Postprint of: Moszyk K., Deja M., Reduction of exceeding the guaranteed service time for external trucks at the DCT Gdańsk container terminal using a six sigma framework, International Journal of Lean Six Sigma (2023), DOI: 10.1108/IJLSS-05-2022-0100

Reduction of exceeding the guaranteed service time for external trucks at the DCT Gdańsk container terminal using a Six Sigma framework

Purpose

The purpose of this research was to investigate ways to reduce the average amount of exceeded guaranteed service time for external trucks at Deepwater Container Terminal Gdańsk Sp z o.o. (DCT Gdańsk) via dosing the gate activities, in particular IN-Gate entry process of trucks carrying import/export/transit containers.

Design/methodology/approach

A Six Sigma methodology with the DMAIC methods along with the SIPOC chart, cause and effect diagram, scatterplot, benchmark and brainstorming and finally multi-voting tool are used as analyses tools in this research.

Findings

Deepwater Container Terminal Gdańsk Sp z o.o. (DCT Gdańsk) reorganized and modernized the Gate Operations. Gate reorganization and modernization includes streaming line traffic at the gates, external parking lot optimization, implementation of dedicated supporting software and installation of dedicated CCTV cameras to provide 24h life view. During gates development, the external truck service times data were collected and analysed. The obtained materials concerned the measurement of the average truck turnaround time before and after the implementation of the improvements.

Originality/value

The proposed approach of reducing the average amount of exceeded guaranteed service time of external trucks at the container terminal is unique and relatively cheap mainly due to organisational changes with some widely available low-cost investments and can be applied on a different scale to other container terminals or to transport and logistics companies.

Paper type: Case study

Keywords: container terminal; gate operation; Six Sigma; container handling; truck service time; DMAIC.

1. Introduction

Shipping is the backbone of world trade, with an estimated 80 percent share of all cargo. Container terminals, on the other hand, are the basic link in this type of transport and as much as almost 20 percent of global maritime trade. Container shipping in 2019 was valued at approximately $ 14 trillion. Containerization is one of the most important forms of unitization of loads and their transport (Park and Suh, 2019). This method made it possible to transport specific loads in one separate form, while maintaining the dimensions and weight during transport, handling, and storage, i.e. during the entire transport process. More than 50 years have passed since the creation of the first container terminal, and this event has radically changed the global transport network (Salomon, 2013).

Container ports are at coastal and riverbanks areas that allow containers to change methods of transport on their way to their final destination. They are located in strategic places, creating a complex logistics network. Often the cargo arrives at the container terminal on one ship and is transferred to several modes of transport for delivery to inland customers. The terminal is an area dedicated to unloading, loading, and storing cargo in containers and temporary storage of containers.

Sea transport has been growing in its activities for many years. The world volume in 2017 was 757 million TEU, and in 2019 it increased to 811 million TEU [I]. TEU (twenty-foot equivalent units) is a unit of capacity often used for ships, ports and trains. It is a representation of a 20-foot container with dimensions of 6.10 meters long by 2.44 meters wide and 2.59 meters high. The standardized ISO series 1 container with a length of 40 'corresponds to the value of 2TEU. A truck can transport up to 2TEU units at a time, a railway train with a length of about 650 meters 84 TEUs, and an ocean container ship even up to several tens of thousands of TEU [II].

Modern ports operate in an increasingly complex and sophisticated transport and logistics environment, embedded within multi-scalar planning regimes (Monios and Wilmsmeier, 2013). The automated terminals will gradually replace the solutions used in specialised terminals and will become the most common type of container terminals in the world around 2030 (Krośnicka, 2021). Due to the variety and number of challenges facing terminals and ports, the concept of

‘Smart ports’ is extensively discussed in ports all over the globe manly due to increasing congestion and the push for a greener modal shift, more reliability and visibility of goods, and more sustainable activities in and related to the port (Boullauazan et al., 2022).

The container transportation is treated as a major component of intermodal transportation and international commerce (Crainic and Kim, 2007). In Poland, the use of container terminals for transport is constantly increasing. The annual throughput capacity of intermodal transport in 2020 amounted to 8.2 million TEU, of which 5.2 million TEU at sea terminals. A total of 77.9 million tonnes of containerized cargo were transhipped, including sea transport - 29.2 million tonnes, road transport - 25.5 million tonnes, and rail transport - 23.3 million tonnes. The main loads transported by intermodal transport belong to the group of unknown goods, in 2020 it was as much as 32.5% of all loads. Mixed goods also constitute a significant share - 24.7%, followed by food products, tobacco and beverages - 11.5%, and various types of loads from the chemical group - 10.2% [III].

Due to the growing quality and economic requirements for container terminals, as well as the constantly increasing competition on the market, they invest in continuous modernization and deployment of available advanced technological products and processes. In this way, new solutions regarding different processes and services provided by the container terminals are developed. One of the key processes is container handling, i.e., changing the mode of transport, from sea to road or rail and vice versa. It has a significant impact on ensuring the appropriate level of the service provided. Container terminals use many different strategies to ensure their smooth and damage-free course, applying the newest and emerging technologies based on artificial intelligence, automation, optical camera recognition, sensors, and scanners (Barasti et al., 2021). The Internet of Things technology provides smart solutions for storage and monitoring the data at the port. RFID technology for identification and location can contribute to safer and shorter handling times (Kosiek et al., 2021). Despite high costs, automatization and modern port technologies allow to increase efficiency and reduce human errors. Container handling processes should be continuously improved so that seaports could handle more and more containers in the shortest possible time, in due safety measures. Limiting the available stacking area and the number of handling equipment extends the time of loading/unloading operations (Grubisic et al., 2020). An effective operational plan at container terminals requires many factors, methods, and simulations to be considered when making decisions (Won and Kim 2009). One of the aims to be achieved is minimizing the turnaround time of vessel unloading at a definite berth location, as studied in (Deja et al., 2017). An automatic scheduling method based on information fusion of association rules for the dynamic loading of shipping container routes in an international logistics environment was proposed in (Wang, 2019). Nevertheless, minimizing gate congestion at a marine container terminal, and thus reducing the truck’s turn-around times is considered to be a major issue faced by container terminals and even local government authorities, as congestions or emissions often become a social problem even in large areas adjacent to the terminal (Hur et al., 2020; Park and Suh, 2019). The disruption of external truck arrivals is an important and complex issue and can significantly impact the entire system performance (Li et al., 2018). Thus, Truck Appointment System (TAS) is crucial for improving operational efficiency and benefits both terminal and truck company. By optimizing the truck turn-around times and thereby the landside shipping cost, the terminals can gain a competitive advantage in the industry, as shown in (Regan and Golob, 2000; Huiyun et al., 2018, Abdelmagid et al., 2022). Xu et al. used mixed integer nonlinear programming (MINP) to determine the best appointment plan for each truck with the target of minimizing the overall operation cost (Xu et al., 2021). A variety of inter-related decisions made during daily operations at a container terminal to minimize the waiting time of customer trucks was described in detail in (Murty et al., 2005).

The Six Sigma methodology was proposed as an optimisation tool for reducing trucks’ congestion in marine container terminals, in both, the entrance and exit gates weighbridges (Nooramin et al., 2011). Six Sigma methodology aims to achieve improvements in the most economical manner possible and is focused on reducing waste in business processes. It encourages companies to look at their processes from the customer's point of view (Arthur, 2011, Raval et al., 2019). It is a data-driven methodology that provides companies with the tools to improve their processes. Increased productivity and a decrease in process variability led to fewer defects, improvement in product quality and customer satisfaction (Keller, 2011). The authors of this paper also applied the Six Sigma methodology for minimizing gate congestion in DCT Gdańsk. Over the past few years, the road gate at the DCT Gdańsk has undergone various modifications, related to the servicing of external trucks at the entrance and exit of the terminal. Nowadays, a new gate automation system uses a combination of smart card technology, optical character recognition (OCR) cameras and unmanned driver kiosks to allow registered drivers to go through the terminal’s gates with no documentation flow or delays (Moszyk et al, 2021). The purpose of this paper is to describe and examine the implemented reorganizations and modernizations to the road gate operations at the DCT Gdańsk which had an impact on the reduction of the average amount of exceeded guaranteed service time for external trucks in DCT Gdańsk. It was decided to set a goal of reducing by 30% the average number of external trucks with exceeded service time of 60 minutes by the end of July 2015, with the assumed increase of the average number of incoming trucks by almost 30%. The company decided to apply appropriate measures to achieve agreed goal.

The framework of Lean Six Sigma was successfully applied as a decision-making optimization tool in strategic/operational levels (Nooramin et al., 2011). It was also to support continuous improvement in the maritime industry (shipbuilding, logistics services and shipping companies) during COVID-19 pandemics (Praharsi et al., 2021). The challenging issues inherent in this problem, and the limitation of existing research related to the topic, robustly motivated presented study. It aimed to apply a Lean Six Sigma framework to reduce the average amount of exceeded guaranteed service time for external trucks at DCT Gdańsk. The Six Sigma methodology used since 2014 in DCT Gdańsk proved to be an effective tool for increasing process efficiency, which led to the improved bottom line results and enhanced satisfaction of customers (truckers) who come to the terminal for container pickup and delivery

2. Assessment of the gate operations at DCT Gdańsk

2.1. Container handling at DCT Gdańsk - current situation

Operations and services provided by the container terminal cover the receipt (export) and delivery (import) of containers (full or empty) into or out of the DCT Gdańsk yard. These services include receiving and delivering containers at the gatehouse and all administrative work related to operations matters, i.e. delivering the documentation and reporting to the shipping lines. The evidence of visible external damage to containers being received or delivered must be reported immediately to the customers. The services may also include the attachment of valid or removal of invalid labels, recording and reporting on the seal number on all full containers (on demand, the attachment of high-security seals to containers received and delivered by truck), and moving containers off chassis to stacking yard area or loading containers onto chassis.

The container terminal provides to the shipping lines and its clients, truck handling in and out of the terminal, 24 hours a day, from Monday to Saturday. Truck handling on Sundays and National Holidays is subject to 24 hours advance notification in writing not later than 1500hrs on Friday and at 1500hrs on to the day before the National Holiday day. DCT Gdańsk provides 24 hours a day, 7 days a week service, excluding time from 02:00 p.m. on Saturday till 02:00

p.m. on Sunday. The container terminal reserves the right to change gate working hours depending on the gate situation, provided the customer has been informed and that it is not deteriorating the quality of the service level. Landside road gate operations in DCT Gdańsk are presented in Figure 1.

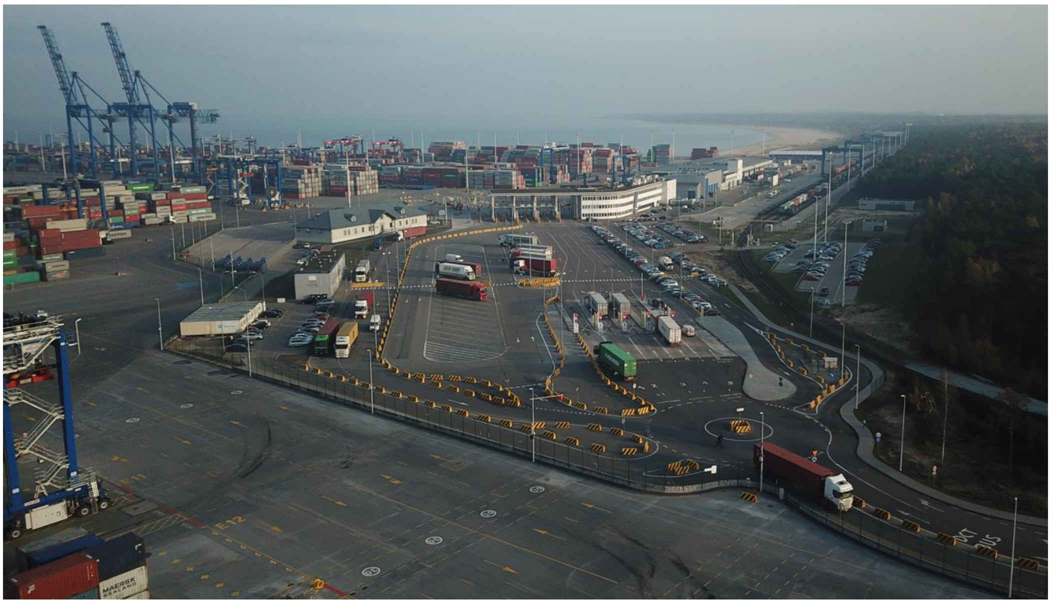


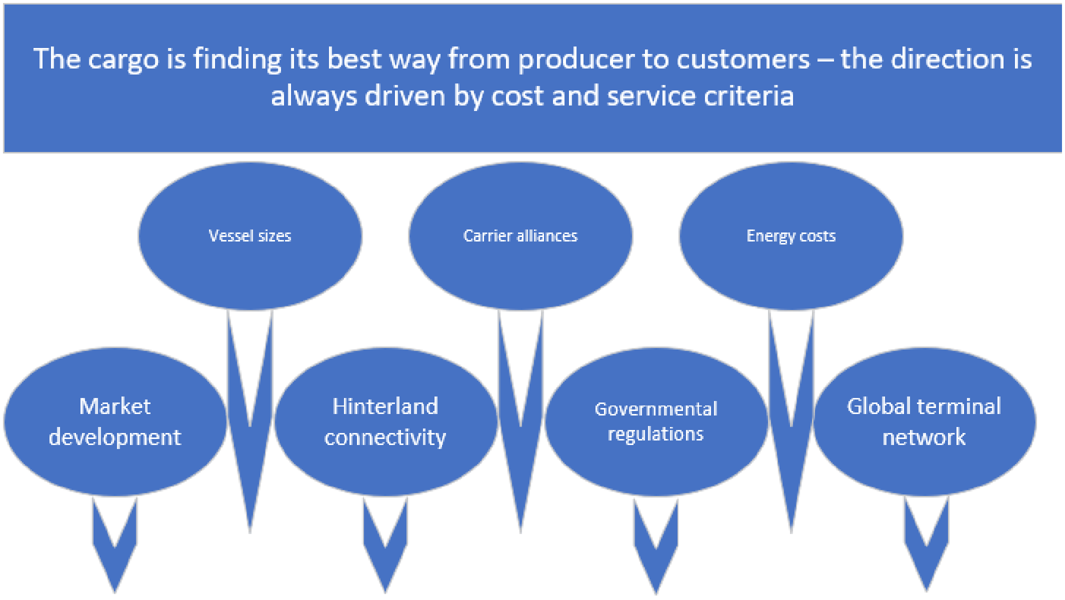
Figure 1. Landside road gate operations – DCT Gdańsk, authors' own work.

The container terminal guarantees a maximum of 60 minutes of turnaround time for a single truck, calculated from the time trucker checks-in on the gate in to the moment of gating-out the terminal provided that the orders/pre-notes of the cargo have been introduced by the customer properly into the Terminal Operating System and that the trucker proceeds immediately to the terminal main gate after the check in at the pre-gate. The container terminal guarantees a readiness to handle up to 100 trucks per hour providing that gate traffic justifies and the container terminal will also look into providing alternative solutions to upgrade the capacity of the parking area.

If the container terminal consistently fails to meet the set standards defined conditions resulting in the trucks waiting time charged to the customer, the customer has the right to seek compensation from the container terminal per truck starting after a grace period of three hours exceeding the guaranteed time.

2.2. Operation Strategies at Container Terminal to guarantee external trucks service time

Global production and consumer markets are in a continuous change and adaptation to new conditions. All implemented developments are being done to reach one target – to improve the competitive situation and help to offer more services as well as more reliable and faster supply chain at better costs. The challenge is based on the known fact that: “The cargo is finding its best way from producers to customers – the direction is always driven by cost and service criteria” as presented in Figure 2 (Ullrich & Baumert, 2018).



How can a container terminal compete in changing market conditions?	
Cost	**Service**
Terminal productivity Labour cost agreement Process & organization	Time Information & transparency Availability

Figure 2. External impacts forcing the container terminals to keep competitive advantage – authors' own work based on the reference (Ullrich & Baumert, 2018).

Operational strategies for adjustment and optimization are being set by the terminal management. In the past, port and terminal constructions were pushed by the strong and sustainable growth of containers worldwide. But the total market demand of the countries or regions wasn’t considered reasonable and the high volatility of trade volumes led regularly to periods of overload and overcapacity. Poorly performing ports can lose volumes as shipping lines (or their alliances) are likely to find capacity in neighboring ports in the region or country. With current expansions, European ports will be capable to handle in 2024 143 million TEUs annually compared with 86 million TEUs in 2014, i.e. an increase by 66% (Prokopowicz and Berg-Andreassen, 2016). Container handling at terminals and ports has been steadily increasing over the past decade. The example of the Port Gdańsk located in Poland confirms the expected increase in container handling by 63 % comparing the years 2021 and 2016, with even four times higher handling when compared 2021 to 2010 [VI]. Thus, the port industry is under pressure to cope with the increasing freight volume. The terminals acting as main hubs can handle containerships of 24,000 TEUs plus which, however, causes allocation problems on the berth (Park and Suh, 2019). A pier length of 500 m or more with proper depth must be secured for a container ship with a capacity of 30,000 TEUs (Son and Cho, 2022).The shallow depth in some seaports requires dredging operations which are associated with high cost to the port operators (Salleh et al., 2021).

The total time of cargo in the port is an essential criterion for freight forwarders to offer their customers (the shippers) the shortest delivery times to consignees. In regions with diverse options to enter the market, as the situation is within the EU, a short port transit time gives a competitive edge to be one of the top performances. This includes, in addition to the quality of infrastructure, the time of border procedure. Thus, for all considerations of port performance in total, the customs procedures including inspections are important. Therefore, the collaboration of customs with the port and terminal operators in the meaning of information flow is relevant for the total time in the port of the containerized cargo and for the logistics performance of countries – the lead time of import and export in one decisive performance indicator to determine logistics performance of countries.

Optimal performance from the customers' point of view is available on demand at any time to the full extent and with perfect reliability. Thus, all considerations regarding port performance must be done in this very general manner availability, time and reliability being the main criteria for satisfactory performance. The most relevant issues regarding the port and terminal optimization are presented in Figure 3.

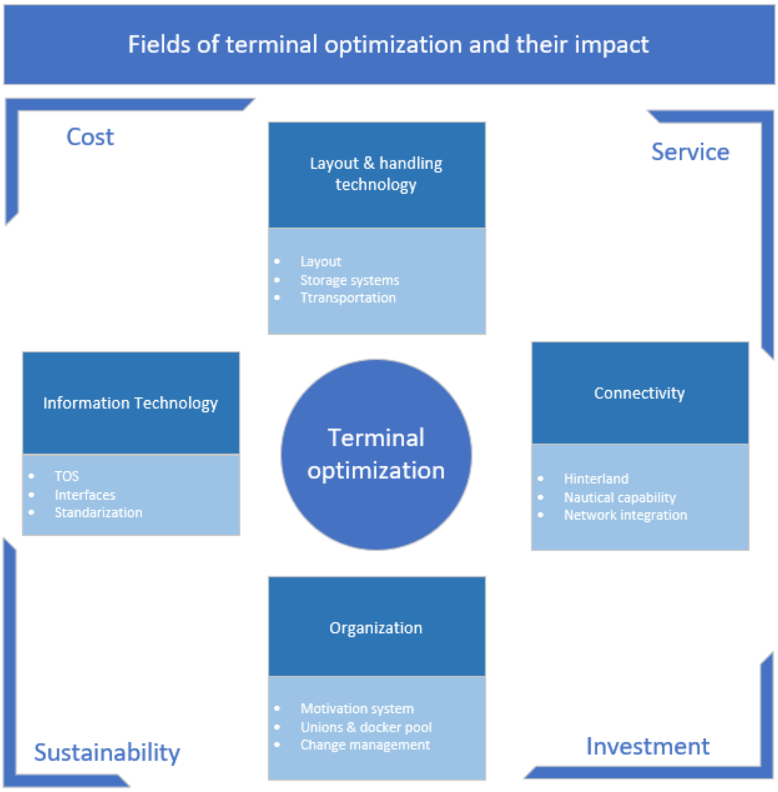


Figure 3. Fields of the container terminal optimization – authors' own work based on the reference (Ullrich & Baumert, 2018).

2.3. Gate operations in 2014 before implementing the changes

DCT Gdańsk gate operation results from the 2014 year can be seen in Table 1. During a single year cargo flows fluctuations and seasonality can be observed, thus container terminal needs to be prepared for different scenarios and volume changes. All of them are directly influencing the yard situation and condition as well as the number of trucks involved in the continuous cargo flow.

Table 1. Terminal gate operation results from 2014 year – DCT Gdansk, authors' own work.

Item	2013 Mnth Av.	Jan-14	Feb-14	Mar-14	Apr-14	May-14	Jun-14	Jul-14	Aug-14	Sep-14	Oct-14	Nov-14	Dec-14	YTD Mnth Av.	Total 2014
Trucks	*8 999*	9 449	8 484	8 815	9 193	9 576	9 465	10 229	9 015	10 705	11 219	9 105	9 338	*9 549*	***114 593***
Containers	*11 077*	12 821	11 409	11 150	11 674	13 326	12 418	13 074	11 461	13 371	14 716	11 713	12 335	*12 456*	***149 468***
Total TEU	*18 473*	19 301	17 358	17 149	18 038	19 610	18 806	15 630	18 764	22 324	23 388	19 057	19329	*19 063*	***228 754***
Productivity															
Time in yard (mins)	*21,0*	23,0	21,0	21,0	21,0	23,0	22,0	21,0	24,0	24,0	23,0	23,0	23,0	*22,4*	***22,4***
Guarantee Time	***60,0***	**60**	**60**	**60**	**60**	**60**	**60**	**60**	**60**	**60**	**60**	**60**	**60**	**60**	**60**
Guarantee not met		241	180	165	149	272	221	202	316	410	339	286	286	*256*	***3067,0***
% of trucks not met		*2,55%*	*2,12%*	*1,87%*	*1,62%*	*2,84%*	*2,33%*	*1,97%*	*3,51%*	*3,83%*	*3,02%*	*3,14%*	3,06%	***2,7%***	

What is important to be noticed is the fact that monthly on average DCT Gdańsk handled between 12 000 containers in 2014. It can be stated that DCT Gdańsk during weekdays handled roughly 550 boxes.

DCT Gdańsk provides clients with an appropriate level of container handling services. The maximum time of the truck's stay in the terminal yard may not exceed 60 minutes, counting from road gate IN to the moment of leaving the terminal – road gate OUT. Since August 2014, the company has noticed a change in truck service time which has increased by over 60%. Together with this, the average number of trucks arriving at the terminal also increased, by more than 7%. DCT Gdańsk decided to set a goal of reducing by 30% the average number of external trucks with exceeded service time by the end of July 2015 with the assumed increase of the average number of incoming trucks by almost 30%. The company decided to apply appropriate measures to achieve agreed goal.

At the beginning, appropriate data collection and measurements were made before implementing the changes. They were collected from February 2014 to the end of January 2015 as presented in Figure 4.

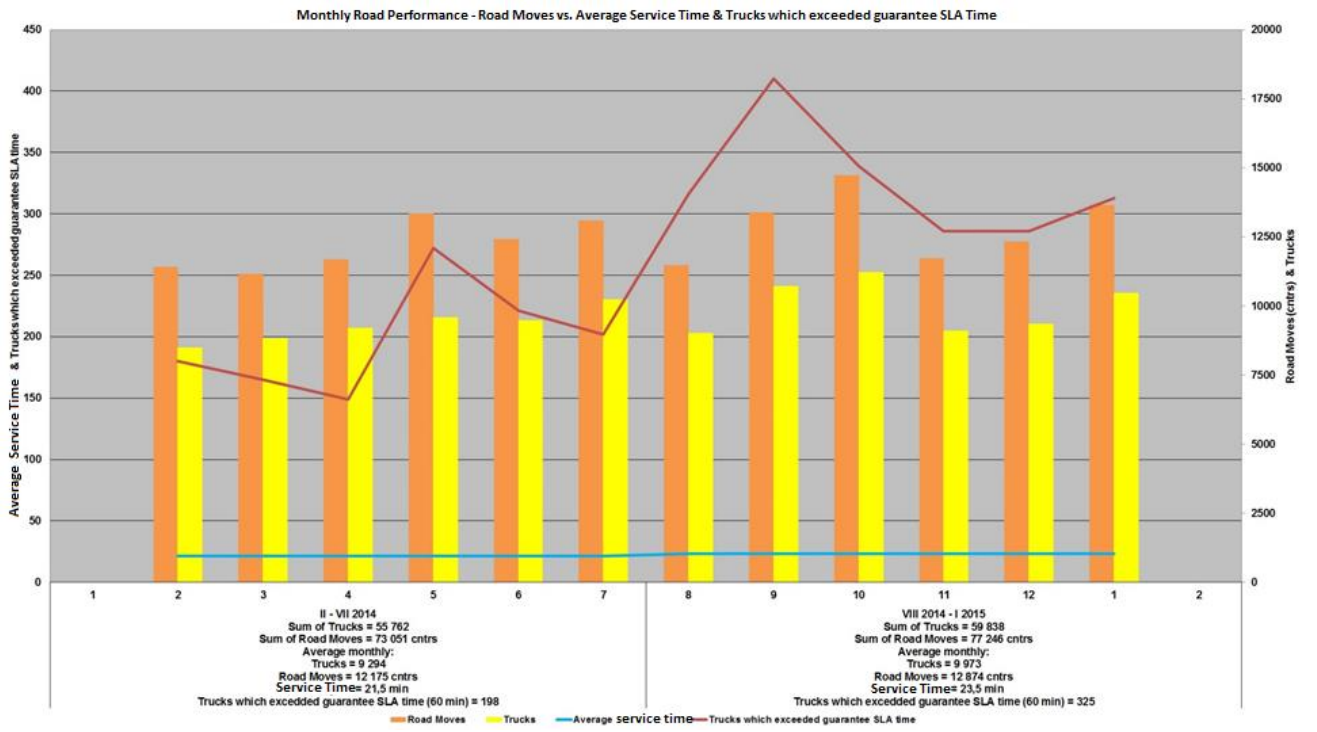


Figure 4. Monthly road performance comparison II – VII 2014 vs. VIII 2014 – I 2015 – road moves vs. average service time & truck which exceeded guaranteed service time at DCT Gdańsk, authors' own work.

The data shows that the average monthly number of external trucks arriving at the port increased by approximately 7.3% (679 trucks), but the average service time of external trucks increased from 21.5 to 23.5 minutes, which gives us about 9% difference. The red line on the chart, which indicates the number of trucks with exceeded guaranteed 60 minutes service time, increased significantly from 198 to 325 trucks, i.e. as much as 64%.

3. Methods and Methodology

Six Sigma methodology was used for achieving process efficiency and effectiveness, resulting in enhanced customer satisfaction and improved bottom line results. The research methodology used in the case study was based on DMAIC methods and included the following phases (Keller, 2011; George et al., 2004; Gygi and Williams, 2012):

- *Define phase* – in which the goal, objectives and deliverables were articulated. The DCT Gdańsk business case was described, with the plan to increase the container handling in gates relation by 100%. Such an increase in the import and export of containers results in a significant, almost 80% increase in external truck traffic. At the moment of defining the scope, an average of more than 3% of external trucks were serviced for more than 60 minutes of contracted service time. The process of defining the objectives of the case study is shown in Section 4.1;
- *Measure phase* – process definition at the detailed level to understand the decision points and comprehensive functionality within the process. It includes the metric definition to verify a reliable means of process estimation, the process baseline estimation to clarify the starting point of the case study, and measurement system analysis to quantify the errors associated with the metric. The objectives of the measure phase are presented in Section 4.2;
- *Analyze phase* – pinpointing and verifying causes affecting the key input and output variables tied to the study goal, to find the critical causes. Preparation of the charts and other analyzes that show the link between the targeted input and process. Identification of value added and non-value added work and calculation of process cycle efficiency. The deliverables of the analyze phase are shown in Section 4.3;
- *Improve phase* – developing, selecting, and implementing the best solutions, with controlled risks. The main purpose of this stage is to learn from the pilot's implementation of selected solutions and execute full scale implementation. After that, the effects of the solutions are measured with the KPIs developed during the *Measure*

phase. The Main goal of this phase is to achieve an improved process that is stable, predictable, and meeting customer requirements. The outcome of this phase is presented in Section 5.1.

- *Control phase* – during which the case study was completed and the improved process handed over to the process owner along with the procedures for maintaining the profits. The main objective of this phase is to document a plan to transfer the improved process back to the process owner and implement a monitoring system for the implemented solutions along with a process control plan with specific metrics to be used in regular process auditing. Competed study documentation, including lessons learned, and recommendations for further actions or opportunities are shown in Section 5.2.

4. Road gate strategies study to reduce the external trucks service time

To improve overall terminal road gate operations, reduce congestion at terminal gates and its resulting economic, operational, and environmental implications different solutions have been proposed and implemented over the last few years. These can be distinguished into two planning/control levels which includes the strategic level (e.g. capacity expansion), and the tactical/operational level (e.g. extending gate hours, appointment systems etc.). As demand increases and operation efficiency decreases at the landside of marine container terminals and the surrounding roadway network, it is expected that more states will follow this paradigm (Maguire et al., 2010).

The DCT Gdańsk container receipt/delivery process identification is presented in Figure 5. It shows the large number of complex activities influencing the efficiency of the container handling due to the possible gate congestion at a marine container terminal.

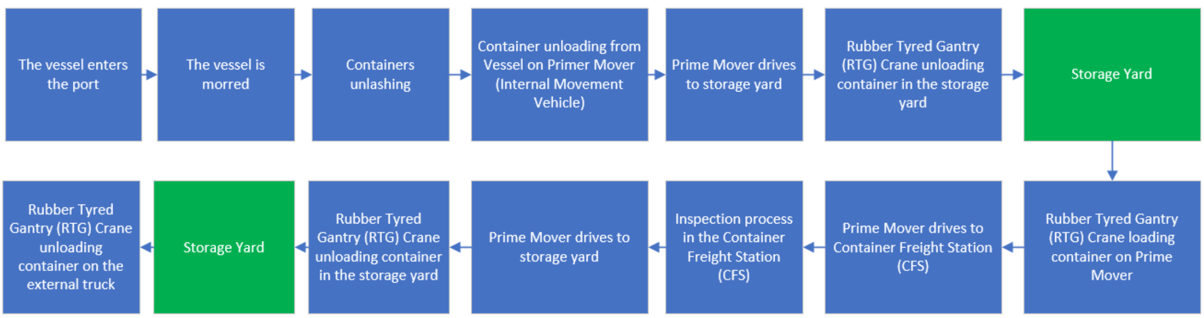


Figure 5. The main processes of container receipt/delivery on/from external truck at DCT Gdańsk, authors' own work.

DCT Gdańsk in fourth quarter of 2015 and during 2016 assumed in the business plan the 100% increase in container handling at the road gate. As a result, the increase of container handling activities in the import and export of containers was expected, i.e., almost 80% of the increase in external truck traffic.

The scope of the gate strategies study included the analysis of the number of external trucks receipting and delivering containers, their average service time and the number of trucks which are exceeding guaranteed service time. The case study team could implement any proposed change based on proper data analysis after approval by the Operations Director. However, the changes were not supposed to concern the activities at the quay and on the railway siding, and there was no budget for the purchase of additional hardware, software, or an increase in employment. It was found that on average, more than 3% of incoming trucks were served longer than the required 60 minutes.

4.1. Define phase

It starts with identifying who the customer is and what their expectations and requirements are for the products and services. These requirements are then translated into the customer's CTQ (Critical to Quality). It focuses on setting the boundaries of the study. It is important to establish what are the goals of the team, the boundaries of the study and its focus (what belongs and what does not belong to the study). It uses process mapping to create a clear picture of the boundaries of a study.

At the case study level, an "outside" perspective helps to understand what the client really wants in relation to the process. An external customer is the person or company that is the originator of the process output and its end user. The crucial thing is to understand how the client perceives the process, on what it is paying attention when measuring process results. What it requires and what needs to be done to meet its requirements.

During the study, it is important to look at the list of clients and divide them into similar groups. This helps to focus on the customers related to the process in the aspect of the most important and similar needs and priorities. Customer segmentation makes it possible to understand the specific needs of different groups and focus on appropriate improvement actions.

The above-mentioned steps were crucial to understanding the trucking companies' and truck drivers' perspectives plus the need for the improvement of the truck service time process. In the terminal operating system of DCT Gdańsk, there are over 2000 trucking companies registered that use almost 7000 truck drivers who utilize close to 13000 trucks on a daily, weekly and monthly basis.

The study began with creation of the study charter, which is a document that allows to define the study framework for the improved process and defines the goals to be achieved. In this card, it is clearly described what is expected from the team and it helps to focus on the most important activities and areas related to the priorities of the organization.

The business case described the general situation with respect to the process that will be tested and outlined the reason why the study should have a business priority. DCT Gdańsk in the business plan for the 4Q of 2015 and 2016 year planned 100% increase in container handling in road gate operations.

Definition of the problem accurately described the problem as it would have to be solved. It represents the observed symptoms and / or effects of the problem. During the case study preparation, an average of more than 3% of external trucks was serviced for more than 60 minutes of contracted service time. The case study goal was to reduce of 30% average amount of exceeded guaranteed service time for external truck drivers in DCT Gdańsk until the end of July 2015, with assumed increase of the average number of trucks serviced by almost 90%.

The SIPOC map is a tool that facilitates the documentation of all processes in the company. It helps to create an "image" of the process by creating a "high-level" flowchart. The external client receives the process output that is the result of the process, such as: product, service, processes, or resources. The process itself is a series of steps or actions that are expected to lead to the expected result (outputs). The key is to identify the input data and their supplier for the process to function properly.

The SIPOC map of the container receipt/delivery process at DCT Gdańsk is presented in Figure 6. The process starts from the verification of the driver’s data and the acceptance of the terminal rules and procedures. Only then data can be verified in the terminal operating system and the system can allow to entry terminal premises. A driver is making its way to the terminal location from which a container will be picked up or delivered. When the container handling process is completed, a driver is in transit to the exit gates where data is verified again by the system to obtain permission to leave the terminal.

S	I	P	O	C
Driver	Data: • First & last name • Vehicle & container number • PIN / Booking	**Verification of drivers data**	Data verified	Pre-Gate Employee
Pre-Gate Employee	Rules of Gate Operations	**Acceptance of the rules**	Permission to go to the gates	Driver
Gate Employee	Verification: • Vehicle & container number • Container damages • Seals / ISO type	**Data verification in system**	Permission to enter the termianl	Driver
Driver	Printing a ticket with location in terminal / Raising barrier	**Entrane into the terminal**	Transit to the yard location	Terminal Equipment Operator
Terminal Equipment Operator	Terminal location	**Pick up/delivering of container**	Transit to the exit gates	Driver
Gate Employee	Verification: • Vehicle & container number • Container damages • Seals / ISO type	**Data verification in system**	Permision to exit the terminal	Driver
Gate Employee	Raising barrier	**Exit from the terminal**	Exit from the terminal	Driver

Figure 6. SIPOC map of the container receipt/delivery process at DCT Gdańsk on/from an external truck, authors' own work.

Quick hits are additional steps in finding solutions for the process improvement at the early stage of the study. They quickly improve the process and motivation to continue working on major changes in the process. During this phase, a decision was made to streamline traffic at the gates. Initially, DCT Gdańsk used 4 gates: 2 for entrance – gates 2 and 4, plus 2 for exit – gates 7 and 8. DCT Gdańsk decided to start operations on additional gates: entrance gate 3 and exit gate 6 as presented in Figure 7. Gate number 5 was not used due to safety and operations reasons.

Figure 7. Quick hits – External truck leaving DCT Gdańsk using gate number 6, authors' own work.

This resulted in the commencement of infrastructure works to facilitate the proper transit at the gates. Implemented idea, allowed drivers to use the gate complex safely and efficiently.

4.2. Measure phase

The main objectives of the Measure phase are the identification of key indicators for the process, defining the desired level for the indicators along with information on the specification and its boundaries as well as defects. During this phase, building a data collection plan, validating the measurement system, collecting data to measure the current state (process), analyzing the volatility of indicators, and determining the type of data are crucial. Measurements can be applied to any type of the process or product in order to evaluate its quality.

The main purpose of realizing the Voice of Customer (VOC) tool is to set priorities and goals consistent with customer needs. Total Quality Management (TQM) is management of philosophy concerned with people and process that focused on customer satisfaction and improves organizational performance (Othman, 2021). Implementing a guaranteed policy that goes beyond the market as a whole, a company indicated that it stands behind the quality of its services, and is ready to demonstrate its commitment by taking a financial risk. This is where the Voice of the customer and Total Quality Management come together. Voice of Customer –

trucking company and external truck driver – who are receipting and delivering containers from/to DCT Gdańsk is presented in Figure 8.

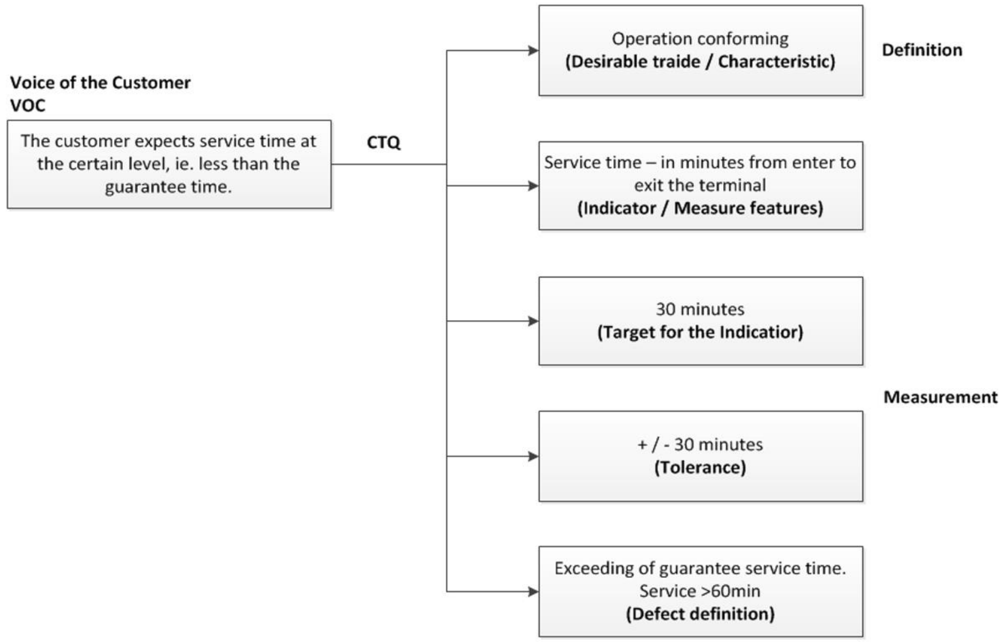


Figure 8. Voice of the Customer – customer service time expectations at DCT Gdańsk, authors' own work.

The proposed data collection plan is presented in Figure 9. The data collection plan determines the segmentation factors and the type of data which should be gathered. If the data is given in the wrong format, it cannot be used in the next phase. The sampling strategy must be determined to collect data not from the entire population but from the representative group. After establishing the measurement system analysis, the final step is to start collecting data.

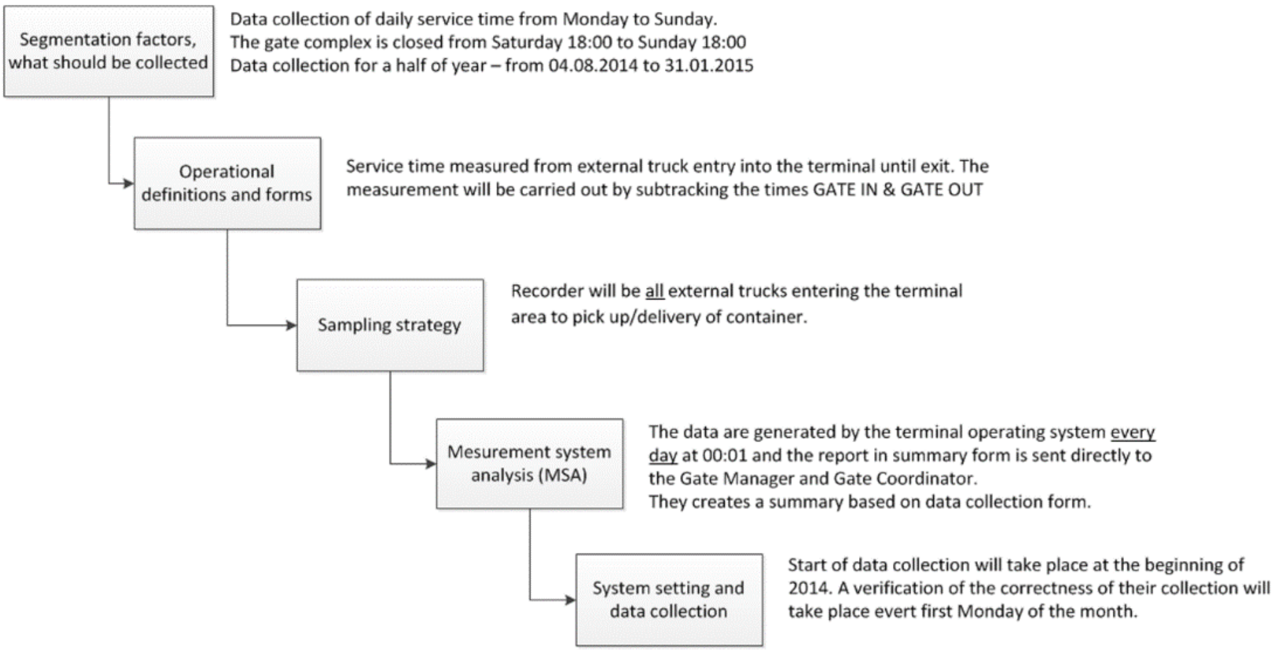


Figure 9. Data collection plan, authors' own work.

Measures of central tendency and span show how tightly data cluster around a central point. The most common measures of central tendency are mean and median values. The histogram shows the shape of the distribution by showing how often the values in each interval (classes or inversions) appeared.

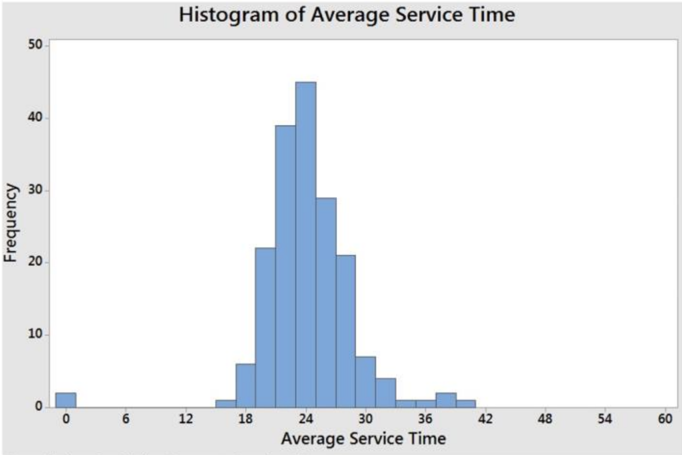
Histograms from the data collected from February 2014 to the end of January 2015, created using the MINITAB software (Brook, 2017), are presented in Figure 10. Results show that:

- the average service time is 23.6 minutes and median 23 minutes – Figure 10 a. It is seen that both measures are close to each other and significantly below target for the described indicator, which was 30 minutes (+/- 30 minutes).
- there are days during which service time exceeded guaranteed time – defect definition. The histogram presented in Figure 10 b shows that there was an average of 10 defect cases per day, with a median of 7 cases.
- the number of vehicle services in DCT Gdańsk during a single day is characterized by a bimodal histogram with two peaks – Figure 10 c. The data represents the same process, however, the first peak refers to the number of trucks over the weekend and on public holidays and the second peak represents the number of trucks on weekdays.

Regarding the number of defects, the goal set in DCT Gdańsk was to reduce by 30% the average number of external trucks with an exceeded service time of 60 minutes by the end of July 2015.

According to this, the number of cases with exceeded service time should not be higher than 7 defects per day by the end of July 2015. Although the results show that the average service time is below the target of 30 minutes, for the analyzed period and the number of trucks served, but the assumed increase in the average number of trucks serviced by almost 90% might disrupt the operations at the gates, and as a result, the average service time may be longer. Due to this, Quick hits were introduced during the Measure phase to quickly streamline the process and to be prepared for an increased number of truck servicing. Quick hits concerned CCTV cameras located in the DCT Gdańsk gate complex. The gate complex, according to the International Ship and Port Facility Security Code (ISPS), is equipped with CCTV cameras to provide a constant 24h preview. During the Measure phase of the case study, the decision was made to change camera locations and settings, so the whole operations department gained a preview of the parking lot situation – Figure 11. The view from the camera is displayed on the monitors in the Control Room. Thanks to the implemented idea, dispatchers who manage the movements of container terminal equipment, gained a constant view of arriving external trucks. This helped them allocate resources adequately and quickly in response to changing requirements.

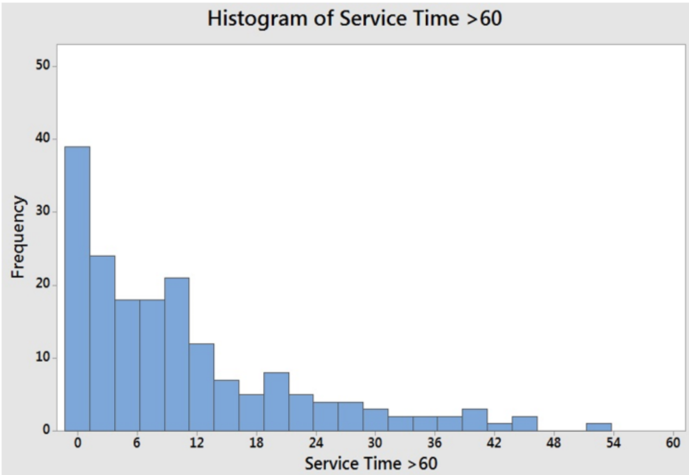
a)



Descriptive Statistics: Average Service Time

Variable	Mean	StDev	Variance	Minimum	Q1	Median	Q3	Maximum
Average Service Time	23,619	4,504	20,282	0,000	21,000	23,000	26,000	39,000

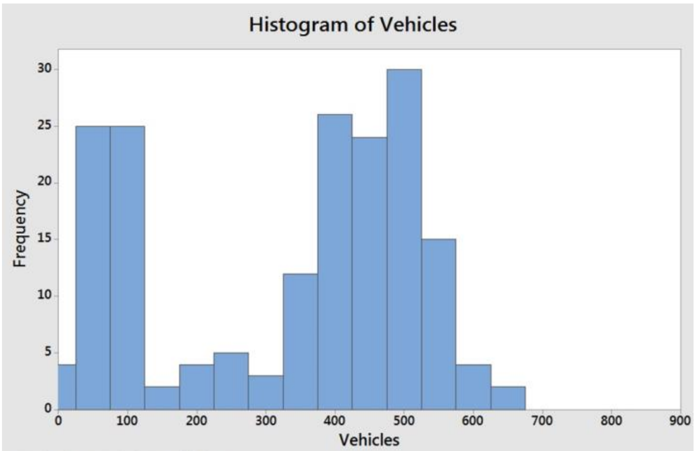
b)



Descriptive Statistics: Service Time >60

Variable	Mean	StDev	Variance	Minimum	Q1	Median	Q3	Maximum
Service Time >60	10,674	11,249	126,532	0,000	2,000	7,000	15,500	53,000

c)



Descriptive Statistics: Vehicles

Variable	Mean	StDev	Variance	Minimum	Q1	Median	Q3	Maximum
Vehicles	327,5	188,9	35680,2	0,0	90,0	393,0	486,0	665,0

Figure 10. Histograms from the data collected in the period from February 2014 to the end of January 2015: a) Average Service Time during a single day, b) Cases per single day of Service Time > 60 minutes, c) Number of Vehicles during a single day, authors' own work.

a)

b)

Figure 11. View on the parking lot at DCT Gdańsk available for the whole operations department after introducing the Quick hits during the Measure phase: a) view on the Parking 1, b) view on the Parking 2, authors' own work.

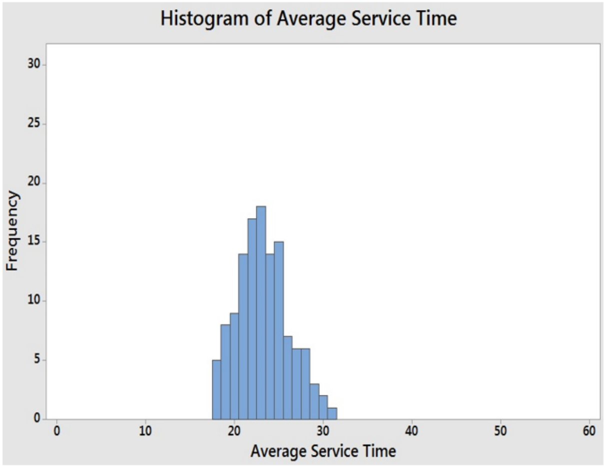
4.3. Analyze phase

The main goal of Analyze phase is to use the collected data to find patterns, trends, relationships that can help in suggesting, supporting, or rejecting theories related to causes or effects. Segmentation of the process output data gives a much better picture of how the process works. As it was shown in the Measure phase, the number of vehicles services in DCT Gdańsk during a single day of the whole week was characterized by a bimodal histogram with two peaks – Figure 10 c. In Analyze phase, the focus will be put on the weekdays peak (the second peak in Figure 10 c) with the bigger number of the vehicles serviced at DCT Gdańsk, and thus with a greater influence on the course of the process.

Histograms from the data from the weekdays, collected from February 2014 until the end of January 2015, are presented in Figure 10. As expected, with heavy traffic on weekdays, it can be stated that:

- the average service time is 23.2 minutes, the median 23 minutes – Figure 12 a. These values are remarkably close to the values obtained for the data from the whole week (Figure 10 c), and both measures are close to each other, significantly below target for the described indicator, which was 30 minutes;
- there are more cases during which service time exceeded guaranteed time comparing to the data from the whole week. Histogram presented in Figure 12 b shows that there was an average of 14 defect cases per day, with a median of 11 cases;
- the average number of vehicle services in DCT Gdańsk during a single weekday was higher when compared to the average number of vehicles from the whole week, amounting to 440 (Figure 12 c) and 328 (Figure 10 c), respectively.

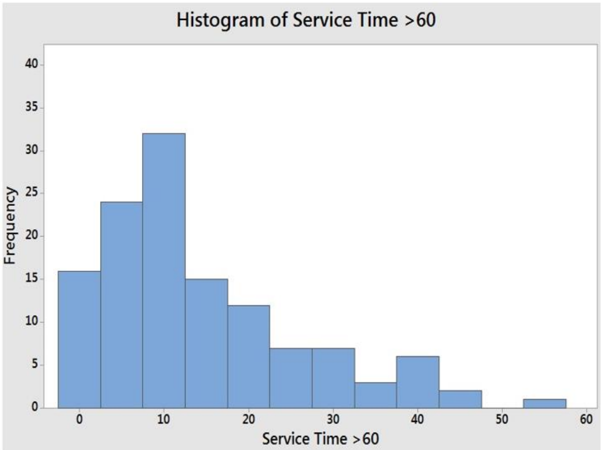
a)



Descriptive Statistics: Average Service Time

Variable	Mean	StDev	Variance	Minimum	Q1	Median	Q3	Maximum
Average Service Time	23,240	2,914	8,490	18,000	21,000	23,000	25,000	31,000

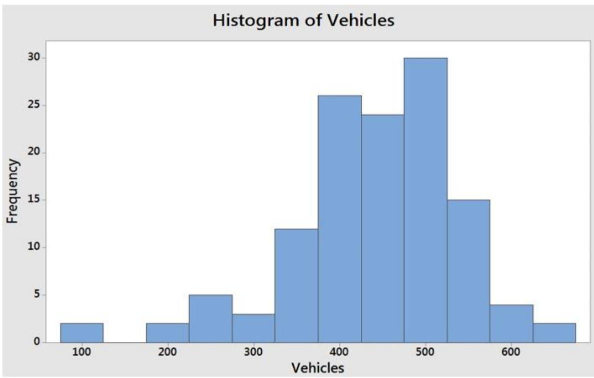
b)



Descriptive Statistics: Service Time >60

Variable	Mean	StDev	Variance	Minimum	Q1	Median	Q3	Maximum
Service Time >60	14,23	11,65	135,62	0,00	6,00	11,00	20,50	53,00

c)



Descriptive Statistics: Vehicles

Variable	Mean	StDev	Variance	Minimum	Q1	Median	Q3	Maximum
Vehicles	440,56	97,50	9507,18	104,00	389,50	448,00	512,00	665,00

Figure 12. Histograms from the data collected during weekdays in the period from February 2014 until the end of January 2015: a) Average Service Time per single day, b) Cases per single day of Service Time > 60 minutes, c) Number of Vehicles during weekdays, authors' own work.

Next step of Analyze phase was to carefully analyze the process before external trucks entered DCT Gdańsk premises. The truck service time (TST) at the Gate Complex is defined as an average time of service of single or multiple transactions on an external truck. The detailed process analysis based on the measurements gave results of 00:01:13 for Pre-Gate office employee, 00:00:54 for Gate-In employee and 00:00:42 for Gate-Out employee.

The average service time for external trucks on the Pre-Gate is slightly longer than the average time for the other two Gates, making it the greatest impact on the smooth flow of trucks that constantly come to DCT. Based on the determined times and assuming a constant flow of containers, a team consisting of one Pre-Gate employee and two Gate employees (Gate-In & Gate-Out), should be able to handle up to 1180 external trucks per day. This can be calculated using the basic formula:

$$n_t = T \,/\, TST \tag{1}$$

where: n_t – number of trucks handled, T – analyzed period, TST – the longest truck service time (in the analyzed case for Pre-Gate).

Taking into consideration the work shift pattern of two employees in Pre-Gate and three / four employees at the Gate-In and Gate-Out, the number of serviced trucks can be doubled. Unfortunately, the immediate but undesirable effect of more efficient service at DCT Gdańsk Gate Complex was the constant congestion inside the terminal. Actions taken to solve this problem are presented in the following Section.

5. Improvements, Controls and Achieved Benefits

This perfect storm of hundreds of external trucks inside the terminal caused multiple challenges to the performance of the terminal. To meet the goal of reducing the average number of exceeded guaranteed service times for external trucks as described in the case study, the first step was to understand the potential process variables. To identify them, the cause-and-effect diagram was created as shown in Figure 13. This helped to look beyond the visible and obvious symptoms to uncover the roots of all potential problems and ensure that a balanced list of ideas was generated during the brainstorming session.

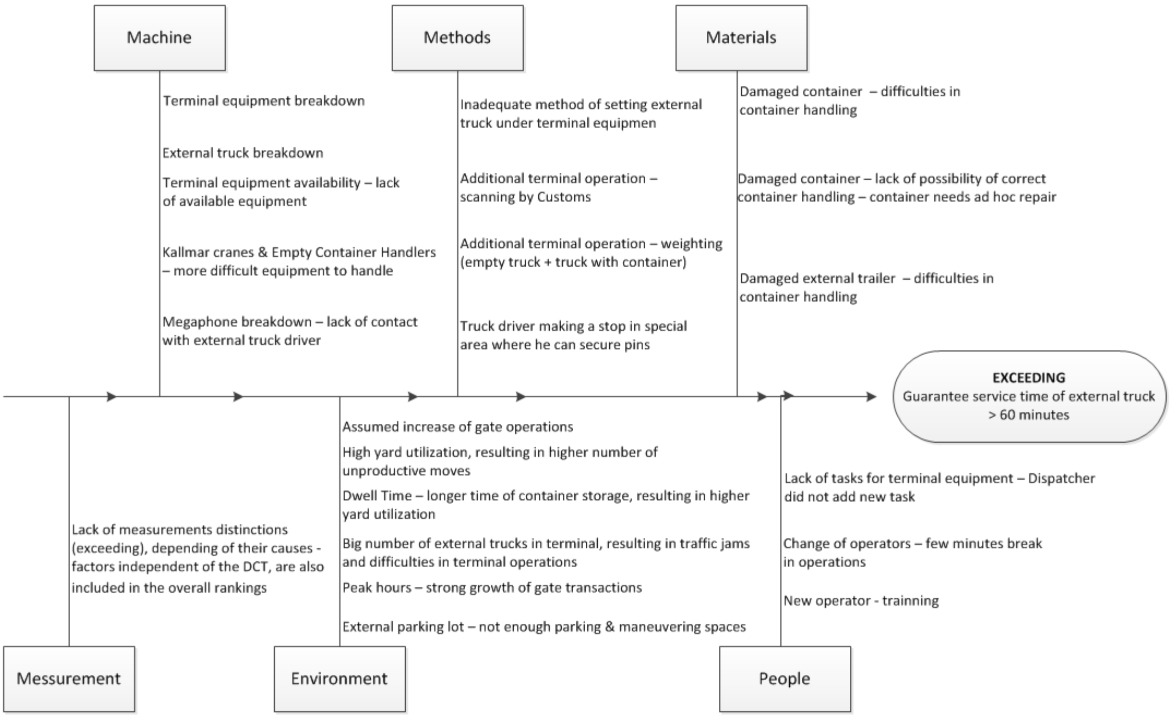


Figure 13. Cause-and-effect diagram for exceeding guaranteed service time at DCT Gdańsk, authors' own work.

The prioritization of the presented process variables is crucial to obtain consensus as to which of them are priorities for further detailed study. Prioritization is done based on the causes that may be under the control of the terminal and an assessment of the effect of the respective causes on the problem.

During the internal case study meetings, after the analysis of available data, the main reasons with the greatest impact on the course of the process, and at the same time with possible terminal control were indicated:

- many external vehicles in the terminal, causing traffic jams and difficulties in terminal operations;
- Peak hours – rapid growth in gate transactions;
- External parking lot – not enough parking & maneuvering spaces

Number of external vehicles in the terminal was analyzed with a scatterplot, which is an important graphical tool for studying the relationship between causes and effects. The rationale behind the scatterplot is that a change in the critical cause causes a change in the critical effect. Figure 14 shows the relationship between the number of vehicles and the number of trucks exceeding the guaranteed time. It is clearly seen that the number of vehicles has an impact of the truck service time in DCT Gdańsk. The more vehicles, the more trucks exceed the guaranteed time and the longer service times.

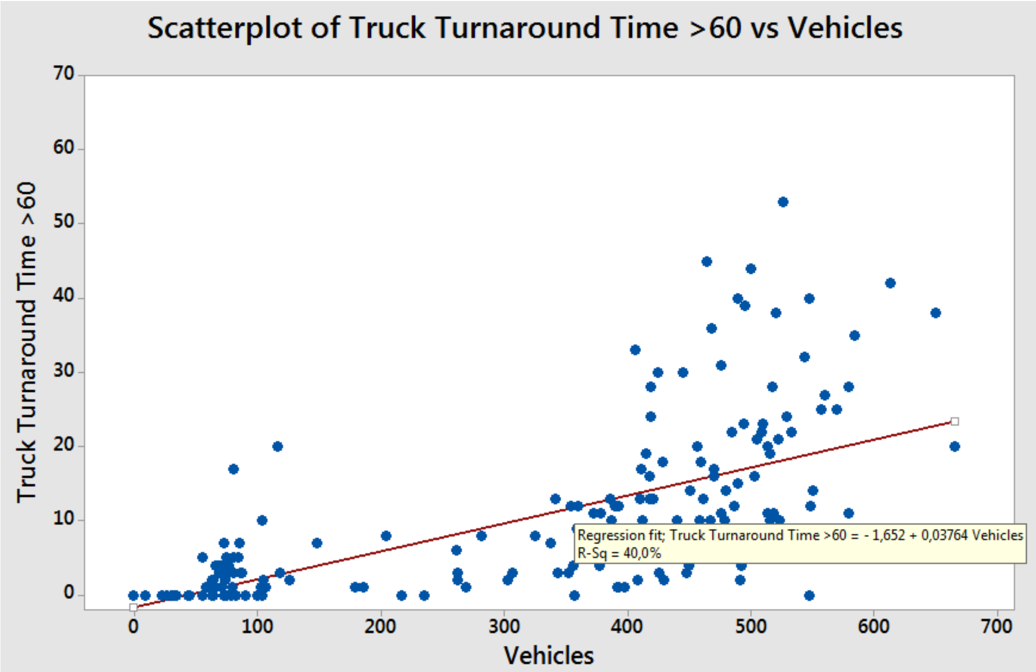


Figure 14. Scatterplot of Truck Turnaround Time >60 vs number of vehicles during weekdays at DCT Gdańsk, authors' own work.

The purpose of justifying the introduced changes and repairs is to understand what the company's profit resulting from the conduct of a given study may be. The idea is to verify that the authors are working on the right issues that could have a significant impact on the business.

According to the internal estimates, if the changes are not introduced, the direct effect of the number of external trucks handled (increased traffic in the terminal will cause its congestion) will reduce the vessel's efficiency, on average by 10%. Potential additional costs resulting from the decrease in the ship's efficiency were calculated at the level exceeding 150 000 USD.

5.1. Improve phase

In the Analysis phase, the root causes of variability have been identified, while in the Improve phase, solutions were designed specifically to reduce or eliminate the root causes that have the greatest impact on the baseline characteristics of the study, thanks to which the new process will be able to meet the client's requirements.

The starting point for the Improve phase is the critical causes and the data analysis performed in the Analyze phase. Using the tools from the Improve phase, the solutions that reduce the outflow of verified critical causes were discovered. The key is to constantly perceive the process from the customer's perspective when looking for the most suitable solutions. When critical causes are clearly defined the potential solutions are more obvious. Designing experiments may be the best path to a satisfactory solution. In situations where the critical cause is a combination of factors and the solution is not obvious, creative thinking may be the better method for a good solution. There are many tools for generating ideas, such as benchmarking, sharing best practices, and brainstorming. The results from these tools are presented below.

Container Terminal Benchmark – Vehicle Booking System for the following process improvements, due to the current situations and anticipated gate traffic growth (30% in 2016, 20% in 2017, 15% in 2018) with higher frequency and magnitude of peaks:

- flattening the peaks level;
- even distribution of gate traffic;
- effective planning of manpower and resources;
- optimal tasks distribution / reducing of unproductive moves in the yard;
- increase in the efficiency of the ship and rail;
- shortening the external trucks service time;
- **implementation costs – around 100,000 EUR**.

Brainstorming - identification of other possible solutions for the process improvements:

- Parking lot optimization – increased throughput;
- CB radio – information for truck drivers about operations status;
- reducing number of employees serving Pre-Gate & Gate – slowing down the entry of trucks to the terminal;
- Guest Paging System – vibrating pagers when driver should enter;
- Gate Complex – open on Sunday from 14:00 (previously Sunday from 18:00)
- Gate Steering System – dosing the number of trucks entering the terminal;
- Information for truck drivers on the website;
- Operations stoppages for 15/30 minutes on Shift Manager signal;
- Change of Parking lot rules – increased throughput;
- Transfer of the non-container vehicles from the gate no 1 to no 9;

- Waiting room / container for drivers – cards with a sequence number;
- Information board with the registration number of the truck that should enter the terminal
- SMS gate - sending SMS to truck drivers when they are allowed to enter the terminal.

During the idea separation works, the multi-voting tool was applied, which is a decision-making technique used to skim a list of ideas down to a manageable number. The multiple voting is an excellent tool for reaching a consensus on the option that is most beneficial to the company according to the group working on the improvements. Team members vote for the options that they believe are best suited to the current conditions and the feasibility of the ideas. The votes were counted and the ideas were separated to most effectively support the case study goal of reducing the average number of external trucks that exceed the guaranteed service time at DCT Gdańsk. Five ideas were identified that were considered the best to implement:

- Gate Steering System;
- Gate Complex – open on Sunday from 14:00;
- Information for truck drivers on the website;
- Parking lot and GATE-IN lines optimization;
- Change of DCT Gdańsk parking lot rules (e.g. shortening the parking time).

The “should be” mapping serves as the basis for the documentation of new procedures, a step that will arise during the Control phase. A created map will link all proposed changes to the process steps, identified as the potential and feasible solutions. It is important to ensure that the map accurately reflects the process. The important thing is that once the solution is implemented, the “should be" map becomes the "as is" map. Regardless of which solution is chosen, at this stage a "should be" map is created for each of the potential solutions. The “should be” map of the implemented ideas for the container handling process process realised by the external trucks is presented in Figure 15.

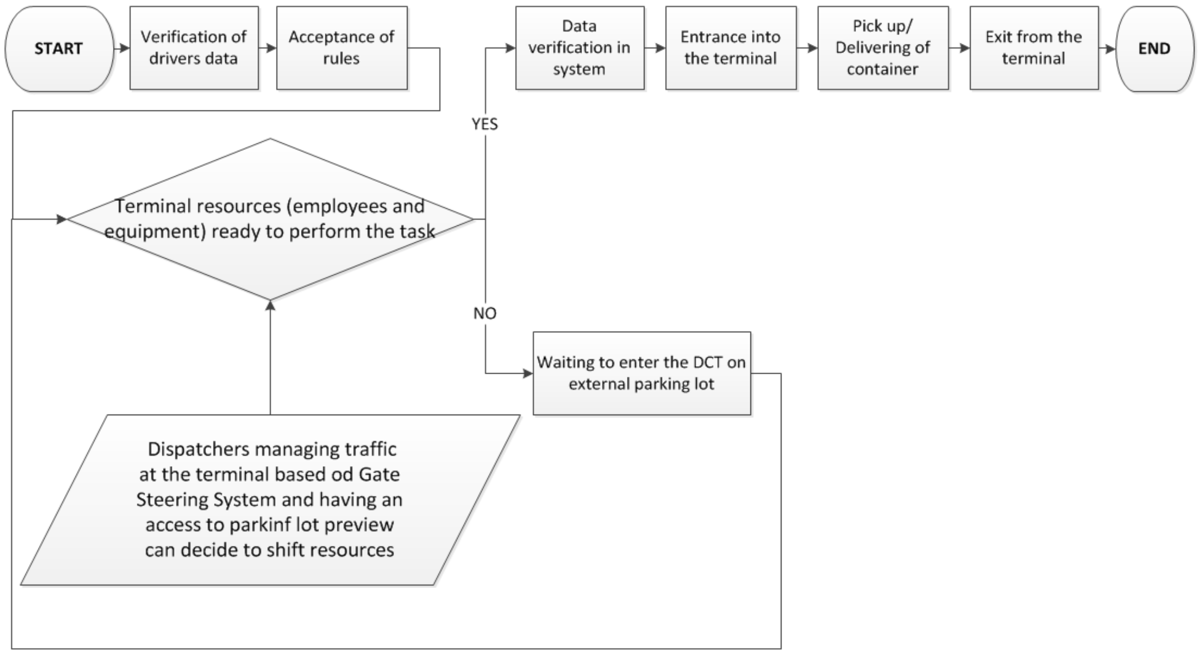


Figure 15. The "should be" map for the new implemented ideas for the container handling process realised by the external trucks at DCT Gdańsk, authors' own work.

The introduced Gate Steering System is the gate signalization management tool deployed on the IN-gates which allows for dosing the declared number of external trucks (transactions) into the terminal yard. The system is controlled by terminal Dispatchers, who based on terminal resources (operators/equipment) and the current state of terminal tasks, properly dispense external trucks. The system was originally designed and integrated with the Terminal Operating System, from which the actual number of terminal transactions is directly collected. The Gate Steering System allows a full preview of the number of transactions and the colour of lights informing about the current status of the IN-gates– closed or open (Figure 16). The number of trucks which can enter the terminal is a key component of the entire system. The limit value is specified by the terminal Dispatcher (based on the operational experience) in "Gates Parametrization" and the lights before entering the gates change automatically (a gate closed/open – red/green light permanently). The Gate Steering System specifies the number of transactions that are currently in progress in the terminal yard. If the number of entering trucks exceeds the number of transactions (value displayed in the information section called "Number of Transactions in the yard"), all lights switch to red colour automatically, until the number of transactions falls below the specified number of trucks given as a value in "Gates Parametrization", as presented in Figure 16. For the situation being analysed at a given time, the value of 44 transactions in the yard is below the value of 45 trucks which can enter the terminal so all lights are green.

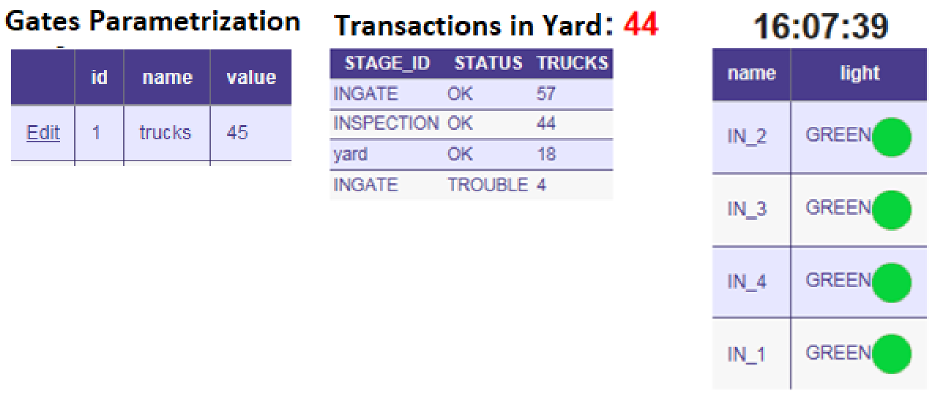


Figure 16. Gate Steering System implemented at DCT Gdańsk to control the number of entering trucks, authors' own work.

The application of the Gate Steering System eliminated the congestion inside the terminal during the whole week but the peak hours were observed on Mondays because the terminal was closed until 18:00 on Sunday. To reduce Monday's peak hours the Gate complex was opened on Sunday from 14:00. The main goal was to facilitate and accelerate the container handling process during the weekend. It resulted in increased handling on Sundays as presented in Figure 17, and consequently, the peaks decreased on Mondays.

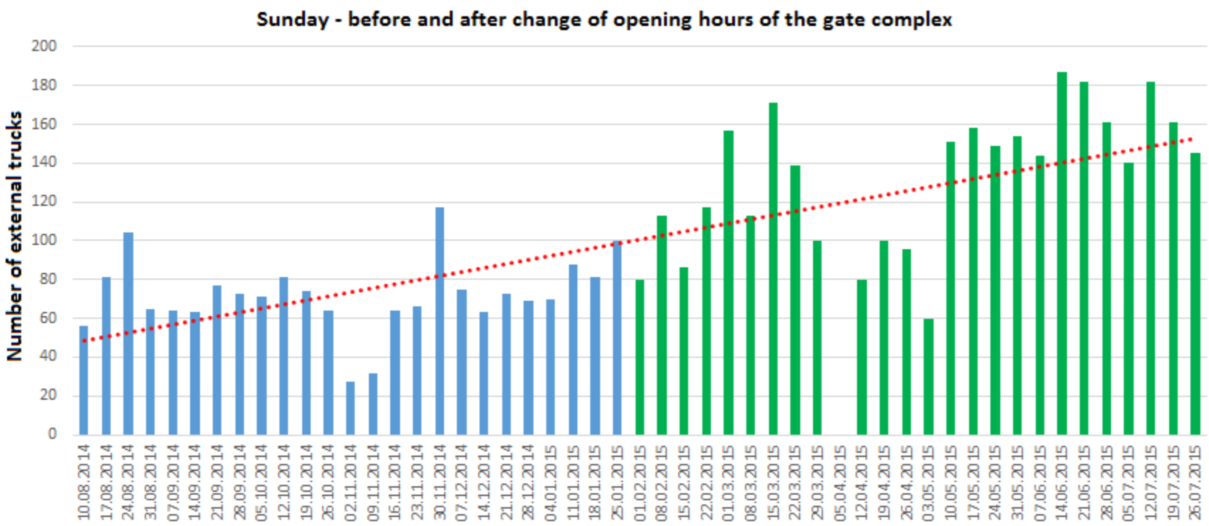


Figure 17. Number of external trucks on Sunday – before (blue bars) and after (green bars) change of opening hours of the gate complex at DCT Gdańsk, authors' own work.

The Gate Steering System streamlined the handling processes inside the terminal, but due to the limitations on the entry of trucks, the traffic in the external parking lot increased periodically. Information for truck drivers about the current situation before entering the terminal to improve traffic in the external parking lot was posted on the DCT Gdańsk website – Figure 18. All information was public, and nothing was hidden. There was 24/7 coverage of the information with a direct linkage to the DCT system and CCTV. It was crucial to provide key information on the number of external trucks waiting to enter the terminal, average service time at the terminal in the last hour, currently handled vessels on the quay and the situation in the parking lot, with photos updated every 5 minutes. All these changes help truck drivers make the final decision if it is sufficient for them to drive to DCT or wait in the parking lot outside the port or city. They can choose if there is time for them to make a break and rest before arriving at the terminal or, based on the information provided, whether they will be able to come to DCT and be served.

Figure 18. Information for truck drivers on the DCT Gdańsk website, authors' own work.

In addition, the external parking lot rules were changed to increase its throughput. The time of waiting for external trucks at the parking lot was reduced from 12 hours to 2 hours. Truck drivers who exceeded the waiting time were blocked and charged with the fee. The external parking was optimized by preparing dedicated queues of external truck drivers in a straight line, as presented in Figure 19. The goal was to improve throughput and safety during entry into the terminal plus increasing the amount of waiting space.

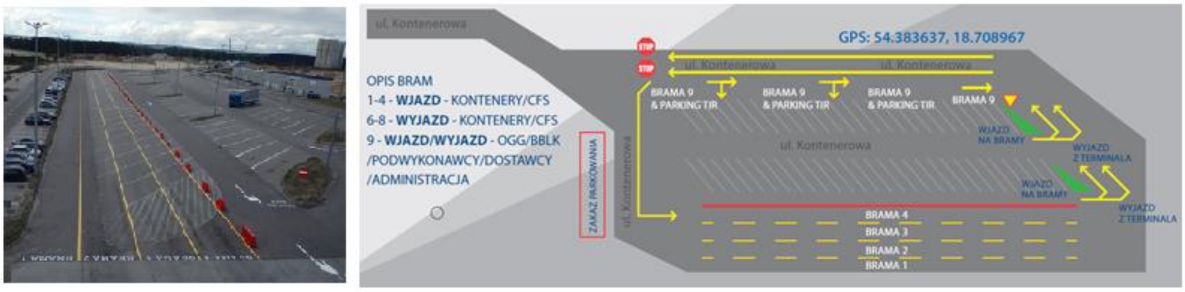


Figure 19. External parking lot of DCT Gdańsk – parking optimization, authors' own work.

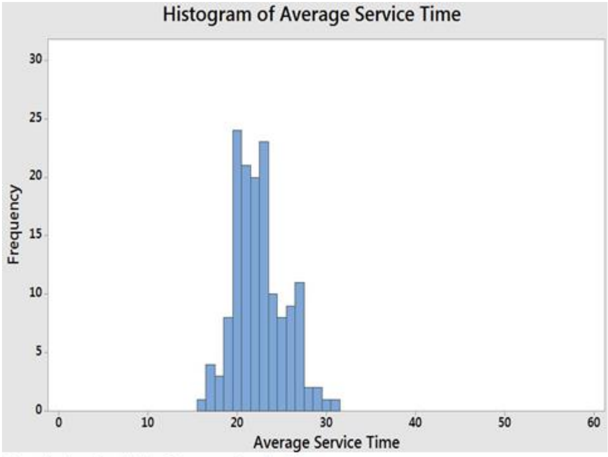
Parking lot infrastructure was also redesigned and rebuilt. Two parking islets were removed and In-gate number 1 (external passenger cars, suppliers etc.) was relocated to gate number 9. Gate number 1 was adopted for external trucks only with empty trailers and trucks proceeding to the terminal Container Freight Station.

5.2. Control phase

The purpose of the Control phase is to make sure that improvements are sustained and reinforced. Selected ideas described in Section 5.1 were implemented due to their importance of the entire project. The Control phase involves implementing the actual changes, rewriting procedures and work instructions; retraining staff on new procedures; putting systems in place to measure and monitor the new process, such as control charts; and writing an action plan.
Improvements are visible in the Histograms from the weekdays data collected from February 2015 until the end of July 2015. It is seen in Figure 20 that:

- the average service time is 22.47 minutes, the median 22 minutes – Figure 20 a. These values are lower than values obtained for the data from the previous period, before introducing the changes (Figure 12 a). Both measures are close to each other, significantly below target for the described indicator, which was 30 minutes;
- there were fewer cases when service time exceeded guaranteed time comparing to the data from the previous period, before introducing the changes (Figure 12 c). Histogram presented in Figure 20 b shows that there was an average of 10 defect cases per day, with a median of 7 cases;
- the average number of vehicles services in DCT Gdańsk during a single weekday was substantially higher when compared to the average number of vehicles from a single weekday from the previous period, amounting to 565 (Figure 20 c) and 440 (Figure 12 c), respectively. The maximum number was also higher amounting to 849 vehicles.

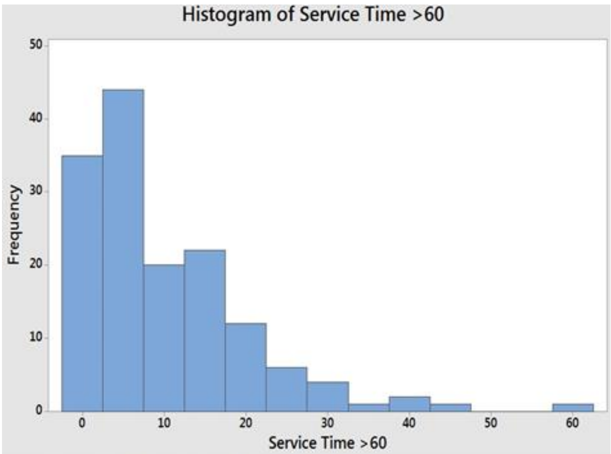
a)



Descriptive Statistics: Average Service Time

Variable	Mean	StDev	Variance	Minimum	Q1	Median	Q3	Maximum
Average Service Time	22,473	2,868	8,224	16,000	20,000	22,000	24,000	31,000

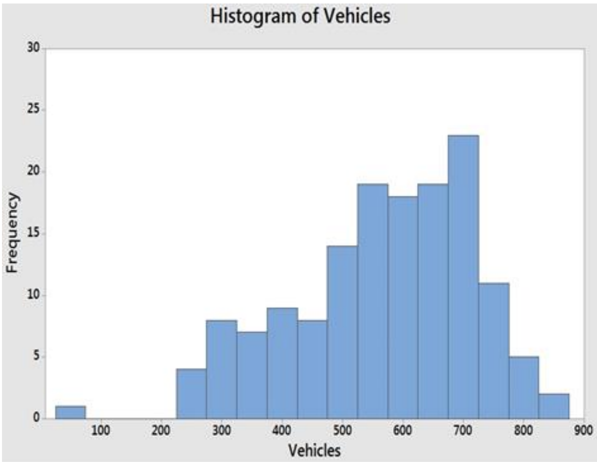
b)



Descriptive Statistics: Service Time >60

Variable	Mean	StDev	Variance	Minimum	Q1	Median	Q3	Maximum
Service Time >60	10,182	10,044	100,885	0,000	3,000	7,000	14,000	59,000

c)



Descriptive Statistics: Vehicles

Variable	Mean	StDev	Variance	Minimum	Q1	Median	Q3	Maximum
Vehicles	565,5	150,8	22747,0	55,0	472,8	587,5	677,8	849,0

Figure 20. Histograms from the data collected during weekdays in the period from February 2015 until the end of July 2015: a) Average Service Time per single day, b) Cases per single day of Service Time > 60 minutes, c) Number of Vehicles during weekdays, authors' own work.

Although the number of vehicles increased significantly in the period from February 2015 until the end of July 2015, the average service time and the number of eternal trucks exceeding the guaranteed time decreased comparing to the measures from the previous period. It was a clear positive effect of the introduced changes.

5.3. Achieved Benefits

The case study was run from February 2014 to July 2015. The case study team was attended by representatives from almost all DCT Gdańsk departments. The key task of the final study findings was the implementation of Gate Steering System, whereby a stream of external trucks entering the terminal yard could be framed and dependent on the current handling capabilities. Subsequent implementations aimed to provide a safe an optimal condition on the external parking lot.

Changing the time of waiting on the parking lot, from 12hrs to 2 hrs. and the introduction of penalties, rebounded a loud echo in the national radio and in the press. DCT Gdańsk parking lot was called „the most expensive parking in Poland" (IV). Nevertheless, the goals were achieved. Figure 21 shows a 28,9% reduction in the average number of exceedances of the guaranteed service time for external trucks in DCT Gdańsk by the end of July 2015, with an increase in the average number of external trucks.

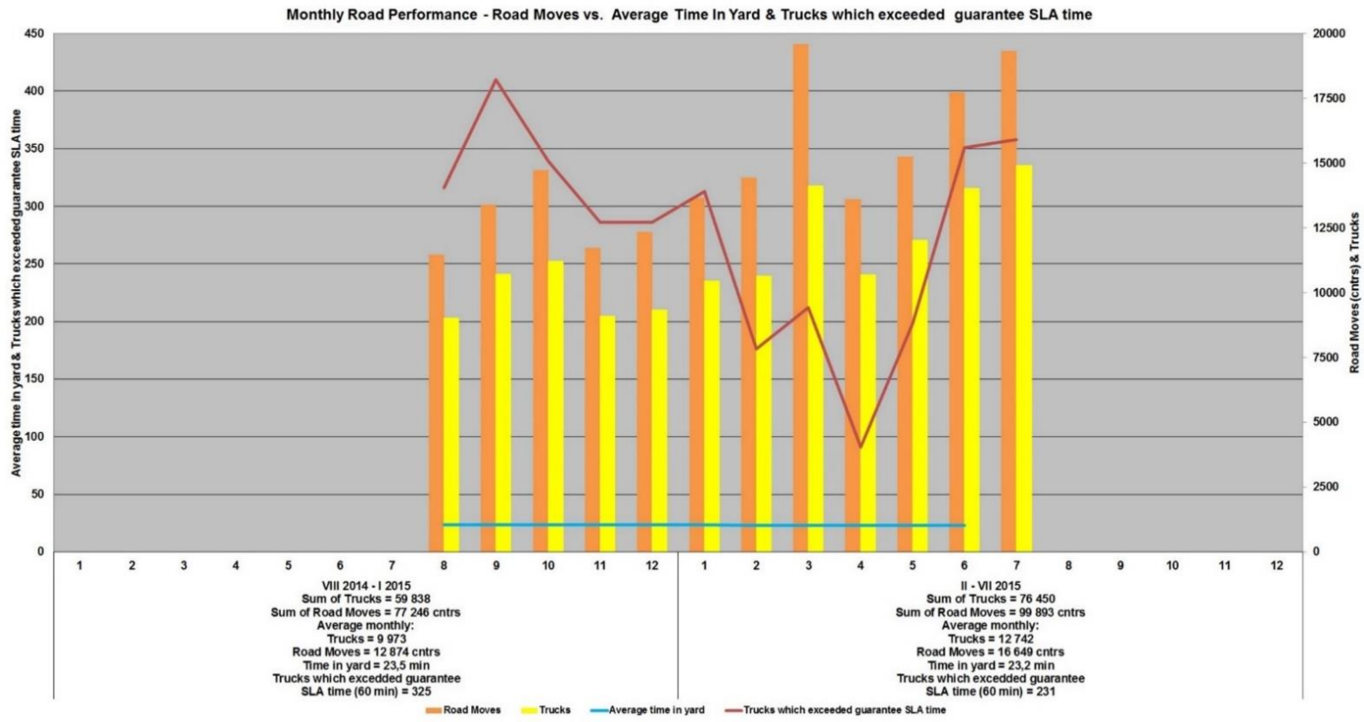


Figure 21. Monthly road performance comparison VIII 2014 – I 2015 vs. II – VII 2015 – road moves vs. average service time & truck which exceeded guaranteed service time at DCT Gdańsk, authors' own work.

The data shows that the average monthly number of external trucks arriving at the port increased by approximately 27.8% (2769 trucks), but the monthly average service time of the external trucks decreased from 23,5 to 23,2 minutes, which is about 1% difference. The red line on the chart, which indicates the number of trucks with exceeded guaranteed 60 minutes service time, decreased from 325 trucks to 231, i.e. as much as 29%.

6. Conclusions

Six Sigma philosophy is an accurate systematic framework for quality improvement and business excellence, which has been limited used in container terminals. This paper proposed a Six Sigma methodology aiming to reduce the average amount of exceeded guaranteed service time for external trucks at DCT Gdańsk via dosing the gate activities, in particular IN-Gate entry process of trucks carrying import/export/transit containers.

The DMAIC methods along with the SIPOC chart, cause and effect diagram, scatterplot, benchmark and brainstorming and finally multi-voting tool were used as analyses tools in this research, focusing at the case study on gate operations in the entrance and exit gates at the DCT Gdańsk.

According to the obtained in Control phase results, followings were fully deployed to reducing of the average amount of exceeded guaranteed service time for external trucks at DCT Gdańsk:

- Gate Steering System – dosing number of trucks entering the terminal;
- Gate Complex – open on Sunday from 14:00 – increased gate transactions during weekend, reduced peaks on Mondays;
- Information for truck drivers on the dedicated website – increased gate operations visibility;
- Parking lot and GATE-IN lines optimization – increased throughput;
- Change of DCT Gdańsk parking lot rules – reduced queues.

The above presented changes implemented in 2014-2015 have made a direct impact for the whole port industry and drivers' community related to DCT Gdańsk. Many changes did not go unnoticed and were discussed within the public in the biggest news media in Pomeranian Region [IV, V]. Further analysis forced the preparation and implementations of the long-term plan with an additional improvement of the gate operations, i.e. Vehicle Booking System and Gate Automation for supporting the predicted for the second half of 2016 year and beyond, increased container road gate volumes (Moszyk et al., 2021).

As expected, container handling at container terminals and ports has been steadily increasing since 2010 [VI]. In 2021 the terminal gate operation volumes in DCT Gdańsk were much higher (~ 4 times) than those achieved in 2014. Meeting the challenges of increased handling was possible thanks to the changes introduced in DCT Gdańsk in previous years, starting from 2014. Although the research is based on data from previous years, the presented methodology can also be applied to ports with similar gate operation volumes as in DCT Gdańsk that plan to shorten the service time of trucks entering the port. Additionally, the presented method does not require too much financial outlay. Terminals that do not yet have such technological development as DCT Gdańsk, or have problems with congestion at the entrance to the port, can benefit from this article.

Acknowledgments

References

1. Abdelmagid, A. M., Gheith, M. S., and Eltawil, A. B. (2022), “A comprehensive review of the truck appointment scheduling models and directions for future research”, *Transport Reviews*, Vol. 42 No 1, pp. 102-126.
2. Arthur, J. (2011), “Lean Six Sigma DeMYSTiFieD”, *McGraw-Hill Education*, 2nd Edition, pp. 1-5.
3. Barasti, D., Troscia, M., Lattuca, D., Tardo, A., Barsanti, I., and Pagano, P. (2021), “An ICT Prototyping Framework for the “Port of the Future”, *Sensors*, Vol. 22 No 1, pp. 246.
4. Boullauazan, Y., Sys, C., and Vanelslander, T. (2022), “Developing and demonstrating a maturity model for smart ports”, *Maritime Policy & Management*, DOI: 10.1080/03088839.2022.2074161, pp. 1-19.
5. Brook, Q. (2017), “Lean Six Sigma & Minitab: The complete toolbox guide for business improvement”, *OPEX Resources Ltd*, pp, 314.
6. Crainic, T. G. and Kim, K. H. (2007), „Intermodal transportation”, *Handbooks in operations research and management science*, Vol. 14, pp. 467-537.
7. Deja, M., Dobrzyński, M., Siemiątkowski, M. S., and Wiśniewska, A. (2017), „Simulation studies into quayside transport and storage yard operations in container terminals. *Polish Maritime Research*, Vol. 24, No s1, pp. 46-52.
8. Grubisic, N., Krljan, T. and Maglic, L. (2020), „The Optimization Process for Seaside Operations at Medium-Sized Container Terminals with a Multi-Quay Layout, *Journal of Marine Science and Engineering*, Vol. 8 No 11, p. 891.
9. George, M. L., Maxey, J., Rowlands, D. T., and Upton, M. (2004), “Lean six sigma pocket toolbook”, *McGraw-Hill Professional Publishing*, pp. 282.
10. Gygi, C., and Williams, B. (2012), “Six sigma for dummies”, *John Wiley & Sons*, 2nd Edition, pp. 408.
11. Huiyun, Y., Xin, L., Lixuan, X., Xiangjun, L., Zhihong, J., amd Zhan, B. (2018), “Truck appointment at container terminals: Status and perspectives. In *2018 Chinese Control And Decision Conference (CCDC)* IEEE, pp. 1954-1960, doi: 10.1109/CCDC.2018.8407446 .
12. Hur, S. H., Lee, C., Roh, H. S., Park, S., and Choi, Y. (2020), „Design and Simulation of a New Intermodal Automated Container Transport System (ACTS) Considering Different Operation Scenarios of Container Terminals. Journal of Marine Science and Engineering, Vol. 8 No 4, p. 233.

13. Keller, P. (2011), “Six Sigma DeMYSTiFieD”, *McGraw-Hill Education*, 2nd Edition, pp. 3-7.
14. Kosiek, J., Kaizer, A., Salomon, A., and Sacharko, A. (2021), “Analysis of modern port technologies based on literature review”, *TransNav: International Journal on Marine Navigation and Safety of Sea Transportation*, Vol. 15 No 3, pp. 667-674.
15. Li, N., Chen, G., Govindan, K., and Jin, Z. (2018), “Disruption management for truck appointment system at a container terminal: A green initiative. *Transportation Research Part D: Transport and Environment*, Vol. 61, pp. 261-273.
16. Krośnicka, K. A., (2021), “Migration of container terminals as their natural process of evolution: Case study of Gdańsk and Gdynia ports”, *Journal of Transport Geography*, Vol. 93, pp. 103045.
17. Maguire, A., Ivey, S., Golias, M. M., and Lipinski, M. E. (2010), “Relieving congestion at intermodal marine container terminals: review of tactical/operational strategies”, *51st Annual Transportation Research Forum*, Arlington, Virginia, March 11-13, 2010, p. 15, DOI: 10.22004/ag.econ.207280
18. Monios, J. and Wilmsmeier, G. (2013), „The role of intermodal transport in port regionalization”, *Transport Policy*, Vol. 30, pp. 161-172.
19. Moszyk, K., Deja, M. and Dobrzynski, M. (2021), „Automation of the Road Gate Operations Process at the Container Terminal—A Case Study of DCT Gdańsk SA”, *Sustainability*, Vol. *13* No 11, p. 6291.
20. Murty, K., Liu, J., Wan, Y. and Linn, R. (2005), “A decision support system for operations in a container terminal”, Decision Support Systems, Vol. 39 No 3, pp. 309-32.
21. Nooramin, A. S., Ahouei, V. R., and Sayareh, J. (2011), „ A Six Sigma framework for marine container terminals”, *International Journal of Lean Six Sigma*, Vol. 2 No. 3, pp. 241-253.
22. Othman, M. R., (2021), “The Sustainability Stimulus of Malaysian Seaport Cluster toward Competitive Vigilance: The Total Quality Management (TQM) Approach. *Turkish Journal of Computer and Mathematics Education (TURCOMAT)*, Vol. 12 No 3, pp. 1636-1646.
23. Praharsi, Y., Jami’in, M. A., Suhardjito, G., and Wee, H. M. (2021), “The application of Lean Six Sigma and supply chain resilience in maritime industry during the era of COVID-19”, *International Journal of Lean Six Sigma*, Vol. 12 No 4, 800-834.
24. Park, N. K. and Suh, S. C. (2019), „Tendency toward mega containerships and the constraints of container terminals”, *Journal of Marine Science and Engineering*, Vol. 7 No 5, p. 131.

25. Prokopowicz, A. K. and Berg-Andreassen J. (2016), „An Evaluation of Current Trends In Container Shipping Industry, Very Large Container Ships (VLCSs), and Port Capacities to Accommodate TTIP Increased Trade", *Transportation Research Procedia*, Vol. 14, pp. 2910-2919
26. Raval, S. J., Kant, R., and Shankar, R. (2019). Benchmarking the Lean Six Sigma performance measures: a balanced score card approach. *Benchmarking: An International Journal*, Vol. *26* No 6, pp. 1921-1947.
27. Regan, A. C. and Golob, T. F. (2000). Trucking industry perceptions of congestion problems and potential solutions in maritime intermodal operations in California. *Transportation Research Part A: Policy and Practice,* Vol. 34 No 8, pp. 587-605.
28. Salleh, N. H. M., Zulkifli, N., and Jeevan, J. (2021), "The emergence of very large container vessel (VLCV) in maritime trade: implications on the Malaysian seaport operations", *WMU Journal of Maritime Affairs*, Vol. *20 No* 1, pp. 41-61.
29. Salomon, A. (2013), „Organization and functioning of port container terminals and prospects for their development (in Polish)", *Scientific Journals of the Gdynia Maritime University*, Vol. 82, pp. 70-80.
30. Torkjazi, M., and Huynh, N. N. (2021), "Design of a Truck Appointment System Considering Drayage Scheduling and Stochastic Turn Time", *Transportation Research Record*, Vol. *2675* No 12, pp. 342-354.
31. Son, W. J., & Cho, I. S. (2022), "Analysis of Trends in Mega-Sized Container Ships Using the K-Means Clustering Algorithm", *Applied Sciences*, Vol. *12* No 4, pp. 2115.
32. Ullrich, M. and Baumert M. (2018). Port and terminal operations. In: Container Logistics. The role of the container in the supply chain, Neise, R. (Ed.). Kogan Page Publishers, London, United Kingdom, pp. 140-168.
33. Wang, D. (2019), „Dynamic Optimization Model of Container Route Loading for International Logistics Ships, *Journal of Coastal Research*, Vol. 93 No SI, pp. 1111-1116.
34. Won, S., and Kim, K. (2009), „An integrated framework for various operation plans in container terminals", *Polish Maritime Research*, Vol. 16 No 3, pp. 51-61.
35. Xu, B., Liu, X., Yang, Y., Li, J., and Postolache, O. (2021), "Optimization for a multi-constraint truck appointment system considering morning and evening peak congestion", *Sustainability*, Vol. *13* No 3, pp. 1181.

[I] “Situation in maritime transport - statistics at the end of 2020 (in Polish)”, available at: https://www.tirsped.com.pl/blog/sytuacja-w-transporcie-morskim-statystyki-i-fakty (accessed 4 March 2022).
[II] „Intermodal transport - what is it and what does the process look like (in Polish)?”, available at: https://inelo.pl/transport-intermodalny-czym-jest/ (accessed 4 March 2022).
[III] „Intermodal transport in Poland in 2020 (in Polish)” Source of data from the Central Statistical Office of Poland GUS, available at: https://stat.gov.pl/obszary-tematyczne/transport-i-lacznosc/transport/transport-intermodalny-w-polsce-w-2020-roku,14,5.html# (accessed 4 March 2022).
[IV] “The most expensive parking in the country. 400 PLN per hour! (in Polish)”, available at: https://www.cargonews.pl/najdrozszy-parking-w-kraju-400-zl-za-godzine/ (accessed 4 March 2022).
[V] “The most expensive parking in Poland? First for free, and then PLN 400 per hour (in Polish), available at: https://radiogdansk.pl/wiadomosci/2015/11/19/dwie-godziny-postoju-gratis-a-potem-400-zlotych-za-kolejna-kierowcy-musimy-chowac-sie-w-krzakach/ (accessed 11 July 2022).
[VI] “Facts and figures - Cargo and container handling from 2010 to 2021 in PORT GDAŃSK”, available at: https://www.portgdansk.pl/en/business/general-information/facts-and-figures/ (accessed 3 August 2022).
[VII] “Ocean shipping worldwide - statistics & facts”, available at: https://www.statista.com/topics/1728/ocean-shipping/#topicOverview (accessed 15 December 2022).