A Systematic Framework for Implementing Six Sigma in the Landside of Marine Container Terminals

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Abstract

In this research, an accurate optimization model, based on the Six Sigma methodology was used in order to assists marine container terminal operators to minimize trucks congestions. to smooth gate activity and to shorten trucks turn-around times. The main purpose of this paper is to report findings of implementing the Six Sigma in the landside of marine container terminals to reduce the average number of trucks in queues and average trucks waiting times in both entrance and exit gates. Risk Priority Numbers (RPNs) obtained from the FMEA analysis denoted that additional control procedures and associated inspections were needed as monitoring tools on the working time and activity of weighbridge operators and truck drivers. In addition, serious consideration should be given to appraisal of operators performance and improving of administrative systems.

Keywords: *Six Sigma, DMAIC, FMEA, Container terminal, Track Congestion*

1. Introduction

Sigma (σ) is the letter in the Greek alphabet used to represent standard deviation, a statistical measurement of variation and the exceptions to expected outcomes. Standard deviation can be thought of as a comparison between expected results or outcomes in a group of operations versus those that fail. The measurement of standard deviation shows that rates of defects or exceptions are measurable. With six standard deviations, we arrive at 3.4 defects per million opportunities, or 99.9997 percent. The purpose in evaluating defects is not only to eliminate them entirely, but also to strive for improvement to the highest possible achievable level.

Six Sigma as a systematic framework for quality improvement and business excellence has been popularized for more than a decade (Goh, 2002). It is best suited to organizations with repetitive and routine operations for specified outcomes. Six Sigma efforts achieve three main areas through three historical generations:

- The 1st Generation, 1987-1994, which focuses on reducing defects,
- The 2nd Generation, 1994-2000, which focuses on reducing cycle time, and
- The 3rd Generation, 2000 to date, which focuses

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on improving customer satisfaction.

In general, container terminals can be described as open systems of material flow with two external interfaces. These interfaces are the quayside designed for loading and unloading of ships, and the landside where containers are loaded and unloaded on/off the trucks (Steenken et al., 2004). Most terminals are taking measures to increase their throughput and capacity by:

- Introducing new technologies,
- Optimizing equipment dwell-times,
- Increasing storage density,
- Optimizing ship turn-around times
- Optimizing truck turn-around times (Huynh and Walton, 2005).

In todays global marketplace, container terminals are regarded as Server-Customer (Queue) systems wherein servers and customers are variable based on the different operational viewpoints. Figure 1 represents the Server-Queue system designed based on the purpose of this study.
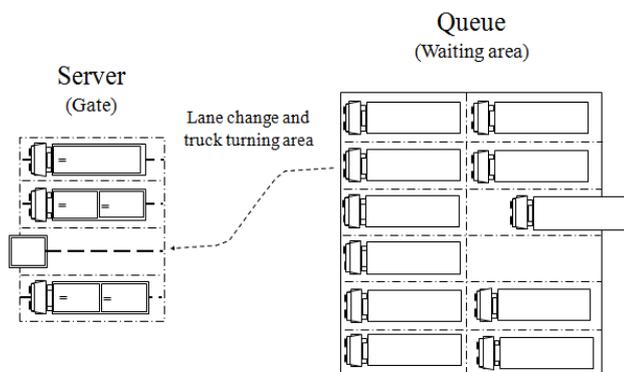

Fig. 1: Server-Queue system in marine container terminals

In this paper, a novel Six Sigma methodology is used to find and reduce defects in the server (gate area) and to improve customer satisfaction via decreasing the turn-around time of the trucks, trucks queue and reducing the overall transfer cost of containers in their supply chain cycle.

1.1. Review of Related Literature

Based on the nature of this study, the literature is reviewed in two different sections, namely Six Sigma philosophy and marine container terminals.

1.1.1. Six Sigma Philosophy

Six Sigma explicitly links the tactical activities with those strategic ones (Yang and Hsieh, 2009). Six Sigma programs improve operational performance in order to enhance customer satisfaction with a company's products and services (Rajagopalan et al., 2004). Hahn et al. (2000) described Six Sigma as a disciplined and statistically based approach for improving product and process quality. Six Sigma is at the top of agenda for many companies that try to reduce costs and improve productivity (Kumar et al., 2008).

Kwak and Anbari (2006) summarized Six Sigma as a strategy, which includes Total Quality Management (TQM), strong customer focus, additional data analysis tools, financial results and project management in order to satisfy customer needs. Naumann and Hoisington (2001) indicated that the concept of Six Sigma was the development of a uniform way to measure and monitor performance and set extremely high expectations and improvement goals.

Das (2005) studied Six Sigma in its Generation II and used it to reduce procurement delays. Su and Chou (2008) proposed a systematic methodology which aimed to identify the procedures of Six Sigma project generation, evaluation and mapping. Chakravorty (2009) developed an effective implementation Six Sigma model which consisted of six steps, including, performing strategic analysis, establishing a high-level team, identifying overall improvement tools, prioritizing improvement opportunities, developing a detailed plan, and implementation.

Scheroeder et al. (2008) used the grounded theory approach in the Six Sigma theory. They identified many critical elements of Six Sigma projects such as management involvement, improvement specialists, performance metrics, a systematic procedure and project selection.

1.1.2. Marine Container Terminals

Many varieties of container terminals exist mainly depending on which type of handling equipments are combined to form a terminal system. Koshnevis and Asef-Vaziri (2000) defined three performance analysis variables including throughput, space utilization and equipment utilization. Kozan (2000) discussed the major factors influencing the transfer efficiency of seaport container terminals by developing a network model. Nishimura et al. (2001) implemented Lagrange's method for optimizing the container yard operation. Similar studies in this field were carried out by Nam and Ha (2001), Lie et al. (2002), Vis and de Koster (2003), and Murty et al. (2003).

Berth planning problems may be formulated as a different combination of optimization problems, depending on the specific objectives, and restrictions that have to be observed. Legato and Mazzo (2001), Nishimura et al. (2001), Imai et al. (2005), Moorthy and Teo (2006) have all carried out numerous studies on berth planning problems. Lee and Chen (2009) optimized the berth operation by evaluating different arrival patterns. Nowadays, the logistics activities, especially at large container terminals, have reached a degree of complexity that further improvements through interaction of scientific solutions are required. Simulation models have become the viable tools for decision-making in port activities. Kia et al. (2002) investigated the role of computer simulation in evaluating the performance of a container terminal in relation to its handling techniques and the impact it made on the capacity of terminal. Parola and Sciomachen (2005) presented a discrete event simulation modelling approach related to the logistic chains of an intermodal network. Bielli et al. (2006) provided a help-tool in a port decision support system implementing simulation via Java environment. Froyland et al. (2008) presented an algorithm to manage the container exchange facility, including the allocation of delivery locations for trucks and other container carriers. Zeng and Yang (2009) developed a simulation optimization method for scheduling loading operations in container terminals.

The time trucks spend at a terminal for loading/unloading of cargo (truck turn-around time) is a real cost scenario which affects the overall cost of the container trade. Historically, truck turn-around times have received a very little attention from terminal operators because landside congestions have never been a barrier to their smooth operations. Truck turn-around times are the times that a truck takes to complete an activity such as picking up an import container. As shown in the studies conducted by Regan and Golob (2000), Klodzinski and Al-Deek (2002) and Huynh and Walton (2005), by optimizing the truck turn-around times and thereby, the landside shipping cost, terminals would gain a competitive advantage in the industry. Murty et al. (2005) have described a variety of inter-related decisions made during daily operations at a container terminal. Their goal was to minimize the waiting time of customer trucks.

To date, no study has adequately examined the philosophy of Six Sigma in marine container terminals as a managerial decision-making optimization tool in strategic/operational levels. The challenging issues inherent in this problem and the limitation of existing research, robustly motivates this study. For the first time in the literature, this research provides a novel decision-making framework for port operators to smoothing the gate activities and reducing truck congestion.

1.2. Problem Statement

The objective of this research is to minimize trucks congestions at the main gates of the container terminal of the Shahid Rajaee Port Complex (SRPC), the major Iranian seaport, and hence to reduce the truck's turn-around times. Generally, weighbridges are regarded as one of the main hindered movement stations in port operation, which cause long queues of trucks. The SRPC is equipped with six main

automatic weighbridges in following patterns:

- Two are located near the main entrance of the gate complex,
- Two are located near the exit gate, and
- Two are located at the transit yard where only one of them is operational.

Even though the case study is unique and distinctive of its kind, the general processes and characteristics are similar to a typical container terminal as shown in Figure 2.

Since there are usually long queues of trucks waiting in the container yard for weighting operation, this research develops a Six Sigma model to find problems, defects and barriers in weighting operation and proposes operational solutions for reducing truck waiting times via smoothing the gate activities.

2. Materials and Methods

2.1. Six Sigma Framework

Six Sigma projects are carried out through two different methodologies (2009):

- The Define, Measure, Analyze, Improve, and Control (DMAIC) methodology for improving existing processes and products, or
- The Define, Measure, Analyze, Design and Verify (DMADV) methodology for designing new or innovative processes or products.

The DMADV is an enhancement to new product development process, not a replacement (2006). Actually it is a business process which concentrates on improving profitability. Respect to the statement of the SRPC problem, i.e. improving the trucks congestion, the DMAIC method suits with the research objective.

As shown in Figure 3, the DMAIC tactical approach to Six Sigma problem, involves five steps (2006):

- Define and set boundaries for problems,
- Measure problems, capabilities, opportunities, and industry benchmark to determine the probable gap(s),
- Analyze causes of the problem through graphical and statistical tools and determine how processes are working,
- Improve processes through reduction of variations found in the processes
- Control implemented improvements, maintain consistency, track progress financially and otherwise.
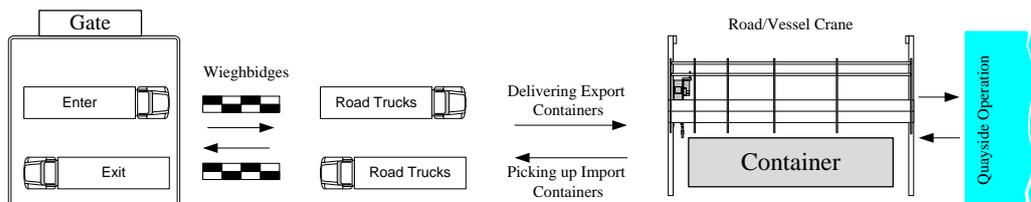

Fig. 2. Process of loading/discharging operation in marine container terminals

Fig. 3: Five Steps of the DMAIC method

2.2. Proposed Method

As stated by Kumar (2006), the main idea behind Six Sigma is that if the numbers of defects in a process are measurable, it will be possible to systematically figure out how to eliminate/reduce them to get as close to zero defects as possible.

Achieving the purpose of this study and finding the bottlenecks in the process of loading and unloading operation, the following four main patterns were examined:

- Arrival pattern of trucks at the main entrance of the gate complex,
- Service pattern of weighbridges located at the both entrance and transit gates,
- Departure patterns of trucks at main gate exit and
- Service patterns of weighbridges located at the main exit of the gate complex.

After perusing the queue and waiting time, histograms for both the entrance and exit and main defects within them will be highlighted. This study examined the applicability of the DMAIC method using the following tools:

- SIPOC (Supplier – Input – Process – Output – Customer) chart,
- Cause and effect diagram and

Failure Mode and Effect Analysis (FMEA) and the data were gathered from the SRPC container terminal during Jan. 2008 - Dec. 2009.

3. Results and Discussion

3.1. Define Phase

Define meant to establish the cause of a problem and to set the boundaries of the problem (2006) and was used to picture the process over time and provided insight about the areas which required improvement efforts.

3.2. SIOPC Chart

The SIOPC was used to analyze the business process mapping (2006) and contained the following terms:

- Supplier: A source or a group of sources that provides the inputs to process.
- Input: Resources and information required to complete the process.
- Process: A series of activities performing over one or more inputs to produce the output according to the customer demands.
- Output: The product/service that results from the process to satisfy customer demands.
- Customer: An individual/organization receiving the final output.

As mentioned earlier, marine container terminals can be adequately modeled as supplier-customer systems within which different service patterns could exist; thus, SIOPC charts were used for analyzing vast operations. Figure 4 represents the SIOPC chart of the case study.
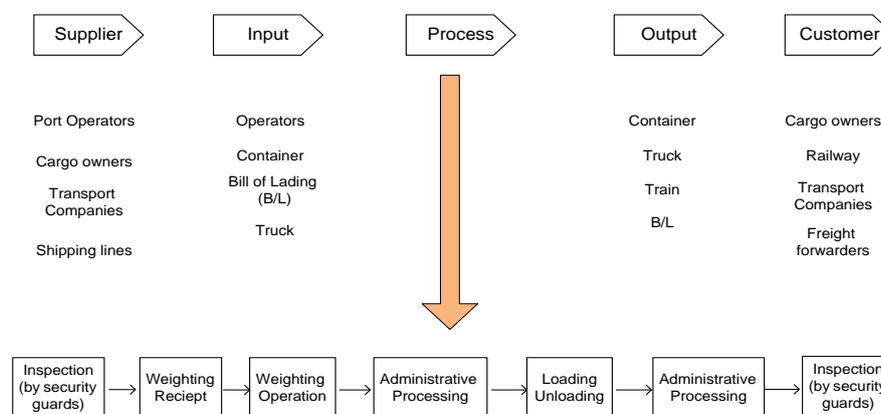

Fig. 4: SIPOC chart (Loading/unloading operation of trucks)

Analysis of the SIOPC chart depicted that optimization of weighing operation was an important step for reducing congestion, achieving customer satisfaction and saving times/costs at loading/unloading operation of trucks. Therefore, Critical to Quality (CTQ) was the waiting time of trucks, which were weighed both at entrance and exit gates. With respect to the defined CTQ, data collection phase was planned due to waiting time of the entrance and exit gates for weighing operation of trucks.

3.2. Measuring Phase and Calculating Sigma Metric

As per definition of CTQs explained earlier, data for waiting time of trucks in weighing operation at entrance and exit gates was collected and shown in Figures 5 and 6, respectively, using the MINITAB software.
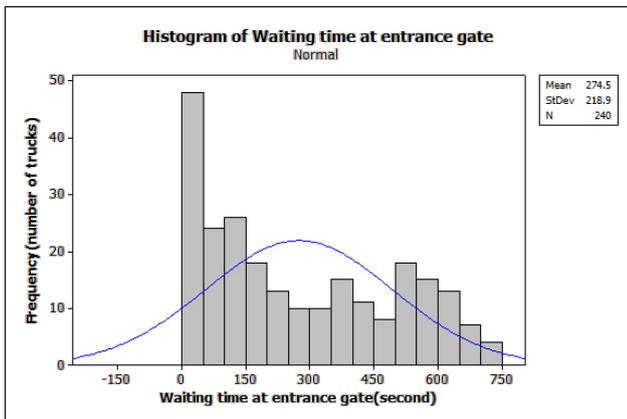

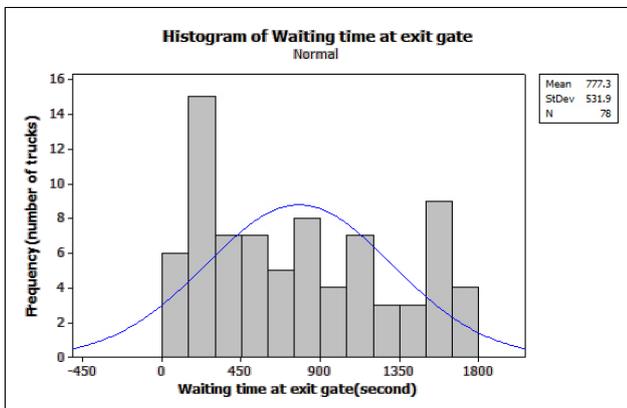Fig. 5: Waiting time histogram of trucks at the entrance gate with normal curve

Fig. 6: Waiting time histogram of trucks at the exit gate with normal curve

Based on the Central Limit Theorem (2006), both the arrival and departure patterns are fitted with the normal distribution. As shown in Fig5, the mean and standard (SD) deviations at the entrance gate were 274.5 and 218.9, respectively.

Values of the mean and standard deviation are 777.3 and 531.9, respectively (Figure 6). Accordingly, current and goal waiting time statistics are presented in Table 1.

Table 1. Current and goal waiting time statistics for weighing operation of trucks

| Queue of trucks | Sample size (N) | Current statistics | | Goal statistics | |
| | | Waiting time at queue (second) | | | |
		Mean	SD	Mean	SD
Entrance	240	274.5	218.5	60	60
Exit	78	777.3	531.9	200	200

Table 1 denotes short term goal statistics (take into account for this case due to the determination of the quantity of defects). Now, we assume the worst case scenario, wherein the long-term goal statistics may shift by 1.5 σ. Therefore, the longest acceptable waiting time satisfying the goal statistics would be:

= Goal mean + 4.5 (goal standard deviation) = 60 + (4.5 × 60) or 330 Seconds

The current sigma metric of the entrance gate was calculated in three steps:

➢ Step 1- Entrance gate

This step was based on the calculation of the Z score for the current waiting time, i.e. 330 seconds. This was an acceptable limit of the goal waiting time:

Z = (Data point – mean value) / (standard deviation) = (330 – 274.5) / 218.9 = 0.2535

Thus, the acceptable limit of the goal waiting time was 0.2535.

➢ Step 2- Entrance gate

The probability value at 0.2535 Z was obtained through an MS Excel spreadsheet as follows:

NORMSDIST (0.2535) = 0.600059

➢ Step 3- Entrance gate

The probability value obtained in the step 2 was used in the Long-Term Yield column of Table 2 and the corresponding value is approximately computed 1.75 from the Process Sigma (ST) column in the mentioned Table. Therefore, the current waiting time for trucks at the entrance gate was 1.75 σ, approximately (in relation to the defined goal for the waiting time).

Current waiting time of the exit gate Sigma metrics for weighing operation of trucks could be similarly calculated:

= Goal mean + 4.5 (goal standard deviation)= 180 + (4.5 × 180)= 990 Seconds

Calculation steps of current sigma metric for exit gate were as follows:

Z score for the current waiting time, 990 seconds: $Z = (990 - 777.3) / 531.9 = 0.3998$

The probability value at 0.3998 *Z* was: *NORMSDIST (0.3998) = 0.655348*

The probability value obtained in the step 2 was used in the Long-Term Yield column of Table 2. Then, the corresponding value was found to be

approximately 1.90 from the Process Sigma (ST) column in the same table. Therefore, the current waiting time for trucks is approximately at 1.90 σ (in relation to the defined goal for the waiting time).

Table 2 represents the quantity of defects per million opportunities for weighing operation of trucks (based on the goal statistics) at the entrance and exit gates which are were obtained as 399,941 and 344,652, respectively.

3.3. Analyze Phase

This phase attempts to identify the root causes of the major defects of the problem.

3.3. 1. Cause and Effect Diagram

Cause and effect diagram is an analysis tool that provides a systematic way of looking at the effects and at the causes that create or contribute to those effects (2006). Figure 7 shows the cause and effect diagram of the SRPC which was designed based on the SIOPC chart.

Table 2. Sigma conversion to quantity of defects and long-term yield

| Long-Term Yield (%)	Process Sigma (ST)	Defects per 1,000,000	Defects per 100,000	Defects per 10,000	Defects per 1,000	Defects per 100
93.32	3.0	66,880	6,680	668	66.8	6.68
91.91	2.9	80,800	8,080	808	80.8	8.08
90.32	2.8	96,800	9,680	968	96.8	9.68
88.5	2.7	115,000	11,500	1,150	115	11.5
86.5	2.6	135,000	13,500	1,350	135	13.5
84.2	2.5	158,000	15,800	1,580	158	15.8
81.6	2.4	184,000	18,400	1,840	184	18.4
78.8	2.3	212,000	21,200	2,120	212	21.2
75.8	2.2	242,000	24,200	2,420	242	24.2
72.6	2.1	274,000	27,400	2,740	274	27.4
69.2	2.0	308,000	30,800	3,080	308	30.8
65.6	1.9	344,000	34,400	3,440	344	34.4
61.8	1.8	382,000	38,200	3,820	382	38.2
58	1.7	420,000	42,000	4,200	420	42.0
54	1.6	460,000	46,000	4,600	460	46.0
50	1.5	500,000	50,000	5,000	500	50.0
46	1.4	540,000	54,000	5,400	540	54.0
43	1.3	570,000	57,000	5,700	570	57.0
39	1.2	610,000	61,000	6,100	610	61.0
35	1.1	650,000	65,000	6,500	650	65.0
31	1.0	690,000	69,000	6,900	690	69.0
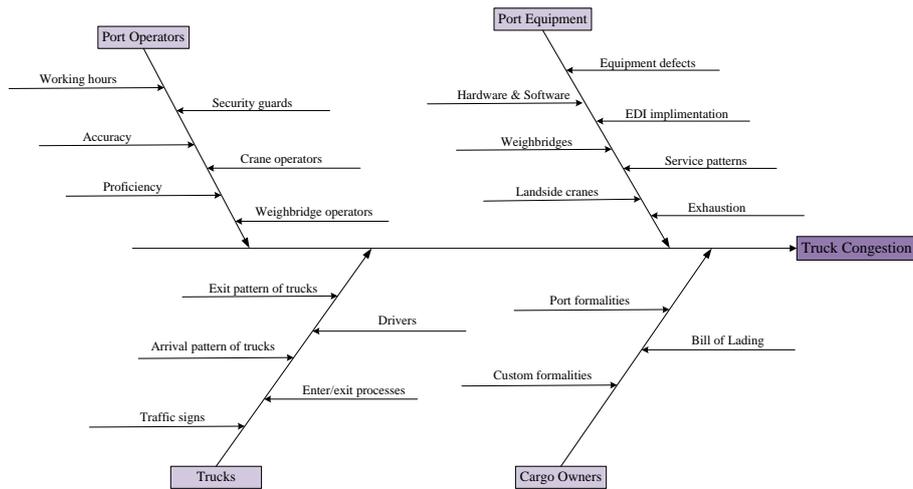
Fig. 7: Cause and effect diagram (Loading/unloading operation of trucks)

As illustrated from the Figure 7, there are four main factors which caused truck congestion in the SRPC as follows:

- Port operators which work on different parts of the SRPC,
- Port equipments (including both the hardware and software),
- Trucks and their drivers and
- Owners of import/export/transit containers.

3.3.2. Failure Mode and Effect Analysis

As stated by Kumar (2006), FMEA is a structured and qualitative analysis of a system or function which identifies potential system failure modes, their causes and the effects on the system operation associated with the failure mode's accuracy. Table 3 represents the FMEA of the SRPC problem, obtained according to the results of group brainstorming among the experts of the container terminal of the SRPC, based on the cause and effect diagram.

According to the results of the FMEA, followings are the main roots of congestion in the landside:

- Working time of weighbridge operators,
- Activity of weighbridge operators,
- Administrative processing,
- Trucks Drivers and
- The accuracy of operators.

Table 3. FMEA for truck congestion at weighing operation step

Failure mode	Potential effect	Severity	Potential cause	Occurrence	Current control	Detection	RPN
Truck congestion	Dissatisfaction of customers	10	Working time of weighbridge operators	8	Indirect supervision	8	640
			Activity of weighbridge operators	7	Indirect supervision	7	490
	Accident	9	Traffic signs	6	Video supervision	3	162
			Trucks' drivers	5	No enough supervision	9	405
	Human error and fatigue	8	Operators' accuracy	6	Indirect supervision	7	336
			Activity of weighbridge operators	5	Indirect supervision	6	240
	Financial penalties	7	Administrative processing	8	Indirect supervision	8	448
	Increment of trucks' waiting time	6	Weighbridges malfunction	5	PM	5	150
			Operators' accuracy	2	Indirect supervision	7	84
	Container dwell time	5	Administrative processing	8	Indirect supervision	6	240
	Drivers confusion	3	Traffic signs	4	Video supervision	3	36

Risk Priority Numbers (RPNs) obtained from the FMEA table denoted that additional control procedures and associated inspections were needed as monitoring tools on the working time and activity of weighbridge operators and truck drivers. In addition, serious consideration should be given to appraising of operator performance and improving the administrative systems, particularly during total working time of weighting operation.

3.3.4. Improvement Phase

Improvement phase focuses on reducing the amount of variations found in a process. The main concept behind this phase in the DMAIC method is that the suggestions are based on the analysis of the cause and effect diagram and the FMEA table, without any structural change in the system. `In this case, any factor which caused truck congestion was considered nonconformity. Table 3 shows a FMEA analysis of the perceived causes to truck congestion. The results suggested that the most relevant potential causes to address were operators working time (working time of weighting process) and their activity. The obtained results suggested that there should be more control (both direct/indirect) on the weighbridge operators and weighting process aiming to increase the operational efficiency and accuracy.

4. Conclusion

Six Sigma is an accurate systematic framework for quality improvement and business excellence which has not been academically used in marine industries. This paper proposed a novel Six Sigma methodology aiming to reduce truck congestion in marine container terminals via smoothing the gate activities, in particular weighting process of trucks carrying import/export/transit containers.

The DMAIC method along with the SIOPC chart, cause and effect diagram, and FMEA were used as analysis tools in this research, focusing on managerial operations in the entrance and exit gates of the SRPC as the case study.

Working time, activity and accuracy of weighbridge operators, drivers of trucks, and administrative processing were the main causes of trucks congestion in the SRPC. As such, it is sugested followings be considered for reducing trucks congestion:

- There should be more control on the weighbridge working time.
- The service pattern of weighting operation should be modified and changed to the normal distribution.
- The activity of weighbridge operators should be under an accurate control system.
- There should be new traffic signs in the landside area, aiming to reduce drivers confusion with the processes.
- EDI should be implemented in the administrative processing, especially custom formalities and B/Ls.

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