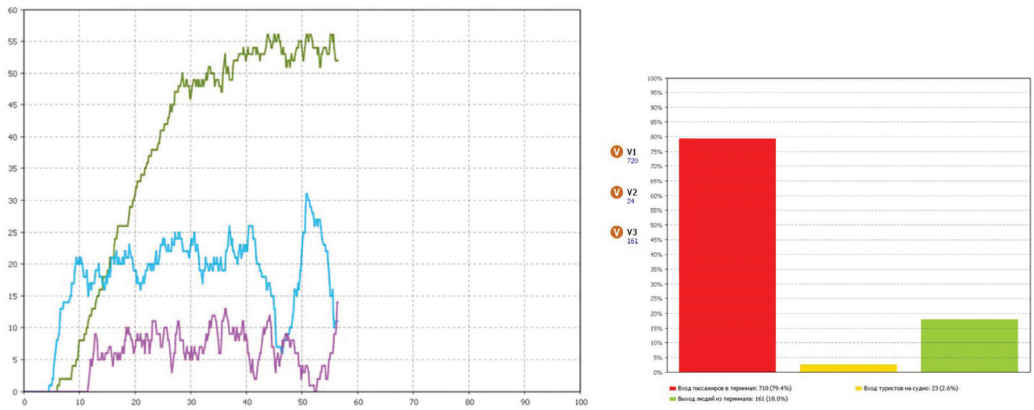

Figure 8 Intensity of passenger traffic in the marine passenger terminal and the number of passengers
Slika 8. Intenzitet putničkog prometa na pomorskom putničkom terminal i broj putnika

This simulation model takes into account all features of the most important elements of the marine station, affecting passenger traffic on both micro and macro levels. One of the main difficulties in the way of solving the problem of modeling the whole complex of berths is the complexity of collecting data on passenger flows throughout the system.

4. CONCLUSION / *Zaključak*

The article discusses the technique to study passenger flows of marine passenger port terminal using simulation. It indicates the presence of structural features of the terminal, which can be a source of delay or weaknesses in passengers processing. We propose a mathematical model of a finding concentration of passengers using the geometric parameters of the terminal. This model can be used to locate the terminal placement service points, as well as to predict the potential centers of accumulation of passengers. The article substantiates the applicability limits of the model. In order to create a single transport model justified the use of simulation as a tool that allows carrying out multi-criteria analysis of the operations of the passenger port. In the logistics chain realized the movement of passengers, provided software tools reflecting the logic of operational processes. The agent-based model includes the behavior of passengers, implements random processes and conditions for fixing the delay in passenger service for the decision-maker. As a result of the simulation analytical parameters of the services and departments are obtained. The developed simulation model not only has a high precision simulation (allows to obtain quantitative characteristics at each stage of passenger service), but also produces a forecast of passenger traffic for a few hours in advance, based on real data. The developed model allows solving a certain circle of economic problems on the organization of the internal space of the terminal. The paper provides a systematic analysis of methods and tools for the study of passenger traffic. We present the logistic chain and move the passenger transport model logic. The paper discusses advantages of using models in their implementation of the initial stages of operation of the terminal.

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