

## Accuracy Evaluation of Ro-Ro and Ro-Pax Ships Arrival to the Ports

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**ABSTRACT:** Ro-Ro and Ro-Pax ships works on basis of regular schedule and try keep this schedule as accurate as possible. In same time difficulties during Ro-Ro and Ro-Pax ships voyages like bad weather conditions, waiting time to entry in to port, ship's failures and others, sometime request more time as it was planned initially. Ro-Ro and Ro-Pax ships arrivals in to port evaluation is important not only just for the Ro-Ro and Ro-Pax shipping lines planning but as well it is very important for passengers, transport units (trucks) and port terminals. In this Article are analyzed delay times of Ro-Ro and Ro-Pax ships arrival to port on basis of statistical data and used mathematical models for calculation of the arrival time pass.

### 1 INTRODUCTION

Ro-Ro and Ro-Pax shipping lines schedules are planned in advance and Ro-Ro and Ro-Pax ships try to keep arrival times to ports as accurate as possible. Accurate Ro-Ro and Ro-Pax ships arrival time to any port is important for the all involved parties in this business: passengers, shipping lines operators, transport units (road and railway), port itself and terminals. In the same time different type of difficulties occur during Ro-Ro and Ro-Pax ships voyage at sea between ports, such as: storm conditions, fog situations, when it is necessary to decrease ship's speed, ships queue at the entrance of the ports and etc. takes additional waiting time for the Ro-Ro and Ro-Pax ships during the entrance to the ports or departures from the ports [2].

Evaluation methods of Ro-Ro and Ro-Pax ships arrival time into the port depends on the weather conditions, ships queue near the port entrance, Ro-Ro ships failures and so on based on statistical data and it is possible used mathematical methods, which can

help for all Ro-Ro and Ro-Pax shipping participants and can assist in better planning of ports and terminals activity, passengers and transport units information regarding possible delays [5,11,13].

### 2 ANALYSIS OF RO-RO SHIPS ARRIVAL TIME TO PORT

Ro-Ro, Ro-Pax and container ships works according to the stable schedule and try to keep maximum possible accuracy of the arrival time, which depends on the departure time from the port of departure. It requests to adopt ship's speed and in case, if Ro-Ro or Ro-Pax vessels have some reserve time, it is possible to fulfill the arrival time schedule [7].

In the same time, during Ro-Ro and Ro-Pax ships voyages sometimes situations occur, like storm conditions, waiting in queue to enter the port, if there are waiting passenger ships, as well as any problems in the port approach and inside navigational

channels, etc. It makes very difficult to keep the schedules [12]. Analysis of Ro-Ro and Ro-Pax shipping lines in South part of the Baltic sea showed that about 30 % of Ro-Ro and Ro-Pax ships arrivals are delayed up to 20 minutes, about 20 % of ships arrivals are delayed up to 40 minutes and about 10 % of ships arrivals are delayed one hour or more. Some statistical data, as the example, of one month of Ro-Ro and Ro-Pax vessels arrival delays on Ro-Ro line Klaipeda – Kiel and Klaipeda – Karlshamn are presented on Figure 1.

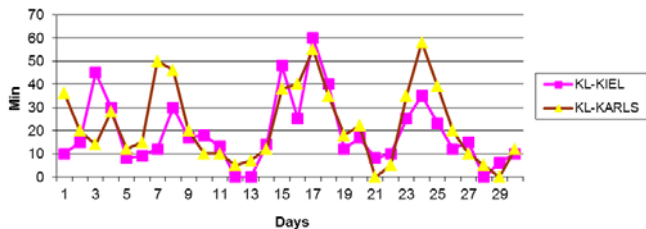


Figure 1. One month of Ro-Pax ships delay in minutes at Klaipeda port on Ro-Pax lines Klaipeda – Kiel (KL-KIEL) and Klaipeda – Karlshamn (KL-KARLS)

Mentioned Ro-Pax ships “Victoria Seaways” (Klaipeda – Kiel line) and “Optima Seaways” (Klaipeda – Karlshamn line) speed distribution during the voyages are presented on Figure 2 and Figure 3.



Figure 2. Ro-Pax ship’s “Victoria Seaways” speed distribution during the voyage Klaipeda – Kiel” (AIS information)

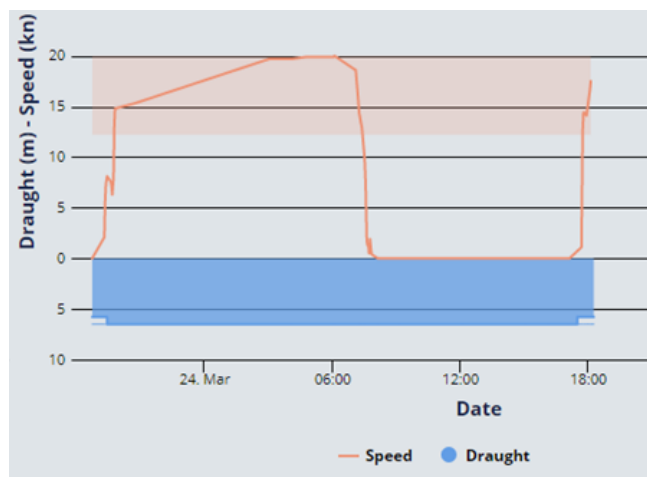


Figure 3. Ro-Pax ship’s “Optima Seaways” speed distribution during the voyage Klaipeda – Karlshamn (AIS information)

Ro-Pax ships arrival time delay increase during autumn and winter periods and more precise to the schedule are in summer time, but it very much depends of the other factors, like holidays, weekends as well as space utilization of the Ro-Pax ships, port terminals capacities.

### 3 THEORETICAL BASIS FOR THE RO-RO AND RO-PAX SHIPS ARRIVALS ACTUAL TIME EVALUATION AND CASE STUDY OF THE RO-PAX SHIPS ARRIVAL TIME DELAY EVALUATION

Ro-Ro and Ro-Pax ships arrival evaluation is important for the port and terminal activity planning. For Ro-Ro ships arrival evaluation could be used several methods, for example maximal distribution method or dispersion method [4, 8]. On basis of maximal distribution method it is possible to receive ships delay time pass, but density in this pass will be different.

#### 3.1 Dispersion and maximal distribution methods for the Ro-Ro and Ro-Pax ships arrival time delay calculation

Dispersion method presents delay time pass and depends on the probability with the same density in pass width.

Average circle error ( $e$ ) in dispersion method is comparable with dispersion ( $\sigma_y$ ) [11]:

$$e = \sigma_y \quad (1)$$

Dispersion can be calculated as follows:

$$\sigma_y^2 = \frac{1}{n_i - 1} \cdot \sum (\Delta T_{ii} - m_{yi})^2, \quad (2)$$

where:  $n_i$  - number of the statistical points (days);  $m_{yi}$  - mathematical hope of the Ro-Pax ships of the arrival time delay can be calculated as follows:

$$m_{yi} = \frac{1}{n_i} \sum \Delta T_{ii}, \quad (3)$$

On the basis of Ro-Pax ships arrival delays, accuracy (arrival time pass) could be calculated as follows:

$$T_{arrival(max)} = T_{arrival(scedule)} + \Delta T_{delay} + e, \quad (4)$$

$$T_{arrival(min)} = T_{arrival(scedule)} + \Delta T_{delay} - e. \quad (5)$$

Ro-Pax ships very rare arrive before the scheduled time. In case, if Ro-Pax ship arrival time is before the scheduled time, captains always decrease speed and save some fuel. That means formula (5) just theoretically can be used, practically just in emergency situations, for example in case of

requested urgent medical assistance for passengers or crew members, Ro-Pax ship can entry in port earlier, because in usual conditions port terminals are not ready for mooring of ships and provide cargo handling or passenger embarkment operations.

In some cases it is possible to use maximal distribution method for the Ro-Pax ships arrival delay calculation. Main dependence could be expressed as follows [14]:

$$\Delta T = T_{AV} + k_n P' T_{\max-\min} \quad (6)$$

where:  $T_{AV}$  - average Ro-Pax ship's arrival time, can be taken as  $m_{yi}$ ;  $k_n$  - coefficient depends on the number of data, in case, if number of data are 3 – this coefficient will be - 0,55; in case number of data 4 – this coefficient will be 0,47 and similar depends of the data number: 5 – 0,43; 6 – 0,395; 7 – 0,37; 8 – 0,351; 9 – 0,337; 10 – 0,329; 11 – 0,325; 12 – 0,322 and so on, but minimum of this coefficient could be about 0,315 in case number of data will be more as 15.  $P'$  - probability dependence coefficient (in case of this coefficient 1 – probability will be 68,3 %, in case of the coefficient 2 – probability will be 95,3 %, in case of this coefficient 3 – probability will be 99,7 %);  $T_{\max-\min}$  - difference between minimum and maximum results, that means between earliest and latest Ro-Pax ships arrival time.

As the case study of Ro-Pax ships arrival time delay evaluation were taken Ro-Pax shipping lines Klaipeda – Kiel and Klaipeda – Karlshamn. Both Ro-Pax shipping lines are daily, just sailing time to one direction on the route Klaipeda – Kiel takes about 20 hours and time in port takes about 4 hours and on the route Klaipeda – Karlshamn sailing time takes about 14 hours and ship's stay at the port takes about 10 hours. Analysis covers few months during summer time in good weather conditions and in winter time, when weather conditions were more complicated.

In winter and summer time were excluded storm days, when wind was more than 20 m/s and Ro-Pax ships cannot entry into the port or leave port according to the schedule. In total were taken more than 100 arrivals and received next results: mathematical hope of the Ro-Pax ships on line Klaipeda – Kiel to port arrival delay was 17 minutes, and on line Klaipeda – Karlshamn - was 21 minutes and dispersions or average circle error received +/- 8 minutes for the Ro-Pax line Klaipeda – Kiel and +/- 6 minutes for the Ro-Pax line Klaipeda Karlshamn.

According to maximal distribution method was taken probability 68,3 %, coefficient depends on the number of data was taken 0,315, and difference between minimum and maximum results for the Ro-Pax line Klaipeda – Kiel was received 62 minutes, for the Ro-Pax line Klaipeda - Karlshamn was received 51 minutes.

Average Ro-Pax ship's arrival delay time for the Ro-Pax line Klaipeda – Kiel was received 17 minutes in comparison with time table and for the Ro-Pax line Klaipeda – Karlshamn was received 12 minutes in comparison with the schedule. Finally according to maximal distribution method Ro-Pax ships delay time for the line Klaipeda – Kiel was 36 minutes and for the Ro-Pax line Klaipeda – Karlshamn – 28 minutes.

Differences between evaluation methods based on different density, because in dispersion method density of the results is similar in all received time pass and in maximal distribution method density is different on received time pass.

Next important problem, which is necessary to solve: sustainable information system, which has be useful for ports, terminals and clients, that means accurate information for passengers and truck drivers, because it links with city limitations to use some streets in rush hours for the heavy transports driving to and from port terminals.

### 3.2 Graph theory possibilities optimize freight and passengers transport rich Ro-Ro terminals

This problem for the rich Ro-Ro terminal in port via cities during rush hours can be solved on basis of graph theory. For developing an optimal streets network, which are not busy during rush hours and could be used for the heavy transport. The application of graph theory method is used, where the model is build in that incorporates a set of vertices, which are representing permit streets cross places and a set of edges, which represents the distances between permit streets crossing points. The optimal permit streets for heavy transports during rush hours network modeled as a graph is expressed as follows [6, 8]:

$$G = (V, E) \quad (7)$$

where:  $V$  - the set of vertices;  $E$  - the set of edges.

As an example, the permit streets network could be created in Klaipeda city streets network, which is not busy during rush hours, as shown on Figure 4.

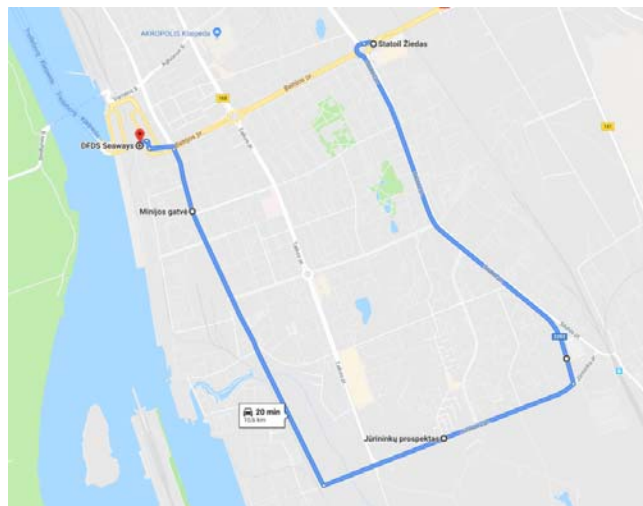


Figure 4. Not busy streets network in rush hours as the graph tree

For the graph tree, presented on figure 4, the sets of vertices and the set of edges can be expressed as follows [1, 4, 9]:

$$V = \{v_1, v_2, v_3, v_4, v_5, v_6\} \quad (8)$$

$$E = \{(v_1, v_2)(v_2, v_3)(v_2, v_4)(v_2, v_5)(v_5, v_6)\} \quad (9)$$

The all-vertex incidence matrix of a non-empty and loop less directed graph for the presented graph tree  $G$  is [3, 6]:

$$A = a_{ij} , \tag{10}$$

$$\text{where } a_{ij} = \begin{cases} 1 & \text{if } v_i \text{ is the initial vertex of } e_j \\ -1 & \text{if } v_i \text{ is the terminal vertex of } e_j \\ 0 & \text{otherwise.} \end{cases}$$

In this study case for permit streets for heavy transports network incidence matrix can be explained as follows [6]:

$$A = \begin{pmatrix} v_1, v_2, v_3, v_4, v_5, v_6 \\ v_2 \\ v_3 \\ v_4 \\ v_5 \\ v_6 \end{pmatrix} \tag{11}$$

For the graph tree covering city streets network, which is explained on Figure 4, mentioned matrix in formula (11) can be computed as follows:

$$A = \begin{pmatrix} 010000 \\ 101110 \\ 010000 \\ 010000 \\ 010001 \\ 000010 \end{pmatrix} \tag{12}$$

Finally for the optimum distances between permit streets cross points for the freight transport in rush hours or optimal price in network could be used next optimization formula [3, 6]:

$$f : E \Rightarrow R^+ , \tag{13}$$

And it is necessary find graph tree  $T = (VE')$  price or optimal distance  $F(T)$  like,

$$F(T) = \sum_{xy \in E} f(xy) , \tag{14}$$

where:  $f(xy)$  - minimum price or optimal distance.

In study case the edges  $e = xy \in E$  as minimum price or optimal distance could be find as follows [3, 4, 6]:

$$f(e) = \min_{xy \in E} f(xy) , \tag{15}$$

Based on the suggestion of graph theory it is possible argues that it is possible to design permit streets to or from terminals for the freight transport in rush hours network, and to consider additionally on Ro-Pax ship's entry to port delay time evaluation, since it is possible to identify the sets of vertices and

the set of edges weights. In consideration of weights of the sets of vertices and edges it is possible to improve or identify the optimal permitted streets location network for heavy transports and passengers cars during rush hours.

The main question, how it is possible to implement or at least take in account results, which are received in the Article. First of all, if Ro-Pax ships have main engine power reserve, it is possible to increase the main engine power and compensate Ro-Pax ship's arrival time delay to the port, but in the same time it will increase fuel consumption and ships sailing costs. It is possible to implement this system on Ro-Pax line Klaipeda – Karlshamn, because on this line Ro-Pax ships often do not used full engine power, or schedule is changed slightly, that means departure time does not change too much.

On Ro-Pax line like Klaipeda – Kiel ship's used main engine power is close to the full (full sea speed), so it is necessary to use full main engine power and as experimental results show, to compensate ship's arrival to port about 36 minutes, additional fuel consumption is around 3,5 tons.

Possibility to keep Ro-Pax ships schedule and decrease arrival to the port delays could be included in tickets for passengers and trucks price and more accurate calculation for possible losses or decrease of profitability.

#### 4 CONCLUSIONS

- 1 Ro-Pax ships entry to the port delay time evaluation methods presented in Article could assist for the Ro-Pax shipping companies for more accurate preparation of schedules to avoid problems for the passengers and heavy road transport.
- 2 More accurate information on delay time of entry into the port of Ro-Pax ships could evaluate requested additional sources and align services tariffs.
- 3 Possibility use graph theory methods for the preparing optimal ways to reach terminals and avoid conflicts with cities authorities can optimize all the transport process especially in big port cities.

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