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REVIEW OF TRANSPORT DECISION PROBLEMS IN THE MARINE INTERMODAL TERMINAL

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Abstract: *The article is a review of the transport problems that appear in a marine intermodal terminal. The importance of intermodal terminals has been increasing since the 1980s as a result of the development of containerized international trade. This increase in the handling of containers cause problems connected with securing adequate space for container storage or efficient usage of available terminal loading equipment such as cranes, AGVs, straddle carriers or terminal tractors with trailers. The equipment of a terminal depends mainly on the size of containers flow. The use of this equipment determine the terminal technology and work organization. That is why the classification of intermodal container terminals is presented in chapter 2. This classification was made according to different criteria. To understand transport problems, the identification of processes performed in the marine intermodal terminal is presented in chapter 3. For the purpose of research an example of an intermodal marine terminal with its individual functional areas is presented. Finally, the literature review on research conducted on the transport processes performed in the terminal are presented in chapter 4. These processes refer to quay side and land side horizontal transport operations. Additionally, the arrangement of containers at the storage yard was investigated.*

Key words: *intermodal terminal, TEU, horizontal transport.*

1. Introduction

The performance of transport processes, have nowadays a huge importance in transhipment points, were handling operations are realized, eg. change of mode of transport, consolidation, de-consolidation, etc. (Jacyna et al. 2015, Pyza et al. 2017). Considering the above, these are the nodes in a transport network or logistic distribution network in which the cargo is temporarily stored or transferred into a different direction. At these points, both storage and transport processes are realized. On the one hand there is a concentration of cargo flow and, on the other hand, their distribution on particular types of modes of transport (Jacyna-Gołda 2015, Kłodawski et. al. 2015). The primary function of the transshipment points is to allow loading and unloading, as well as changing the means of transport and the transport modes. It is also possible to rationalize the use of various forms of transport combined with the reduction of the travel distance and therefore the negative impact on the environment (Palagin et al. 2014).

An important role in the cargo transport play intermodal terminals (Jacyna 2012). These terminals provide transhipment and storage services for intermodal transport units and other services related to the handling of these units. The importance of intermodal terminals has been increasing since the 1980s as a result of the development of containerized international trade. The intermodal transport offer regarding the possibility to transport the cargo in the one loading unit on the entire route of transport, is highly desirable by commercial partners (Merkisz-Guranowska et al. 2014). That is why increasing container flowr is a challenge for transport vehicles and container service points (intermodal terminals).

In the intermodal terminals, with the increase in the handling of containers, there are problems with: securing adequate space for container storage and having adequate handling equipment, sufficient quay lengths and rail and road cargo loading fronts. Hence, the optimization of container transit processes in the intermodal terminals is becoming increasingly important.

2. Types of intermodal terminals

As defined by the European Conference of Transport Ministers ECMT), the United Nations Economic Commission for Europe (UNECE) and the Organization for Economic Co-operation and Development (OECD), the terminal is an area for storage of intermodal transport units (ITU) that is equipped with loading machinery and equipment for operation on ITU (West et al. 2005). On the other hand, authors of (Kisperska-Moroń et al. 1996) detail this definition by stating that: the intermodal terminal is the spatial object with its proper organization and infrastructure enabling the transhipment of ITU's: containers, swap bodies and semitrailers between means of transport belonging to different modes of transport and performing operations on these units in connection with their storage and use.

Intermodal terminals, as the hubs of cargo handling and change of means of transport, and as places of services concentration are located in places that provide access to linear transport infrastructure (rail and public roads) and provide the possibility to combine transport within different transport modes in accordance with the rules laid down for intermodal combined transport (Jacyna 1999, Jacyna et al. 2011, Jacyna 2012).

In the intermodal transport, the in-land and marine terminals can be distinguished. In the first case, there are terminals located on the railway network with access to road infrastructure and, in some cases, inland waterway infrastructure.

In the second case, however, there are terminals located in seaports. Due to the functions performed in intermodal transport, intermodal marine terminals have access to liner infrastructure for maritime, rail and road transport and, in some cases, inland waterway infrastructure. Terminals that handle large cargo flows are fully automated terminals, resulting in high throughput, operation speed and low unit cost of ITU's handling.

Classification of intermodal transport terminals may be carried out due to different criteria:

- type of ITU's being handled,
- types of means of transport used for the deliveries from customers to the terminal,
- annual number of TEU being serviced in the terminal,
- functions of the terminal in intermodal transport networks and others.

A detailed classification of intermodal terminals, taking into account the division criteria, is shown in the figure 1.

3. Marine intermodal terminals

Port intermodal terminals are the area where different modes of transport are handled. The functional area of a container terminal can be divided into a maritime transport area and thr area serving other modes of transport (mainly road and rail). Intermodal transport units (usually containers) arriving (imported) into the port container terminal after their unloading from the ship, are temporarily stored or transhipped for road or rail transport.

Upon arrival at the port, the container vessel is moored to the indicated quay, equipped with quay cranes. Unloading containers are transported to the storage yards of the terminal. From the storage yard containers are transported by road or by rail to the inland terminals. The process of shipping of a container by sea look exactly the same, but in opposite way. Containers delivered to the container terminal by rail or by road using port loading equipment are transported to the appropriate locations on the storage yards from where the loading on the container ship takes place. In addition to the typical transport of containers, generally in seaports, additional customs or phytosanitary operations are carried out on containers.

A diagram of the flow direction of containers in marine intermodal terminals is shown in the figure 2.

Marine intermodal terminals are the point of contact between sea and land transport. They differ mainly in equipment, technology and organization of work, which is influenced by the size of the cargo flow. Depending on the size of the cargo flow, the intermodal marine terminals can be divided into terminals:

- Peripheral - of local importance, serving several hundred thousand TEU a year;
- Large - of regional importance, serving at least one million TEU a year;
- Very big - of continental importance, working as transhipment hubs, usually consisting of several large container terminals.

The size of the marine intermodal terminal also depends on the size of the container vessels that can be serviced. The size of the vessel will affect the size of the berth, the depth of the berth, the class of quay cranes, and indirectly the capacity of the terminal's storage area.

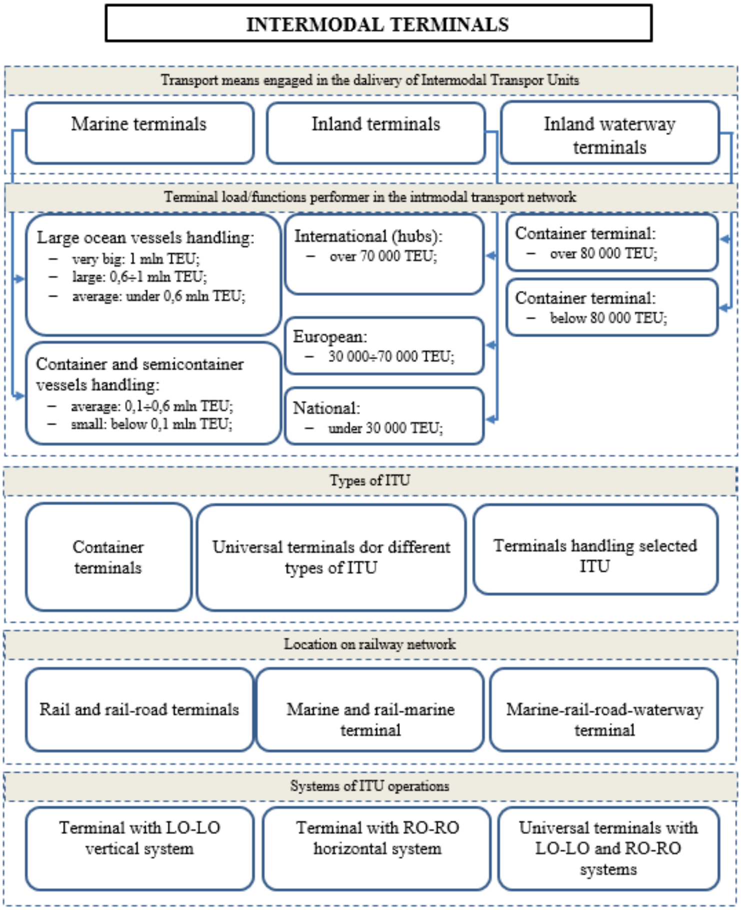

Fig. 1 Intermodal terminals classification (Lowe 2005, Stokłosa 2011)

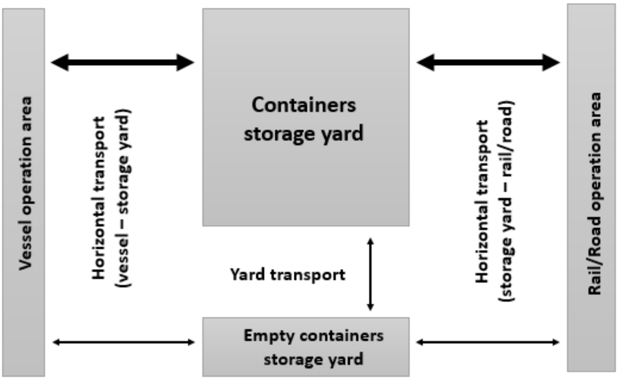

Fig. 2 Flow direction of containers in marine intermodal terminals

Currently the largest container vessels in the world reach 400 m long, 59 m wide, 19.2 thousand TEU capacity and immersion of 16 m. Such vessels can only be operated in large and very big intermodal terminals. Feeder vessels with capacities ranging from several hundred to one thousand TEU are usually used for the operation of peripheral terminals. They connect smaller regional ports with large ports providing export containers for large ocean vessels. The last type of vessel supplying essentially all of the above-mentioned types of container terminals are inland barges of up to several hundred TEUs, which carry inland containers from inland ports. An example of intermodal transhipment terminal is shown in Figure 3. Schematically, an example of an intermodal marine terminal with its individual functional areas is shown in Figure 4.

The technology and organization of container storage in a container terminal depends mainly on the area the terminal occupies and the handling equipment used to handle the ITUs. For this reason, there are two main ways of storing containers: block storage and row storage.

In block storage technology, the units are placed in a yard next to each other and piled up to form stacks. In the area of container storage, gantry cranes used, with working range the enables the handling of containers can be used. These cranes work together with horizontal transport equipment.

In case of row loading, the containers are handled by straddle carriers. This equipment doesn't require co-operation with additional equipment to place the container in the storage yard. Their capacity to stack containers is limited by the height of the straddle carrier. In addition, the placement of the container transported by the straddle carrier requires the use of free space between container rows (1÷1.5 m).

The block-storage technology is widely used in marine intermodal terminals. The row storage technology is used in terminals with a small cargo flow and with a relatively large storage area for containers.

Fig. 3 Marine intermodal terminal in Gdynia

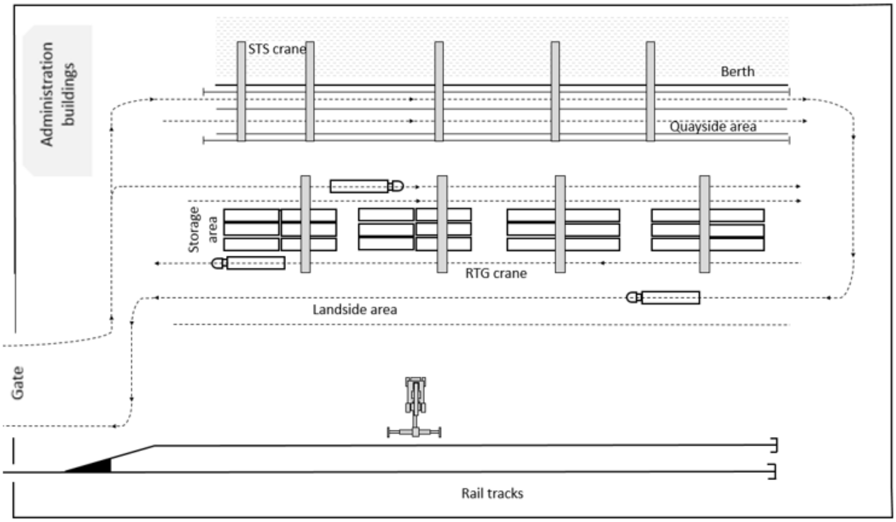

Fig 4. Marine intermodal terminal example

Basically, the terminal consists of a quay side and a landside area. At the quay side, container ships are allocated to the berth on which quay cranes operate. The quay crane can take a container from the ship and lay it down along the quay on the floor or on a specific transport vehicle (AGV, terminal trailer). Unloaded containers (import containers) are then transported to the storage yard. Subsequently from the storage area, the containers are moved to the areas where they are loaded onto the road or rail transport. In the case of export containers, this process is repeated in the opposite direction. Of course, there are other possible transitions of containers in the intermodal terminal. Containers may be moved from storage to warehouse where the contents of the container may be deconsolidated. In addition, the deconsolidated containers can be moved into storage areas for empty containers and in the opposite direction.

The functional areas of the terminal and container handling technology depend on the available area on which the terminal is located and the type of handling equipment used and the means of transport working within the terminal. It should be noted here that the growing turnover of containers at intermodal terminals requires the modernization of terminal equipment. Therefore, existing intermodal terminals are often equipped with more and less modern devices of different capacities, which will determine the nature of the processes.

The decision how to equip the intermodal terminal with transportation/loading equipment depends on several key factors: the available space for handling vessels and containers, economic factors and historical factors. Economic factors will influence the partial or complete automation of processes in the terminal. Historical factors, in turn, include the possible expansion or modernization of the terminal. The limited availability of the manipulation and storage space will increase the storage height of the containers. Nevertheless, storage height cannot be increased indefinitely. Hence, the increase in capacity of existing terminals should be searched for the optimization of the transport and handling processes. This is mainly the case for large intermodal terminals located in seaports that have already reached their capacity limit. In such cases, the increase in containers flow requires optimization methods for containers handling processes. These processes occurring in intermodal terminals are dynamic. This is due to the fact that long-term planning in relation to the real aspects of the present is difficult. Although the process of handling containers is planned in the short run. In fact, the errors regarding even the gross weight of the container to be loaded on the vessel may cause disruption of the vessel loading schedule (this is due to the stowage containers on the vessel to maintain its stability). Likewise, the delay of the road vehicle delivering the container to the terminal may cause a change in the schedule of vehicle reception at the entry gate of the terminal.

4. Decision problem in the intermodal terminals

Literature analysis indicates that decision problems occurring in container terminals are described quite extensively in (Steenken et al. 2004). The author has characterized the decision problems concerning, unloading of a container vessel, transporting containers from customers do the storage area in the terminal, transporting containers from the quay side the storage yard as well as arrangement of containers at the storage yard.

The types of decision problems depend on the type of transport that a particular container terminal handles. Generally, in container terminals, decision problems can be divided into problems related to: unloading of ships, problems of ground transportation of containers and handling of road and rail transport, optimizing the work of cranes. This article is devoted to the problem of quay side and land side transport as well as to arrangement of containers at the storage yard.

Among the issues related to vessel unloading ships we can distinguish:

- Berth Allocation Problem,
- Stowage planning,
- Quay Crane Assignment and Scheduling.

Among the issues related to ground transport we can distinguish:

- Arrangement of containers at the storage yard,
- Quay side Transport,
- Land side Transport.

Arrangement of containers at the storage yard

The problem of container location in the storage yard is due to the increasingly shrinking space for container storage because of the rapidly growing international trade. The height of the containers storage is limited by their compressive strength. Loaded containers can be stacked up to level 6. Actually (apart from the above mentioned maximum values) container storage is limited by the loading equipment in the storage site. The number of storage rows will determine the cranes width and also the way of delivering the containers to the operating area of the crane.

In general, the problem of the location of containers in the storage yard is reduced to the exact storage location of the container. In addition, container storage yards are usually divided into storage areas for import, export, empty containers, dangerous goods containers, damaged containers or refrigerated containers requiring power. The storage location of a container in a storage yard will determine the time of access to this container. Because containers can be stacked, direct access to every container is not possible. Thus, it is necessary to move one or even several containers into another place to pick up a given container. I will generate costs associated with lowering the daily productivity of the crane. Therefore, knowing the loading plans of containers temporarily stored in the yard, the location of their storage should be determined so that the number of empty loading equipment moves are minimal. Unfortunately, in fact, incorrect or incomplete data characterizing the containers (information about the vessel to be loaded, destination port information, or gross container weight information) preclude the exact location of their storage.

Two container storage strategies are used in intermodal terminals. According to the first strategy, the container location in the storage yard are assigned to the vessels that are about to arrive at the port. The number of these container storage locations is determined on the basis of the expected number of import containers (to be unloaded from the ship) and export containers (those to be loaded on ship). Depending on the strategy, the storage areas for export containers may be further subdivided into the: port of destination, container type and gross weight of the container (heavier containers should be loaded onto the ship as the primary purpose of maintaining ship stability). Only the space that can accommodate containers is provided for the import containers in the storage area. This is due to the uncertainty of data about containers and means of transport as well as the time when the container is ready to be unloaded at the terminal. Relatively, in the actual terminals, planning strategies also assume the storage of import containers relative to the time of their arrival at the terminal.

The above mentioned strategies under certain conditions make it impossible to make high use of the storage area, as the delivery of containers to the terminal is a stochastic process. Therefore, a second strategy seems to be better where the storage areas are allocated to berths on the quay. In this situation, regardless of whether the ship is delayed or not, it is possible to service another vessel while reserving in real time the space for unloaded containers. At this point, it is possible to stack containers one on top of on another taking into account: their destination, gross weight or dimensions. In addition, the storage location may be selected in such a way as to minimize the time of shipment of containers from the ship to the yard. Analysis of the above container storage processes indicates that optimization of the containers is to minimize the unnecessary movement of the loading equipment, maximize the use of the storage space, and minimize the distance between the ship and the place of storage.

Among the publications addressing the issue of minimizing the replacement of containers in the storage yard, the following works can be distinguished: (Kim 1997, Kim et al. 1998, Kim et al. 1999). In the first paper (Kim 1997), the author considered various options for setting up containers at the storage yard and their impact on subsequent shifts of containers. In turn, the second paper (Kim et al. 1998) presents a dynamic programming model for container location to minimize container shifts. In the third paper (Kim et al. 1999) the author focused on strategies for allocating storage areas for containers. Various supply scenarios (static and dynamic) of import containers were considered. The number of shifts in the container yard has been minimized. Among publications focusing on maximizing the use of storage space for containers we can be distinguished publications of: (Kim at al. 2002, Kim et al. 2003).

In the first paper (Kim at al. 2002), the authors considered the optimization of the use of the storage space and the number of cranes serving this space. The optimization model was based on the expenditures on the yard surface, loading equipment as well as the operating costs associated with the use of this equipment. In the second paper (Kim et al. 2003), the authors developed a dynamic model of the allocation of export containers to locations in the storage yard. The mathematical model of integer programming was formulated. Heuristic algorithms were used to solve the problem.

Among the publications dealing with the problem of storage of containers from the point of view of minimizing the distance between the ship and the storage area were: (Cao et al. 1993, Kim et al. 1998, Zhang et al. 2003). In the works of (Cao et al. 1993, Kim et al. 1998) the authors dealt with the issue of the location arrangement of export containers. It was proposed that the containers for which the storage locations on the square was arranged, should be arranged in the same way in the quay crane operating area. The distance between the storage area and the temporary storage of containers at the quay has been minimized. Such an operation was also aimed at minimizing the service time of the ship at the berth.

In the work of (Zhang et al. 2003) the author deals with the problem of allocation of storage locations for both import and export containers as well as containers in transit. The problems of storage location and minimizing the distance between a storage yard and a ship is considered in two stages. In the first stage, it is possible to store containers in a given block from the point of view of the performance of the gantry cranes. In the second stage, the selection of the storage block (from the previously examined) is made, taking into account its distance to the place where the containers are loaded onto the ship.

The above-mentioned publications concerned the planning of the location of load containers. In the intermodal terminals, empty containers are usually stored in other areas of the storage yard. Their location planning is no different from the planning of loaded containers.

More about operations at the storage yard can be found in (Héctor et al. 2014).

Quay side container transport

The problem of container transport on the quay side is connected with the necessity of transporting containers between the storage area and the quay cranes area. Import containers are putted down by quay cranes on terminal loading equipment such as terminal trailer), or AGVs. The construction of terminal trailer and AGV vehicles prevent them from taking the container from the floor. Hence, the unloading crane can put down the container only on such a vehicle. The lack of a specific vehicle on the quay side during vessel loading/unloading cause the necessity for crane to wait, which extent the crane operating cycle. The situation looks identical in the case of export containers.

Consequently, the issue of container transport at the quay side aims to minimize the time when the crane waits for the horizontal transport vehicle to pick up the container. The loses connected with that crane waiting time reduce the crane's efficiency.

The necessity of waiting for the horizontal transport vehicle to pick up the container from the crane usually results from the congestion of these vehicles on the quay. Due to the dynamic nature of the actual transport of containers between the berth and the storage area, the appropriate (at the right place and time) horizontal transport vehicle arrival over the quay crane is difficult to achieve. Increasing the number of vehicles operating cranes, or even their speed, does not solve the problem, as it quickly leads to congestion.

The work technology of horizontal transport vehicles makes it possible to realize single and double cycles. The single cycle of a terminal vehicle is to transport the import container from the berth to the storage yard and return to the berth to for the next container. In a double cycle, the terminal vehicle can handle multiple gantries at a given quay and carry import and export containers in the same cycle (without empty runs as in a single cycle)

The nature of the single cycle for import containers does not allow it to be optimized. Only the designation of a container storage location near the place of unloading of the vessel may affect the shortening of its route. The situation of export containers is different. The order of containers transported from the storage area to the quay side in fact does not exactly match the order they are loaded on the ship. The order of containers delivered over the quay crane will depend on the congestion, the need to shift the containers in the storage yard, or the special type of container requiring additional service. Therefore, taking into account the priority for the ship's loading plan, the plan of container transportation to the working area of the crane must be modified all the time.

The nature of the dual cycles (Kang et al. 2008) of terminal vehicle provides significant optimization possibilities. In this case, terminal vehicles are no longer allocated to a specific crane, but they can handle many of them, both in terms of import and export containers in one cycle. In addition, a terminal tractor with several trailers are capable of handling several containers in one double cycle. Double cycles greatly reduce the time loss (cranes waiting for horizontal transport vehicle), while being very complex at the same time. In the actual intermodal terminals, double cycles are usually carried out with the use of automatic vehicles, and the management of the transport process is focused on the coordination of these devices. Both in the single cycle and the double main purpose of optimization is to minimize the waiting time of the crane to load/unload the terminal vehicle.

The literature on the problem of transport optimization between the storage area and the quay is very rich. Most publications discuss the issue of scheduling AGV vehicles. Mostly these publications regarded:

- Development of control systems in automatic intermodal terminals (Evers et al. 1996);
- Optimizing AGV waiting locations (Bruno et al. 2003, Gademann et al. 2000);
- Separation of AGV jobs into containers (Chan 2001, Palagin et al.2014);
- AGV routing (Reveliotis 2000);
- AGV routing and scheduling (Qiu et al. 2000, 2001, 2002);
- Optimization of AGVs performing dual cycles (Grunow et al. 2004, Hanafi et al. 2003);

Definitely less space in the literature is dedicated to the optimization of transport using straddle carriers and terminal trailers. The allocation of tasks to the straddle carriers and the design of the routes to minimize the total distance they have travelled, has been the subject of work (Kim et al. 1999, Bose et al. 2000). In addition, in work of (Bose et al. 2000), the author examined different strategies for the separation of job for the straddle carriers in the yard to maximize the use of cranes in the storage yard by the appropriate schedule for the straddle carriers arriving over the crane.

The use of terminal trailers was devoted to the work (Bish et al. 2001, Kim et al. 2004, Li et al. 2001). In the work of (Li et al. 2001), the authors minimized the time of unloading of a ship at a fixed number of terminal trailers. In turn in work of (Bish et al. 2001) the author additionally allocated the container storage location in the storage yard to individual containers and allocated terminal trailers to containers.

Land side container transport

The land area of the intermodal terminal covers the area where the container is transhipped between the terminal storage area and the terminals of rail and road transport area. Depending on the location of the transhipment area and the handling equipment, these transhipments can be carried out either by cranes, straddle carriers as well as by reach stackers and lifting trucks. In sea intermodal terminals, rail cars are usually loaded / unloaded by cranes. The transport of containers between the storage yard and the railway area is performed by straddle carriers, terminal trailers or reach stackers in selected cases. Road transport vehicles (tractors with semitrailers) can be loaded / unloaded directly by gantry cranes, or these operations may be carried out in the separated area where containers intended for road transport are buffered. In the latter case, road vehicles will be loaded by lifting tracks or reach stackers.

The terminal entry process for road vehicles with containers takes place at the terminal gate. The vehicle and container data are checked. Missing data is added to the terminal management system. Only then the road vehicle can be directed to the place of container loading / unloading. Because intermodal terminals handle hundreds or even thousands of road vehicles a day, it is necessary to sequence these vehicles. An additional problem is the difficulty of anticipating the arrival times of road vehicles (even in the case of a previous arrival notification). In such a situation loading / unloading of road vehicles with the cooperation of handling equipment must be optimized all the time. In this case, the optimization criterion is minimizing empty runs of cargo equipment carrying containers between the storage yard and the place of road vehicle unloading. It is achievable in the case of double cycles, where the loading equipment in one cycle brings the export container out of the storage yard and then takes the import container to the storage area. The aim is to minimize transport times in this area.

The same is with the process of trail transport handling (Ambrosino et at. 2013). The issue of loading / unloading of rail cars is essentially the same as loading / unloading of vessels.

Significant importance for the railway operator (from the point of view of minimization of work connected with rail cars management) is the number of the car on which a given container will be loaded (Ambrosino et al. 2015). Typically, a loading plan for rail cars is developed by the railway operator or operator of the intermodal terminal. In the case of the terminal operator, its aim will be to minimize the displacement of containers at the storage yard, minimize the time and distance of the containers transport from the storage yard over the rail terminal, and to minimize empty runs of horizontal transport vehicles in the case of dual cycles performance.

The issue of transporting containers between the storage yard and the rail or road terminal was not quite widely considered in the literature. In the paper of (Steenken 1992), author has considered the double cycles of straddle carriers transporting containers between storage yard and the road terminal. The same author in paper (Steenken et al. 1993, Steenken 2003) made similar research, but this time he focused on the transport between storage yard and the rail terminal.

In work of (Kim et al. 2003) the problem of cranes work scheduling and loading/unloading road vehicles was discussed. In turn, the work of (Koo et al. 2004), authors addressed the problem of minimizing the required fleet of horizontal transport vehicles for carrying out transport between the storage yard and the road and rail terminal while minimizing transport routes.

5. Summary

The growing international trade cause the development of transport in containers. This increase the handling operations performed at intermodal terminals, which cause problems connected with securing adequate space for container storage or efficient usage of available terminal loading equipment such as cranes, AGVs, straddle carriers or terminal tractors with trailers. Growing costs operations performed in the intermodal terminals demand a reduction of unproductive times. One of the way for the unproductive time reduction is an optimization of terminal processes. Effective use of equipment requires a systematic approach to optimizing the processes they perform. At the same time, optimization of processes requires their simultaneous automation to rule out human errors. Therefore, the integration of processes in intermodal terminals requires the use of simulation tools that allow the process to be investigated under uncertainty.

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