Scientific Journals
of the Maritime University of Szczecin

Zeszyty Naukowe
Akademii Morskiej w Szczecinie

2020, 63 (135), 69–76
ISSN 1733-8670 (Printed)
ISSN 2392-0378 (Online)
DOI: 10.17402/441

Received: *26.06.2020*
Accepted: *23.09.2020*
Published: *30.09.2020*

Robotic automation of inland container terminals

Nikolay V. Malyshev✉**, Evgenii K. Koroviakovskii, Svetlana A. Rostovceva**

Emperor Alexander I Petersburg State Transport University
9, Moskovsky pr., Saint Petersburg, Russian Federation
e-mail: kol.pgups@mail.ru; ekorsky@mail.ru
✉ corresponding author

Key words: robotic automation, simulation modelling, advanced technology, transshipment system, inland terminal, container transport system

Abstract

The article presents the analysis of options for a transshipment terminal system with consideration of Russian transport system development. The aim is to determine the premises and possible problems, considering human absence, in the technological process at an inland container terminal. Statistical methods are used to analyze the market of robotic automation and the perspective for unmanned technology introduction. Simulation modeling of inland container terminal operation with various types of equipment, to study the applicability of robotic automation. The choice of modeling equipment results from the impossibility of completing an experiment on the real object, difficulties of analytical modeling (the system contains casual relations, nonlinear logic, stochastic variables), and the necessity to analyze the system's time behavior. Consideration of robotic automation in a terminal warehouse complex is of particular importance due to technological progress followed by the freight terminal to be an area with highly organized technological processes and the need for highly paid specialists.

Introduction

Following the growth of containerization at inland terminals, linking inland and sea shipping, the volume of handling has increased. Based on the average annual rate of containerization growth and expected average growth rate of Russia's gross domestic product by 1.5–2% per year over the past 5 years, it is possible to predict that the average growth rate of the container market at around the 7–8% per year for the next 5 years. In the estimation of Public Joint-Stock Corporation "TransContainer", the proportion of containerized cargo transported in containers by the Russian Railways network increased by 0.4% in 2018. The market increased from 2.3 million twenty-foot equivalents (TEU) in 2010 to 4.4 million TEU in 2018 (TransContainer, 2019). Despite the growth, the level of containerization of up to 6.6% on Russian Railways is insignificant compared to 16.6% on railways in the European Union (United Nations Economic Commission for Europe, 2018), which may slow down the positive dynamics in the near term forecast unless the necessary infrastructure and new transport products are developed. In many concepts and regulatory documents, JSC Russian Railways, and the Government of the Russian Federation (Russian Railways, 2012a; 2012b; 2013; President of The Russian Federation, 2018) have changed their attitude to the introduction of innovative projects in the terminal and warehouse complex.

Literature review

The following works (Steenken, Voss & Stahlbock, 2004; Stahlbock & Voss, 2008; Carlo, Vis & Roodbergen, 2014) present a general overview of state-of-the-art equipment, appropriate usage, and operations performed at container terminals. Several authors (Vis, 2006; Luo, Wu & Mendes, 2016; Yang, Zhong & Dessouky, 2018) have focused on the design and operation of transshipment and transportation systems of robotics container terminals using automated guidance vehicles (AGVs). Although mobile autonomous robots are ideal for cargo movement, their operation requires sophisticated planning and routing tasks to be solved (Grunow, Günther & Lehmann, 2006; Stavrou et al., 2017). Stavrou and Panayiotu (Stavrou et al., 2018) defined a task to help solve the routing problem and coordinating movements of robots to minimize the time required to deliver the containers to the destination point with conflict free movement of all the robots. The problem of running a container yard serviced by several semi-automatic railway gantry cranes is considered (Froyland et al., 2008; Hu, Sheu & Luo, 2016; Gharehgozli, Vernooij & Zaerpour, 2017). Some research work (Dekker, Voogd & van Asperen, 2006; Kovalyov, Pesch & Ryzhikov, 2018; Briskorn, Jaehn & Wiehl, 2019) has focused on strategies for container stacking and the change in the workload of stacking cranes at automated container terminals in the context of increasing transportation volume.

Various simulation techniques have recently been employed to study the transport systems of port terminals (Nam, Kwak & Yu, 2002; Rizzoli, Fornara & Gambardella, 2002; Lee, Park & Lee, 2003). Simulation models have been developed to compare the performances of equipment such as cranes, vessels, and trucks in docks by analyzing the characteristics of the equipment (Briskorn & Hartmann, 2006). Ottjes et al. (Ottjes, Hengst & Tutuarima, 1994) developed a simulation model for a sailing container terminal in the Netherlands to evaluate the feasibility of a system that could reduce the transshipment time of a container (via ship). Liu et al. (Liu, Jula & Ioannou, 2002) performed a numerical simulation to compare the performance of four different automated container terminal concepts: AGVs, a linear motor conveyance system, an overhead grid rail system, and a high-rise automated storage and retrieval structure. However, few studies have investigated the design and simulation of an intermodal ACTS connected by a rail system.

Review of container terminals automation in the Russian Federation and worldwide

The level of automation of container terminals in Russia is far behind other countries. System TESKAD (automated system for managing terminal and warehouse activities) is developed to automate the work of the staff by the directorates of terminal and warehouse complex management of JSC “Russian Railways”. The program is designed to improve the efficiency of the terminal and warehouse operations and quality of services provided to shippers and consignees. However, its main functionality is aimed solely at the electronic document management system.

On November 2, 2017, a new information system “Intelligent container terminal” from SOLVO was presented at the Kleschikha station (Trans-Container terminal) in Novosibirsk. This system is already focused on optimizing and automating the technological processes of container processing (loading and unloading the container, arrival and departure of the container train). Its use has made it possible to reduce the idle time of the car under cargo operations by 0.1 days, the turnover of the car by 0.1 days, downtime of the container by 2 days, the turnover of the container by 0.2 days, as well as to minimize unproductive runs during loading and unloading operations on-site, which, intern, reduces electricity and fuel consumption and maintenance costs of the lifting and transport equipment and container site repair. Besides, solutions for managing automated terminals based on SOLVO.TOS are used at many terminals: JSC “Bronka”, JSC “Container terminal Saint Petersburg”, JSC “Novorossiysk commercial seaport”, and JSC “Seaport of Saint Petersburg”.

Automated container handling in the world practice dates back to the first use of automatic railway gantry cranes at the ECT Delta Terminal in Rotterdam (Hutchison Ports ECT, 2018). Originally, the technology started developing the direction of a working crane in stacks and terminal transport, since these operations are the most time-consuming and most strongly affect the processing capacity of the terminal. Following the successful implementation of the technology at ECT Delta Terminal, the practices were adopted in the London port Thamesport, at the Altenwerder container terminals in Germany, Ohi in Japan, and Evergreen in Taiwan.

Among the first attempts for complete human exclusion in the practice was the project “Moorebank Logistics Park”, implemented by the Australian logistics company “Qube”.The terminal will use the terminal operation system “N4 Navis” and equipment from the manufacturer of loading and unloading equipment “Kalmar”, the main being: four automated stacking cranes, eight automated rail-mounted gantry cranes, and eight rubber-tyred gantry cranes. The project is expected to operate on electricity generated from solar panels located on the terminal’s territory (Moorebank Logistics Park, 2018).

Background of unmanned technologies implementation in Russia

The cost of implementing and operating robotics technology at container terminals is extremely high, although there are economic reasons for changing the situation. First, the average monthly cost of a railway employee is increasing: in 2005 taking into account inflation, it was 34,797.9 rubles, while in 2017 it was 53,005.1 rubles (ROSSTAT, 2017).

Second, the average cost of industrial robots decreased from 3.2 million rubles in 2012 to 2.6 million rubles in 2017, which makes companies increasingly likely to invest in the research for unmanned technologies. Data on the dynamics of sales of industrial robots in the world are shown in Figure 1 (International Federation of Robotics, 2018).

Third, there is a significant potential for increasing container traffic on Russian Railways; the anticipated growth rate for the demand of services on the Russian container transport market will exceed the global average by 1.5 times (President of The Russian Federation, 2018). Container transshipment at seaports will continue to increase, contributing to the accumulation of cargo flows and wider development of accelerated container train technology. Due to geographical features and the size of Russia, transit transport and specifically accelerated container trains as a service will continue to develop and not just on the Trans-Siberian railway.

In terms of the technology used at the terminals, the working conditions of handling equipment operators aggravate information flow which leads to emotional overload. For a robot, this environment is almost ideal on the provision of necessary and sufficient information; the machines perform the work as quickly as possible, flawlessly and following the shortest routes. Working automatically the system "crane – horizontal transport – crane" was developed to exclude human.

Being the points of high container traffic concentration, Russian seaports handle insufficient volumes for the introduction of high-performance systems in the coming years. In Russia, in addition to a large number of low cost though highly qualified specialists in the transport industry, almost all railway container terminals have a third night shift, the absence of which in Western European and North American multi-modal terminals makes it economically profitable to use robotics. The implementation of new technology is associated with risks and a long debugging period, which under the difficult economic conditions in Russia negatively affects the payback period. To return the investment, the operating costs of an automated terminal should be 25% lower than that of a conventional one, or productivity should increase by 30%, and operating costs should decrease by 10% (McKinsey, 2018).

Organization of work in the context of unmanned technologies

According to the layout railway container terminals (Figure 2) are traditionally divided into 4 types, with 5 main sections: warehouse, railway cargo front, automobile cargo front, container storage area, direct reloading section (Arefev & Korovyakovsky, 2018).

Taking into account the cost of the technology, two transport and reloading systems of the container

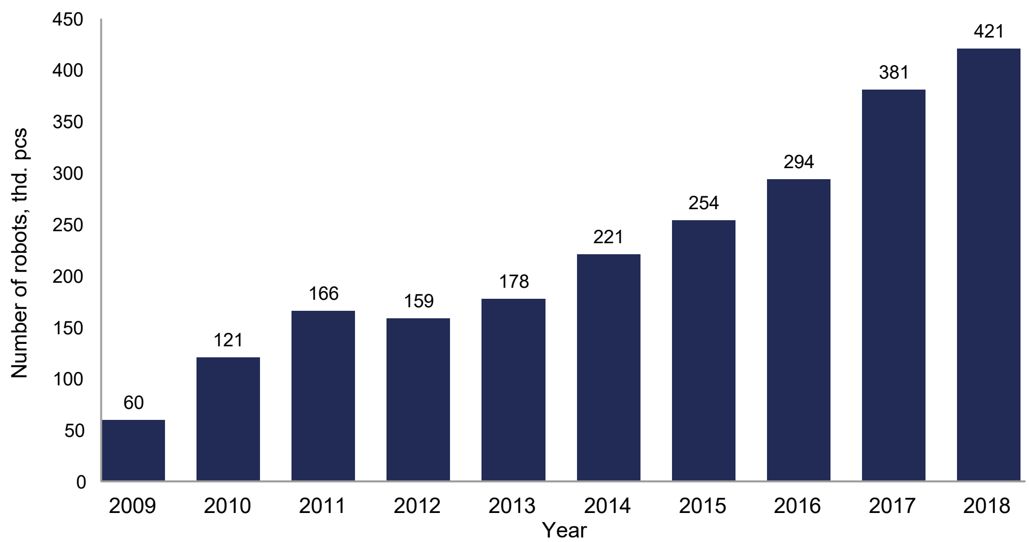

Figure 1. Dynamics of industrial robots sales

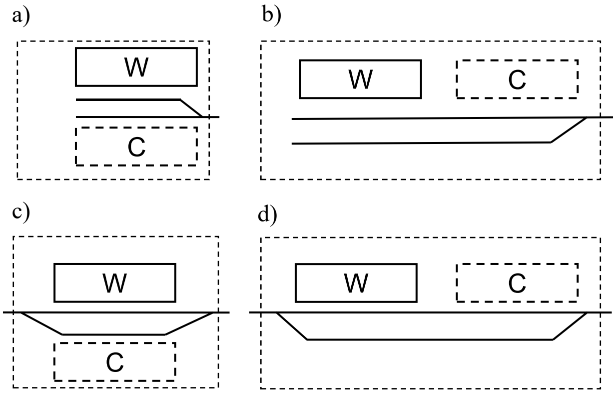

Figure 2. Container terminal layouts: transverse stub (a), axial stub (b), transverse through (c), axial through (d); W – sheltered warehouses, C – container yards

terminal are considered (Figure 3), based on railway tracks with automated gantry cranes for handling road and rail transport. For greater reliability and security, a semi-automatic mode is most effective, when monitoring or remotely controlling operators on remote workstations.

The first system using robotic rubber-tyred gantry crane is suitable for medium-sized terminals where high technology flexibility and accessibility to container stacks are important. Cranes are independent of the other equipment and are able to transport and stack containers as well as handle trucks. In case the equipment needs relocation, cranes can be transferred to another terminal or used in other parts of the terminal. Also, cranes can be used in case of an unforeseen increase in container traffic as additional transport and reloading equipment. The combination of a robotic gantry crane and a robotic rubber-tyred gantry crane offers a lot of advantages:

- fast horizontal transport along the tracks, independent of crane movement;
- pre-sorting in a stack of containers near the train;
- due to the presence of portal cranes, capital cost savings are achieved, excluding gantry cranes in the storage area;
- the ability to quickly change the layout of the terminal to meet the requirements of the processing technology, as cranes are redistributed between sections.

The second system demonstrates the additional use of AGV and a rubber-tyred gantry crane, which is typically for big terminals – hubs, where there is a necessity for fast container interchange between trains or trains and storage area. The area of containers for AGV close to railway tracks are also used for buffering and container presorting for departing trains. In this case, rubber-tyred gantry cranes form long blocks of the containers taken from AGV and vehicles. The system offers the following advantages:

- the simplicity of robotic automation;
- the higher capacity of container carrier stacking due to the absence of loader lanes and the ability to provide more stack layers;
- higher reliability and durability of rubber-tyred gantry cranes and AGV than that of portal loaders;
- relatively unsophisticated design and lower maintenance costs;
- in case of the necessity of movement within the terminal, AGVs are more effective than portal

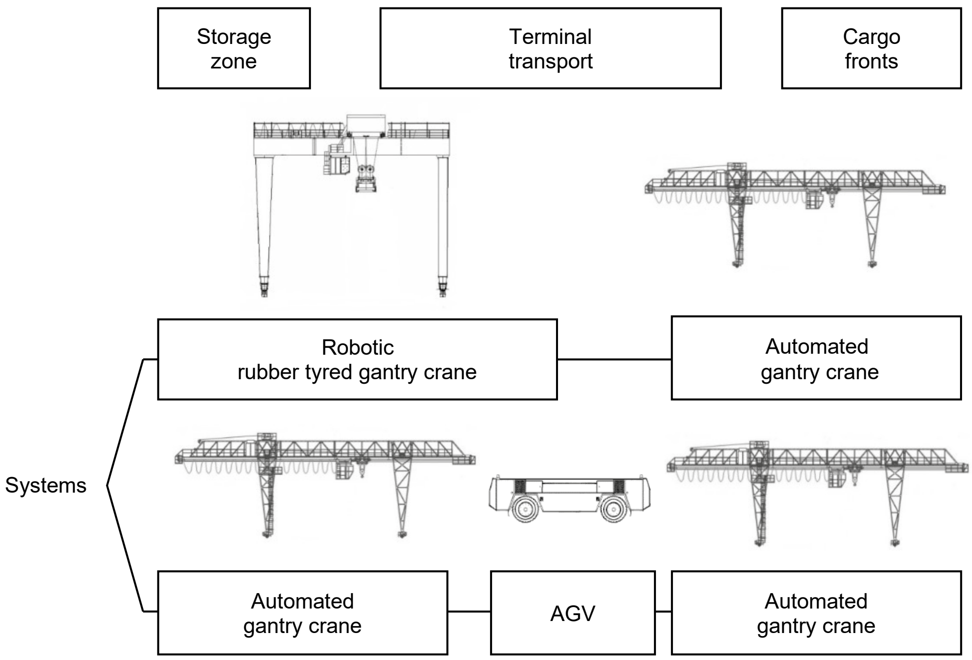

Figure 3. Variants of container terminal transport reloading systems

loaders due to their faster operation and lower cost.

Nevertheless, Russia rail gantry cranes are preferable to be used due to easier automation under commensurable capital investments. A significant drawback of the system is two transfers of the container are required due to the use of different equipment for handling loading at the front and in the storage zone.

Simulation model of robot-aided container terminal

The development of simulation model of railway container terminal (Figure 4) using the Anylogic program was aimed at studying a completely new freight handling structure, as well as the search for the best possible technical and technological solutions. The method of the discrete-event simulation was developed in the 1960s by Jeffrey Gordon and is chosen for modeling inland terminal. Now the method is used for modeling both mass service complex systems and transport systems. It is most appropriate for designing a complex system such as a container terminal.

The model is based on the data concerning the location of the container in the due blocks of the studied system. The transfer from one block to another is performed in accordance with the terminal operation technology and the time gap is dependent on the simulated operations.

The model considers the handling of a train set for loading and unloading as well as train handling in case of necessity. The terminal includes a handling track serviced by gantry crane, storage zones, service tracks for AGV to move containers from the loading front to the storage zone and back, and service roads for the trucks to move from the checkpoint to the storage zone and back.

Experiment

The main factor that determines the volume of the warehouse and the necessary amount of transshipment equipment is the random number of incoming containers. In this case, the randomness is determined by the unevenness of their receipt. As a result, the first stage in the development of a simulation model, which calculates the indicators of the container terminal, is to create an adequate method for generating a flow of random events (arrival of trains), which determines the arrival of the container groups. The controlled parameters here are the nature of the organization of transport (on schedule or with a significant unevenness of the flow), the number of containers in a separate train and the total volume of container flow. Simulation of the container terminal using the developed method with the generation of group income allows a high degree of reliability to calculate the required characteristics and the number of equipment cargo fronts of the projected terminal. At the same time, the results of this stage allow us to obtain the necessary data for analysis of the dynamics of the changes in the volume of the warehouse with the given initial data and the uneven nature of the arrival and departure of trains (Figure 5).

Statistical processing of rows of data describing the dynamics of changes in the container warehouse allows you to determine the requirements for the volume of storage (Figure 6). The results obtained may be sufficient for a preliminary assessment of the required amount of technological resources – capacity, equipment, personnel, etc. However, the main

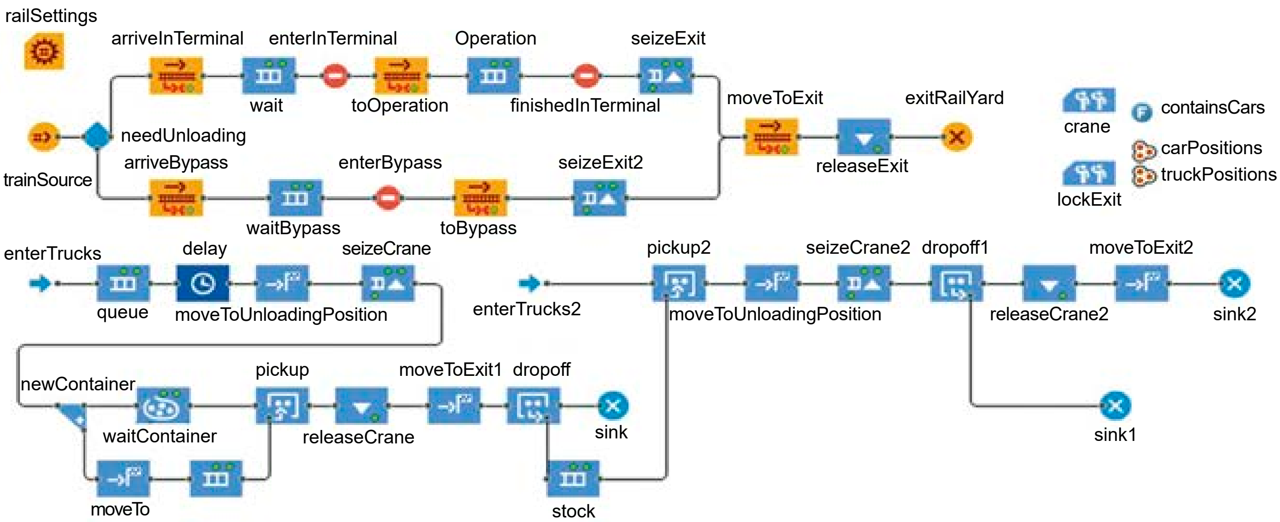

Figure 4. Simulation model of the railway terminal

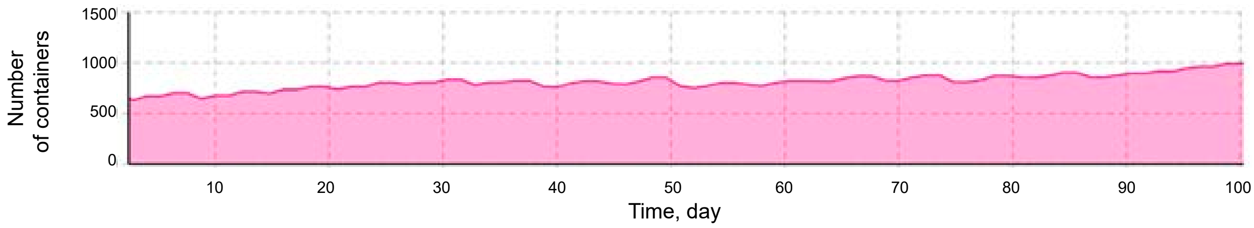

Figure 5. Dynamics of change in the number of containers at the terminal

factor that affects the required amount of technological resources is its productivity. For hoisting and transporting equipment, productivity is determined not only by technical parameters but also by the specifics of storage and selection containers from the stack, which constitute the technological scheme of the terminal. In the initial stages, reference values are used as performance indicators.

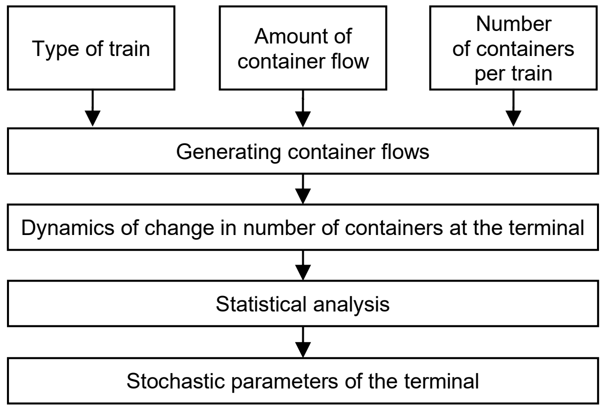

Figure 6. Evaluation of warehouse characteristics as random variables

At the same time, the labor-intensive selection of the container from the stack, which determines the productivity of the equipment, is highly variable. On the technological side, labor intensity is characterized by a parameter called selectivity. In turn, selectivity is a function of the arguments, which are the structural parameters of the chosen scheme: the type of equipment used, the size of the stack, as well as the operating technology for forming and disassembling the stack.

The random sequence of container ingress and egress makes the assessment of selectivity a complex task, to which deterministic algebraic calculation methods cannot be applied. As a consequence, the next step after the assessment of the terminal capacity is to calculate the productivity of equipment under certain local operations performed when processing a given (generated) cargo flow. This calculation is necessary to clarify the value of the required amount of equipment obtained in the previous stages. For this purpose, lists of individual container departures at certain points in time are generated on the basis of data obtained by the generation of random batch receipts and average storage periods (Figure 7).

Thus, the dynamics obtained in the second stage of modelling in the form of mass indicators are specified: the following models take into account each individual container. This is done to obtain a more precise characterization of the selectivity of the transshipment equipment.

In the last stage of the development of the simulation model, the operation of the transshipment equipment at the container terminal is being simulated. The input data for the simulation is the stack size and technology for stacking and moving containers in the stack (equipment operation strategy).

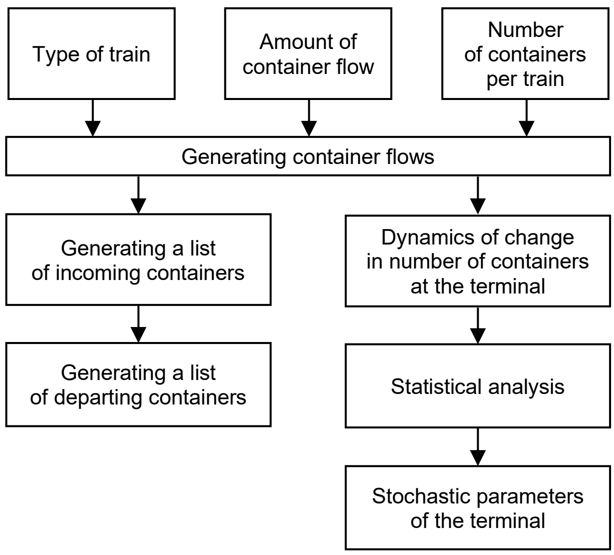

Figure 7. Generation of incoming and departing container lists

The results of the modelling are not "dotted" deterministic values of the assessed parameters, but defining their "functions" – probability distributions of the required storage area capacity, the size of cargo fronts and operating areas, working areas, and the required number of equipment and associated personnel (Figure 8).

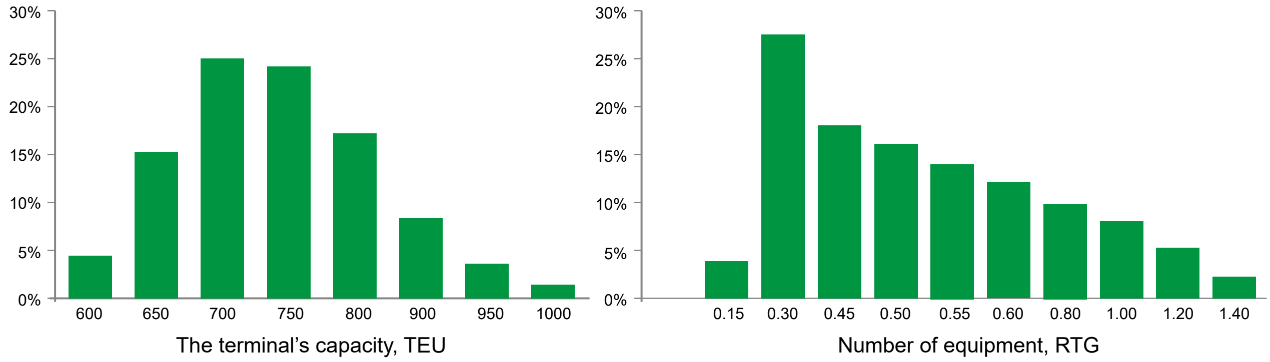

Figure 8. Distribution of the probability of resource requirements

Decisions on the capacity of the container terminal and the required amount of equipment must be made jointly, rather than individually, as the required amount of equipment depends primarily on the size of the storage area and stacks selected. That is why any analysis of any characteristic of the object under study must be carried out through 'system modelling' of that object, i.e. through the creation of a system of interrelated simulation models.

Conclusions

Unmanned technology introduction is a complicated process which requires the detailed design, consideration of technological issues, as well as operational safety in the zones of automated equipment. The problem of choosing an optimum route by the robot in an uncertain environment is still to be solved. However, robots employed by men contribute to the stabilization of the technological process, increasing capacity, accuracy, and operating speed. Moreover, it allows us to avoid human presence in hazardous environments of the working zone.

Since lifting equipment is in the core process at inland terminals, any failure can result in negative consequences of container transportation. Idle hours, which are quiet, often during loading containers at the platform, or their unloading, are especially unprofitable at these terminals. Intelligent algorithms able to predict equipment behavior as well as to prevent its failure, have great potential and allow us to increase the capacity of the container terminal significantly. At the same time, robot automation is to be seen not as a goal in itself, but as a means of optimization of terminal operation and cost lowering.

In general, the process of robot automation of railway container terminals is at the initial stage of its development. Currently, the number of computer-assisted container terminals does not exceed several dozen.

References

1. Arefev, I.B. & Korovyakovsky, E.K. (2018) *Analysis and modelling of transport nodes: monograph*. Moscow (in Russian).
2. Briskorn, D. & Hartmann, S. (2006) Simulating dispatching strategies for automated container terminals. In: Haasis H.D., Kopfer H., Schönberger J. (eds) *Operations Research Proceedings*, 2005. Berlin, Heidelberg, German: Springer, pp. 97–102.
3. Briskorn, D., Jaehn, F. & Wiehl, A. (2019) A generator for test instances of scheduling problems concerning cranes in transshipment terminals. *OR Spectrum* 41, pp. 45–69.
4. Carlo, H., Vis, I. & Roodbergen, K. (2014) Transport operations in container terminals: Literature overview, trends, research directions and classification scheme. *European Journal of Operational Research* 236, pp. 1–13.
5. Dekker, R., Voogd, P. & van Asperen, E. (2006) Advanced methods for container stacking. *OR Spectrum* 28, pp. 563–586
6. Froyland, G., Koch, T., Megow, N., Duane, E. & Wren, H. (2008) Optimizing the landside operation of a container terminal. *OR Spectrum* 30, pp. 53–75.
7. Gharehgozli, A.H., Vernooij, F.G. & Zaerpour, N. (2017) A simulation study of the performance of twin automated stacking cranes at a seaport container terminal. *European Journal of Operational Research* 261, 1, pp. 108–128.
8. Grunow, M., Günther, H. & Lehmann, M. (2006) Strategies for dispatching AGVs at automated seaport container terminals. *OR Spectrum* 28, pp. 587–610.
9. Hu, Z.H., Sheu, J.B. & Luo, J.X. (2016) Sequencing twin automated stacking cranes in a block at automated container terminal. *Transportation Research Part C* 69, pp. 208–227.
10. Hutchison Ports ECT (2018) *Hutchison Ports ECT Delta.* [Online] Available from: https://www.ect.nl/en/terminals/hutchison-ports-ect-delta [Accessed: December 15, 2019].
11. International Federation of Robotics (2018) *Representing the global robotics industry*. Frankfurt.
12. Kovalyov, M., Pesch, E. & Ryzhikov, A. (2018) A note on scheduling container storage operations of two Non-passing stacking cranes. *Networks* 71.
13. Lee, T., Park, N. & Lee, D.A. (2003) Simulation study for the logistics planning of a container terminal in view of SCM. *Maritime Policy & Management* 30, pp. 243–254.
14. Liu, C.I., Jula, H. & Ioannou, P.A. (2002) Design, simulation, and evaluation of automated container terminals. *IEEE Transactions on Intelligent Transportation Systems* 3, 1, pp. 12–26.

15. Luo, J., Wu, Y. & Mendes, A. (2016) Modelling of integrated vehicle scheduling and container storage problems in unloading process at an automated container terminal. *Computers & Industrial Engineering* 94, pp. 32–44.
16. McKinsey (2018) *The future of automated ports.* [Online]. Available from: https://www.mckinsey.com/industries/travel-transport-and-logistics/our-insights/the-future-of-automated-ports [Accessed: December 15, 2019].
17. Moorebank Logistics Park (2018) *Moorebank Logistics Park (MLP) is Australia's largest freight infrastructure project and will link Port Botany direct to rail terminals and warehousing on a 243 hectare site.* [Online] Available from: http://qubemlp.com.au/about [Accessed: December 15, 2019].
18. Nam, K., Kwak, K. & Yu, M. (2002) Simulation study of container terminal performance. *Journal of Waterway, Port, Coastal and Ocean Engeenering* 128, pp. 126–132.
19. Ottjes, J.A., Hengst, S. & Tutuarima, W.H. (1994) *A simulation model of a sailing container terminal service in the port of Rotterdam*. In Proceedings of the European Conference on Modelling and Simulation ESM-94, Barcelona, Spain.
20. President of The Russian Federation (2018) *Decree of The President of The Russian Federation No. 204*. Moscow.
21. Rizzoli, A.E., Fornara, N. & Gambardella, L.M. (2002) A simulation tool for combined rail/road transport in intermodal terminals. *Mathematics and Computer in Simulation* 59, pp. 57–71.
22. ROSSTAT (2017) *Labor and employment in Russia*. Moscow (in Russian).
23. Russian Railways (2012a) *The concept of complex development of container business in JSC Russian Railways Holding*. Moscow (in Russian).
24. Russian Railways (2012b) *The concept of designing terminal and logistics centers on the territory of the Russian Federation*. Moscow (in Russian).
25. Russian Railways (2013) *The concept of development of transport and logistics business JSC Russian Railways*. Moscow (in Russian).
26. Stahlbock, R. & Voss, S. (2008) Operations research at container terminals: A literature update. *Operations Research-Spektrum* 30, pp. 1–52.
27. Stavrou, D., Timotheou, S., Panayiotou, C.G. & Polycarpou, M.M. (2017) Assignment and Coordination of Autonomous Robots in Container Loading Terminals. *IFAC-PapersOnLine* 50, 1, pp. 9712–9717.
28. Stavrou, D., Timotheou, S., Panayiotou, C.G. & Polycarpou, M.M. (2018) Optimizing Container Loading With Autonomous Robots. *IEEE Transactions on Automation Science and Engineering* 15, 2, pp. 1–15.
29. Steenken, D., Voss, S. & Stahlbock, R. (2004) Container terminal operation and operations research – A classification and literature review. *OR Spectrum* 26, pp. 3–49.
30. TransContainer (2019) *Annual report of PJSC TransContainer for 2018. Annual report.* TransContainer – container transportation. [Online]. Available from: https://ar2018.trcont.com/download/full-reports/ar_ru_annual-report_pages.pdf [Accessed: December 15, 2019] (in Russian).
31. United Nations Economic Commission for Europe (2018) *Railway role in intermodality and the digitalization of transport documents.* Geneva.
32. Vis, I. (2006) Survey of research in the design and control of automated guided vehicle systems. *European Journal of Operational Research* 170, pp. 677–709.
33. Yang, Y., Zhong, M. & Dessouky, Y. (2018) An Integrated Scheduling Method for AGV Routing in Automated Container Terminals. *Computers & Industrial Engineering* 126, pp. 482–493.