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SIMULATION OF THE ROUTE NETWORK AND FERRY TRAFFIC INTENSITY BASED ON THE PROCESS OF DISCRETIZATION AND CIRCOS PLOT INTENSITY DIAGRAM

Summary. Today, one of the main important tasks is to analyze the states of achievement related to the required levels for marine passenger terminals and their route networks, depending on the influence of the external environment (based on the discretization of processes). This proposal is relevant both to increase the passenger traffic and to change the route network of ferry lines. There is an uneven congestion of individual directions of ferry lines and passenger terminals, which determines the need to select a finite number of states for the efficient operation of the «passenger terminal–ferry line» system. For the research of changes and assessments, it is proposed to use the process discretization methodology and the formation of a new circos plot intensity diagram. This study focuses on the passenger terminals in the Adriatic Sea and the existing route network in this region. As a result of the analysis, a set of points in time are selected that are characterized by various intensities and passenger traffic. For the selected set of values, a set of new intensity circos plot diagrams are constructed. On their basis, it is possible to analyze the mutual influence of the passenger terminals on each other to analyze the ferry transportation market and the number of shipping companies on it.

New scientific approach can improve the quality of research and decision-making process for research of the «passenger terminal-ferry line» system. The practical results we can see in the form of circos plot diagrams for sea passenger transportation in the Adriatic Sea region and the proposed research methodology for research and operation analysis of the «ferry line - marine passenger terminal» system based on process discretization.

1. INTRODUCTION

Maritime–passenger ports are one of the substantial preconditions for the development of traffic, tourism, and economic activities for a range of tourist services and to meet passenger needs for transportation. An increase in the average size of passenger ships and the total volume of passenger marine also had an effect on maritime–passenger ports [1]. Such momentum in quality and quantity has required that ports designed to passenger traffic change their appearance and has led to new requirements for modeling of ferry line systems, new methodological basis and new requirements for practical tasks simulation of the route network and ferry traffic intensity.

A well-known means to avoid the slightest flaws when solving the predictive task of the operation of liner ships is to perform simulation. Particularly relevant is the simulation, for example in the AnyLogic software. The simulation model describes the operation taking into account the whole set of specific conditions that are necessary to perform certain operations with the ferry shipping line and passenger terminal. In addition to simulation, it is necessary to determine the state of the system, assess the influence of the external environment, and evaluate the competition between marine and passenger terminals in the market. Therefore, when making management decisions, it is necessary to use special tools to analyze system states for making decisions, tools reflecting the interdependence and mutual influence of systems.

Among the many logistical tasks, considered in the organization of systems (marine passengers terminal systems), there is always the task of developing a strategy to achieve the best indicators, the best states of the system. The best result may be to achieve the maximum possible, taking into account the capabilities of the infrastructure, the volume of cargo or passenger traffic, or it may be the best development of the infrastructure of the port or the sea marine terminal, which allows handling of increasing cargo traffic or passenger traffic. The state of the transport system at any time can be described with the help of certain variable parameters. For example, statistical information on the operation of the terminal is often presented in a discrete form and each subsequent value, after a certain equal time interval of monitoring the system, is provided with a certain set of parameters of the terminal infrastructure. The number of these parameters can be quite large, depending on the level of consideration and the details of studying the structures of processes. When performing research, there is a problem of choosing the most significant variables, and, as a result, there is always the probability of losing certain data. In a number of sources, such problems are solved using the decision-making apparatus under uncertainty [2]. But since this method is based on probabilistic data, its precise use is difficult. In addition, it is necessary to highlight the emerging new opportunity to conduct a study to assess whether the system has achieved a certain specified or planned state. Is it possible to analyze how it has worked in the past, and to solve the problem of forecasting? Is it possible to achieve better system states with existing infrastructure parameters? There is no direct need to rely on the methods of linear optimization of the system. Optimization allows you to identify the most important variables and their relationships. Classical optimization methods, usually applied to our problem, will be used after analyzing the best possible system states. The discrete nature of most of the variables does not allow the use of classical methods of functional analysis, but at the same time, the enumeration of various variants of the system states does not provide accuracy of decision-making. The difficulty in studying the state of port systems is also due to the presence of such conditions as seasonality and periodicity. In this case, it is necessary to formulate exception conditions to analyze the state of the system, or add new variables to ensure the seasonality conditions.

2. CURRENT STATE AND MAIN TRENDS OF THE PASSENGER FERRY TRANSPORT IN THE ADRIATIC SEA

For the marine passenger system, there is an uneven congestion of individual directions of ferry lines [3] and passenger terminals, which determines the need to select a finite number of states of operation of the «passenger terminal-ferry line system». The state of the system refers to such characteristics as the number of routes of ferry lines, the number of sea passenger terminals, the value of passenger traffic, and the intensity of ferry ships. Based on the state of the system, it is possible both to solve operational tasks and to evaluate forecasts in the development of the system. The main passenger terminals and intensities of ferry ships in the Adriatic Sea are presented in Fig. 1. These baseline data are based on intensity diagrams in the marine traffic information service [4].

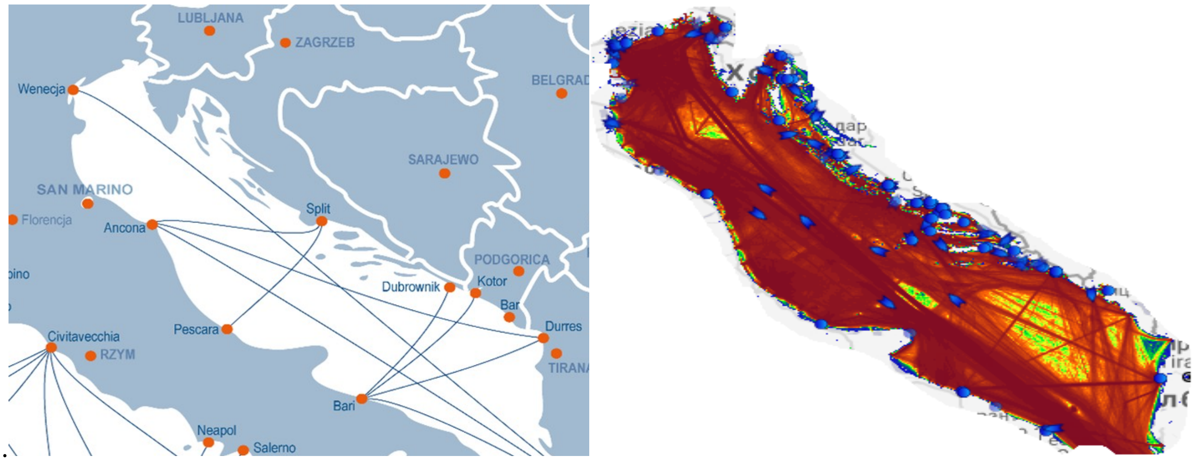

Fig. 1. Main passenger terminals and intensities of ferry ships in the Adriatic Sea

If we will look at the ESPON policy brief [5] and working documents “Revealing territorial potentials and shaping new policies in specific types of territories in Europe”, we can find statistical information about the frequencies of ferry routes (see Fig. 2).

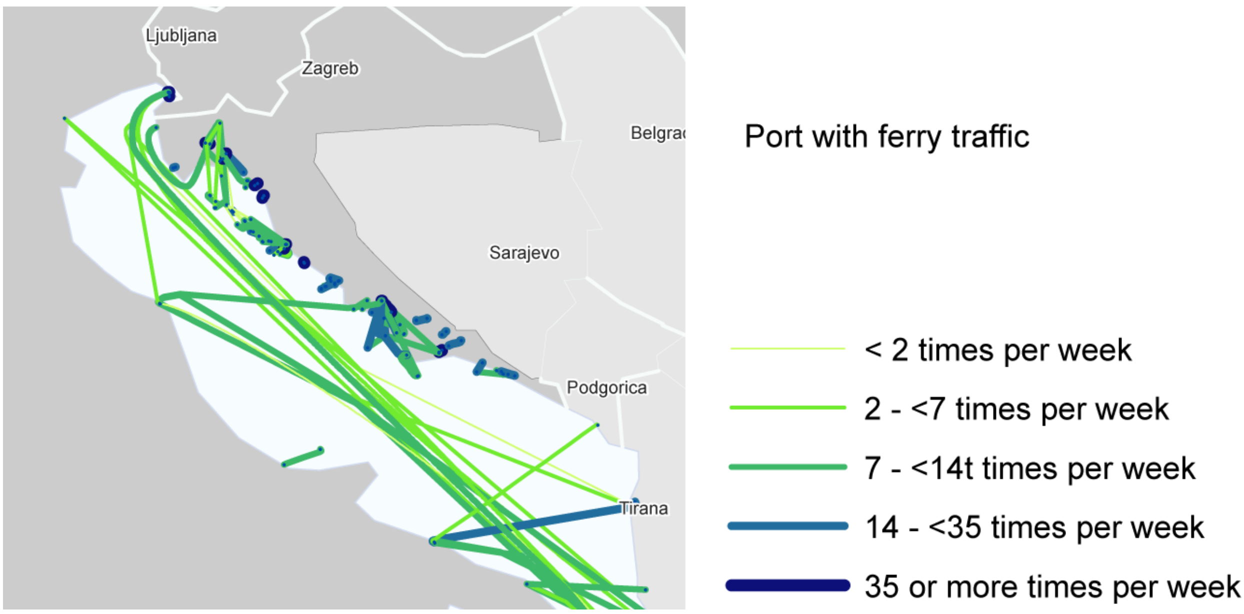

Fig. 2. Frequencies of ferry routes

Ferries to Croatia connect Croatian ports with Italy and nearest countries. The major Croatian passenger (cruise and ferry) ports are Split, Zadar, Rijeka, Šibenik, and Dubrovnik. Dubrovnik is an Adriatic Sea cruise port and city in Croatia, and one of Europe's historically most prominent and popular vacation travel destinations. According to the statistical data from EUROSTAT [6], given in table 1, there is a significant increase in passengers transported to/from main ports of Croatia in quarterly data.

For research on such system «marine passenger terminal system - cruise line or ferry line», it is necessary to form a set of states and implementation based on new circos plot intensity diagrams. Only then is it necessary to determine the conditions on the basis of which the discretization of processes and the formation of individual states can be applied. Based on new system states, it is proposed to investigate changes in the system of terminals and ferry lines.

Table 1
Passengers transported to/from main ports - Croatia - quarterly data (in thousand passengers)

Ports	2016/ Q3	2016/ Q4	2017/ Q1	2017/ Q2	2017/ Q3	2017/ Q4	2018/ Q1	2018/ Q2	2018/ Q3	2018/ Q4
Dubrovnik	691	103	38	357	777	117	30	374	827	130
Porec	150	10	0	56	160	11	0	58	157	14
Preko	706	328	294	451	724	324	283	451	737	323
Pula	242	55	20	168	231	58	21	173	248	62
Rovinj	29	3	:	10	38	1	:	17	59	4
Sibenik	286	60	37	139	286	60	34	154	276	62
Split	2 170	594	441	1 117	2 190	591	445	1 212	2 369	625
Zadar	918	378	333	542	960	372	322	551	980	375

3. CONDITIONS AND MATHEMATICAL MODELS OF PROCESS DISCRETIZATION

It is known that the problem under consideration can be solved based on a formalized geometric interpretation of the state and the motion of the system in the so-called phase space R_n.[7] The state space should be considered as discrete; therefore, any value representing the state of the system cannot be anywhere in the region of permissible states, but only at certain fixed points in this region. For states that depend on infrastructure variables, only the number of berths involved, the number of handling equipment, or the number of passenger inspection frames in the maritime passenger terminal can be changed discretely. In this case, the state of the transport system at a certain moment can be represented as a set of variables correlated with specific infrastructure objects in the form

$$\begin{aligned} x_0(t=0) &= \{a_{01}, a_{02,}.., a_{0n}\}, \\ x_1(t=1) &= \{a_{11}, a_{12,}.., a_{1n}\}, \\ &\dots \\ x_n(t=n) &= \{a_{n1}, a_{n2,}.., a_{nn}\}, \end{aligned} \tag{1}$$

where x_n (in every t = 0,1, .., n) are specific discrete states of the marine transport system; t –values of time at which observations are made or measurements are made on passenger handling; and a_{11}, ..., a_{nn} are quantitative variables, reflecting the number of transport infrastructure facilities that were involved in the process of passenger handling.

To solve the problem of research the work of the «marine passenger terminal - ferry line» system, it is necessary to introduce the following restrictions:

1. of the many ports in the region, only passenger terminals are selected and the terminals are ranked by intensive ship calls;
2. then, when considering the statistics of each port operation, data taken at a close time are selected and this discrete state is selected as the main one at T_0;
3. source terminals form two data arrays:
   - the first array is one-dimensional and consists of passenger terminals *n;*
   - the second array is a two-dimensional array, the elements of which reflect the intensities of ferry or cruise ships between specified ports at a selected discrete point in time.
4. cruise and ferry intensities are determined at a selected time T_0. When deciding to predict any cruise ship call at the port belongs to the full group of events.

To find the exact states of the system, it is necessary to apply the Kotelnikov theorem [8, 9]. According to this theorem, all processes are smooth functions of time. Leaps of values n them are practically not observed. Therefore, such a process can be represented by a sequence of their values, taken with a certain time step. With a small step, for example, with continuous monitoring of system states, the sequence of values accurately describes the graph of system states. With the available large intervals of the availability of information on the operation of the system, it is difficult to accurately

restore the graph of the function since its extremum points are missing. Kotelnikov's theorem allows one to find the necessary system states. Any graph is represented by a set of its discrete values. The function of the marine system *F(t),* consisting of a certain discrete set of states, can be continuously determined with any accuracy using the values of the states following each other through $\Delta t = \frac{1}{F_n}$.
The time moments of the system states are defined as $t_k = k\Delta t$, subject to distance from each other for a time interval $\Delta t = \frac{1}{2f}$. Recovery of any state of the system is determined by the formula

$$x(t) = \sum_{k=0}^{K} x_k \frac{\sin \omega_в (t - k\Delta t)}{\omega_в (t - k\Delta t)}, \tag{2}$$

where $\omega = 2\pi f$.

Based on the interpolation of the system states, the decision-maker must form a system for making corrective decisions. In this case, these mathematical models justify the discrete nature of the processes for sea passenger terminals.

4. BASELINE DATA FOR THE RESEARCH OF THE MARINE PASSENGER TERMINAL SYSTEM AND FERRY LINE

The main passenger terminals, which formed the basis of the research, in the Adriatic Sea are presented in table 2 and shown in Fig. 3. Consider the traffic flow in the Adriatic Sea for a week - the number of ships sent in the direction of the connection per week. The interconnections between ports and intensities were determined on the basis of data from https://www.directferries [10], which contains information about ferries. Data for modeling are presented in table 3.

Table 2

The main ports

№	Port	Country	№	Port	Country
1	Bari	Italy	11	Pula	Croatia
2	Civitanova-Marche	Italy	12	Mali Losinj	Croatia
3	Ancona	Italy	13	Rab	Croatia
4	Pesaro	Italy	14	Novalja	Croatia
5	Cesenatico	Italy	15	Zadar	Croatia
6	Venice	Italy	16	Split	Croatia
7	Trieste	Italy	17	Stari Grad	Croatia
8	Umag	Croatia	18	Hvar	Croatia
9	Porec	Croatia	19	Dubrovnik	Croatia
10	Rovinj	Croatia	20	Bar	Montenegro

All terminals are interconnected bi-directionally; from table 2, it can be seen that the intensity is basically the same in all opposite directions. The exceptions are the routes «Ancona - Stari Grad», «Trieste - Rovinj», on which ships depart with different intensities depending on the starting point.

We can compare a traditional way of graph representation with possibilities of a circos plot intensity diagram. The routes are displayed with different GDB colors, so we can say that it is solved on similar way [11 - 15]. But instead of real distances on the graph, we have length1 and length 2 (see Fig. 4); thus, we do not need to use GIS data maps. Also, with a circos plot, we can define the time of ship departure (arrival), and so we can see time duration of the route. The most significant factor is that we can display interference od different routes on each other, especially for the same starting/ending ports, serving many different routes (Fig. 4).

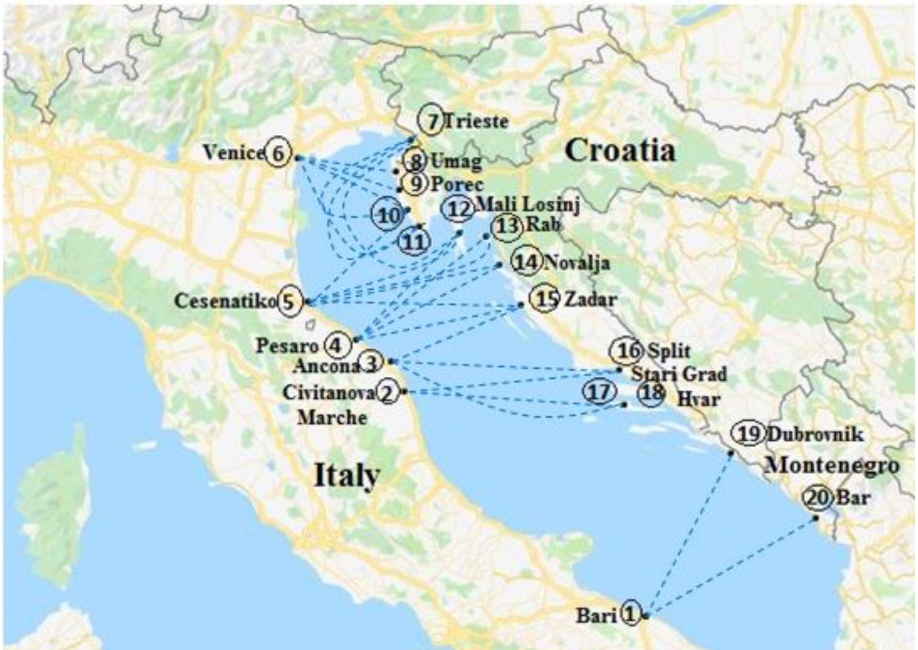

Fig. 3. The location of the transport nodes of the Adriatic Sea and the links between them

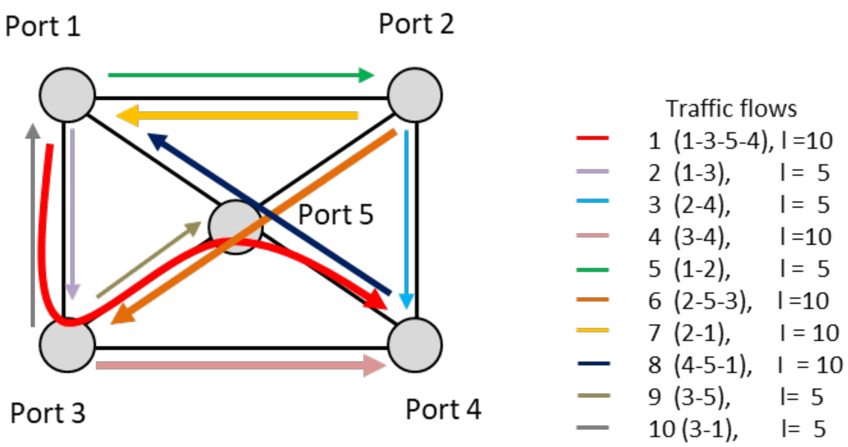

Fig. 4 Traditional method of graph representation for the number of routes (traffic flows)

Since the external environment directly affects the processes of ferry transportation, it is necessary to evaluate the effect of terminals on each other. Passenger terminals compete with each other for passenger traffic. It is necessary to evaluate the role of the sea ferry company in the regional market.

5. PRACTICAL IMPLEMENTATION OF A CIRCOS DIAGRAM BASED ON THE DISCRETIZATION OF PROCESSES

To solve the research problems posed, it is proposed to use the special software J-Circos [16]. J-Circos is an interactive visualization tool for complex systems, with the ability to dynamically change graphic data. Building a system model in J-Circos requires the creation of special files describing the nature of the system elements. To add links and their intensities to the original graph, use the of the Circos plot bridge type. The practical realization of such a file for the marine system is presented in Fig. 5. The following data are set in the file:

• Color - color of the connection in the RGB format. Since the intensities are not large, the difference in the width of the lines of links is not visible. Therefore, we will display connections with the same intensity in one color.

Table 3

Routes between passenger terminals and intensity of ferry lines

№	Passenger terminal	Passenger terminal	Number of crossings per week	Number of crossings per week in the opposite direction
1	Ancona	Split	10	10
2	Ancona	Zadar	5	5
3	Ancona	Stari Grad	1	2
4	Bari	Dubrovnik	4	4
5	Bari	Bar	2	2
6	Cesenatico	Rovinj	2	2
7	Cesenatico	Zadar	2	2
8	Cesenatico	Mali Losinj	3	3
9	Cesenatico	Rab	2	2
10	Cesenatico	Novalja (Pag)	1	1
11	Civitanova-Marche	Split	1	1
12	Civitanova-Marche	Stari Grad	2	2
13	Civitanova-Marche	Hvar	1	1
14	Pesaro	Zadar	2	2
15	Pesaro	Mali Losinj	3	3
16	Pesaro	Rab	2	2
17	Pesaro	Novalja (Pag)	1	1
18	Trieste	Rovinj	4	5
19	Trieste	Pula	1	1
20	Trieste	Mali Losinj	2	2
21	Venice	Pula	8	8
22	Venice	Porec	13	13
23	Venice	Rovinj	10	10
24	Venice	Umag	2	2

• Chrom1 (2) - connected elements of the system. We will start counting the elements from the most south-western terminal - Bari, and continue, describing the circle in a clockwise direction.

- Start1 - position on the circuit section occupied by the source/end point.
- Length1 - traffic flow from port 1 to port 2. Length 2 is in the reverse direction.
- Description1 - the name formed by the link.

Circos plot bridge is a special fragment of program code according to the listing rules of the J-Circos environment software language. As a result, we obtained the visualization of interrelations in the Adriatic Sea between passenger terminals on a circos plot intensity diagram (Fig. 6).

A circular Circos plot model was built for the passenger terminal network in the Adriatic Sea based on the identified traffic intensity of passenger ships between the main ports of the network. The constructed model is very visual and can be perceived as an alternative to the classical graph. An important advantage of the Circos plot visualization tool is the ability to visually explore the performance of the system over time by generating a model based on actual data in different periods of time.

```
Radius 180
Color           chrom1  start1   length1         description1   chrom2  start2   length2 description2
255,0,0         chr1    80000000 4               port1           chr19  40000000 4       port19
0,0,255         chr1    10000000 2               port1           chr20  40000000 2       port20
255,0,255       chr2    10000000 1               port2           chr16  40000000 1       port16
0,0,255         chr2    80000000 2               port2           chr17  40000000 2       port17
......          ...     ...      ...             ...            ...     ...      ..      ....
255,0,255       chr7    80000000 1               port7          chr11   100000000 1      port11
Radius   205    Color           chrom             start    text   type
0,0,0    chr1   120000000       Bari              circumference
0,0,0    chr2   120000000       Cvitanova         circumference
0,0,0    chr3   100000000       Ancona            circumference
...      ...    ...             ...              ...
0,0,0    chr20  35000000        Bar              circumference
Radius 220      Color           chrom            start text type
0,0,0    chr2   120000000       Marche           circumference
0,0,0    chr12  70000000        Mali             circumference
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Fig. 5. Circos plot bridge file (circos bridge data type) for mapping element relationships between marine passenger terminals

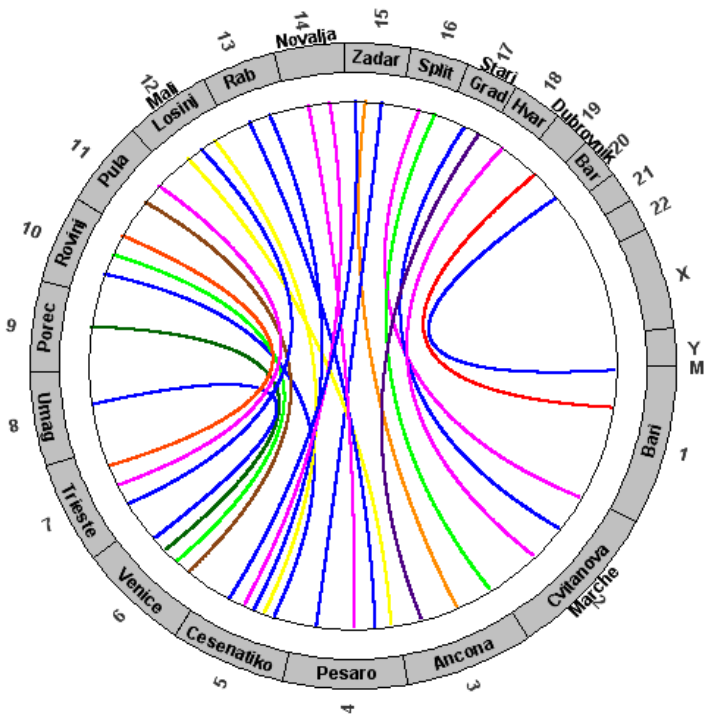

Fig. 6. The circos plot model of the system «marine passenger terminals – ferry lines» in the Adriatic Sea basin on table 3

6. CONCLUSION

The main goal of this research is to develop a new methodology for the study of the state of the marine passenger traffic and the subsequent analysis of the ferry lines network for a particular region of the sea. A new technique is based on the formation of conditions for sampling the states of a terminal system, taking into account a coherent set of variables defining each terminal state, obtaining an array of discrete data of intensities in the route network.

When forming the initial data, the discrete approach is justified. All available data should form a complete group of events that fully describe the interaction of the «marine passenger terminal - ferry line» at a selected discrete point in time.

This study focused on the Adriatic Sea region and the existing ferry route system. The role of individual ferry companies in the region's transportation market is being determined. Based on the discretization of processes, it is proposed to perform interpolation and restoration of system operation values. By recalculating the states and values of intensities, it is possible to estimate the loss for a particular region for the case of a negative impact of the external environment on transportation. The practical results we can see in the form of circos plot diagrams for sea passenger transportation in the Adriatic Sea region and the proposed research methodology for research and operation analysis of the «ferry line - marine passenger terminal» system based on process discretization. Specialized new program files are developed and a new circos plot intensity diagram is constructed. When analyzing a data set of circos plot, it is possible at a qualitatively new level to study changes in the route network, to form trends of traffic intensity, and to assess the influence of the external environment. The selected tool has a built-in editor that allows one to make quick changes to the model. The proposed research path can be used for any number of passenger terminals and the model can be scaled. When the system is formed from data diagrams built over a selected time interval, one can identify system changes that cannot be found by working only with individual tables of statistics.

The result should be used to make decisions on the operation of the «marine passenger terminal - ferry line» systems at the macro level of planning and it opens up a new way to study the shipping processes of the region.

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