**RIGA TECHNICAL UNIVERSITY**

Department of Transport and Machine Engineering

Institute of railway transport

**Fjodors MIHAILOVS**

Ph.D. student of Doctoral Degree Program “Railway Transport”

# MANAGEMENT OF THE INTERACTION OF RAILWAY STATION AND HARBOR BASED ON SIMULATION MODELING

**Summary of Doctoral Thesis**

Academic Advisor

Dr. sc. ing., professor D. SERGEJEVS

Dr. sc. ing., professor P. BALCKARS

**RTU Publishing House**

**Riga 2012**

UDK 656.213+627.35 (043.2)
Mi 292 d

Mihailovs F. Management of the interaction of railway station and harbor based on simulation modeling. Synopsis.-R.: RTU Publishing House, 2012.-38 p.

Printer in accordance with “RTU P-20” council act dated by 20th of June 2012, proceeding report No. 03/2012

This work has been supported by the European Social Fund within the project «Support for the implementation of doctoral studies at Riga Technical University»

ISBN 978-9984-9990-3-6

**DOCTOR DIPLOMA**
**SUBMITTED TO RIGA TECHNICAL UNIVERSITY**
**TO OBTAIN ENGINEERING DOCTOR DEGREE**

Doctor diploma to obtain engineering doctor degree has been openly presented on 27th of December, 2012 at 12:00 in the Institute of Transport Vehicle Technologies of Riga Technical University, Riga, Lomonosova street 1-V, room 218.

OFFICIAL OPPONENTS

Professor, Dr.habil.sc. Gaļina Merkurjeva
Riga Technical University, Latvia

Professor, Dr.habil.sc.ing. Ramūnas Palšaitis
Vilnius Gediminas Technical University, Lithuania

Professors, Dr.habil.sc.ing. Genady Groshev
Petersburg State Transport University, Russia

CONFIRMATION

It is hereby confirmed, that I completed the following thesis, presented in Riga Technical University for doctoral degree in engineering independently. The thesis is not presented in any other university for academic degree.

Fjodors Mihailovs ……………… (signature)
Date: 27.11.2012.

The thesis is written in Latvian, includes introduction, 4 chapters, conclusions, list of references, 7 annexes, 42 drawings, 30 tables, 126 pages in total. List of references consists of 185 items.

## ANNOTATION

Thesis "Management of the interaction of railway station and harbor based on simulation modeling" is completed by Fjodors Mihailovs in order to receive doctoral degree in engineering. Academic Advisor, Dr.sc.ing., asoc. professor Dijs Sergejevs un Dr.sc.ing., asoc. professor Pēteris Balckars.

Main objective is the implementation of simulation methods of the interaction of railway station and harbor in order to improve the performance of operational work, ensuring rhythmic processing load, reducing the idle time of wagons at harbor stations.

The system of parameters of finding of optimal train arriving time intervals' to the harbor stations is formed.

Distribution laws of incoming train traffic to transport node and their compliance to the laws of theoretical distribution has been checked.

The algorithm of finding of optimal train arriving time intervals' to harbor stations is developed on the base of method of multiagent optimization.

On the basis of investigations is worked out simulation model with the finding of optimal train arriving time intervals' to harbor stations for the simulation of interaction processes at transport node „harbor station – about terminals" with material flows and cargo units from the entrance into the system to the exit from it.

The results of investigation are offered for implementation on JSC "Latvian railway" (LDZ).

**CONTENTS**

# 1. RELEVANCE OF WORK

Today's transport policy of Republic of Latvia is aimed to provide transit cargo shipment and related services, as well as the development of transport corridors to attract additional cargo flow in case of cargo volume increasing.

However, there are significant delays of wagons and trains (from several days to months) operating with the existing train traffic waits for the delivery to harbor terminals.

One of the main reason for these delays and of making "warehouses on wheels" is the lack of technology of train guidance according to ships' approaching the harbors. That fact brings LDZ and transport industry in total significant losses taking into consideration the shortage of freight cars.

Last year's processing ability and volumes of the overhauled loads of Rīga-Krasta harbor station practically reached functional limit on a basis of existent technologies. The analysis stresses on many difficulties at the production of shifting operations at transport node „harbor station – about terminals", especially taking into account the prognosis of increase of volumes of goods. Consignee and LDZ sometimes are forced to declare conventional prohibitions on shipping due to difficulties at the transactions of loads from railway to marine transport due to the lack of carrying and processing capacity. It in turn discredits LDZ as a reliable partner on delivery of load to the consignee. For example, during 2000 conventional prohibitions operated during 40 days, in 2002 - 35 days, in 2005 - 20 days. In addition to that there is putting of wagons on a safekeep, which provides heavy expenditures to LDZ from the creation of so-called „warehouses on wheels".

The absence of effective interaction leads to situation, when about 80 trains on LDZ network are waiting for the handling operation at harbors of Rīga, Liepāja and Ventspils (Fig. 1).

In fact of wagons' standstill decrease, the provision of concordant transport interaction at transport node „harbor station – about terminals" is more critical.

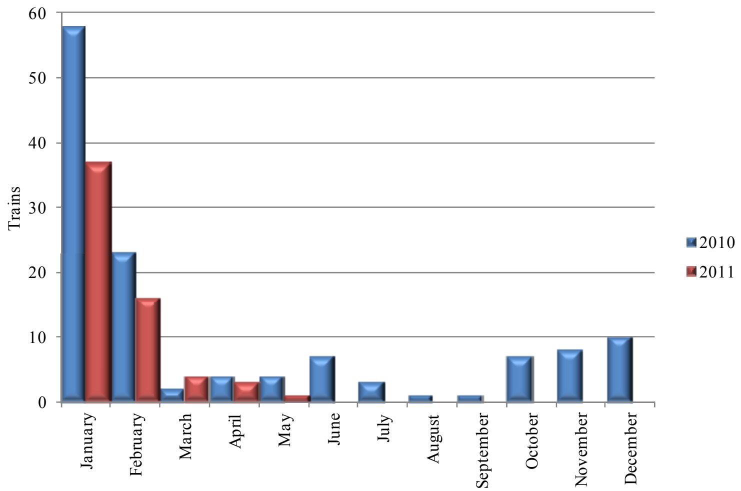



Fig.1. Amount of the abandoned trains for Rīga-Krasta station in the period of 2010-2011.

## 2. WORK OBJECTIVE AND TASKS

Work **objective**. Work objective is the development of simulation model and the improvement of methods of simulation modeling to decrease wagons' standstill at harbor station sidings. Taking into consideration the difficulties of investigation object analytical imagination, the development of simulation model of transport node „harbor station – about terminals" is sufficient. It allows evaluating the processes of interaction between some kinds of transport when incoming parameters to harbor station and terminals are not constant.

**The tasks** are defined to reach the work objective:

1. The identification of cargo shipment, as investigation object, using the analysis of factors that influence the cargo shipment management by railway to harbor destinations.
2. The suggestion of algorithm of finding of optimal train arriving time intervals' to harbor stations due to absence of planning arrivals of trains according to the schedule.
3. The development of simulation model of transport node „harbor station – about terminals".
4. The evaluation of simulation model reliability and simulation modeling results.
5. The formalization of simulation model of harbor station using factors listed below:
   - train guidance to harbor stations by strict schedule;
   - implementation of additional shunting locomotives to supply wagons between harbor stations and terminals;

- harbor no-failure functionality.

6. Ways of wagons' standstill time decrease implementing factors of interaction of harbor stations and terminals.

**Objects of investigation** of the Thesis are processes within complex structurally-technological objects, which differ:

- weak formalization;
- complex structure of links and actions;
- presence of unknown and hard-noticeable factors;
- multicriteria functionality;
- unstable processes in the system.

The examples of objects, listed above, are processes within transport nodes proceeding cargo shipment, processes of raw materials' delivery to manufacturers.

Subject of investigation – the formalization and simulation modeling of processes, taking place in transport node „harbor station – about terminals".

## 3. RESEARCH METHOD AND METHODICS

Methods of system analysis, probability theory, theory of mathematical statistics, mass service theory, graphs theory, theory of decision taking, methods of simulation modeling of interaction of harbor station and terminals have been utilized.

## 4. MAIN RESULTS

1. System of parameters of finding of optimal train arriving time intervals' to the harbor stations.
2. Development of algorithm of finding of optimal train arriving time intervals' to harbor stations.
3. Simulation model of executable processes at transport node „harbor station – about terminals", having the option of wagons' standstill index forecast and evaluation.

## 5. SCIENTIFIC NOVELTY OF WORK

1. The system of parameters of finding of optimal train arriving time intervals' to the harbor stations is formed using operational indexes of transport service subjects, involved in cargo shipment processes.

2. Distribution law of input trainflows to transport node and their compliance with the laws of theoretical distribution has been checked.
3. The task of optimal guidance of trains to harbor stations is formalized as a quadratic task which allows managing the guidance of trains to harbor station in accordance with the situation and formed system of parameters.
4. The algorithm of finding of optimal train arriving time intervals' to harbor stations is developed on the base of method of multiagent optimization.
5. The algorithm of finding of optimal train arriving time intervals' to harbor stations is developed on the base of method of multiagent optimization. Person, who takes the decision, can evaluate possibilities and take correct decision.
6. Simulation model of interaction processes at transport node „harbor station – about terminals" is worked out to make forecasts for the effectiveness of interaction of kinds of transport. Model is easy to set-up according to technological processes and to definite transport node specification, easy to operate, simplifies communication processes between the developers of model and persons who take the decisions.

## 6. PRACTICAL VALUE OF WORK

References of wagons' standstill decrease are worked. Solutions for cargo flow forcement are done for transport node „harbor station – harbor terminals". Simulation model is worked out with the finding of optimal train arriving time intervals' to harbor stations implementing the method of multiagent optimization. Suggested way provides the opportunity to make forecasts for the effectiveness of interaction of kinds of transport.

## 7. WORK APPROVAL

On the results of the work has been reported and are discussed:

**Latvia:**

1. RTU 46. starptautiskā zinātniskā konference. Rīga, Latvija 13.-15.10.2005.
2. 8. starptautiskā konference „ŪDENS TRANSPORTS UN INFRASTRUKTŪRA 2006", Latvijas Jūras akadēmija, Rīga, 20.04.2006.
3. RTU 47. starptautiskā zinātniskā konference. Rīga, Latvija 12.-14.10.2006.
4. 9. starptautiskā konference "ŪDENS TRANSPORTS UN INFRASTRUKTŪRA 2007", Latvijas Jūras akadēmija, Rīga, 19-20.04.2007.
5. RTU 48. starptautiskā zinātniskā konference. Rīga, Latvija 11.-13.10.2007.

6. 10. starptautiskā konference "ŪDENS TRANSPORTS UN INFRASTRUKTŪRA 2008", Latvijas Jūras akadēmija, Rīga, 24-25.04.2008.
7. RTU 49. starptautiskā zinātniskā konference. Rīga, Latvija 13.-15.10.2008.
8. Starptautiskā zinātniski pētnieciskā konference „Latvijas dzelzceļi: pagātne, tagadne, nākotne". Rīga. 26.-27.03.2009.
9. 11. starptautiskā konference "ŪDENS TRANSPORTS UN INFRASTRUKTŪRA 2009", Latvijas Jūras akadēmija, Rīga, 23-24.04.2009.
10. RTU 50. starptautiskā zinātniskā konference. Rīga, Latvija 12.-16.10.2009.
11. 12. starptautiskā konference "ŪDENS TRANSPORTS UN INFRASTRUKTŪRA 2010", Latvijas Jūras akadēmija, Rīga, 29-30.04.2010.
12. RTU 51. starptautiskā zinātniskā konference. Rīga, Latvija 11.-15.10.2010.
13. 13. starptautiskā konference "ŪDENS TRANSPORTS UN INFRASTRUKTŪRA 2011", Latvijas Jūras akadēmija, Rīga, 28-29.04.2011
14. RTU 52. starptautiskā zinātniskā konference. Rīga, Latvija 11.-15.10.2011.
15. Riga Technical University 53rd International Scientific Conference Dedicated to the 150th Anniversary and The 1st Congress of World Engineers and Riga Polytechnical Institute / RTU Alumni. 11.-12.10.2012.

**Abroad:**

1. 8. Viļņas jauno zinātnieku konference „Lietuva bez zinātnes – Lietuva bez nākotnes". Viļņas Gedemina Tehniskā universitāte. 12.05.2005.
2. 9. Viļņas jauno zinātnieku konference „Lietuva bez zinātnes – Lietuva bez nākotnes", Viļņas Gedemina Tehniskā universitāte. 25.05.2006.
3. 10. Viļņas jauno zinātnieku konference „Lietuva bez zinātnes – Lietuva bez nākotnes", Viļņas Gedemina Tehniskā universitāte. 03.05.2007.
4. 11. Viļņas jauno zinātnieku konference „Lietuva bez zinātnes – Lietuva bez nākotnes", Viļņas Gedemina Tehniskā universitāte. 15.05.2008.
5. 12. Viļņas jauno zinātnieku konference „Lietuva bez zinātnes – Lietuva bez nākotnes", Viļņas Gedemina Tehniskā universitāte. 14.05.2009.
6. 13. Viļņas jauno zinātnieku konference „Lietuva bez zinātnes – Lietuva bez nākotnes", Viļņas Gedemina Tehniskā universitāte. 06.05.2010.
7. 15. Viļņas jauno zinātnieku konference „Lietuva bez zinātnes – Lietuva bez nākotnes", Viļņas Gedemina Tehniskā universitāte. 04.05.2012.

**Publications**

The main theses, conclusion and recommendations are reflected in the following scientific publications:

1. 8. Viļņas jauno zinātnieku konference „Lietuva bez zinātnes – Lietuva bez nākotnes". Viļņas Gedemina Tehniskā universitāte. 12.05.2005. 254.-260., 289-294 p.
2. 8. starptautiskā konference „ŪDENS TRANSPORTS UN INFRASTRUKTŪRA 2006", Latvijas Jūras akadēmija, Rīga, 20.04.2006. 210 p.
3. 9. Viļņas jauno zinātnieku konference „Lietuva bez zinātnes – Lietuva bez nākotnes", Viļņas Gedemina Tehniskā universitāte. 25.05.2006. 357-361 p.
4. 9. starptautiskā konference "ŪDENS TRANSPORTS UN INFRASTRUKTŪRA 2007", Latvijas Jūras akadēmija, Rīga, 19-20.04.2007. 38-45 p.
5. 10. Viļņas jauno zinātnieku konference „Lietuva bez zinātnes – Lietuva bez nākotnes", Viļņas Gedemina Tehniskā universitāte. 03.05.2007. 544-551 p.
6. 10. starptautiskā konference "ŪDENS TRANSPORTS UN INFRASTRUKTŪRA 2008", Latvijas Jūras akadēmija, Rīga, 24-25.04.2008. 82-88 p.
7. Starptautiskā zinātniski pētnieciskā konference „Latvijas dzelzceļi: pagātne, tagadne, nākotne". Rīga. 26.-27.03.2009. 91-97 p.
8. 11. starptautiskā konference "ŪDENS TRANSPORTS UN INFRASTRUKTŪRA 2009", Latvijas Jūras akadēmija, Rīga, 23-24.04.2009. 55-60 p.
9. 12. starptautiskā konference "ŪDENS TRANSPORTS UN INFRASTRUKTŪRA 2010", Latvijas Jūras akadēmija, Rīga, 29-30.04.2010. 106-111 p.
10. 13. starptautiskā konference "ŪDENS TRANSPORTS UN INFRASTRUKTŪRA 2011", Latvijas Jūras akadēmija, Rīga, 28-29.04.2011. 45-50 p.
11. 15. Viļņas jauno zinātnieku konference „Lietuva bez zinātnes – Lietuva bez nākotnes", Viļņas Gedemina Tehniskā universitāte. 04.05.2012. 362-365 p.
12. Riga Technical University 53rd International Scientific Conference Dedicated to the 150th Anniversary and The 1st Congress of World Engineers and Riga Polytechnical Institute / RTU Alumni. 11.-12.10.2012. 610 p.

## 8. STRUCTURE OF WORK

Dissertation consists of introduction, four chapters, conclusions, list of references and annexes.

**Introduction** includes thesis relevance argumentation; objective, scientific novelty and practical value of work are presented.

## 8.1. Status of the question. Problem investigation

**In the first chapter** is given description of the object and of IT systems, created for the needs of railway and marine transport, which are the informing systems for delivery of the detail information about distribution, nomenclature, sender, recipient of loads and subjects engaging in transportations. Cause and effect analysis of problems of the management of cargo shipment is done. The analysis contains factors and causes, which occur proceeding cargo shipment operations.

The analysis is done for cargo shipment simulation methods and methods of transport task optimization.

Cargo shipment effective performance is depend on complex and logistical management based on continuous improvement of transport servicing of manufacturing processes of production supply and distribution.

The analysis stresses on many difficulties at the production of shifting operations at transport node „harbor station – harbor terminals", especially taking into account the prognosis of increase of volumes of goods. Consignee and LDZ sometimes are forced to declare conventional prohibitions on shipping due to difficulties at the transactions of loads from railway to marine transport due to the lack of carrying and processing capacity. It in turn discredits LDZ as a reliable partner on delivery of load to the consignee.

The absence of effective interaction leads to situation, when about 80 trains on LDZ network are waiting for the handling operation at harbors of Rīga, Liepāja and Ventspils.

Due to the condition listed above, the concordant transport interaction at transport node „harbor station – harbor terminals" is more critical. There are no effective methods suggested for task solving. This fact leads to financial expenditures.

Cargo shipment quality is ensured:

- in the process of shipment;
- at the destination and departure stations;
- at transport nodes where the transshipment takes place.

Cargo shipment quality is the result of set of factors and causes, which occur in execution process.

Is mentioned that the most impact to cargo flow comes from:

- the development of IT structure of transport node „harbor station – harbor terminals";
- interaction and coordination of kinds of transport involved in transshipment;
- collaboration with the subjects of market of transport services;
- influence of environment.

Diagram of factors, influencing the interaction of harbor station and terminals, is shown at figure 1.1.

Conclusions based on the analysis of diagram are:

- factor "collaboration with the subjects of market of transport services" is outside the Thesis;
- factor "influence of environment" is external and is not managed. It has to be marked in process of management impact;
- factors "interaction and coordination of kinds of transport involved in transshipment" and "the development of IT structure of transport node „harbor station – harbor terminals" are the most actual in process of insurance of cargo shipment quality.

There is a lot of investigations done by scientists in the field of transport interaction and functionality of transport nodes „harbor station – harbor terminals", also in the field of IT insurance of transshipment and the management of cargo shipment.

Basic methods for simulation modeling creation of the interaction of kinds of transport are observed. They are classified as:

- analytical models;
- models based on mass service theory (MST);
- simulation models.

Application of analytical methods for model construction has some difficulties: model construction complexity, which depicts objects interaction with high precision; overloads solving process of given system of equations. System of equations, combining lots of equations and their parameters can be calculated only using computers. Nevertheless the analytical method has advantages to find precise quantitative characteristics of observed processes.

Models, constructed using MST are limited by query-flows, which are described by distribution laws. For instance, model can be inadequate for small ranges or evaluation of operative situation. Mostly MST is not utilized for real models construction, but MST can be helpful as a basis for simulation models of explored systems.

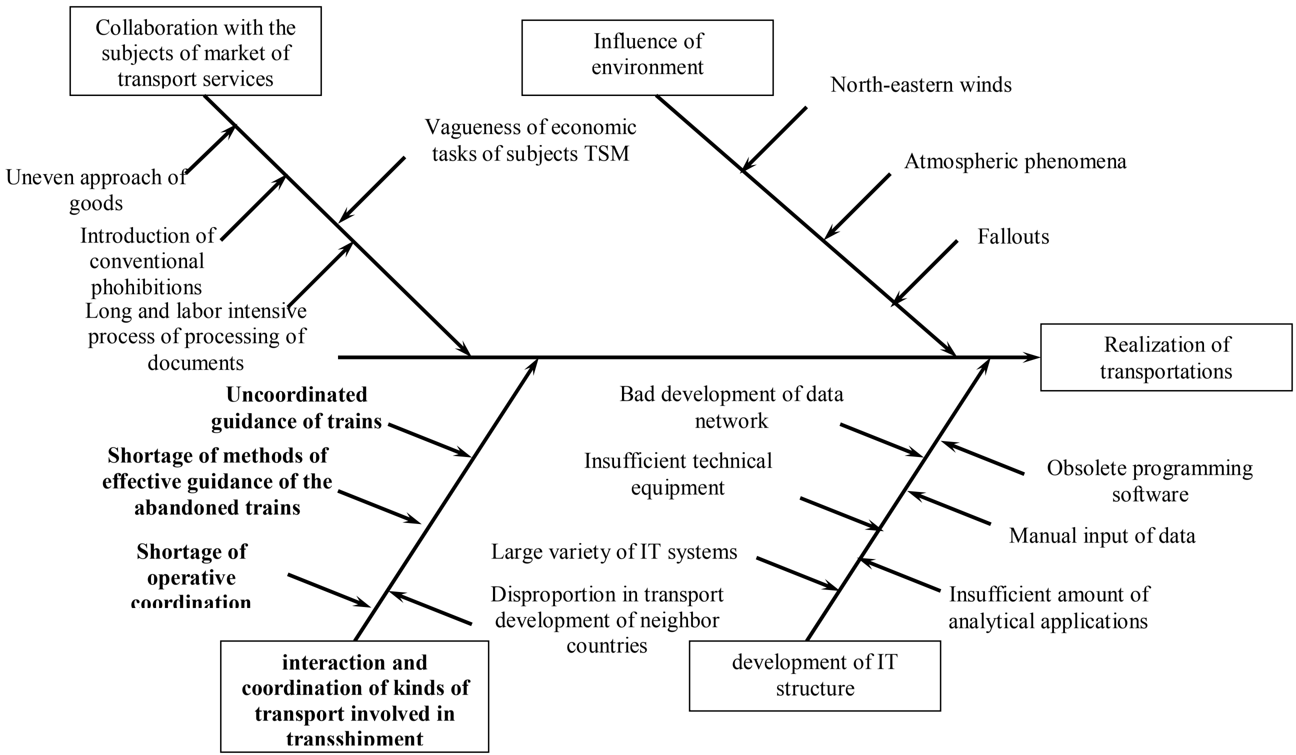



Fig. 1.1. Diagram of factors, influencing the interaction of harbor station and terminals

Probable conditions of systems have to be described in tables for the construction of simulation models. Events are made stochastically, by probable parameters definition in advance. Simulation modeling provides the investigation of exploring and projecting system corresponding to the operation's investigation, which consists of interrelated stages [137]:

- substantional definition of task;
- creation of concept model;
- realization of simulation model;
- adequacy and reliability verification and evaluation of precision of modeling results;
- trials planning and realization;
- decision making process.

It allows using simulation modeling as universal way for the decision taking in situation of uncertaincy taking into account factors in models, which realization has some difficulties. Also it gives an opportunity to apply basic ways of system accessibility to solve practical tasks.

Scientist in observed above works developed methodic for definite tasks solving for transport interaction not taking into consideration their integrated interaction, links between transport and cargo flows with IT and financial flows.

For the simulation of interaction of railway station and harbor creation of simulation model is to be produced with outgoing stream from the harbor station and incoming stream on harbor terminals and back, carrying out multimodal transportations in direction „harbor station-harbor terminal- harbor station".

For the decision of task of optimal guidance of trains at transport node is necessary to depict next tasks:

1. Forming of the system of parameters and their formalization to completion of algorithm of finding of optimal train arriving time intervals' to harbor stations to get rid of trains' blocking up harbor station.
2. Development of algorithm of finding of optimal train arriving time intervals' to harbor stations.
3. Development of simulation model of executable operations of transport node „harbor station – harbor terminals".

The analysis of cargo transshipment system is done and general description of the system of transportation of goods is defined, which characterizes by the large degree of unevenness of approach of goods, unstationarity of functioning of elements, great number of criteria, poorly formalized description and uncertainty. Completed analysis of cargo traffic transported by LDZ to harbor station stresses on notable volume grow of incoming cargo (Fig. 1.2.)

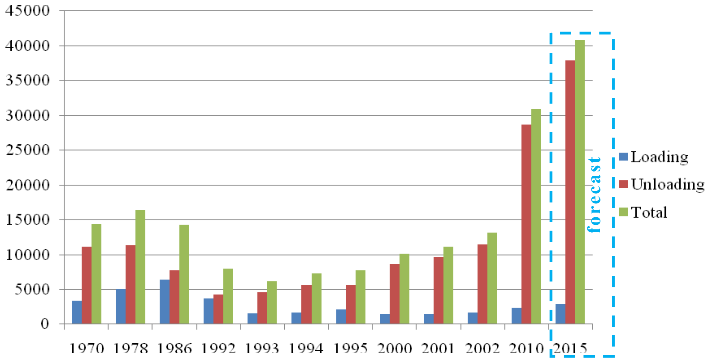



Fig. 1.2. Volumes of goods transshipped at Riga transport node based on forecast for 2015 (thousand tons)

Forecast for transshipped goods for 2015 is given taking into account the reconstruction of infrastructure of Freeport of Rīga and equals to 41 million tons, it is 32 % more than volume in 2010, equals to 31 million tons.

Completed analysis shows the opportunity to increase the effectiveness of cargo transshipment when the task of railway and seas transport interaction is solved. It can be done noting and using the similarity of technological operations, incoming train traffic and availability of sidings and handling mechanization of harbor. Developed simulation model of transport node „harbor station – harbor terminals" provides the forecast of object performance and effective utilization of harbor resources.

### 8.2. Finding of optimal train arriving time intervals

**In the second chapter** the formal presentation of task of optimal train arriving time intervals of trains to harbor station is done. It contains the definition of aggregate of criteria of optimization $J_i\left(i=\overline{1...n}\right)$.

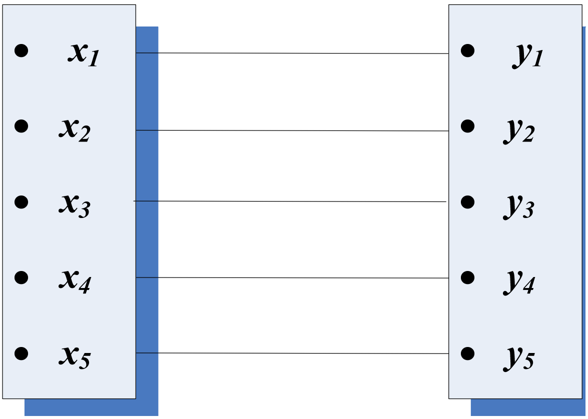
If $X$ – amount of alternatives (trains), $Y$ – amount of probable consequences (train arriving moments according to the train traffic diagram). Caused link is devised between the selection of alternative of train $x_i \in X$ and result taking (train arriving moments according to the train traffic diagram) $y_i \in Y$. Selection quality assessment is anticipated, where the selection quality mostly is the result quality.

Then the link between the alternative and result has to be defined. Link cab ne determined, and its view is:

$$x \xrightarrow{\varphi} Y, \tag{2.1}$$

in other words, is realized function $y = \varphi(x)$, $x \in X$, $y \in Y$ (Fig. 2.1.)

Link can be probable, if the selection $x$ (train) defines some distribution density of probability in massive $Y$ (train arriving moments according to the train traffic diagram). In this case the selection of $x_i$ (train) does not guarantee the definite result taking $y_i$ (train arriving moments according to the train traffic diagram). The task of decision taking calls the task of decision taking in risk condition.




$X$ (trains) $Y$ (train departure moments due to train traffic diagram)

Fig. 2.1. att. Determined link between the alternatives and the results

Graph (Fig. 2.2.) is suspended, every nod of graph contains $P_{ij}$ value – the probability of train traffic schedule line $y_i$ signing to train $x_i$.

Then:

$$\sum_J P_{ij} = 1 \tag{2.2}$$

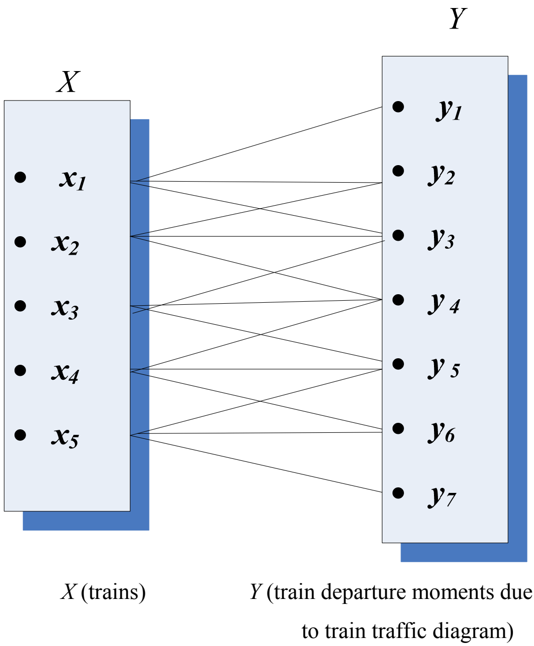



Fig. 2.2. Probable link between the alternatives and the results

The task of finding of optimal train arriving time intervals of trains to harbor station consists of optimal distribution of paths of train traffic diagram between by trains directed from a marshalling yard in the direction of the harbor station of transport node.

Basic parameters are defined for the finding of optimal train arriving time intervals of trains to harbor station:

1. Time of wagons location at the harbor station holding technological operations and waiting for supply to harbor terminals.
2. Loading of all harbor terminals.
3. Time of unloading of wagons in a planned period.
4. Volume of processing of wagonflows in a planned period.
5. An amount of the "abandoned trains" at transport junction.

Train traffic diagram strictly sets the moments of arrivals of trains to the station. Train traffic diagram sets probable moments $t_i$ of arrivals of trains to the station during 24 hours. The amount of trains among which is necessary to distribute paths of train diagram designate as $m_i$.

Time periods corresponding to paths of train traffic diagram, when train arrives to harbor station, is $t_i\left(i=\overline{1...n}\right)$. Then element $d_{ij}\left(i=\overline{1...n}, j=\overline{1...n}\right), d_{ij}\in Q^{+}$ of matrix *D* with elements *n*×*n* describes time periods between trains *i* and *j* to the paths of train traffic diagram $d_{ij}=t_i-t_j, t_i>t_j, i\neq j$.

*Matrix of attraction* is:

$$F=\left\{f_{hk}\left(h=\overline{1...m}, k=\overline{1...m}\right)\right\}, f_{hk}\in Q^{+} \quad (2.3)$$

Matrix characterizes the attraction of trains to each other, when they arrive to the station. If there are two trains with coal and one with containers, the degree of attraction is higher between the train with coal and the container train than between two trains with anthracite coal.

Coefficient of attraction of *h* train and *k* train *is* composition is a complex function and depends on parameters of the station and the harbor:

$$f_{hk}=function(PSt, TO_h, TO_k, TP_h, TP_k, ZP_h, ZP_k), \quad (2.4)$$

where: *PSt* – parameter of track infrastructure of the station;

$TO_h$ – parameter of technological operations at the station with *h* train;

$TO_k$ – parameter of technological operations at the station with *k* train;

$TP_h$ – parameter of time of transshipment of *h* train;

$TP_k$ – parameter of time of transshipment of *k* train;

$ZP_h$ – parameter of loading of harbor terminal where *h* train is processed;

$ZP_k$ – parameter of loading of harbor terminal where *k* train is processed.

Methodology of calculation of coefficient of attraction is determined by technical description of transport junction, amount of the specialized sidings, cancellation devices, by their power, amount of branch lines and sidings joined to the harbor station.

*Coefficient of attraction* transport node „harbor station – harbor terminals”:

$$f_{hk}=k_1\cdot k_2\cdot k_3\cdot k_4, \quad (2.5)$$

where: $k_1$ – coefficient, setting similarities of technological operations. Depends on the nomenclature of goods and internal network marking of the station;

$k_1 = 1$, if two trains have common destination;

$k_1 = 2$, if two trains have different destinations;

$k_2$ - coefficient, setting the amount of wagons in a train;

$k_2 = 1$, if $N_{wag} > 57$;

$k_2 = 2$, if $20 < N_{wag} \leq 57$;

$k_2 = 3$, if 20 $\leq N_{wag}$;

$k_3$ – coefficient, characterizing utilization of branch lines of the harbor and unloading operations in definite harbor terminal;

$k_3 = 1$, if two trains are set to common terminals;

$k_3 = 2$, if two trains are set to different terminals;

$k_4$ – coefficient, taking into account simultaneity of utilization of transshipment facilities of quaysides.

$k_4 = 1$, if two trains are transshipped to one motor vessel;

$k_4 = 2$, if two trains are transshipped to different motor vessels.

Coefficient of attraction can take next values: $1 \leq f_{hk} \leq 24$. The best value – 24, because in this case there the biggest differences between operated trains.

Matrix $C = \{c_{ih}\left(i = \overline{1...n}, h = \overline{1...m}\right)\}$ sets the signed value of paths $i$ to the train $h$ of train traffic diagram. It sets the time period of unconformity to guidance between the harbor dispatcher query and realistic train arrival from the train traffic diagram :

$$C_{ih} = |gdp_i - tdp_h|, \tag{2.6}$$

where: $gdp_i$ – train arrival according to the path $i$ of train traffic diagram;

$tdp_h$ – train $h$ arriving moment to harbor station in compliance to the harbor dispatcher query.

Moving function $\prod :\rightarrow \pi(i)$ is train traffic diagram path's $i\left(i = \overline{1...n}\right)$ separate signing to the train $j = \pi(i)$.

For finding out the optimal distribution of train traffic diagram paths between trains, it is necessary to find out $\prod$ moving function to all indexes $\left(i = \overline{1...n}\right)$, which minimizes function:

$$\min z = \sum_{i,h=1}^{n} d_{ih} f_{\pi(i)\pi(h)} + \sum_{i=1}^{n} c_{i\pi(i)} , \tag{2.7}$$

The equation system (2.3-2.6) forms mathematical model. This model describes the finding of optimal train arriving time intervals of trains to harbor station.

Task formulation can depict as quadratic task of assignment, which is preferable to combinatory optimization complex tasks. As a target function to define quadratic content, task is based: moving matrix $X$ with elements $n \times n$, satisfy:

$$z_{QAP} = \min z = \sum_{i,j=1}^{n} \sum_{h,k=1}^{n} d_{ih} f_{jk} x_{ij} x_{hk} + \sum_{i,j=1}^{n} c_{ij} x_{ij} , \tag{2.8}$$

where:

$$x_{ij} = \begin{cases} 1, \text{ if path of train traffic diagram is signed to the train } j, \\ 0, \text{ opposite case.} \end{cases} \quad (2.9)$$

with restrictions:

$$\sum_{i=1}^{n} x_{ij} = 1, \qquad \left(i = \overline{1...n}\right), \quad (2.10)$$

$$\sum_{j=1}^{n} x_{ij} = 1, \qquad \left(j = \overline{1...n}\right), \quad (2.11)$$

$$x_{ij} \in \{0,1\} \qquad \left(i, j = \overline{1...n}\right), \quad (2.12)$$

Below is shown algorithm of finding of optimal train arriving time intervals' to harbor stations (Fig 2.3. and Fig. 2.4.)

Algorithm efficiency is depend on parametres $\alpha$ (trace importance coefficient), $\beta$ (suitability importance coefficient) un $m$ (amount of agents' population).

Tabele 2.1. shows the types of combination of $\frac{\alpha}{\beta}$ to find the best solution in proper time period.

Table 2.1.

**Combination of *α* and *β* coefficients**

| No. | $\alpha$ | $\beta$ |
|---|---|---|
| 1 | 0,5 | 5,0 |
| 2 | 1,0 | 1,0 |
| 3 | 1,0 | 2,0 |
| 4 | 1,0 | 5,0 |

As a factor of result of algorithm of finding of optimal train arriving time intervals' to harbor stations, are:

- proceeding time of algorithms, more than signed value;
- the difference between calculated local solution and the best solution less than signed value $\varepsilon$;
- local solutions of the all agents have the same value.

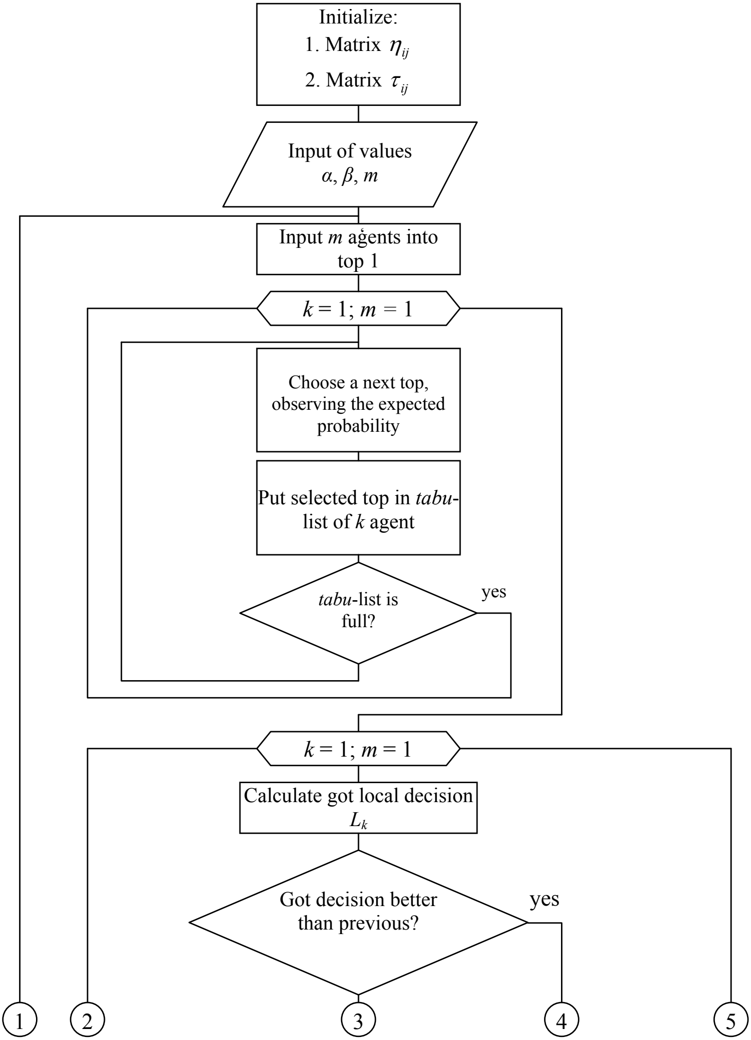



Fig. 2.3. Algorithm of finding of optimal train arriving time intervals' to harbor stations

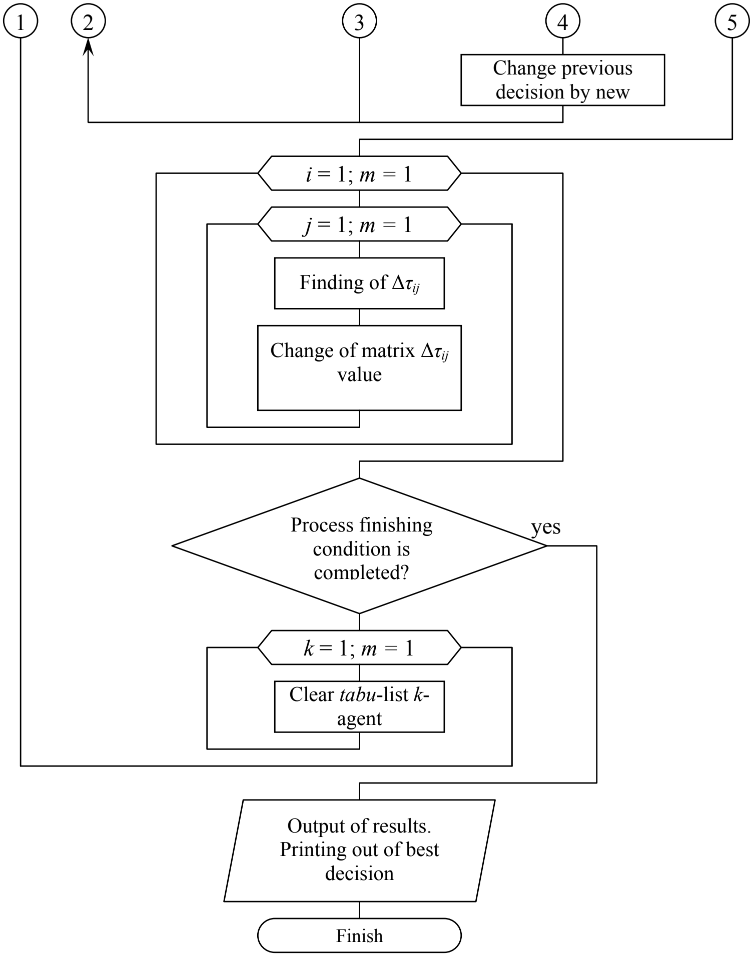



Fig. 2.4. Algorithm of finding of optimal train arriving time intervals' to harbor stations (Continue)

## 8.3. System of imitation modeling of processes transport node „harbor station – harbor terminals”: development and analysis

**In the third chapter** development of simulation model of a transport node is executed with next tasks:

1. Selection procedure of a simulation modeling tool (SMT) from alternatives.
2. Simulation modeling of basic incoming parameters of transport node „harbor station – harbor terminals”.
3. Simulation modeling of structure of transport node „harbor station – harbor terminals”.
4. Simulation modeling of elements.

Selection procedure of SMT from the amount of alternatives contains the creation of criteria vector with the list of alternatives, evaluation procedure to find out the most suitable result. Table 3.1. shows selected alternative SMT.

The most important criteria in selection procedures are:

- high level language presence;
- adequate academic version presence;
- SMT price.

Table 3.1.

**Descriptions of system of imitation modeling**

| Title | Price, EUR | Qualitative documentation existence | Possibility of creation of continuous models | Possibility of creation of discreet models | Presence of facilities of models' visualization and animation | Presence of high level language | Presence of adequate academic version | Presence of basic reports |
|---|---|---|---|---|---|---|---|---|
| *Enterprise Dynamics* | 1500 | + | + | + | + | + | + | - |
| *FlexSim* | 20000 | + | + | + | + | + | + | - |
| *GoldSim* | 0 | + | + | - | + | + | + | - |
| *GPSS World* | 1000 | + | + | + | + | + | + | + |
| *Imagine That Extend* | 1995 | + | + | + | + | + | + | + |
| *iThink* | 1100 | + | + | + | + | - | - | - |
| *PowerSim* | 145 | + | + | - | + | + | + | - |
| *Process Model* | 635 | - | - | + | + | - | + | + |
| *Rockwell Arena* | 2700 | + | + | + | + | + | + | + |
| *Simplex 3* | 0 | - | + | + | - | + | + | - |
| *SimProcess* | 1450 | + | + | + | + | + | - | + |
| *Simul 8* | 1000 | + | + | + | + | + | + | + |
| *VenSim* | 1100 | + | + | - | + | - | + | - |
| *Witness* | 3800 | + | + | + | + | + | - | + |

For the estimation of imitation modeling system's efficiency is formed the list of substantial criteria for the review. Tool *Simul8* got the greatest priority, after which *Extend* and *GPSS World* follows accordingly.

*Simul8* simulation software is a product of the *Simul8* Corporation used for simulating systems that involve processing of discrete entities at discrete times. This program is a tool for planning, design, optimization and reengineering of real production, manufacturing, logistic or service provision systems. *Simul8* allows its user to create a computer model, which takes into account real life constraints, capacities, failure rates, shift patterns, and other factors affecting the total performance and efficiency of production. Through this model it is possible to test real scenarios in a virtual environment, for example simulate planned function and load of the system, change parameters affecting system performance, carry out extreme-load tests, verify by experiments the proposed solutions and select the optimal solution also using *Visual Logic* language. A common feature of problems solved in *Simul8* is that they are concerned with cost, time and inventory.

Calculating task of wagons in arriving trains for the identifying of incoming train traffic (Fig. 3.1.) and definition of distribution laws of incoming train traffic are solved (Fig. 3.2.).

Statistic data is collected from the train traffic table and invoices of trains arriving to harbor stations for further transshipment.

Amount of train arriving intervals is calculated by equation (3.1):

$$L = 1 + 3{,}32 \cdot \lg n \tag{3.1}$$

Widths of train arriving intervals are calculated by equation (3.2):

$$h = \frac{x_{\max} - x_{\min}}{L}, \tag{3.2}$$

where: $x_{min} \le x_1$, $x_{max} \le x_n$. Value $h$ is roundup to higher value.

Minimal value of the interval between two trains arrivals is $x_{min}$ = 0 min (trains can arrive to different sidings simultaneously), maximum $x_{max}$ = 290 min. Total amount of records is $n$ = 399.

Statistical row describing train arriving intervals is show in Table 3.2.

Mathematical expectation $\bar{t}$ is calculated using equation (3.3):

$$\bar{t} = \sum_{i=1}^{r} f_i \cdot \overline{t_i}, \tag{3.3}$$

where: $\overline{t_i}$ - middle point of interval $i$.

Dispersion of empirical distribution $\hat{\sigma}^2$ is calculated using equation (3.4):

$$\hat{\sigma}^2 = \hat{\sigma}^2 \cdot (\vec{x}_n) = \sum f_i \cdot (\bar{t}_i - \bar{t})^2 , \tag{3.4}$$

Defined values of mathematical expectation and dispersion of empirical distribution are: $\bar{t} = 188.15$, $\sigma^2 = 11764.42$. Value of standard deviation is equals to $\hat{\sigma}(\vec{X}_n) = \sqrt{\hat{\sigma}^2(\vec{X}_n)}$ = 108.46.

Table 3.2.

**Statistical row of intervals between the moments of trains' arrivals to the harbor station**

| Interval, min | Observing frequency, $n_k(\vec{X}_n)$ | Relative frequency, $f_i$ | Accumulated relative frequency, $F_i$ |
|---|---|---|---|
| 10:72 | 54 | 0,19355 | 0,19355 |
| 72:134 | 79 | 0,28315 | 0,47670 |
| 134:196 | 74 | 0,26523 | 0,74194 |
| 196:258 | 38 | 0,13620 | 0,87814 |
| 258:320 | 19 | 0,06810 | 0,94624 |
| 320:382 | 5 | 0,01792 | 0,96416 |
| 382:444 | 3 | 0,01075 | 0,97491 |
| 444:506 | 1 | 0,00358 | 0,97849 |
| 506:568 | 4 | 0,01434 | 0,99283 |
| 568:630 | 1 | 0,00358 | 0,99642 |
| 630:692 | 0 | 0,00000 | 0,99642 |
| 692:754 | 1 | 0,00358 | 1,00000 |
| **Total:** | **279** | **1,00000** | |

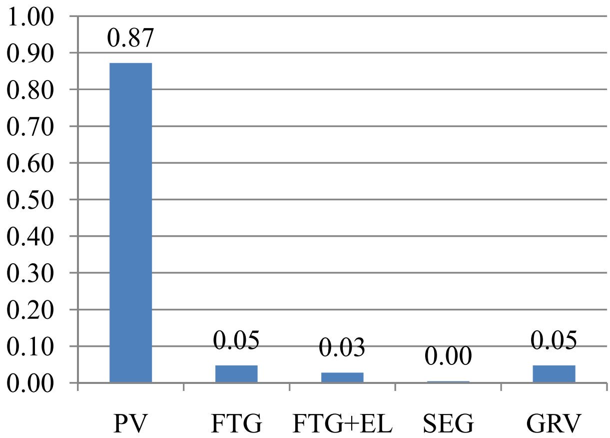



Fig. 3.1. Distribution of loaded wagons by types in arriving trains

PV – open wagons, FTG – container flatcars, FTG – refrigerator flatcars, SEG – box cars, GRV – hoppers.

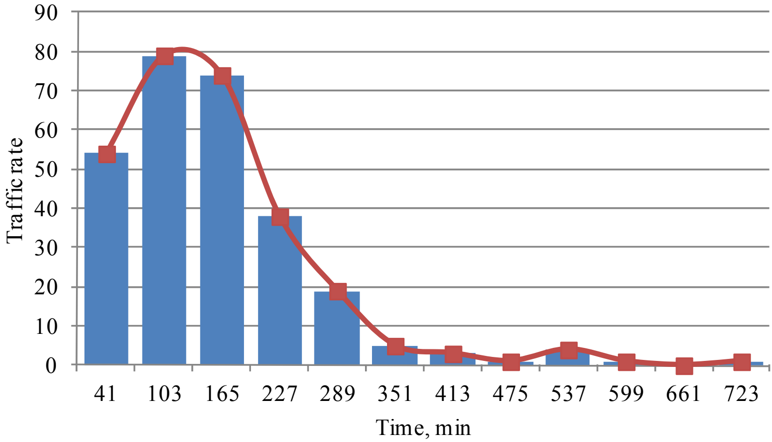



Fig. 3.2. Distribution of arriving intervals of trains

Software *Stat-Fit for Simul8* is being used to find out the law of distribution of arrival intervals of freight trains to the harbor and conditional accordance to Weibull distribution is got (*Create a combination distribution with a fixed offset of 10. then add Weibull, 1.43, 160*).

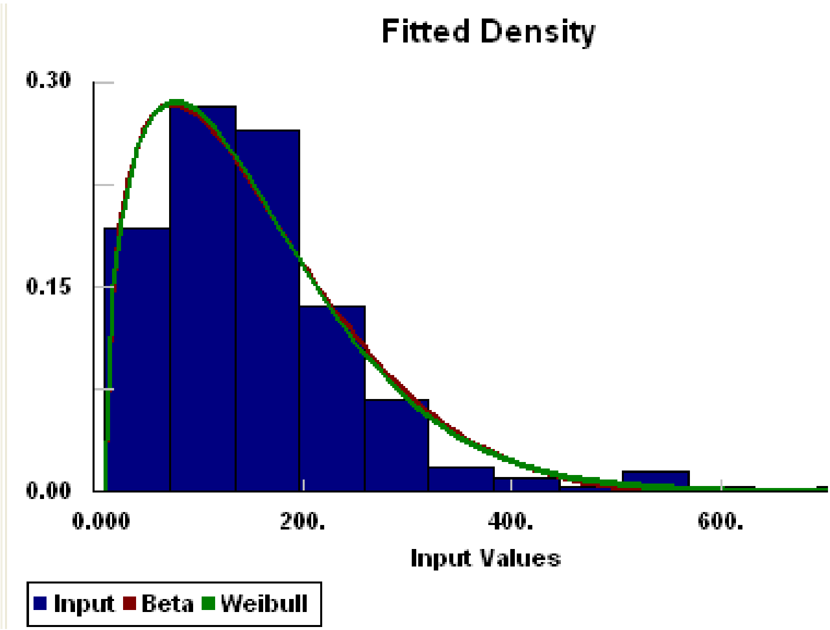



Fig. 3.3. Definition of distribution law of arriving intervals of trains

### 8.4. Creation of simulation model of the investigated object

Prototype of simulation model is LDZ Rīga-Krasta station – extra class harbor station of Riga district of exploitation, situated inside the territory of Freeport of Rīga.

Train is dynamic object in the modeling system. Features of train:

- type of train (loaded, empty);
- amount of wagons (57 conditional wagons);
- division of wagons by types of goods (every type of good certain wagon is intended);
- arriving time to station.

Trains, arrive to the harbor stations consist of in average of 88 % - loaded and 12 % empty wagons. Wagons are divided by type (open wagons, container flatcars, refrigerator container flatcars, box cars, hoppers or grain wagons).

Whereas Table 4.1 and Table 4.2. found that the interval time of arrival of trains at the station Rīga-Krasta by simulation results using "strict schedule" compared with the empirical distribution has a significant difference. It also ascertained the differences in the types of trains arrive at station Rīga-Krasta.

Distribution of wagons by type corresponds to the types of cargo and can be specified using a discrete distribution, displayed in Table 4.3.

After the arrival, train settles at arriving siding. At the same time there can be three trains with 57 wagons at arriving siding. At arriving siding inspection of wagons takes 40-120 minutes, depending on the type of train. The train is located in arriving siding until an opportunity appears to get to the point of dissolution for a further supply of the consignee.

After the dissolution of the train, wagons are moved to harbor areas and terminals. Wagons are fitted to wagon weight scales in case of check-weighing procedures (tare prior to loading, after loading, after loading of wagons before loading), and these cars are about 5% of the total. In each area of the harbor handled a certain type of wagons with a certain type of cargo.

The logical structure of a functioning model of transport node „harbor station – harbor terminals" is shown at fig. 4.1. A simulation model of transport node „harbor station – harbor terminals" in *Simul8* mode is shown at fig. 4.2. During the development of functioning model the decision was made to create separate functioning models of terminals of Riga harbor from general model of terminals of Riga harbor for the best visualization of current processes.

Table 4.1.

**Time intervals of trains' arrivals to Rīga-Krasta station based on Empirical dispersion**

| No. | Train type | Open wagon | Container wagon | El. container wagon | Box wagons | Grain wagons | Arrival time*, min | Arrival time*, h | Interval, h |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 44 | 6 | 1 | 0 | 6 | 273 | 4,5 | |
| 2 | 1 | 49 | 2 | 1 | 1 | 4 | 800 | 13,3 | 8,8 |
| 3 | 2 | 0 | 26 | 0 | 18 | 13 | 881 | 14,7 | 1,3 |
| 4 | 1 | 52 | 3 | 1 | 0 | 1 | 1043 | 17,4 | 2,7 |
| 5 | 2 | 0 | 21 | 0 | 19 | 17 | 1278 | 21,3 | 3,9 |
| 6 | 1 | 50 | 3 | 1 | 1 | 2 | 1441 | 24,0 | 2,7 |
| 7 | 1 | 46 | 3 | 2 | 0 | 6 | 1540 | 25,7 | 1,7 |
| 8 | 1 | 46 | 3 | 3 | 0 | 5 | 1650 | 27,5 | 1,8 |
| 9 | 1 | 52 | 1 | 2 | 0 | 2 | 1877 | 31,3 | 3,8 |
| 10 | 2 | 0 | 22 | 0 | 13 | 22 | 2003 | 33,4 | 2,1 |
| 11 | 1 | 51 | 2 | 0 | 0 | 4 | 2079 | 34,6 | 1,3 |
| 12 | 1 | 50 | 6 | 0 | 0 | 1 | 2156 | 35,9 | 1,3 |
| 13 | 1 | 50 | 3 | 2 | 0 | 2 | 2333 | 38,9 | 3,0 |
| 14 | 1 | 53 | 1 | 1 | 0 | 2 | 2600 | 43,3 | 4,4 |
| 15 | 1 | 49 | 3 | 1 | 0 | 4 | 2747 | 45,8 | 2,4 |
| 16 | 1 | 50 | 1 | 2 | 1 | 3 | 3100 | 51,7 | 5,9 |
| 17 | 1 | 51 | 1 | 4 | 0 | 1 | 3141 | 52,4 | 0,7 |
| 18 | 1 | 46 | 2 | 5 | 0 | 4 | 3309 | 55,2 | 2,8 |
| 19 | 1 | 52 | 0 | 2 | 0 | 3 | 3425 | 57,1 | 1,9 |
| 20 | 2 | 0 | 29 | 0 | 11 | 17 | 3472 | 57,9 | 0,8 |
| 21 | 1 | 51 | 2 | 1 | 1 | 2 | 3560 | 59,3 | 1,5 |
| 22 | 1 | 44 | 4 | 3 | 2 | 4 | 3705 | 61,8 | 2,4 |
| 23 | 1 | 53 | 2 | 1 | 0 | 1 | 3786 | 63,1 | 1,3 |
| 24 | 1 | 50 | 1 | 2 | 0 | 4 | 3934 | 65,6 | 2,5 |
| 25 | 1 | 51 | 4 | 1 | 1 | 0 | 4003 | 66,7 | 1,1 |
| 26 | 2 | 0 | 28 | 0 | 11 | 18 | 4263 | 71,0 | 4,3 |
| 27 | 1 | 54 | 0 | 1 | 0 | 2 | 4320 | 72,0 | 1,0 |
| 28 | 2 | 0 | 27 | 0 | 11 | 19 | 4361 | 72,7 | 0,7 |
| 29 | 1 | 46 | 2 | 3 | 0 | 6 | 4465 | 74,4 | 1,7 |
| 30 | 1 | 47 | 4 | 2 | 0 | 4 | 4734 | 78,9 | 4,5 |
| 31 | 1 | 52 | 2 | 2 | 0 | 1 | 4945 | 82,4 | 3,5 |
| 32 | 1 | 47 | 1 | 4 | 1 | 4 | 5093 | 84,9 | 2,5 |
| 33 | 2 | 0 | 26 | 0 | 14 | 17 | 5280 | 88,0 | 3,1 |
| 34 | 1 | 51 | 5 | 1 | 0 | 0 | 5321 | 88,7 | 0,7 |
| 35 | 2 | 0 | 17 | 0 | 17 | 23 | 5383 | 89,7 | 1,0 |
| 36 | 1 | 48 | 2 | 3 | 0 | 4 | 5768 | 96,1 | 6,4 |

* - moment of time of train arrival from simulation process beginning

Table 4.2.

**Time intervals of trains' arrivals to Rīga-Krasta station based on modeling data during 3 days („strict schedule")**

| No. | Train type | Open wagon | Container wagon | El. container wagon | Box wagons | Grain wagons | Arrival time*, min | Arrival time*, h | Interval, h |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 44 | 6 | 1 | 0 | 6 | 79 | 1,3 | |
| 2 | 1 | 49 | 2 | 1 | 1 | 4 | 119 | 2,0 | 0,7 |
| 3 | 1 | 52 | 3 | 1 | 0 | 1 | 245 | 4,1 | 2,1 |
| 4 | 2 | 0 | 21 | 0 | 19 | 17 | 343 | 5,7 | 1,6 |
| 5 | 1 | 50 | 3 | 1 | 1 | 2 | 387 | 6,5 | 0,7 |
| 6 | 1 | 46 | 3 | 2 | 0 | 6 | 620 | 10,3 | 3,9 |
| 7 | 1 | 46 | 3 | 3 | 0 | 5 | 660 | 11,0 | 0,7 |
| 8 | 2 | 0 | 22 | 0 | 13 | 22 | 868 | 14,5 | 3,5 |
| 9 | 1 | 51 | 2 | 0 | 0 | 4 | 968 | 16,1 | 1,7 |
| 10 | 1 | 53 | 1 | 1 | 0 | 2 | 1328 | 22,1 | 6,0 |
| 11 | 1 | 49 | 3 | 1 | 0 | 4 | 1427 | 23,8 | 1,7 |
| 12 | 1 | 51 | 1 | 4 | 0 | 1 | 1530 | 25,5 | 1,7 |
| 13 | 1 | 46 | 2 | 5 | 0 | 4 | 1592 | 26,5 | 1,0 |
| 14 | 1 | 52 | 0 | 2 | 0 | 3 | 1666 | 27,8 | 1,2 |
| 15 | 2 | 0 | 29 | 0 | 11 | 17 | 1755 | 29,3 | 1,5 |
| 16 | 1 | 51 | 2 | 1 | 1 | 2 | 1799 | 30,0 | 0,7 |
| 17 | 1 | 44 | 4 | 3 | 2 | 4 | 2032 | 33,9 | 3,9 |
| 18 | 1 | 50 | 1 | 2 | 0 | 4 | 2169 | 36,2 | 2,3 |
| 19 | 2 | 0 | 28 | 0 | 11 | 18 | 2380 | 39,7 | 3,5 |
| 20 | 1 | 54 | 0 | 1 | 0 | 2 | 2467 | 41,1 | 1,5 |
| 21 | 2 | 0 | 27 | 0 | 11 | 19 | 2529 | 42,2 | 1,0 |
| 22 | 1 | 46 | 2 | 3 | 0 | 6 | 2740 | 45,7 | 3,5 |
| 23 | 1 | 47 | 4 | 2 | 0 | 4 | 2839 | 47,3 | 1,7 |
| 24 | 1 | 47 | 1 | 4 | 1 | 4 | 2942 | 49,0 | 1,7 |
| 25 | 2 | 0 | 26 | 0 | 14 | 17 | 3004 | 50,1 | 1,0 |
| 26 | 1 | 51 | 5 | 1 | 0 | 0 | 3069 | 51,2 | 1,1 |
| 27 | 2 | 0 | 17 | 0 | 17 | 23 | 3167 | 52,8 | 1,6 |
| 28 | 1 | 48 | 2 | 3 | 0 | 4 | 3211 | 53,5 | 0,7 |
| 29 | 1 | 50 | 3 | 0 | 1 | 3 | 3444 | 57,4 | 3,9 |
| 30 | 1 | 51 | 1 | 1 | 1 | 3 | 3581 | 59,7 | 2,3 |
| 31 | 1 | 49 | 3 | 5 | 0 | 0 | 3692 | 61,5 | 1,9 |
| 32 | 1 | 50 | 3 | 1 | 0 | 3 | 3792 | 63,2 | 1,7 |
| 33 | 1 | 48 | 7 | 2 | 0 | 0 | 3879 | 64,7 | 1,5 |
| 34 | 1 | 49 | 2 | 2 | 0 | 4 | 4315 | 71,9 | 7,3 |
| 35 | 1 | 47 | 3 | 2 | 0 | 5 | 4355 | 72,6 | 0,7 |
| 36 | 1 | 55 | 0 | 2 | 0 | 0 | 4579 | 76,3 | 3,7 |

* - moment of time of train arrival from simulation process beginning

Table 4.3.

**Distribution of wagons by type**

| No. | Type of cargo | Amount of records | Relative frequency |
|---|---|---|---|
| 1 | Coal | 523 | 0,86 |
| 2 | Containers | 29 | 0,05 |
| 3 | Refrigerator containers | 17 | 0,03 |
| 4 | Cotton | 3 | 0,00 |
| 5 | Grain | 29 | 0,05 |
| 6 | Crushed stone | 10 | 0,02 |
| 7 | Total: | 611 | 1,00 |

A model presents an opportunity to change the number of locomotives engaged in marshalling operations, also change the availability of cargo handling facilities at harbor terminals.

The results of simulation of the coal terminal of Freeport of Rīga summarized in Tables 4.4.-4.7.

Table 4.4.

**The results of simulation of the coal terminal of Freeport of Rīga**

<table>
<tr><th rowspan="2">No.</th><th rowspan="2">Time period</th><th rowspan="2">Incoming cargo flow, groups of wagons/ time period</th><th colspan="2">Cargo distribution by terminals, groups of wagons, time period / %</th><th colspan="3">Locomotive occupation, %</th><th colspan="2">Terminals occupation, %</th></tr>
<tr><th>„STREK”</th><th>„Skonto”</th><th>No. 1</th><th>No. 2</th><th>No. 3</th><th>„STREK” both terminals</th><th>„Skonto” both terminals</th></tr>
<tr><td>1</td><td>1 day</td><td>11</td><td>11/100</td><td>0 / 0</td><td>2</td><td>16</td><td>2</td><td>91 / 76</td><td>0 / 0</td></tr>
<tr><td>2</td><td>1 month</td><td>325</td><td>262/81</td><td>62 / 19</td><td>6</td><td>19</td><td>6</td><td>90 / 86</td><td>32 / 11</td></tr>
<tr><td>3</td><td>1 year</td><td>3696</td><td>2942/80</td><td>754 / 20</td><td>4</td><td>18</td><td>4</td><td>86 / 81</td><td>32 / 11</td></tr>
</table>

Table 4.5.

**Distribution of wagons by groups**

| Amount of wagons | 36 | 37 | 38 | 39 | 40 | 41 | 42 |
|---|---|---|---|---|---|---|---|
| Relative frequency, % | 0.01 | 0.19 | 0.9 | 5.2 | 21.4 | 57.7 | 14.6 |

After analyzing the changes in cargo coal terminal during 1 year, when the freight cars loaded with coal are divided as follows: 60 % of the total number of cars arriving at the terminal „STREK” and 40 % at the terminal „Skonto”, is shown in Table 4.6.:

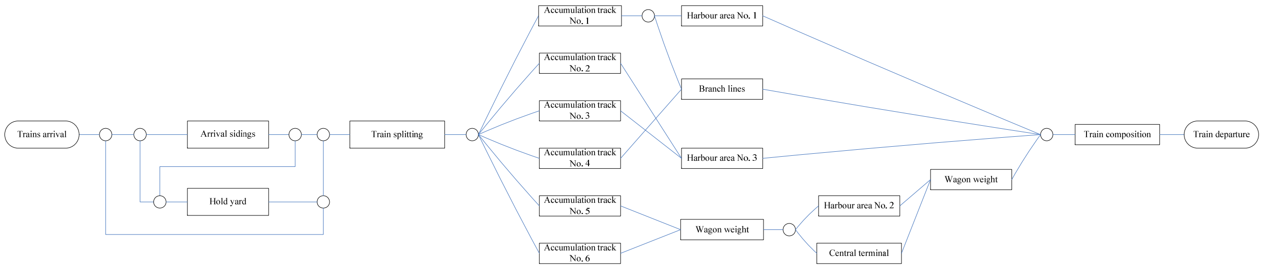



Fig. 4.1. Logical structure of functioning model of transport node „harbor station – harbor terminals”

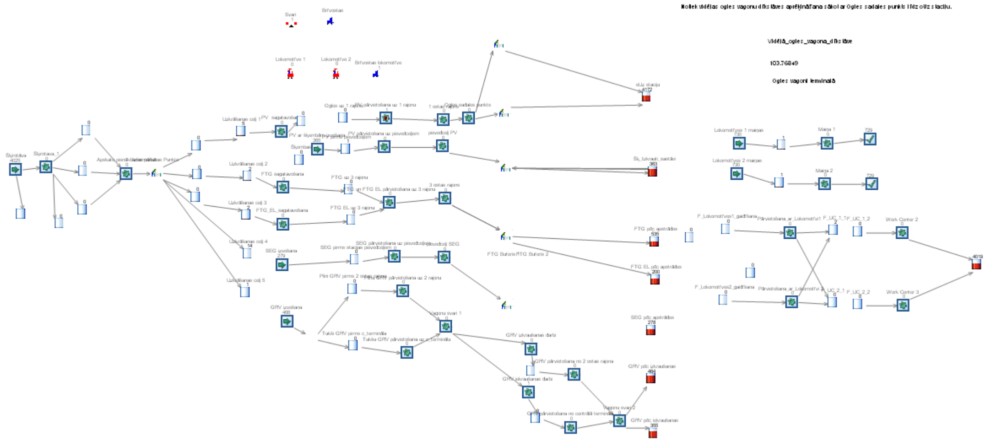


Fig. 4.2. General overview of simulation model of transport node „harbor station – harbor terminals” in *Simul8*

Table 4.6.

**The results of simulation of the coal terminal of Freeport of Rīga in period of cargo transshipment distribution**

| No. | Time period | Cargo distribution by terminals, % | | Locomotive occupation, % | | | Terminals occupation, % | |
|---|---|---|---|---|---|---|---|---|
| | | „STREK” | „Skonto” | No.1 | No.2 | No.3 | „STREK” both terminals | „Skonto” both terminals |
| 1 | 1 year | 80 | 20 | 4 | 18 | 4 | 86 / 81 | 32 / 11 |
| 2 | 1 year | 60 | 40 | 4 | 15 | 4 | 77 / 65 | 52 / 27 |

After analyzing the changes in cargo coal terminal during 1 year, in period of coal transshipment growth by 25 % and 50 %, when the freight cars loaded with coal are divided as follows: 80 % of the total number of cars arriving at the terminal „STREK” and 20 % at the terminal „Skonto”, are shown in Table 4.7.:

Table 4.7.

**The results of simulation of the coal terminal of Freeport of Rīga in period of cargo transshipment growth**

| No. | Transshipment growth, % | Incoming cargo flow, groups of wagons/ time period | Cargo distribution by terminals, groups of wagons / % | | Locomotive occupation, % | | |
|---|---|---|---|---|---|---|---|
| | | | „STREK” | „Skonto” | No. 1 | No. 2 | No. 3 |
| 1 | 25 | 4550 | 3655 / 80 | 895 / 20 | 20 | 22 | 20 |
| 2 | 50 | 5469 | 4381 / 80 | 1088 / 20 | 20 | 22 | 20 |

Note: during the simulation of cargo transshipment growth by 25 % and 50 %, it was noted the use of the buffer of terminal „STREK” 141 and 862 times. These results indicate that the 25 % growth can be successfully processed due to the available spare capacity of the terminal. In turn, the increase in freight traffic by 50% significantly troubles the functioning of the terminal.

As a result, terminal capacity to handle transshipment increased by 25% is evaluated as adequate, while increasing by 50% - insufficient processing capacity of terminal to handle given amount of cargo. This fact is borrowed from the indicator „The use of buffer” and the data from the simulation model - the total load of terminal „STREK” is equal to 99.8%, in turn, the total loading of terminal „Skonto” is equal to 31%.

For the estimation of influence of management factors to the efficiency indexes of work of harbor station (wagon standstill time), in the process of experiment a hypothesis is considered about influence of factors on wagon's standstill time, mentioned below:

- train traffic guidance by „strict schedule";
- amount of shunting locomotives, served harbor areas and terminals;
- duration of period, when harbor terminals cannot operate wagons' handling operations due to some reasons (weather terms, impossibility of handling operations).

Table 4.8.

**Matrix of application of Factors 1, 2 and 3**

| Plan point | Factor 1 | Factor 2 | Factor 3 | Wagon standstill, min |
|---|---|---|---|---|
| 1 | - | - | - | 504 |
| 2 | + | - | - | 501 |
| 3 | - | + | - | 468 |
| 4 | + | + | - | 468 |
| 5 | - | - | + | 504 |
| 6 | + | - | + | 500 |
| 7 | - | + | + | 468 |
| 8 | + | + | + | 467 |

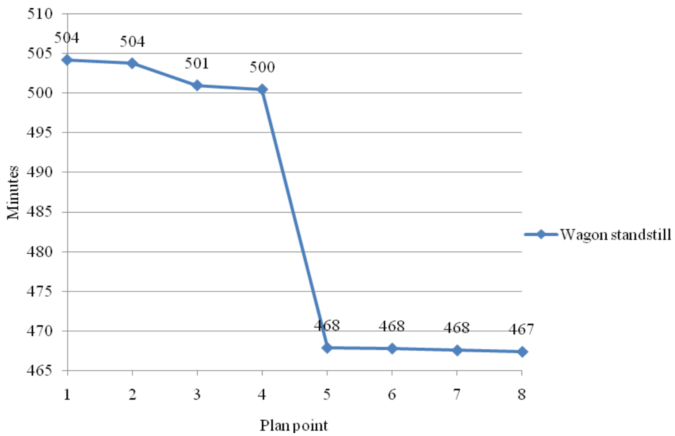



Fig. 4.3. Alterations of average standstill of wagons on harbor station according to matrix of application of factors

Table 4.9. depicts the results of train traffic guidance application, affecting wagons handling operations at harbor terminals and sidings of Freeport of Rīga.

Table 4.9.

**Train traffic guidance application, affecting wagons handling operations**

| Title | Actual graph of train running | „Strict schedule” | Weibull distribution | „Strict schedule” + maximum carrying capacity |
|---|---|---|---|---|
| Amount of trains | 4025 | 4055 | 3599 | 5585 |
| Completed addition of open wagons to coal terminals | 4031 | 4174 | 3730 | 4223 |
| Completed addition of container flatcars to container terminals | 714 | 737 | 659 | 736 |
| Completed addition of hoppers to grain elevator | 456 | 466 | 439 | 459 |
| Completed addition of open wagons to sidings | 3399 | 3486 | 3118 | 3534 |
| Completed addition of box cars to sidings | 273 | 279 | 259 | 371 |

As is evident from the simulation results, the potential of traffic node for cargo handling will be fully utilized increasing cargo transshipment. In this situation, the possibility of increasing of amounts of cargo transshipment to coal terminals and harbor sidings.

In turn, the possibility of container terminal and elevator to handle wagon at present moment is almost fully realized. Therefore, it is recommends to improve and modernize the infrastructure of container terminal to fulfill operations in moment of increasing of cargo volumes. As an example for container terminal is suggested to operate with container flatcars with capacity of 4 TEU (Twenty-foot equivalent unit).

Figure 4.4. shows the resulting histogram of the simulation during the calendar year. The possibility of a combination of factors 1, 2 and 3, with an increase of train traffic by 38% (estimated capacity of the site Šķirotava - Rīga-Krasta according to actual graph of train running). Implementation of the above mentioned factors on the transport node „harbor station – harbor terminals” has reduced wagons standstill 8-12% at Rīga-Krasta station with an overall increase in turnover.

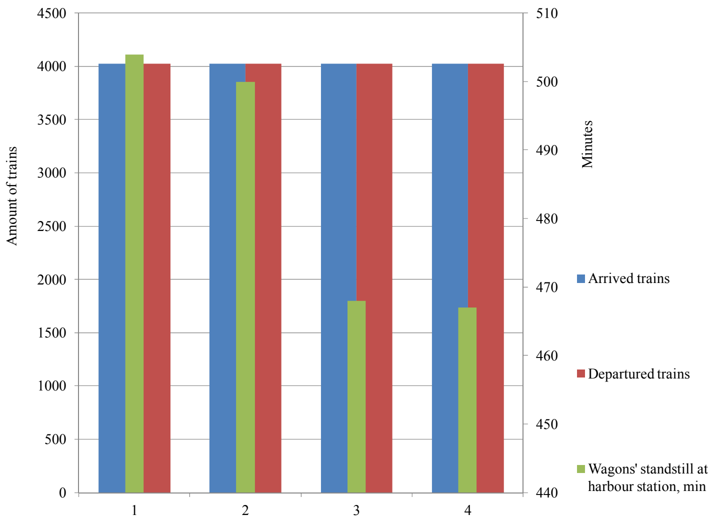



Fig. 4.4. Simulation results during the year

1 - actual graph of train running; 2 – “strict schedule”; 3 - “strict schedule” + additional shunting locomotive at harbor; 4 – “strict schedule” + additional shunting locomotive at harbor + fully realized harbor efficiency

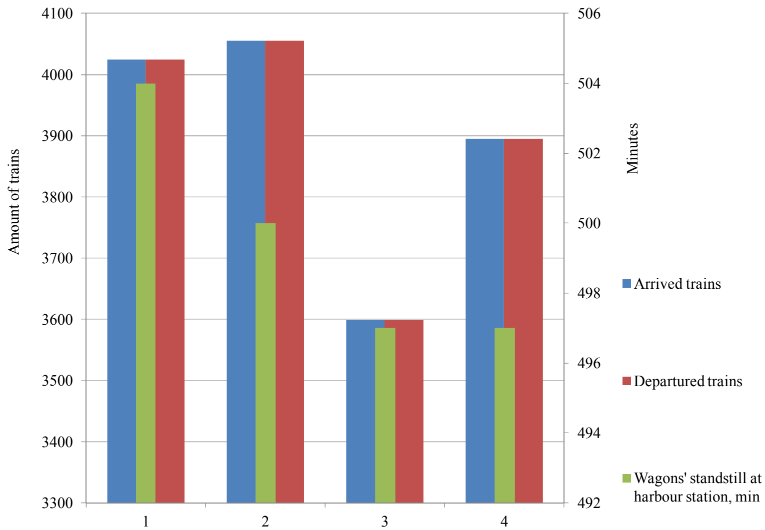



Fig. 4.5. Train traffic guidance application affecting wagons’ standstill

1 - actual graph of train running; 2 – “strict schedule”; 3 - Weibull distribution; 4 – actual graph of train running with deviations.

The experiments of train traffic guidance application to harbor station are done using "strict schedule" in couple with probable distribution and using incoming train traffic described by Weibull distribution. Results of affected wagons' standstill in shown at figure 4.5.

Analyzing the work of Rīga-Krasta harbor station in 2006 noted the presence of two shunting locomotives (marshalling operations and provision of wagons), which was a major halting factor to reduce standstill time of wagons.

Research results showed the need by 2010, the presence of four shunting locomotives at the station (one for marshalling operations and others for provision of wagons).

Based on the forecast of an increase in the volume of goods transshipped through Freeport of Riga in 2015, five shunting locomotives presence is obligatory (one for marshalling operations, one for marshalling and provision of wagons, others for provision of wagons).

## 9. CONCLUSION

**The tasks** have been solved to reach the work objective:

1. System of parameters of finding of optimal train arriving time intervals' to the harbor stations.
2. Suggested and based:
   - methodology of finding of optimal train arriving time intervals' to the harbor stations to eliminate trains unmanaged departures to Rīga-Krasta station due to the lack of train carrying capacity of others stations;
   - methodology of selection procedure of simulation tool for the imitation of processes in a transport node.
3. Simulation model of processes is worked out for forecasts of processes and evaluation of qualitative indexes of station and terminals of harbor.
4. Simulation of processes is made by modeling tool with material streams and freight units from the entrance to the exit from the system.
5. The most effect in decreasing of wagons' standstill at the station is reached, applying additional shunting locomotives at harbor station, as well as at harbor terminals, "strict schedule" and fully realized harbor efficiency. The implementation of factors mentioned

above at transport node „harbor station – harbor terminals" allows to reduce wagons standstill by 8-12 % at Rīga-Krasta station increasing general cargo transshipment.

6. The insufficient amount of harbor shunting locomotives is defined. It is suggested and executed that LDZ from 2010 utilizes four shunting locomotives at harbor station and terminals (one for marshalling operations and others for provision of wagons). Based on the forecast of an increase in the volume of goods transshipped through  Freeport of Riga in 2015, five shunting locomotives presence is obligatory (one for marshalling operations, one for marshalling and provision of wagons, others for provision of wagons).
7. Decrease of wagon standstill at the station is resulted due to the change of technology without investing in infrastructure. It is experimentally set and recommended to LDZ that increased quantity of shunting locomotives, "strict schedule" of the actual graph of train running, faultless functioning of transport note and full usage of carrying capacity of line increasing  traffic rate by 38 % from existing, wagon standstill will be 469 minutes.
8. On a basis of simulation modeling experiments were held, and it is defined that coal terminal carrying capacity allows to increase coal transshipment by 25 %. If there is 50 % of increased transshipment, terminal throughput is insufficient. Recommendations of improvement of wagons handling operations are done by equipping terminal with open wagon dumper to force coal handling operations at harbor.
9. For further implementation of developed methodology of simulation of interaction of railway harbor station and harbor within LDZ polygon is recommended:
   - to increase shunting locomotives amount to five units at harbor station by 2015;
   - to organize coordinated guidance of trains on Šķirotava – Rīga-Krasta line using "strict schedule" of the actual graph of train running;
   - to organize local inter-station trains interval movements to harbor station to get rid of train traffic jams due to restrictions of train traffic in the morning and evening hours;
   - to work out the set of imitation models-analogues of marshalling yard and freight cargo terminals and harbor stations in couple with harbor terminals of Riga transport node.
   - to offer LDZ to apply simulation models for cargo terminals and harbor stations in process of planning and forecasting.

**Fjodors MIHAILOVS**

**MANAGEMENT OF THE INTERACTION OF RAILWAY STATION AND HARBOR BASED ON SIMULATION MODELING**

**Summary of Doctoral Thesis**


Registered for printing on 04.12.2012. Registration Certificate
No. 2-0282. Format 60x84/16. *Offset* paper. 2,5 printing sheets,
1,94 author's sheets. Calculation 20 copies. Order Nr. 120.
Printed and bound at the RTU Printing House, 1 Kalku Street,
Riga LV- 1658, Latvia.

Fjodors Mihailovs , Zura Sansyzbajeva , Mareks Mezitis, Simulation of the Interaction of Railway Station and Harbor, Procedia Computer Science, v.104 n.C, p.222-226, March 2017. Mark W. Isken , Steven J. Littig, Simulation Analysis of Pneumatic Tube Systems, Journal of Medical Systems, v.26 n.1, p.9-19, February 2002.Â  Arnold H. Buss, Architecture initiatives: component-based simulation modeling, Proceedings of the 32nd conference on Winter simulation, December 10-13, 2000, Orlando, Florida. Dima Nazzal , Mansooreh Mollaghasemi, Critical tools identification and characteristics curves construction in a wafer fabrication facility, Proceedings of the 33nd conference on Winter simulation, December 09-12, 2001, Arlington, Virginia. Data analytics for rail maintenance management Stephen Mayowa Famurewa, LuleÃ¥ University of Technology The wear of rail is considered to be a critical degradation mode in heavy haul transport, thus rail wear are keenly studied with dynamic simulation models, contact theories, field measurement data and other methods.Â  Finally, based on these studies the question will be asked how to work smarter as far as maintenance issues on the line are concerned.