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Optimization of Maintenance Downtime for Handling equipment in a Container Terminal using Taguchi Scheme, Taguchi-Pareto Method and Taguchi-ABC Method

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ABSTRACT

This paper examined the behavior of selected maintenance downtime parameters of handling equipment in a container terminal and established the system's optimal parameters. Taguchi method, Taguchi–Pareto method, and Taguchi–ABC method were applied to analyze it. The chosen process parameters are the downtime, probability density function, and cumulative density function. The L25, L25, and L20 orthogonal arrays were selected for the Taguchi, Taguchi-Pareto, and Taguchi–ABC methods. Data were acquired from a container terminal in the southern part of Nigeria, and we deployed the Weibull function to analyze the parameters at three shape functions of β = 0.5, 1, and 3 from twenty-five experiments. The signal–to–noise quotient and analysis of variance were used to establish the optimal level and contributions of the parameters. The results indicated that using the Taguchi method, for all the shape parameters of β = 0.5, 1, and 3, the most and the least significant parameters were downtime and cumulative density function, respectively. For the Taguchi-Pareto method, the most and the least significant parameters were downtime and probability density function, respectively, at β = 0.5. At β = 1, the most and the least significant parameters were downtime and cumulative density function, respectively. However, at β = 3, the most and the least significant parameters were probability density function and downtime, respectively. Finally, using the Taguchi-ABC method, at β = 0.5, the most and the least significant parameters were probability density function and downtime, respectively. Nonetheless, at β = 1 and 3, the most and the least significant parameters were downtime and probability density function, respectively. The proposed model would assist seaport maintenance managers in the effective control of downtime

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1. INTRODUCTION

Port terminal pieces of equipment are pivotal devices to serve the utility of loading and unloading cargoes from the ships to the berths and vice-versa (Asteris et al., 2012; Chen and Liu, 2016). A growing number of scholars, however, continued to debate on the significance of ports in the economic development of nations: Han et al. (2019), Jonili (2016), Sharapiyeva et al. (2019), Munimz and Schramm (2018), Emenyonu et al. (2016), Cheng et al. (2015). Even now, researchers' prevailing view is that investments in port infrastructures have become a key area of attention of many governments (Pallis et al., 2008; Meersman and Van de Voorde, 2014a; Tsamboulas and Ballis, 2014). For example, Onwuegbuchunam (2018) reviewed the influence of the Nigeria government on ports within its territory and concluded ship turnaround times and long container dwell times characterized the pre-reform age in ports due to infrastructural limitations. Furthermore, Adenigbo and Enyinda (2016) and Nyema (2014) emphasized that poor infrastructure such as the quay/gantry crane equipment causes cargo transfer inefficiency in ports.

Although the downtime response stimulates reactive actions, there is no previous historical information regarding it in the literature. Yet history may provide insight to anticipate the future downtime of the system. But such predictive and optimization models have been established in the ports literature, chiefly for any loading or unloading equipment (Saeed and Larsen, 2010; Lacoste and Douet, 2013). The principal equipment for berth-to-ship services such as the rubber tire gantry cranes, empty handlers, mobile harbor cranes, reach stackers, terminal trucks, and forklifts has not been investigated interpretation in equipment prediction and optimization. This work focuses on the mobile harbor cranes, which are the bottleneck equipment in port operations, and they are studied for downtime reduction and reliability improvement. At the outset, the port operations were studied and noticed to be complicated.

The port terminal needs to satisfy the growing customers' work demands through rail, water, and intermodal road connection. At the center of this service, important equipment such as rubber tire gantry cranes, empty handlers, mobile harbor cranes, reach stackers, terminal trucks, and forklifts must be coordinated to avoid downtime. The complication that arises from this huge number of equipment raises the question of if the equipment were analyzed for the past breakdown. To the investigators' surprise, scanty records exist on this equipment, and they are best managed with intuition and the experience of the maintenance manager. It was then concluded that if sustained improvement in downtime reduction and reliability enhancement is to be achieved, then a policy of stepwise downtime forecasting and immediate repair of the bottleneck equipment should be adopted for utmost performance (Lacoste and Douet, 2013; Jiang et al., 2017). Consequently, it is sensible to adopt models of prediction and optimization on the key (bottleneck) equipment, the mobile harbor cranes (Saeed and Larsen, 2010; Lacoste and Douet, 2013).

In this paper, the following objectives were pursued:

1. To determine if the optimization of maintenance downtime parameters of handling equipment in a container terminal is feasible using the Taguchi method, Taguchi-Pareto method, and Taguchi-ABC method.
2. To use the preceding item methods to establish the effects of three downtime parameters, their sensitivity, and the optimum setting for the minimization of downtime response.
3. To establish the best combinations of maintenance downtime parameters for the mobile harbor crane with lower maintenance downtime.

2. LITERATURE REVIEW

2.1. General

Striving to achieve excellence in port maintenance offers ports management an opportunity for enhanced goodwill, improved employee morale, improved economic gain, and profit generation. This is important to ports as the present economic challenges threaten ports' survival. In the past two decades, several studies have been conducted. To start with, the studies by Gertwagen (2000) and Brooks (2004) are frontlines on port maintenance. Gertwagen (2000) discussed the maintenance of ports from a historical perspective. While this study provides insight into the past historical events, there is no clear understanding of how port maintenance can be made more effective since no quantitative measures were considered in work. It is a consensus in the engineering literature that whatever is quantified could be improved. However, no improvement efforts may be meaningfully achieved as no data for guidance exists in this instance.

Brooks (2004) discussed the framework of governance in ports. The administration of ports is of two basic parts, notably operations and maintenance. While the author's discussion acknowledges these aspects of government, no quantitative data was given to support maintenance's governance effectiveness. But maintenance is more than carrying out instructions; quantitative figures must be relied upon. This is absent in the report given by Brooks (2004), and there is an urgency to correct this literature deficiency. By limiting the information provided by these two articles, excellence in port maintenance activities may be difficult to attain. A condition where maintenance activities are controlled at the least cost, and planned maintenance is achieved effectively is only attainable by deploying metrics in maintenance.

Iyer and Nanyam (2020) offered a technical efficiency analysis of container terminals in India. This study that provides a comprehensive examination of the shipping and logistics practices in ports is global. However, extremely miniature details are given about maintenance. Yet it is difficult to control maintenance and attain the excellence desired. Perhaps optimization of maintenance parameters would provide useful insight into the attainment of excellence. But optimization models are ignored in the present discussion in port literature regarding maintenance. Keskinen et al. (2017) discussed the idea of maintenance planning for container handling equipment, focusing on the factors that drive automated terminals' maintenance. Practices, attitudinal changes and more reliable information technology were emphasized as the promoters of maintenance effectiveness.

Besides, the authors emphasized the conversion of maintenance strategy from reactive ad-hoc repairs to focused preventive maintenance schedules. The authors further declared that an understanding of the evolution of maintenance from the start-up stage through the equipment's lifespan would promote effectiveness in an automated terminal. While this report is central to our study, it lacks quantitative metrics to guide progress in measurements. Throughout the work, optimization of activities and parameters was not quantitatively described. Yet Taguchi scheme and the modified version as Taguchi-Pareto and Taguchi-ABC are accountable for optimization of maintenance performance while also prioritising the factors.

However, Keskinen et al. (2017) called for the optimal running of a terminal, asserting that maintenance attention needs to be given to port services. They declared that optimal parametric attainment for maintenance systems must commence at the planning stage and optimization should spread throughout the life-time of the terminal. By considering this discussion, literature was searched. It became evident that no study in the ports literature has optimized maintenance parameters. But by optimizing terminal maintenance parameters, the reliability of the maintenance system can be improved. But no research seems to appreciate this wide gap and bridge the important knowledge gap to ports' benefit. Thus, we follow the call of Keskinen et al. (2017) to declare the need to bridge this gap using Taguchi optimization models. Thus, there is ample room for the proposed models of Taguchi architecture, Taguchi-Pareto and Taguchi-ABC to be a better option for terminals to run optimally them the use of intuition and experience presently demonstrated by ports maintenance managers to solve ports optimization problems. Therefore, this study analyzed the port's maintenance parameters and optimized them by deploying three models, namely Taguchi scheme, Taguchi-Pareto, and Taguchi-ABC. The work provides the basic data to intervene in optimization and concurrent prioritization effort in a port terminal maintenance section.

Furthermore, a section of the literature evaluates the influence of ports on businesses and its competitiveness. Iimi et al. (2019) analyzed and associated the linkage of ports and rail to agricultural production. Streit-Juotsa and Haasis (2018) related the activities at seaport and pharmaceutical chains in the same theme. Still on port activities, van Dyck and Ismavel (2015) established an analytical hierarchy process framework for port competitiveness. Interestingly, all these reports focused on Africa, which is the primary data collection region and focus of the present study. Undoubtedly, the logistics aspects of seaports greatly influence seaports' sustainability; it greatly determines how much patronage of the customers the seaport will experience compared to road and air goods conveyance options. Without an efficient logistic chain process, the seaport operations will be on the verge of collapse. But can this option be substituted for maintenance effectiveness and optimization?

The current review of literature certainly revealed that they are different and efforts on logistics as contributed by the innovative studies of Iimi et al. (2019), Sreit-Juotsa and Haasis (2018), and van Dyck and Ismael (2015) may not assist in elevating the level of maintenance efficiency, effectiveness, and optimization. So, there is inadequate information on how these studies could aid maintenance effectiveness. While these studies promote logistic activities, there is no guidance on how the maintenance's principal parameters could be optimized. But without optimization, resources will be wasted, and sub-optimal goals that lead to the organization's partial success will be pursued. There is, therefore, the need to respond to calls by the previous authors on the optimization of process parameters for seaports.

2.2 Literature Gaps and Observations

From the survey of literature, the following gaps and observations were raised:

1. It is necessary to determine a workable method to assess the performance of handling equipment in a container terminal. However, more pressing is the need to exploit a competent appraisal approach to handling maintenance downtime.
2. Taguchi method offers a viable approach to assess the downtime of both service and manufacturing systems.
3. It is compelling to determine the most important parameters controlling the downtime. Moreover, this will provide direction on the magnitude of resources to channel to each parameter and ensure judicious utilization of resources.
4. Taguchi-Pareto and Taguchi-ABC methods are useful tools with proven utility in the literature.
5. There is no study with clear directions on the performance of mobile harbor cranes in container terminals.
6. Many studies are associated with ships and harbors and their interactions have been extensively discussed. However, studies regarding the handling equipment in container terminals are hardly found in the shipping and logistics literature.
7. A reasonable optimization and prioritization approach is needed to compare the prevailing optimization methods in engineering practices accurately. Consequently, the Taguchi-Pareto method and the Taguchi-ABC method are needed in the container terminal handling equipment maintenance.

3. RESEARCH METHOD

In this paper, three variants of Taguchi methods, namely the traditional Taguchi scheme, were used to optimize the downtime process parameters in maintaining mobile harbor cranes for a container terminal. The Taguchi-Pareto method is the second approach from which the user prioritizes the parameters in order of importance, but according to the Pareto principle while incorporating the Pareto method into the Taguchi optimization method. The Taguchi-ABC method is the third approach in which the maintenance manager in the container terminal gains a prioritized knowledge of the parameters. Based on this, the maintenance system's scarce maintenance resources may be prudently distributed according to the needs of the parameters, from the analysis of maintenance downtime using the ABC principle.

The three novel models were used to assess the optimal values of the process parameters and/or prioritize the parameters for the important distribution of scarce resources according to the prioritized scale. At first, the Taguchi method was applied, and the optimal parametric values of the downtime parameters were determined. In the next steps, the Taguchi-Pareto method and the Taguchi-ABC method are established from the ANOVA computations that indicate each parameter's variance contributions and terms from which cumulative frequencies are evolved and further steps to determine the optimal parametric sets of values are made.

Furthermore, in this paper, two of the proposed approaches integrate two different theories with the Taguchi theory to appraise the downtime parameters influencing the performance of handling equipment in the container terminal. The sketch of the handling equipment maintenance appraisal is given in Fig. 1.

3.1 Equipment Selection and Downtime Hours

The mobile harbor cranes are chosen as the equipment whose parameters are studied regarding the downtime evaluation. Maintenance logbooks are examined and eight mobile cranes labelled here as L1, L2, L3, L4, L5, L6, L7 and L8 were closely examined. Some information regarding the cost, capacity, projected lifespan and the length of time the studied cranes have been in use is provided as follows. The mobile harbor crane L1-500 model is a fourth-generation crane of engine type MAN-12cylinders and weighs 504 tons. It costs around $500,000 to $800,000, depending on the company's specification. The capacity of cranes is measure in nominal power output, which is 670 kW for L1. Its useful life is about eight years. However, it depends on the adequacy of maintenance practice. This crane has been in use for the past three to four years. The descriptions concerning L2 to L8 are the same for L1 except that the model changes from 500 to 550 with marginal differences in capacities and cost of the cranes compared to L1.

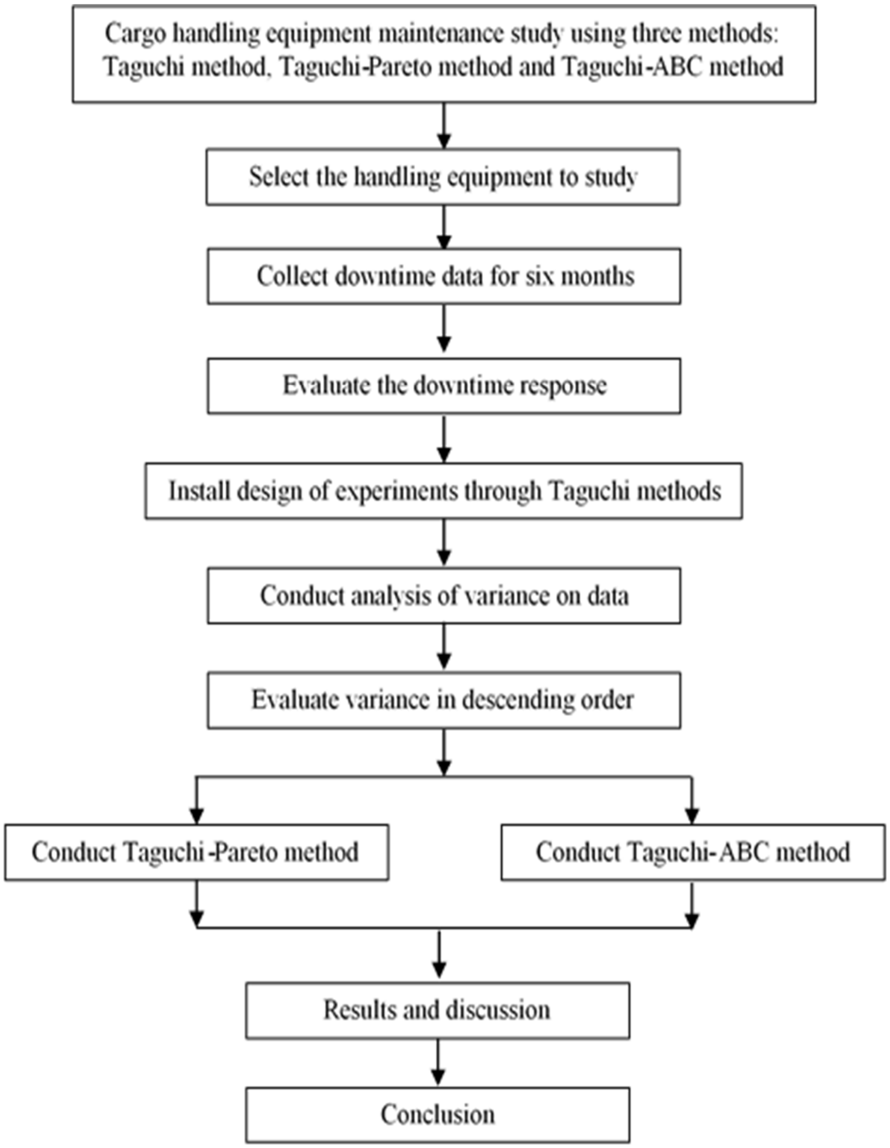

Fig. 1. Scheme of the research

3.2 Evaluating Response Parameters

This work's key objective is to evaluate the downtime response of the mobile harbor cranes in the maintenance process of a container terminal. The evaluation entails the collection of downtime data for the eight cranes, L1 to L8. The weekly downtime data for six months were collected. In the next step, twenty-five experiments with different levels of the chosen parameters are applied according to the Taguchi scheme and the Taguchi-Pareto method. However, for the Taguchi-ABC method, twenty experiments with various levels of the selected parameters were executed. Then the data analysis on the cranes' downtime to obtain the significant parameters, associated levels, and contribution ratios is executed through the signal-to-noise quotient and the analysis of variance method.

3.3 Process of Experimental Design

The process of experimental design involves choosing the parameters. Numerous parameters are known to influence downtime response when considering the maintenance of mobile harbor cranes. To obtain correct choices of parameters, literature concerning container terminals is explored coupled with visits to a seaport whose handling equipment is studied. The idea also is to use as much relevant data in the process this, it was decided that the mobile harbor crane be studied. The selected parameters are downtime hours, probability density function, and cumulative density function. It is ascertained that based on the authors' knowledge, it is difficult to find a reference study in the literature that had examined the performance of mobile harbor crane regarding maintenance performance.

3.4 Taguchi Method

The Taguchi scheme, which was introduced decades ago to tackle quality problems with tangible output systems, has gained wide acceptance beyond the production domain to service systems. Once a system is identified to contain factors (parameters) that take various quantifiable positions (levels), the Taguchi method remains a powerful tool to optimize such. In the paper, the Taguchi scheme has been thought to potentially influence the maintenance activities' performance in the handling equipment of container terminals, and mobile harbor crane in particular. In the Taguchi method, an important element to describe is the signal to noise quotient mechanism. The key idea regarding this mechanism is to lessen the noise, which is undesirable in the maintenance system to the least possible according to the description of the system's quality attributes. The quotient is widely recognized as the objective function with a significant impact on the outcome of the system. Accordingly, the quality attributes, regarded as criteria associated with the quotient, are three, namely, the lower-the-better, the normal-the-best, and the higher-the-better (Moayyedian et al., 2020). As defined in the principal objective of this research, the researchers' interest is drawn towards lowering the downtime and based on the literature (Moayyedian et al., 2020; Ajibade et al., 2019; Oji and Oke, 2020), the criterion defining the lower-the-better quality attribute of the maintenance downtime process is chosen:

$$S/N = -10\log_{10}(1/n\sum_{i=1}^{n} y_i^2) \tag{1}$$

Here, n is specifying the total data positions for each of the experiments, y_i defining the downtime response for the various trials.

3.5 Analysis of Variance

According to Moayyedian et al. (2020), the immediate step after establishing the principal parameters, and in this case, downtime response together with their optimal levels, is the evaluation percentage contributions. This approach is followed in this paper, and the following attributes of ANOVA were determined: the sum of squares, degrees of freedom, F values, P-values, $F_{critical}$, sources of variations by rows, columns and error definitions

3.6 Taguchi-Pareto Method

Putting in mind the complicated nature of handling equipment maintenance in container terminals, it is challenging to achieve an efficient maintenance appraisal system using a theory. Multiple theories and methods may be needed to tackle the maintenance of resource distribution and optimization problems. The Taguchi-Pareto consists of two theoretical frameworks, namely Taguchi theory and the Pareto theory. Each of these serves the purpose of optimization and order of parameters, respectively. The hybrid method, Taguchi-Pareto that integrates the Taguchi method and Pareto theory, is consequently proposed to tackle the handling equipment maintenance problem. The Pareto principle's fundamental usage was to reveal the regular of defeats, which is an aesthetic characteristic that declares that a product has failed.

Pareto measures the impact of these defeats on the system. Adopted to the downtime process and in the context of optimization, Taguchi-Pareto reveals the regularly of any of the studied parameters and its influence in the optimization performance on the process being studied. Taguchi-Pareto method, therefore, reveals the impact of each studied parameter on the outcome of the system. As the most influential parameter is identified with information from the ANOVA method, resources are more prudently distributed to the parameters according to the scale of preference revealed by the method of Taguchi-Pareto. The qualitative expression for this is indicated in Equation (2) (Ajibade et al.; 2019; Oji and Oke, 2020):

$$S/N = -10\log_{10}(1/n\sum_{i=1}^{n} P_{80-20}\, y_i^2) \qquad (2)$$

Here, y_i is the measured quantity reflecting the lower-the-better criterion, n assumes the number of trials, S/N is the quotient regarding the system's signal-to-noise. However, the $P_{80\text{-}20}$ is acquired from the analysis of variance statistics.

3.7 Taguchi-ABC Method

The original design of the ABC analysis was in inventory systems. There was serious concern on lowering the working capital, which was achieved by establishing the elements that may be reordered loss- and more-frequently. This idea was borrowed and applied in different situations, first in the water absorption process by Ajibade et al. (2019) and to the bottling process plant by Oji and Oke (2020). By acknowledging the model's success, the Taguchi-ABC method is applied in a new way in the present work. The concern shown was to lower the downtime experienced by the mobile harbor crane. Determining the parameters may have more resources to control the downtime hours and those whose resources should remain low to have good control of the mobile harbor crane. The quantitative measure for the Taguchi-ABC method as in Equation (3), defined in Ajibade et al. (2019) and Oji and Oke (2020):

$$S/N = -10\log_{10}(1/n(ABC)\sum_{i=1}^{n} y_i^2) \qquad (3)$$

Here, y_i is the measured quantity reflecting the lower-the-better criterion, n assumes the number of trials, S/N is the quotient regarding the system's signal-to-noise. However, ABC is the index acquired from ABC analysis regarding factors and levels.

4. RESULTS AND DISCUSSION

4.1 Taguchi Scheme, Taguchi-Pareto Method, and Taguchi-ABC Method

Several pieces of equipment contribute to the efficiency of the port operations. When equipment ceases to function, they contribute to the downtime of port operations. While it is possible to model the downtime parameters for all the container terminal equipment with system dynamics model, it is thought to be extremely complex to follow the approach since the implementation of the results of such a complicated solution may require some specialized training and cost-intensive. The management of the container terminal studied is unwilling to invest in such a project. Consequently, a research strategy is deployed to easily understand and novel models of Taguchi schemes to solve the downtime problem in the container terminal.

The new model's use strongly motivated the current researchers as a result of its success by previous researchers, Oji and Oke (2020), in implementing them in a bottling process plant. Consequently, as revealed in the introduction, this paper considers the novel methods of the Taguchi scheme, the Taguchi-Pareto scheme, and the Taguchi ABC method. The first method, the Taguchi scheme is the traditional method that considers the factors responsible for downtime in the container terminal in handling equipment, and the principal factors were identified as downtime function and the cumulative density function. The second and third methods (Taguchi-Pareto and Taguchi-ABC) find the optimal parameters in the maintenance of the container terminal's handling equipment.

Also, it has the advantage of prioritizing the factors according to an important mechanism such that the optimal selection of parameters is complemented with the important criterion. The implication of this is that of resource sharing and its judicious utilization. In this paper, mobile harbor cranes were studied. There are about eight functional mobile harbor cranes analyzed. The downtime was collected for all the studied cranes and synch rinsed to find the port's downtime. Concerning resource sharing mentioned above, the maintenance engineer would determine the ordering of the factors and allocate the most resource in the proportion given by the delta value at the computation of the optimal parametric setting.

To analyse the data collected from the active port operations in southern Nigeria, the Weibull distribution function was first deplored to understand the handling equipment's maintenance behavior in the container terminal. Although the Weibull function analysis is outside the discussion of this paper, this work uses the idea of the shape parameter of the Weibull function to extensively test the proposed optimization models regarding their sensitivity to the data collected. For a comprehensive analysis, the shape parameter β, having their values, including β=0.5, β=1 and β=3 were used for the study. The shape parameter deals with the pattern of the Weibull function when plotted. The corresponding descriptions of β=0.5, β=1 and β=3 are the infant mortality, useful life and near out period. At infant mortality stage, less number of breakdowns are experienced where a learning experience of the maintenance team regarding the behavior of machines and the best maintenance practice to adopt is cultivated at the constant/useful life period, the breakdown is controlled appropriately by the maintenance team, and less breakdown is experience. The third part of the shape parameter is the wear-out period where the handling equipment (mobile harbor crane) is old. They may not be effectively controlled. By trying these shapes parametric scenarios, the models are expected to reveal which of the three-stage best suits the case study.

In this work, the L_{25} orthogonal array of the Taguchi method was employed to structure the computational platform in readiness for the signal-to-noise evaluation of the Taguchi method and the Taguchi-Pareto method. However, for the Taguchi-ABC method, the orthogonal matrix utilized is of a special mix kind of L_{20}. Consequently, twenty-five and twenty experiments were used for each of the respective L_{25} and L_{20} groups.

Every experiment was conducted such that changes in levels according to the dictates of the orthogonal array were made. (Tables 1a, 2a and 3a). To implement an experiment, the value of an individual factor is considered and substituted into the signal-to-noise criterion expression of lower-the-better while the outcome is a value with a negative or positive sign.

In Table 1a, the signal-to-noise ratio for the first experiment when β=0.5 is computed by following the orthogonal matrix that allocates the first level to each of the three factors, meaning 19.30 hrs for downtime, 0.012 for probability density function, and 0.657 for the cumulative probability density function. Moayyedian et al. (2020) employed the design of an experiment with the Taguchi method, considering some parameters to determine the responsibility for the process.

However, no study has evaluated the influence of downtime parameters in handling container terminals' equipment maintenance on the down-time response. But from the literature survey, there is an emerging necessity to analyze the downtime response with downtime, probability density function, and cumulative density function as the parameters. The twenty-five experiments and their results are shown in Table 1a to 3c are evaluated based in Equations (1) to (3) and the respective orthogonal matrix of L_{25} and L_{20}. Next, the response tables (Tables1c, 2c and 3c) are used to establish the optimal parametric setting by observing the minimum S/N ratio in each level. This is because the lower-the-better S/N ratio criterion is utilized in this work. The S/N ratio responses in Tables 1c, 2c and 3c prompts us to conclude that the greater S/N quotients of the various parameters for diverse levels reveal the most optimal level for each parameter. Consequently, the greatest difference of the highest to the lowest values for the S/N quotient in each parametric consideration reveals the most significant parameters influencing the results of the experiment.

Table 1a. Taguchi's orthogonal arrays L_{25} (5**3), factors and signal to noise ratios (β = 0.5, 1 and 3)

	β = 0.5							β = 1				β = 3			
	Orthogonal array			**Factors**				**Factors**				**Factors**			
Expt. No.	**DTM**	**PDF**	**CDF**	**DTM**	**PDF**	**CDF**	**S/N ratios**	**DTM**	**PDF**	**CDF**	**S/N ratios**	**DTM**	**PDF**	**CDF**	**S/N ratios**
1	1	1	1	19.30	0.012	0.657	-16.09	19.30	0.32	0.68	-20.96	19.30	0.03	0.68	-20.99
2	1	2	2	19.30	0.007	0.749	-15.96	19.30	0.20	0.80	-20.96	19.30	0.03	0.86	-20.95
3	1	3	3	19.30	0.008	0.709	-16.02	19.30	0.22	0.78	-20.96	19.30	0.02	0.76	-20.95
4	1	4	4	19.30	0.011	0.704	-16.03	19.30	0.24	0.76	-20.96	19.30	0.01	0.70	-20.94
5	1	5	5	19.30	0.006	0.768	-15.94	19.30	0.14	0.89	-20.97	19.30	0.01	0.83	-20.95
6	2	1	2	44.64	0.012	0.749	-26.66	44.64	0.32	0.80	-28.23	44.64	0.03	0.86	-28.22
7	2	2	3	44.64	0.007	0.709	-26.66	44.64	0.20	0.78	-28.23	44.64	0.03	0.76	-28.23
8	2	3	4	44.64	0.008	0.704	-26.72	44.64	0.22	0.76	-28.23	44.64	0.20	0.70	-28.23
9	2	4	5	44.64	0.011	0.768	-26.63	44.64	0.24	0.89	-28.23	44.64	0.01	0.82	-28.23
10	2	5	1	44.64	0.006	0.657	-26.78	44.64	0.14	0.68	-28.23	44.64	0.01	0.68	-28.23
11	3	1	3	24.08	0.012	0.709	-18.59	24.08	0.32	0.78	-22.88	24.08	0.03	0.76	-22.87
12	3	2	4	24.08	0.007	0.704	-18.59	24.08	0.20	0.76	-22.88	24.08	0.03	0.70	-22.87
13	3	3	5	24.08	0.008	0.768	-18.50	24.08	0.22	0.89	-22.88	24.08	0.02	0.82	-22.88
14	3	4	1	24.08	0.011	0.657	-18.66	24.08	0.24	0.68	-22.87	24.08	0.01	0.68	-22.87
15	3	5	2	24.08	0.006	0.749	-18.53	24.08	0.14	0.80	-22.88	24.08	0.01	0.86	-22.88
16	4	1	4	29.27	0.012	0.704	-21.01	29.27	0.32	0.76	-24.57	29.27	0.03	0.70	-24.57
17	4	2	5	29.27	0.007	0.768	-20.92	29.27	0.20	0.89	-24.57	29.27	0.03	0.82	-24.57
18	4	3	1	29.27	0.008	0.657	-21.07	29.27	0.22	0.68	-24.57	29.27	0.02	0.68	-24.56
19	4	4	2	29.27	0.011	0.749	-20.94	29.27	0.24	0.80	-24.57	29.27	0.01	0.86	-24.57
20	4	5	3	29.27	0.006	0.709	-21.00	29.27	0.14	0.78	-20.88	29.27	0.01	0.76	-24.57
21	5	1	5	35.60	0.012	0.768	-23.48	35.60	0.32	0.89	-23.18	35.60	0.03	0.82	-26.26
22	5	2	1	35.60	0.007	0.657	-23.64	35.60	0.20	0.68	-23.57	35.60	0.03	0.68	-26.26
23	5	3	2	35.60	0.008	0.749	-23.51	35.60	0.22	0.80	-23.38	35.60	0.02	0.86	-26.27
24	5	4	3	35.60	0.011	0.709	-23.57	35.60	0.24	0.78	-23.41	35.60	0.01	0.76	-26.26
25	5	5	4	35.60	0.006	0.704	-23.57	35.60	0.14	0.76	-23.48	35.60	0.01	0.70	-26.26

Note: PDF – probability density function; DTM – downtime; S/N ratio – signal-to-noise ratio; β – shape parameter for Weibull distribution

Table 1b. Parameters and their levels

			β = 0.5					**β = 1**					**β = 3**		
Factors	**Level 1**	**Level 2**	**Level 3**	**Level 4**	**Level 5**	**Level 1**	**Level 2**	**Level 3**	**Level 4**	**Level 5**	**Level 1**	**Level 2**	**Level 3**	**Level 4**	**Level 5**
DTM	19.30	44.64	24.08	29.27	35.60	19.30	44.64	24.08	29.27	35.60	19.30	44.64	24.08	29.27	35.60
PDF	0.01	0.01	0.01	0.01	0.01	0.32	0.20	0.22	0.32	0.14	0.03	0.03	0.02	0.010	0.01
CDF	0.66	0.75	0.71	0.70	0.77	0.68	0.80	0.78	0.76	0.89	0.68	0.86	0.76	0.70	0.82

Note: PDF – probability density function; DTM – downtime; S/N ratio – signal-to-noise ratio; β – shape parameter for Weibull distribution

Table 1c. Taguchi S/N ratios response table ratios for equipment downtime with β = 0.5, 1 and 3

		β = 0.5			**β = 1**			**β = 3**	
Level	**DTM**	**PDF**	**CDF**	**DTM**	**PDF**	**CDF**	**DTM**	**PDF**	**CDF**
1	***-16.01**	-21.16	-21.25	***-20.96**	-23.96	-24.04	***-20.96**	-24.58	-24.58
2	-26.70	-21.13	-21.12	-28.23	-24.04	-24.00	-28.23	-29.49	-24.58
3	-18.57	***-14.76**	-21.18	-22.88	-24.00	***-23.27**	-24.05	-24.58	-24.58
4	-20.99	-21.16	-21.19	-23.83	-24.01	-24.02	-24.57	***-24.58**	-24.57
5	-23.55	-21.16	***-21.09**	-23.40	***-23.29**	-23.97	-26.26	24.58	**-23.58**
Delta	10.69	6.41	0.09	7.27	0.72	0.69	7.27	4.92	0.01
Ranks	1	2	3	1	2	3	1	2	3
*Optimal level	$\text{DTM}_1\text{PDF}_3\text{CDF}_5$			$\text{DTM}_1\text{PDF}_5\text{CDF}_3$			$\text{DTM}_1\text{PDF}_4\text{CDF}_5$		

Note: PDF – probability density function; DTM – downtime; S/N ratio – signal-to-noise ratio; β – shape parameter for Weibull distribution

Table 2a. Taguchi-Pareto's orthogonal arrays L_{25} (5**3), factors and signal to noise ratios (β = 0.5, 1 and 3)

					β = 0.5				**β = 1**				**β = 3**		
		Orthogonal array			**Factors**				**Factors**				**Factors**		
Expt. No.	**DTM**	**PDF**	**CDF**	**DTM**	**PDF**	**CDF**	**S/N ratios**	**DTM**	**PDF**	**CDF**	**S/N ratios**	**DTM**	**PDF**	**CDF**	**S/N ratios**
1	1	1	1	0	0.01	-	44.69	0	0.32	0.68	8.50	19.30	0.32	-	-19.69
2	1	2	2	0	0.01	-	48.85	0	0.20	0.80	7.71	19.30	0.20	-	-19.69
3	1	3	3	0	0	-	0	0	0.22	0.00	19.10	19.30	0.22	-	-19.69
4	1	4	4	0	0.01	-	45.31	0	0.24	0.76	8.01	19.30	0	-	-19.69
5	1	5	5	0	0.01	-	51.06	0	0.00	0.89	7.07	19.30	0.01	-	-19.69
6	2	1	2	44.64	0.01	-	-26.97	44.64	0.32	0.80	-26.98	44.64	0.32	-	-26.97
7	2	2	3	44.64	0.01	-	-26.97	44.64	0.20	0.00	-26.97	44.64	0.20	-	-26.97
8	2	3	4	44.64	0	-	-26.97	44.64	0.22	0.76	-26.98	44.64	0.22	-	-26.97
9	2	4	5	44.64	0.01	-	-26.97	44.64	0.24	0.89	-26.98	44.64	0	-	-26.97
10	2	5	1	44.64	0.01	-	-26.97	44.64	0	0.68	-26.97	44.64	0.01	-	-26.97
11	3	1	3	0	0.01	-	44.69	0	0.32	0	15.93	0	0.32	-	15.93
12	3	2	4	0	0.01	-	48.85	0	0.20	0.76	8.14	0	0.20	-	19.92
13	3	3	5	0	0	-	0	0	0.22	0.89	6.80	0	0.22	-	19.10
14	3	4	1	0	0.01	-	45.31	0	0.24	0.68	8.84	0	0	-	0
15	3	5	2	0	0.01	-	51.06	0	0	0.80	7.98	0	0.01	-	45.51
16	4	1	4	0	0.01	-	44.69	29.27	0.32	0.76	-23.31	0	0.32	-	15.93
17	4	2	5	0	0.01	-	48.85	29.27	0.20	0.89	-23.31	0	0.20	-	19.92
18	4	3	1	0	0	-	0	29.27	0.22	0.68	-23.31	0	0.22	-	19.10
19	4	4	2	0	0.01	-	45.31	29.27	0.24	0.80	-23.31	0	0	-	0
20	4	5	3	0	0.01	-	51.06	29.27	0	0.00	-23.31	0	0.01	-	45.51
21	5	1	5	35.6	0.01	-	-25.01	35.60	0.32	0.89	-25.01	35.60	0.32	-	-25.01
22	5	2	1	35.6	0.01	-	-25.01	35.60	0.20	0.68	-25.01	35.60	0.20	-	-25.01
23	5	3	2	35.6	0	-	-25.01	35.60	0.22	0.80	-25.01	35.60	0.22	-	-25.01
24	5	4	3	35.6	0.01	-	-25.01	35.60	0.24	0.00	-25.01	35.60	0	-	-25.01
25	5	5	4	35.6	0.01	-	-25.01	35.60	0	0.76	-25.01	35.60	0.01	-	-25.01

Note: PDF – probability density function; DTM – downtime; S/N ratio – signal-to-noise ratio; β – shape parameter for Weibull distribution

Table 2b. Parameters and their levels - Taguchi-Pareto method

			β = 0.5					**B = 1**					**β = 3**		
Factors	**Level 1**	**Level 2**	**Level 3**	**Level 4**	**Level 5**	**Level 1**	**Level 2**	**Level 3**	**Level 4**	**Level 5**	**Level 1**	**Level 2**	**Level 3**	**Level 4**	**Level 5**
DTM	0	44.64	0	0	35.60	0.00	44.64	0.00	29.27	35.60	19.30	44.64	0.00	0.00	35.60
PDF	0.01	0.01	0	0.01	0.006	0.32	0.20	0.22	0.24	0.00	0.32	0.20	0.22	0.00	0.01
CDF	-	-	-	-	-	0.68	0.80	0.00	0.76	0.89	-	-	-	-	-

Note: PDF – probability density function; DTM – downtime; S/N ratio – signal-to-noise ratio; β – shape parameter for Weibull distribution

Table 2c. Taguchi-Pareto's S/N ratios response table ratios for equipment downtime with β = 0.5, 1 and 3

		β = 0.5			**β = 1**			**β = 3**	
Level	**DTM**	**PDF**	**CDF**	**DTM**	**PDF**	**CDF**	**DTM**	**PDF**	**CDF**
1	37.98	16.42	-	**-10.08**	-10.17	-11.59	**-19.69**	-7.96	-
2	*-**26.97**	18.91	-	-26.98	-11.89	-11.92	-26.97	**-6.37**	-
3	37.98	***-10.40**	-	-23.31	**-9.88**	**-8.05**	20.10	-6.70	-
4	37.98	16.80	-	-29.27	-11.69	-11.83	20.10	-14.33	-
5	-25.01	20.24	**-**	-25.01	-12.05	-10.24	-25.01	3.87	**-**
Delta	12.97	9.6	-	19.19	2.17	3.87	7.28	10.46	-
Ranks	1	2	-	1	3	2	2	1	-
*Optimal level		DTM_2PDF_3			$DTM_1PDF_3CDF_3$			DTM_1PDF_2	

Note: PDF – probability density function; DTM – downtime; S/N ratio – signal-to-noise ratio; β – shape parameter for Weibull distribution

Table 3a. Taguchi-ABC's orthogonal arrays L_{20}, factors and signal to noise ratios (β = 0.5, 1 and 3)

			β = 0.5			**β = 1**			**β = 3**		
	Orthogonal array		**Factors**			**Factors**			**Factors**		
Expt. No.	**DTM**	PDF	**DTM**	**PDF**	**S/N ratios**	**DTM**	**PDF**	**S/N ratios**	**DTM**	**PDF**	**S/N ratios**
1	1	1	19.30	0.01	-22.70	19.30	0.32	-22.70	19.30	0.03	-22.70
2	1	2	19.30	0.01	-22.70	19.30	0.20	-22.70	19.30	0.03	-22.70
3	1	3	19.30	0.01	-22.70	19.30	0.22	-22.70	19.30	0.02	-22.70
4	1	4	19.30	0.01	-22.70	19.30	0.24	-22.70	19.30	0.01	-22.70
5	1	5	44.64	0.01	-29.98	44.64	0.14	-29.98	44.64	0.01	-29.98
6	2	1	44.64	0.66	-29.99	44.64	0.68	-29.99	44.64	0.68	-29.99
7	2	2	44.64	0.75	-29.99	44.64	0.80	-29.99	44.64	0.86	-29.99
8	2	3	44.64	0.71	-29.98	44.64	0.78	-29.99	44.64	0.76	-29.99
9	2	4	24.08	0.70	-24.63	24.08	0.76	-24.63	24.08	0.70	-24.63
10	2	5	24.08	0.77	-24.63	24.08	0.89	-24.63	24.08	0.82	-24.63
11	3	1	24.08	0.01	-24.62	24.08	0.32	-24.62	24.08	0.03	-24.62
12	3	2	24.08	0.01	-24.62	24.08	0.20	-24.62	24.08	0.03	-24.62
13	3	3	29.27	0.01	-26.32	29.27	0.22	-26.32	29.27	0.02	-26.32
14	3	4	29.27	0.01	-26.32	29.27	0.24	-26.32	29.27	0.01	-26.32
15	3	5	29.27	0.01	-26.32	29.27	0.14	-26.32	29.27	0.01	-26.32
16	4	1	29.27	0.66	-26.32	29.27	0.68	-26.32	29.27	0.68	-26.32
17	4	2	35.60	0.75	-28.02	35.60	0.80	-28.02	35.60	0.86	-28.02
18	4	3	35.60	0.71	-28.02	35.60	0.78	-28.02	35.60	0.76	-28.02
19	4	4	35.60	0.70	-28.02	35.60	0.76	-28.02	35.60	0.70	-28.02
20	4	5	35.60	0.77	-28.02	35.60	0.88	-28.02	35.60	0.82	-28.02

Note: PDF – probability density function; DTM – downtime; S/N ratio – signal-to-noise ratio; β – shape parameter for Weibull distribution

Table 3b. Parameters and their levels - Taguchi-ABC method

	β = 0.5					**β = 1**					**β = 3**				
Factors	**Level 1**	**Level 2**	**Level 3**	**Level 4**	**Level 5**	**Level 1**	**Level 2**	**Level 3**	**Level 4**	**Level 5**	**Level 1**	**Level 2**	**Level 3**	**Level 4**	**Level 5**
DTM	19.30	44.64	24.08	29.27	35.60	19.30	44.64	24.08	29.27	35.60	19.30	44.64	24.08	29.27	35.60
PDF	0.01	0.01	0.01	0.01	0.01	0.32	0.20	0.22	0.32	0.14	0.03	0.03	0.02	0.010	0.01
CDF	0.66	0.75	0.71	0.70	0.77	0.68	0.80	0.78	0.76	0.89	0.68	0.86	0.76	0.70	0.82

Note: PDF – probability density function; DTM – downtime; CDF – cumulative density function; β – shape parameter for Weibull distribution

Table 3c. Taguchi-ABC's S/N ratios response table ratios for equipment downtime with β = 0.5, 1 and 3

	β = 0.5		**β = 1**		**β = 3**	
Level	**DTM**	**PDF**	**DTM**	**PDF**	**DTM**	**PDF**
1	**-22.70**	**-20.73**	-22.70	-32.91	**-22.70**	**-31.09**
2	-29.99	-32.91	**-14.99**	-32.92	-29.99	-32.91
3	-24.63	-32.91	-24.64	**-32.91**	-24.62	-32.91
4	-26.32	-32.91	-26.32	-32.91	-26.32	-32.91
5	-28.02	-	-28.02	-	-28.02	-
Delta	5.36	12.18	13.03	0.01	7.29	1.82
Ranks	2	1	1	2	1	2
*Optimal level	DTM_1PDF_1		DTM_2PDF_3		DTM_1PDF_1	

Note: PDF – probability density function; DTM – downtime; β – shape parameter for Weibull distribution

It follows that the downtime response was largely affected by downtime hours, probability density function. From Table 1c, by choosing the lowest level of the S/N quotient, it may be concluded that the optimal level for the chosen parameters for the least downtime response is the downtime at 16.01 hours (level 1), PDF at -14.76 and CDF at -21.09, all when β=0.5.

This is stated as $DTM_1PDF_5CDF_3$. It means that by choosing the lowest level of the S/N quotient, it may be concluded that the optimal level for the chosen parameters for the least downtime response is the downtime at 20.96hrs (level 1), PDF at 23.29 (level 5) and CDF at 23.27(level 3). Besides, when β=3, the optimal parametric setting $DTM_1PDF_4CDF_5$. It means that by choosing the lowest level of the S/N quotient, it may be concluded that the optimal level for the chosen parameters for the least downtime response is the downtime of 20.96hrs (level 1), PDF of 24.58 (level 4) and CDF of 23.58 (level 5).

From Table 2c, by choosing the lowest level of the S/N quotient, it may be concluded that the optimal level for the chosen parameters for the least downtime response is the downtime at 26.97hrs (level 2) and PDF at 10.40 (level 3), all at β=0.5. This is stated as DTM_2PDF_3. Besides, when β=1, the optimal parametric setting yields $DTM_1PDF_3CDF_3$. This is interpreted as follows. By choosing the lowest level of the S/N quotient, it may be concluded that the optimal level for the chosen parameters for the least downtime response is the downtime at 10.08hrs (level 1), CDF at 8.05 (level 3). Furthermore, when B=3, the optimal parametric setting is $DTM_1PDF_5CDF_3$. This implies that by selecting the least level of the S/N quotient, it may be concluded that the optimal level for the chosen parameters for the least downtime response is the PDF at 6.37 (level2) and downtime at 19.69hrs (level1).

From Table3c, by selecting the least level of the S/N quotient, it may be concluded that the optimal level for the chosen parameters for the least downtime response is the PDF at 20.73 (level1) and downtime at 22.70hrs (level 1), all at B=0.5. This is stated as DTM, PDF. Besides, when β=1, the optimal parametric setting yields DTM_2PDF_3. It follows that by choosing the lowest level of the S/N quotient, it may be concluded that the optimal level for the chosen parameters for the least downtime response in downtime at 14.99 (level 2) and PDF at 32.91 (level 3). Moreover, when β=3, the optimal parametric setting is DTM, PDF. This means that by selecting the least level of the S/N quotient, it may be concluded that the optimal level for the chosen parameters for the least downtime is 22.70 hours (level 1) and PDF at 31.09 (level 1).

A key goal in testing the model under three conditions of β=0.5, 1 and 3 is to test the sensitivity of the model on the assumption that the container terminal is newly established and the equipment is newly bought. This is the infant state at which β=0.5 in practice, we may choose one year in the company's operations and the use of the mobile labor areas. A second condition is when the container terminal has existed for a while, referred to as the stabilization stage. At this state, β=1 and it is assumed that both the equipment and the resources to operate them are in a stable condition. This means that an extremely low turnover of staff is experienced to have caused instability in the container terminal's maintenance activities. When key and experienced staff leaves the company, inexperienced maintenance staff are deployed for maintenance, and the quality of repairs may not be "as-good-as-new" to restore the mobile labor areas to a "perfect state" such that a recurring breakdown within the shorter mean time between failures will not be experienced. The period concerned may be between 1 and 4 years usage of the areas. At β=3, the wear-out period, the equipment are old, perhaps with demotivated staff. At this instance, significant efforts in repairs yield extremely little out-comes.

A period of more than 4 years in the service life of the mobile harbor crane is considered. To illustrate the three proposed models' sensitivity, the Taguchi scheme, the Taguchi-Pareto method and the Taguchi-ABC method, the optimal parametric values of downtime hours one used. Starting with the Taguchi scheme, consider the container terminal's infant stage and the mobile harbor cranes. Downtime hours of 16.01 are given for the infant stage. This means that the maximum permissible time for a gang manning the crane is 16.01 hours in a week of 168 hours nearing 10% of the available time. Although be company-wide. The campaign by the management is the attainment of zero downtime, the management makes provisions for downtime as some situations such as the arrival of replacement parts for cranes from ordering, which may not be on time. At the stabilization stage, the downtime hours increased by 30.92% as the provision for a change of state, which is envisaged to reduce the machine's capability and the downtime hours experienced is expected to increase. The model is sensitive to the result of this outcome.

Compared to β=3 at the wear-out region of the container terminal, the downtime hours is still maintained. This may have been done to the retention of experienced maintenance staff and the proactive actions of the management to respond quickly to pants and financial requests concerning repairs. Thus, the conclusion from the results obtained through the Taguchi method's use is that the downtime parameter is sensitive to changes in the condition of the container terminal. Consider the Taguchi-Pareto method, at the infant stage of the container terminal and the mobile harbor cranes, the downtime hours of 26.97 is given for the infant stage. This means that the maximum permissible time for a gang manning the crane is 26.97 hours in a week of 168 hours, which is roughly 16.05% of the available time. But these downtime hours far exceed that obtained for the Taguchi method for infant stage by 68.46%. This extra amount is the contribution or involvement of the prioritization mechanism offered by the method. The Taguchi-Pareto method is said to be sensitive as it reflects a reasonable value for the method while considering the infant stage of the container terminal. At the stabilization stage, the downtime hours decreased by 62.63%, probably due to sustained adaptation to the cranes, updated equipment straining programs, and quick management responses to spare pant orders. The model is sensitive to measure the downtime hours. Compared with β=3, at the container terminal's wear-out region, the downtime hours increased from its initial value at β=1 to a value with about 95.34% increase. This is expected since at this stage the equipment is old. This may have been coupled with employee turnover for the experienced maintenance crew.

Consider the Taguchi-ABC method, at the infant stage of the container terminal, and the mobile harbor cranes, the downtime of 22.70 hours is given for the infant stage. This means that the maximum permissible time for a gang manning the crane is 22.70 hours in a meek of 168 hours, which is roughly 13.51% of the available time. But these downtime hours for exceeds that obtained for Taguchi method considering the infant stage by 41.79%. This extra amount is the contribution or involvement while instituting the prioritization mechanism of the Taguchi-ABC method. The Taguchi-ABC method is said to be sensitive when considering the results of the infant stage of the container terminal. At the stabilization stage, the downtime hours decreased by 33.96%. This probably results from the overwhelming adaptation of the maintenance crew to the crane downtime pattern. It may also be due to updated training of the maintenance gang on equipment maintenance and the management team's quick actions whenever requests are made. The model is sensitive to measure the downtime hours. When weighed against β=3, the wear-out region that the equipment (Crane) is expected to be old, the downtime increased from its original threshold at =1 to a value equal to what it was β=0.5. This is expected since at this stage the equipment is old. This may have been coupled with employee turnover for the experienced maintenance crew.

4.2 Analysis of Variance in Examining the Downtime Data

The field data on the handling equipment were analyzed using ANOVA to establish the significant parameter responsible for performance changes based on the total variance of the computed results. A typical ANOVA table comprises of the following elements: Sources of variations, which classified as depending on the rows, columns or errors. The degree of freedom, which is the total number of each the rows, columns and errors less one unit; the sum of squares, the mean square, $F\text{-}_{\text{values}}$ F_{critical} and $P\text{-}_{\text{values.}}$

Table 4a should the results regarding the ANOVA of downtime. The data examination was conducted for 95% confidence level (significance level, α = 0.05). The ANOVA for downtime, β =0.5, is given in Table 4c. It reveals that DTM most significantly influence the downtime with an F value of 1.53, next is PDF with an F value of 0.38. The ANOVA for downtime, β=1 is given in Table 4c. It reveals that DTM most significantly influence the downtime with an F value of 1.57, next is PDF with an F value of 0.02. The ANOVA for downtime, β=3 is given in Table 4c. It reveals that DTM most significantly influence the downtime with an F value of 2.57, next is PDF with an F value of 0.5.

4.3 Comparison of Taguchi-Pareto Method and Taguchi-ABC Method

In this paper, the need to concurrently optimize the downtime parameters and prioritize them motivated the development of two methods to achieve this goal. These methods are Taguchi-Pareto and Taguchi-ABC. The two methods were applied under the three conditions that the container terminal equipment could be subjected to over its lifespan, notably the infant stage, the stabilization stage and the wear-out stage. Tables 2b and 3b show the data, which can be compared.

For β=0.5, downtime hours predicted by the Taguchi-Pareto method is more than the one predicted by the Taguchi-ABC method, making the latter, which is less more acceptable to the maintenance manager.

For β=1, the estimated downtime by the Taguchi-Pareto method is lower than that estimated by using the Taguchi-ABC method, showing a preference for the Taguchi-Pareto method, which is less. For β=3, the hours of downtime predicted by the Taguchi-Pareto method is not up to the threshold suggested by the Taguchi-ABC method, making the way to prefer the Taguchi-Pareto method by the maintenance manager, which is less. Overall, Taguchi-Pareto method, which predicts lower values than Taguchi-ABC method is preferred of the two methods.

5. NOVELTY AND CONTRIBUTIONS OF THE ARTICLE

5.1 Novelty of the Article

This work's main objective is to optimize the downtime response, which is dictated by the downtime parameters, using three novel methods regarding the maintenance of handling equipment in a container terminal. These methods are namely the Taguchi scheme, the Taguchi-Pareto method, and the Taguchi-ABC method. Although many researchers have examined service enhancement in container terminals, their bulk efforts have focused on the interaction between ships and the berth.

Unfortunately, scarce reports have been documented on handling equipment in container terminals and unnoticeable efforts are made concerning the maintenance and optimization of downtime for handling equipment in container terminals for the relevant literature. Yet, to attain zero downtime campaign program of management concerning mobile harbor cranes in the studied organization, deep understanding of the downtime parameters' interactions is needed. They need to be controlled as well. Since downtime hours, probability density function and cumulate density function are key parameters that control mobile harbor cranes' downtime, and they are optimized in this paper for the first time. Taguchi method with the mechanism of aggregating factors and finding out their optimal thresholds is contributed for the first time in this paper.

Table 4a. Anova: two-factor without replication with β = 0.5, 1 and 3

		β = 0.5			**β = 1**			**β = 3**		
Summary	**Count**	**Sum**	**Average**	**Variance**	**Sum**	**Average**	**Variance**	**Sum**	**Average**	**Variance**
1	3	-58.42	-19.47	9.01	-68.96	-22.99	3.08	-70.12	-23.37	4.39
2	3	-68.95	-22.98	10.35	-77.07	-25.69	4.97	-82.29	-27.43	6.51
3	3	-54.51	-18.17	10.43	-70.15	-23.38	0.33	-73.21	-24.40	0.09
4	3	-63.34	-21.11	0.01	-71.86	-23.95	0.01	-73.72	-24.57	2.27E-05
5	3	-65.81	-21.94	1.96	-70.65	-23.55	0.13	-75.42	-25.14	0.95
DTM	5	-105.82	-21.16	17.42	-119.30	-23.86	7.16	-124.07	-24.81	7.32
PDF	5	-99.38	-19.88	8.20	-119.30	-23.86	0.10	-127.80	-25.56	4.83
CDF	5	-105.82	-21.16	0.003	-120.10	-24.02	0.29	-122.89	-24.58	1.42E-05

Note: PDF – probability density function; DTM – downtime; CDF – cumulative density function; β – shape parameter for Weibull distribution

Table 4b. Taguchi-ABC's S/N ratios response cumulative table with β = 0.5, 1 and 3

	β = 0.5			**β = 1**			**β = 3**		
Expl. No.	**S/N ratio (ordered)**	**Cumulative value**	**% Cumulative**	**S/N ratio (ordered)**	**Cumulative value**	**% Cumulative**	**S/N ratio (ordered)**	**Cumulative value**	**% Cumulative**
1	-26.70	-26.70	0.09	-28.23	-28.23	0.08	-20.96	-20.96	0.06
2	-23.55	-50.25	0.16	-24.04	-52.27	0.15	-29.49	-50.45	0.13
3	-21.25	-71.50	0.23	-24.04	-76.31	0.21	-28.23	-78.67	0.21
4	-21.19	-92.68	0.30	-24.02	-100.33	0.28	-26.26	-104.94	0.28
5	-21.18	-113.87	0.37	-24.01	-124.34	0.35	-24.58	-129.52	0.35
6	-21.16	-135.03	0.43	-24.00	-148.34	0.41	-24.58	-154.11	0.41
7	-21.16	-156.20	0.50	-24.00	-172.34	0.48	-24.58	-178.68	0.48
8	-21.16	-177.36	0.57	-23.97	-196.31	0.55	-24.58	-203.26	0.54
9	-21.13	-198.49	0.64	-23.96	-220.27	0.62	-24.58	-227.83	0.61
10	-21.12	-219.61	0.71	-23.83	-244.10	0.68	-24.58	-252.41	0.67
11	-21.09	-240.71	0.77	-23.40	-267.51	0.75	-24.58	-276.99	0.74
12	-20.99	-261.69	0.84	-23.29	-290.79	0.81	-24.58	-301.56	0.80
13	-18.57	-280.27	0.90	-23.27	-314.06	0.88	-24.58	-326.14	0.87
14	-16.01	-296.28	0.95	-22.88	-336.94	0.94	-24.57	-350.70	0.94
15	-14.76	-311.03	1	-20.96	-357.90	1	-24.05	-374.76	1

S/N ratio – signal-to-noise ratio; β – shape parameter for Weibull distribution

Table 4c. Anova variation table

	β = 0.5						**β = 1**						**β = 3**					
Source of Variation	**SS**	**Df**	**MS**	**F**	**P-value**	**F_{crit}**	**SS**	**Df**	**MS**	**F**	**P-value**	**F_{crit}**	**SS**	**Df**	**MS**	**F**	**P-value**	**F_{crit}**
Rows	44.46	4	11.12	1.53	0.28	3.84	13.29	4	3.32	1.57	0.27	3.84	27.33	4	6.83	2.57	0.12	3.84
Columns	5.53	2	2.77	0.38	0.69	4.46	0.09	2	0.04	0.02	0.98	4.46	2.63	2	1.32	0.50	0.63	4.46
Error	58.00	8	7.25				16.96	8	2.12				21.24	8	2.66			
Total	108.00	14					30.33	14					51.21	14				

β – shape parameter for Weibull distribution; SS – sum of squares; MS – mean square; Df – Degree of freedom

Besides, the two new Taguchi Pareto and Taguchi-ABC methods that employ the mechanism of optimization and prioritization with the respective composite elements of Pareto and ABC analysis are contributed for the first time. After the optimization and prioritization using the two methods, the maintenance manager would have sufficient information to distribute the scarce maintenance resources to the parameters according to needs.

This data offers usefulness in the design and re-design of maintenance systems regarding handling equipment for container terminals. A further value of this research is that it confirms the sensitivity of the model parameters to changes in values as it recognizes the handling equipment and container terminals at the three conditions of their lifespan, including infant stage (when the handling equipment and system are newly introduced, β =0.5), Stabilization stage, (when the equipment and system have worked for a while, β=1) and wear-out stage (when the equipment and system are old, β=3). Details on ANOVA are shown in Tables 4a to 4c.

5.2 Contributions

This study tackles a critical limitation in the extant literature on the optimization of maintenance of port operations handling equipment. Much of the past studies examine the operations between ships and wharves (Soriguera et al., 2006). As these studies highlight how to handle important issues such as the transportation of refrigerated containers, international maritime dangerous goods, and out-of-gauge cargo, they do not capture the maintenance characteristics of mobile harbor cranes during the loading and discharging of cargo. Consequently, they fail to specify downtime and how they could be optimized and the key parameters of downtime with which decisions to optimize may be made.

This paper draws attention to a necessary yet undocumented consider by which machine uptime may be maximized, enhancing the number of moves a gang can make in the loading and unloading activities of the mobile harbor crane. In doing so, this work emphasizes the influence of probability density function and cumulative density function and downtime hours on the downtime response in mobile harbor crane maintenance. By including probability density function, this work offers a guide on the likely outcome of the downtime elements. The introduction of the cumulative density function provides an opportunity to explain the random variables of downtime hours. Our findings suggest that it is essential for forthcoming studies in this research domain to capture the downtime parameters' interaction instead of directing attention to their assessments.

6. CONCLUSION

From the results of the analysis obtained from the implementation of the models on the data collected, the following conclusions are valid:

1. Optimization of maintenance downtime parameters of handling equipment in a container terminal, using the Taguchi method, Taguchi-Pareto method and Taguchi-ABC method is feasible with the proposed methods and in real-life situation.
2. The methods were used to establish the effects of three downtime parameters, namely, downtime hours, probability density function on the responses. It was established that the model parameters are sensitive to changes in the conditions in the life phases of the container terminal. Hence, these methods may be applied over the lifespan of the container terminals handling equipment. The three methods were instituted to control the performance of the field measurement data while optimizing, using the Taguchi scheme, and concurrent optimization and prioritization using the Taguchi-Pareto and Taguchi-ABC methods. The optimum setting for the minimization of downtime response for specific downtime hours, probability density function and cumulative density function for the three life phases of infant, stabilization and wear-out were found feasible in a real-life circumstance.
3. The best combinations of maintenance downtime parameters for the mobile harbor crane were found to offer lower maintenance downtime devoid of constraints, and utilizing the downtime hours, probability density function and cumulative density function as the selected parameters.

There is an emerging issue during this investigation. It was found that the management of the company has set a standard of 17 moves per hour for each gang operating the crane. A gang consists of crew members of a driver and a worker on the ground that controls the activities of the driver in picking and dropping containers from the ship to the berth. Five gangs are presently scheduled to work daily according to the capacity of the plant. The eight cranes in the facility have eight gangs each of which work for twelve hours with one hour of break inclusive. It is unknown on what premises these number of moves was set by the management. With this number of moves as the standard per shift, it is unknown how much downtime has been incorporated by setting this standard. Is the downtime allowance realistic? Now that the management's slogan is zero downtime attainment for the loading and unloading operations can this be attained without any system procedural modifications? Future studies are also envisaged to include optimization models such as genetic algorithms and ant colony optimization.

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