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FORECASTING THE OPERATIONAL ACTIVITIES OF THE SEA PASSENGER TERMINAL USING INTELLIGENT TECHNOLOGIES

Summary. Modern transport systems are characterized by the development and implementation of intelligent transport technologies. Today, dynamic forecast models are not used in practice in the operation of a passenger terminal. Decision making is based on some regulatory values for passenger traffic, but this is not sufficient for efficient terminal management. Modern passenger terminals are characterized by dynamic process variability and consideration of diverse options, 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 dynamics. Only 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 service, transport safety, some forecasting tasks and so on. 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 intelligent simulation-based terminal services provides a new mathematical model of passenger movement inside the terminal and presents a new software instrument. Moreover, the conditions of implementation of some transportation models during the operation of marine passenger terminal are examined. The study represents an example of analytical information used for the forecast of the terminal operations, the analysis of the workload and the efficiency of the organization of the marine terminal.

1. INTRODUCTION

One of the most dynamically developing segments of tourism is cruise shipments. According to the World Tourism Organization, in 2012, cruise ships carried over 16 million passengers. Despite the chance of seasonal bad weather the cruises are very popular. Cruises in the Baltic Sea make up the largest share of such traffic in Northern Europe. Similar situation is for ports in Adriatic Sea in relation to Mediterranean. At the same time, the passenger traffic of the North European market is the third largest after the Caribbean and Mediterranean. Fig. 1 shows the statistical data on the operation of Croatian passenger ports and statistics of the passenger terminal "Marine Facade" (St. Petersburg, Russia).

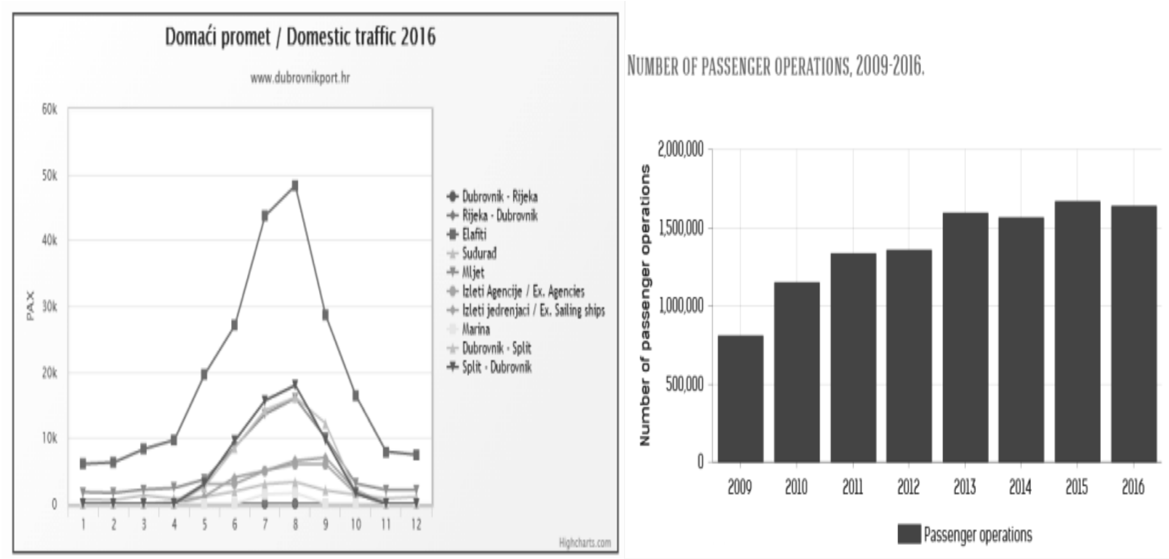

Fig. 1. The statistical data on the operation of Croatian passenger ports and passenger terminal "Marine Facade" (St. Petersburg, Russia) (source: http://portdubrovnik.hr/statistika/?idKat=1&godina=2016)

Plans for the development of the various components of the passenger port system depend to a large extent on the activity levels which are forecast for the future. Since the purpose of an passenger port is to process passengers and ground transport vehicles in an efficient and safe manner, passenger port performance is judged on the basis of how well the demand placed upon the facilities within the system is handled.

Over the years, certain techniques have evolved that enable passenger port planners and designers to forecast future demand. The principal items for which estimates are usually needed include the following:

• the volume and peaking characteristics of passengers, vessels and cargo;
• the number and types of vessels needed to serve the above traffic; and
• the performance and operating characteristics of passenger port access systems.

For effectively managing the passenger seaport, it is necessary to use modern information intelligent systems. These technologies must solve prediction problems based on real data. Using forecasting techniques, estimates of these parameters and a determination of the peak period volumes of passengers can be made. From these estimates, concepts for the layout and sizing of sea terminal buildings and ground access facilities may be examined. There are different approaches to intellectual methods in logistics. This article provides an intelligent method based on simulation using real data. The terminal's traffic forecasting unit should be included in the terminal services in Fig. 2.

According to Fig. 2, x(t) shows the input flow of passengers, y(t) shows the number of passengers passed to a cruise ship, F(z) shows intelligent information system predicting the functioning of the seaport based on real data, and $K_1…K_n$ show characteristics of the work of individual port services when processing passengers.

Intelligent simulation models use mathematical or logical constructs and calculate the final solution. Simulation in itself does not optimize the solution for the problem; it simply runs the model according to the specifications. However, simulations, heuristics and optimization often work in conjunction. A simulation model may be based on some heuristics, which are then improved using an optimizer. Design of experiments is also frequently done with simulations. Simulations are also frequently used to enhance learning, where the main purpose is not to improve a system.

For forecasting passenger processes in transport systems [1], the most widely used tools are as follows:

- Linear programming; Network optimization; Game Theory; Dynamic Petri networks;
- Decision Analysis; Markov Chains; Queueing Theory; and
- Simulation (based on mathematical models of passenger behavior).

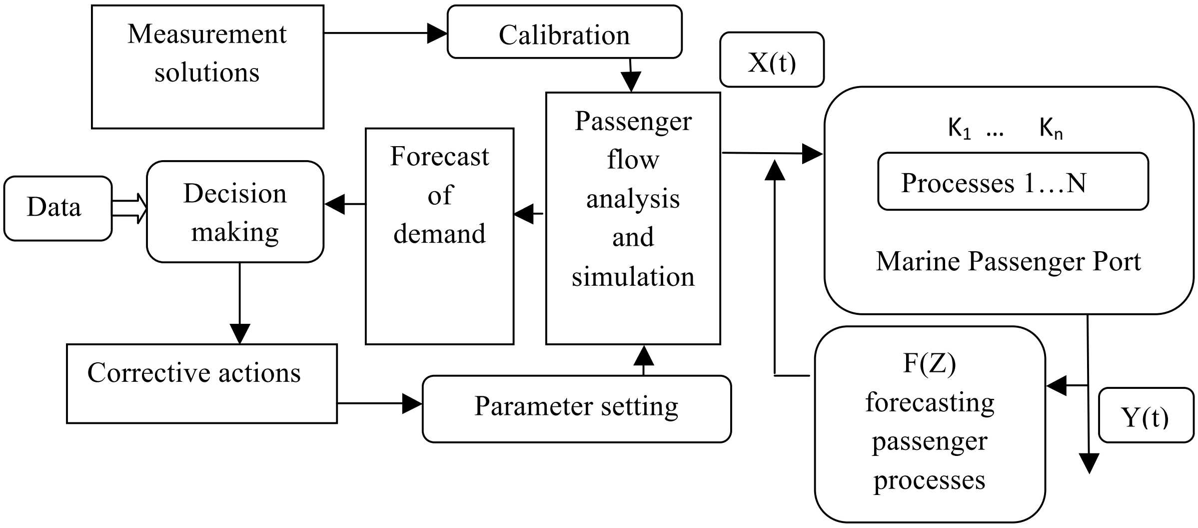

Fig. 2. Block for forecasting passenger processes in the terminal structure

Comparison of the efficiency of building an intelligent system on the basis of analytical model and simulation modeling is given in table 1.

Table 1

Comparison of the efficiency of building an intelligent system on the basis of analytical model and simulation modeling

Analytical (e.g. Excel-based model)	Simulation model (e.g. Anylogic software [12])
• Static, mostly deterministic model + Helps to find some solutions + Easy to implement - Hard to capture time, dynamics - Hard to capture complex causal dependencies - Hard to model time-related constraints - Cannot play the model in time	• Executable simulation model + Naturally captures causal dependencies and timed constraints of any complexity + Easily captures stochastic nature of the problem + Can play the model behavior in detail + Enables to measure virtually anything - Takes more time and skills to develop + Gives better, more informed solutions.

Some of the advantages can be achieved with other methods as well (such as linear optimization, queuing theory), but when systems become more complex, it is more difficult to construct analytical models about the problem. Depending on the chosen simulation approach, there are different methods to accomplish this. In system dynamics, causal loop, model boundary and policy structure diagrams are usually formed. In agent-based modelling, the potential agents in the model and how they make their decisions need to be considered. In discrete-event simulation, the potential entities in the system, events, activities and delays are considered. This needs to be conducted before the actual intelligence computer simulation model can be created.

However, it is possible to see that there are five disadvantages associated with simulation:

- it requires special training;
- simulation modeling and analysis are time-consuming and expensive;
- it is difficult to interpret simulation results;
- simulations require a lot of data; and
- simulation may be used inappropriately and people may have overconfidence in the results.

Overall, intelligent technologies on the basis of simulation for the passenger marine terminal have a lot of advantages for real process forecasting.

2. METHODS OF ANALYSIS OF PASSENGER FLOWS INSIDE THE PASSENGER TERMINAL

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 Mason basis [3] a link between any two nodes of the graph may be found, eliminating everything in between. However, 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. 3.

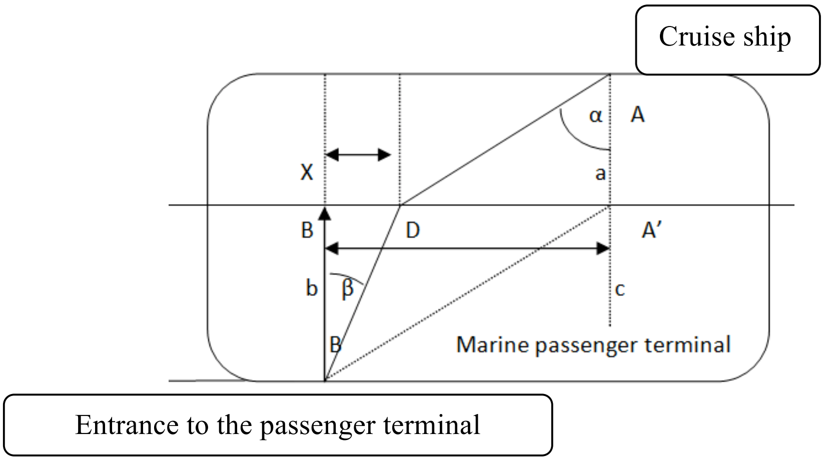

Fig. 3. Moving passengers inside the terminal (top view)

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 (L1 and L2) (1)

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

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

Parameters S_1 and S_2 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)

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

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 very large equations, which are 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 his/her 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.

Necessity in creation of intelligent simulation model [12] areas can appear at different stages of using. For example, during the analysis of efficiency of passenger port terminal, we can understand the ability of the model to manage with high loading of the system and satisfying security rules. Besides it becomes real to compare different models and situations of new object to find out the best one. In addition, a list of things can be changed while simulation, or even finishing work, like the following:

- passengers queue modeling (including high loading);
- work of services (staff number and schedule vessels);
- location of signs in passenger terminal;
- location of advertisement banners and market places in passenger port; and
- vulnerability during terrorist attack or disaster.

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 [13, 14]. 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 attention 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 microlevel or macrolevel of the passenger terminal. Selected level will determine the number of passengers involved in the simulation process. At the microlevel, 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 macrolevel, one can not select individual passenger. At this level, the objects of study are passenger flows, which can be structurally represented in the form of different graphs.

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 news stand, and then return to the original purpose.

In the simulation process, one has 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 first model leads to greater complexity, with increase in the number of variables and response times, as it will be able to handle a large amount of data. The model with a lower accuracy will be more easily implement, and it will work faster, but one 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 and the model of social forces [8-12, 15]. These models are based on specific mathematical models of passenger flows. It is also necessary to point out the computational model, in 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.

3. PRACTICAL DEVELOPMENT OF INTELLIGENT SIMULATION OF THE PASSENGER TERMINAL

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 appropriate for both 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 [4-7] and used in the 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 solve the following tasks:

1. calculation of the passenger terminal capacity;
2. 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. simulation of the behavior of passengers who use the shops and food outlets in services, in order to optimize the location of the trade areas; and
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 the following:

1. the length of the queues at passenger 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 service;
6. the passenger capacity; and
7. the total time of service processes of the passengers.

Thus, it leads to achievement of operational process optimization to ensure stability. As a result, the analysis offers the opportunity to identify congested areas in passenger terminal.

When a simulation model is created for the most realistic reflection, one should focus on the key points. A close to reality simulation model calibration is required 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 have been calculated [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), the serving devices (metal detectors and introscopes) for the passage of all border control sectors, and the effluent. With each of them is associated a number of possible assumptions about the course of the service processes. To simulate this, libraries such as AnyLogic Pedestrian Library are used. The models created with the Pedestrian Library allow passengers to move continuously in response to different types of obstacles [9-11]. Passengers are modeled as interacting agents with complex behavior. For a quick description of the Pedestrian Library, a high-level interface flow in the form of a block diagram is provided. AnyLogic [13] allows one 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. 4).

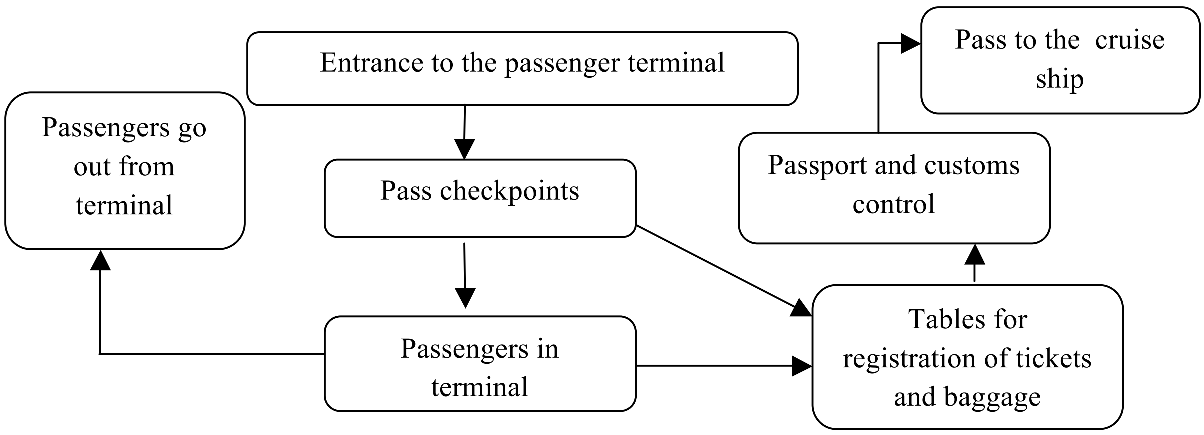

Fig. 4. The logistical chain of movement of passengers in the port

Logistical chain in Fig. 4. is discrete even dynamic system (DEDS), and can be modelled by using Petri net (PN). PN is a graphical and mathematical modeling tool that can be used as a visual communication aid. Basically, PN is a bipartite graph consisting of two types of nodes, places and transitions, connected by arcs. Petri net is a 6-tuple:

$$PN = (P, T, I, O, M, m_0). \tag{4}$$

where: $P = \{p_1, p_2, ..., p_m\}$ represents set of places, $T = \{t_1, t_2, ..., t_n\}$ - set of transitions, $P \cap T = \varnothing$, $I_{(n,m)} : T \times P \rightarrow \{0,1\}$ - an input incidence matrix, $O_{(n,m)} : T \times P \rightarrow \{0,1\}$ - an output incidence matrix, $M : [I : O] \rightarrow \{1, 2, 3...\}$ - is a weight function, m_0 - initial marking.

Places and transitions $v \in P \cup T$ are called nodes and denote states and events in the discrete event dynamic systems (DEDS). Given any node *v*, let $\bullet v$ and $v\bullet$ respectively denote the pre-set and post-set of *v* in usual way, i.e. the set of nodes that have arcs to and from *v*, respectively. An available resource or an ongoing job in DEDS is indicated by tokens in respective places. A transition $t \in T$ is enabled at a marking $m(p)$ if $\forall p \in \bullet t, m(p) \geq w(I(p,t))$ ($\bullet t$ is a set of input places to transition *t*, and $w(I(p,t))$ is weight of the arc between *p, t*. A transition *t* that meets the enabled condition is free to fire. When a transition *t* fires, all of its input places lose a number of tokens, and all of its output places gain a number of tokens.

In a Petri net *PN* with *m* places and *n* transitions, the incidence matrix **W** is a $m \times n$ matrix where elements are $a_{ij} = w(t_j, p_i) - w(p_i, t_j)$. If all arcs in PN have weight equal to 1, it should be noted that

$$W = O - I. \tag{5}$$

The matrices **I** (input matrix) and **O** (output matrix) provide a complete description of the structure of a Petri net. If there are no self loops, the structure may be described by **W** only. The incidence matrix allows an algebraic description of the evolution of the marking of a Petri net. The marking of Petri net changes from marking $m_k(p)$ to marking $m_{k+1}(p)$:

$$m_{k+1}(p) = m_k(p) + W^T \bullet \sigma. \tag{6}$$

where σ is a transition vector.

The transition vector σ is composed of non-negative integers that correspond with the number of times a particular transition has been fired between markings $m_k(p)$ and $m_{k+1}(p)$.

Fig. 5. shows Petri net model of the logistical chain of movement of passengers in the port.

Places (states) and transitions (events) of Petri net in Fig. 6 are described in table 2.

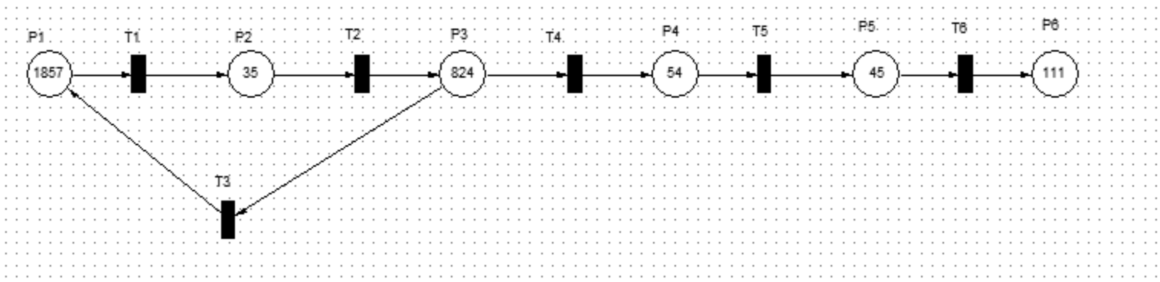

Fig. 5. Petri net model of logistical chain of movement of passengers in the port

Table 2

Places (states) and transitions (events) of Petri net

P1	Point B (entrance to the passenger terminal)
T1	Entering into the passenger terminal
P2	Checkpoint
T2	Pass checkpoint
P3	Passengers in terminal
T3	Passengers leave from terminal
T4	Entering into tables for registration of tickets and baggage
P4	Tables for registration of tickets and baggage
T5	Entering into passport and customs control
P5	Passport and customs control
T6	Pass to the cruise ship
P6	point A (exit to a passenger vessel)

Numbers in places P1 ... P6 show number of passengers. Firing of the transitions T1 ... T6 is stochastic function of time. Using a tool for simulation stochastic Petri net (HPsim - http://www.winpesim.de/) [13] or HiQPN tool for queuing Petri net (http://ls4-www.cs.tu-dortmund.de/QPN/) [14], it is possible to simulate moving of passengers between port locations (places).

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.

In the study, it was decided to reproduce 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. 6).

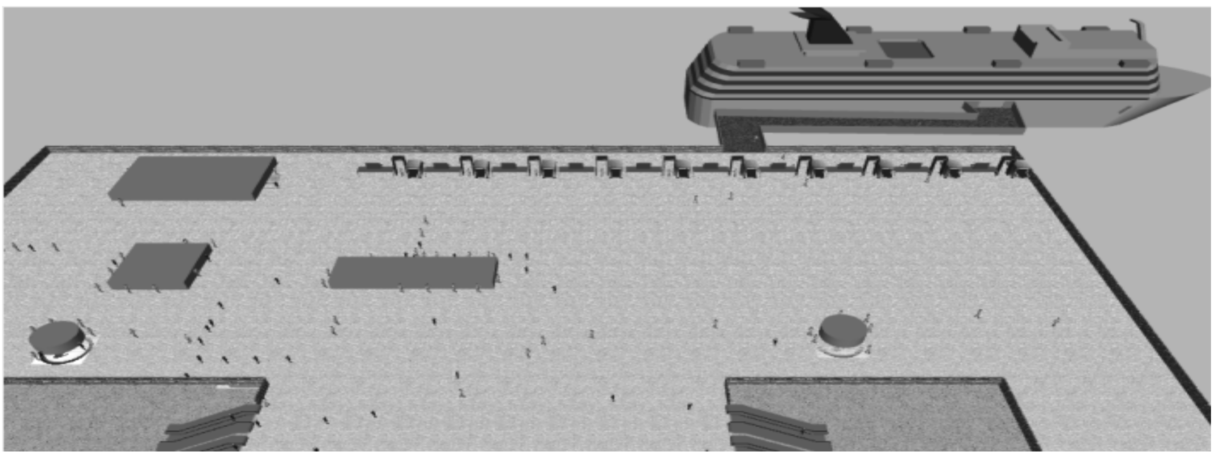

Fig. 6. Simulation results passenger flows in the terminal (3D model)

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. 7. 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.

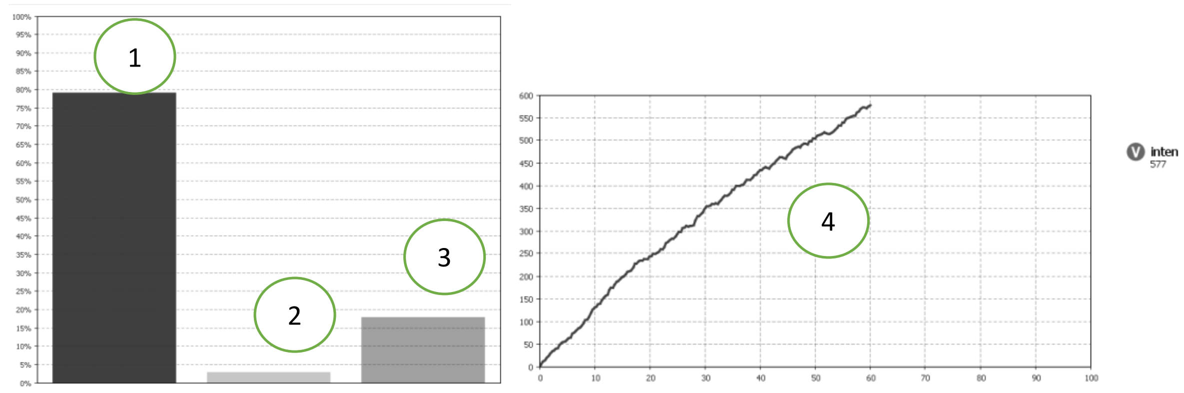

Fig. 7. Intensity of passenger traffic in the marine passenger terminal and the number of passengers

On Fig. 7, graph number one shows the number of passengers who entered the terminal, graph number two shows the number of tourists entered the cruise ship, and graph number three shows the number of people who came out of the terminal. Graph number four shows the number of passengers on the 2nd floor in the passenger terminal. The model is a dynamic model that is performed in the simulation time. We have many graphs showing the movement of passengers across all floors of the terminal.

This intellectual simulation model takes into account all features of the most important elements of the marine station, affecting passenger traffic on both microlevel and macrolevel. 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

The article describes a new intelligent technique to study passenger flows of marine passenger port terminal using simulation. To achieve this goal, it was required to analyze mathematical models describing the movement of passenger traffic, analyze the types of modeling, and develop a new software tool based on the proposed model. 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. The use of this model allowed creating a new software tool that allows to predict the movement of passengers on the basis of real data. The developed system can be integrated into the management systems of the marine passenger terminal. The corresponding capabilities are present in the system. For the description of the movement of passengers, an agent model was chosen. The agent-based model includes the behavior of passengers and 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 it also produces a forecast of passenger traffic for a few hours in advance, based on real data. Additionally, the developed model allows to solve a certain circle of economic problems on the organization of the internal space of the terminal, which is also an actual task. The conducted research showed that the use of specialized models and software systems makes it possible to reduce errors in decision making and to manage the operation of the marine passenger terminal at a new level. The study also revealed, since each terminal has its own peculiarities, it is necessary to implement the appropriate software systems taking into account these features. In this case, mathematical models, which are presented in the article, of the movement of passengers do not need to be changed for another marine passenger terminal.

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