Aspect Ratio Consideration in the Optimisation of Maintenance Downtime for Handling Equipment in a Container Terminal

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Abstract. *The idea of downtime optimisation is an effective means of minimizing losses of handling equipment in the container port terminal. Unfortunately, previous research relies on the direct factors of downtime, namely downtime parameter (DTM), probability density function (PDF), cumulative density function (CDF) but fails to use the aspect ratios of parameters to more effectively control downtime using the Taguchi method. This gap has resulted in the wrong results and decision making. To correct this problem, this article proposes six aspect ratio parameters to replace existing parameters, namely DTM/PDF, DTM/CDF, PDF/CDF, PDF/DTM, CDF/DTM, and CDF/PDF. These factors were used to obtain the signal-to-noise ratios, the response table and the optimal parametric settings for each Weibull distribution function parameter of β=0.5, 1 and 3. It was found that the outcome at β=3 had the best values and should be used for decision making. For instance, at β=1, DTM/PDF of 92.56 hrs <DTM/PDF of 1222.33 hrs at β=3 <DTM/PDF of 1706.50 hrs at β=0.5. Consequently, the optimal parametric setting at β=1 is DTM/PDF_1 DTM/CDF_1 PDF/DTM_5 CDF/DTM_4 PDF/CDF_3 CDF/PDF_2. This is interpreted as 92.52 hrs of DTM/PDF, 24.87 hrs of DTM/CDF, 0.0063 hr^{-1} of PDF/DTM, 0.267 hr-1 of CDF/DTM, 0.2897 hr^{-1} of CDF/DTM, 0.2897 of PDF/CDF and 3.68 of CDF/PDF. The novelty of this article is the use of aspect ratios of the parameter to effect maintenance optimisation. The presented approach aids the ports engineer in the proper planning and control of ports activities.*

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1. Introduction

Maintenance downtime of handling equipment in port terminals is a critical issue that dictates the sustainability of the port terminal in the maritime industry [1]-[5]. Optimally controlling the maintenance downtime can maximize the gross moves per hour, productivity and concurrently may be cost-effective by exploring customer goodwill and the economic development of the port [1], [5]-[9]. However, the dominant literature suggestion regarding the optimisation of downtime through the Taguchi method and its variants is to define the key parameters of the system limited to three: downtime, probability density function and cumulative density function [5],[10]. Unfortunately, this dominant method of maintenance optimisation for port handling equipment fails to recognize the aspect ratios of the mentioned parameters [5]. However, introducing aspect ratio into the maintenance downtime domain is an original idea supported in a few fields in the literature. For instance, Ujiie et al. [11] established the aspect ratio as a reliable measure in rupture prediction within the neurosurgery field. They concluded that the aspect ratio is a useful predictor of ruptures. Furthermore, within the material field, Lim [12] declared the aspect ratio influence in mechanical metamaterial analysis involving Young's modulus enhancement. They ascertained the usefulness of aspect ratio in this respect. Besides, in television service, Cardwell [13] introduced the proportional (aspect ratio) concept as a fundamental idea using quantitative measures. Also, in composite development, Celzard et al. [14] analyzed a percolation threshold by employing elevated aspect-ratio filler and declared its utility. Thus, from neurosurgery to material and composites to television service, aspect ratios have been confirmed as applicable and useful and could be extended to maintenance downtime systems. However, from the foregoing, eliminating aspect ratios in Taguchi optimisation is unacceptable and harmful to the organisation’s progress, leading to underestimation of the actual optimal parametric settings and inadequacy of Taguchi methodical optimisation values [5],[11],[12],[15]. However, incorporating these aspect ratios into the framework for the computation of the signal-to-noise ratios, based on orthogonal array inputs propels enhanced downtime analysis and optimisation [13],[14].

So, it is compelling to incorporate aspect ratios into the signal-to-noise evaluation inputs for superior and largely practical evaluation of maintenance downtime of handling equipment in the container port terminal [11]-[14]. Today, the concern to incorporate the aspect ratios of the key parameters into the signal-to-noise computation is more compelling than ever given the pressure to reduce downtime and enhance the gross moves per hour from the management of the container ports terminal [16]-[19]. Consequently, this paper offers an optimisation method of sizing the downtime of mobile harbour cranes considering the aspect ratios as input factors to complement previously defined inputs in the extant literature [20]-[22]. The multiple aspect ratios like DTM/PDF, DTM/CDF, PDF/DTM, CDF/DTM, PDF/CDF and CDF/PDF are introduced. In the context of maintenance downtime for handling equipment in a port terminal, the aspect ratios describe the pairs of inputs such as DTM and PDF, DTM and CDF, and PDF and CDF for the downtime of handling equipment, where the ratio between these pairs reveals the number of tunes the first downtime input in less or higher than the second one. A1:1 aspect ratio seems to create a balanced value representation of the entities i.e. DTM to PDF. However, a ratio having a higher value on one side such as 2:1 of DTM to PDF offers more of DTM than the PDF and the benefit is an increased representation of input over the other. This issue of aspect ratio has been omitted in downtime analysis research concerning the mobile harbour crane equipment of port terminals [5], [9],[21]-[25].

This work uses the Taguchi method to study the effect of varying the shape parameters from infant mortality (β=0.5), to constant life (β=1) to wear out region (β=3) for the Weibull function used to model the downtime process parameters for the handling equipment (mobile harbour cranes) of container terminals in a case study obtained from the literature [5]. Consequently, optimal parametric settings are defined for the three situations and comparison is obtained with the performance measures of the three scenarios studied [5],[15]. The proposed approach involves developing the Taguchi orthogonal array method based on the Taguchi method. The proposed approach was applied to establish the optimal downtime of a port using published data while considering the Weibull distribution model with shape parameters of β = 0.5, 1 and 3 [5]. Based on the results of optimisation, the optimal thresholds for the port terminal's downtime activities are compared with the literature data and conclusions made.

The principal motivation for using aspect ratios in the computation of optimal parameters while deploying the Taguchi variant methods is to enhance how to compose the signal-to-noise ratio to obtain the optimal parametric settings for the maintenance downtime [5],[15]. A high aspect ratio may reflect an extended downtime and a narrow probability density function while a low aspect ratio may indicate the reverse [5],[15].

Therefore, this work applies theories in union to update the present understanding of Taguchi's optimisation of downtime of handling equipment in container terminals [5]. The theories applied are those of proportional relationship, revealed in the application of aspect ratios in this work. The theory of proportional relationship in the evaluation of maintenance downtime context states that an association exists among any two variables of downtime (DTM), probability density function (PDF) and cumulative density function (CDF) such that a variable is always uniform value multiplied by the other [10]. The Taguchi theory dictates the economy of experimentation and enhanced performance of downtime quality, implying reduced downtime of the handling equipment in the container terminals.

The research proposed here is significant to practice and it helps the maintenance manager in a careful evaluation, planning and optimisation of downtime variables [26]-[29]. The study also assists to establish a structure to indicate and solve the important deficiency in previous studies. Also, it provides substantial details to maintenance managers regarding the essential constituents of a Taguchi optimisation method and the essential features of the method. Moreover, by tackling and establishing the aspect ratio idea as a problem not previously discussed in the literature, and the weaknesses of the optimisation literature concerning downtime in container terminals, future research is stimulated.

Furthermore, in the current discussions in journals, service improvement has been a focal point of container terminals and maintenance systems within the manufacturing organisation have been the reference [5, 24, 30]. As discussion continues to intensity, downtime optimisation has become an emphasis and arguments about its effectiveness in terms of the needed procedures, tools and experimentation continue to dominate the discussions of experts. As the present article focuses on downtime optimisation using the Taguchi methods within the container port terminals, it is situated around the current discussions in the literature and it is within the main scope of the present journal [31]-[33]. Moreover, in the container port terminals, several measures are currently discussed in the literature, including traffic, trade, output and throughput [34-40]. While some of these terms imply utilisation and productivity, others may mean production [37],[39]-[40]. Unfortunately, none of these terms adequately represent the true measure of maintenance performance but the downtime measure [23],[25],[41].

It is argued that if downtime is ignored, the container port terminal cannot function to its full potential [5]. Overworked equipment may be detrimental to the port system loading to challenges within the workplace negatively influencing the profit margin of the port. In this article, it is argued that without the stoppage of handling equipment for periodic maintenance, the handling equipment may face significant jeopardy and this could trigger unexpected downtime. Consequently, to permit the optimum functioning of the handling equipment, optimisation approaches, particularly using the Taguchi method in the context of considering the aspect ratio of factors, including downtime, probability density function should be deployed to the mobile labour crane handling equipment. This may be complemented with planned downtime for preventive maintenance activities. Unfortunately, despite the awareness of the management on the need to monitor the downtime of the container terminal, there is still a general lack of models to optimise downtime. Furthermore, as the Taguchi method is deployed to optimise downtime, emphasis has often been placed on the three principal parameters of downtime, probability density function and cumulative density function while aspect ratios that capture more of these parameters in a ratio of two parameters but with emphasis on one parameter while the other is missing.

This study contributes to the downtime evaluation and optimisation literature in the following ways:

- By highlighting new parameters in aspect ratios and measures that are previously unclear in downtime optimisation research, this work enlarges the understanding of researchers on how to appraise downtime of container terminals.
- By implementing theories concerning aspect ratios and the Taguchi method to develop a new way of reasoning regarding downtime optimisation while introducing the Taguchi method.
- By establishing flaws in the literature that positions the work in the right context of optimisation of a service unit

2. Literature Review

In this section, the literature review is offered on container terminals and associated concepts to reveal the research gap that is pursued in the current article. It is interesting to note that worldwide commerce can only develop if the port industry continues to control and improve practices in the lifting and shifting of all types of commodities [39], [40]. These practices ensure that the continuity of the global shipping lanes hugely depends on maintenance practices in the ports [21]. Since the ports serve as the link between sea freight and land-based transport, ensuring effective downtime control and improvement is critical [10],[17],[18],[42]. This serves as the gateway to ports' prosperity and sustenance, providing durable and reliable equipment with the exported gross moves per day target achieved. The literature has a scanty number of publications, which promotes a high quality of equipment maintenance in operations as a requirement to attaining enhanced efficiency, overall reliability and productivity in port operations but the direct measures of parameters such as downtime (DTM) and cumulative density function (PDF) fail to capture the potential downtime losses for control purposes and aspect ratios are effective for this task [5].

In a work, Pachakis and Kiremidjian [42] embarked on a two-fold objective including approximating the losses due to downtime of a port from the earthquake and evaluating the cumulative distribution function for the losses. Compared to the present work, their report utilized the following factors: revenues, total aggregate loss, exposure period and cumulative distribution function. Although the cumulative distribution function is common to both works, the present study diverges by considering the aspect ratios. Furthermore, the problem is modelled as a Weibull function. Nonetheless, the Poisson process, including discounting losses considered by the authors enriches the literature, it does not accurately account for the aspect ratio gap created in the evaluation process.

In a study, Mohseni [43] presented a framework of a tool to organize ideas on terminal layout and obtain approximates areas of those ideas. The design was segregated into landside and waterside aspects. The study is different from the present work as it fails to consider downtime as a critical issue in achieving effective operations. Nonetheless, the authors claimed that the framework is competent enough to assist designers in evaluating diverse design scenarios. In a study by Kim et al. [2], some developments associated with the container terminals, particularly the handling equipment were discussed. The work proposed diverse new ideas about the handling systems focusing on the quayside handling, yard system and the transmutation system and the transmutation system. The idea includes analysis on automated storage and retrieval systems, AUTOZONE, automated container system using the ZPMC, super dock overhead grid rail, linear meter conveyance system and SPEEDPORY. Compared with the present work, this reviewed article ignores the downtime aspect and these aspect ratios are not considered.

In an article, Said and El-Harbaty [3] proposed a framework to optimize container handling problems by applying genetic algorithms. The authors developed a case study in Egypt. The authors reported a 56% decrease in ship service time regarding the loading and unloading activities within the port. Although optimisation was the main focus of this reviewed work, no consideration of aspect ratios of parameters was shown in the article. Thus, by pursuing this goal of optimisation of the aspect ratios in the present article, a completely new approach has been introduced in the literature.

In another study, Rezarei et al. [44] developed and established a port performance assessment approach using the best-worst method with application from empirical studies. The principal factors in the present study differ from the reviewed article in that while the current study attaches importance to the aspect ratios involving blends of downtime (DTM), probability density function (PDF) and cumulative density function (CDF), the concern of the referenced work involves transport costs and times, reputation, satisfaction and flexibility. Notwithstanding, an important conclusion is that the availability of various model options influences the standing of a port.

In a dissertation, Shahjahan [1] studied cargo handling equipment and its productivity to enhance equipment and port efficiency. The author declared that the studied equipment did not show satisfactory performance. The attributed reasons include inadequate equipment inventory, operations, maintenance problems and insufficient facilities. However, the present study differs from the referenced work as it considers the optimisation of parameters and the parameters used are aspect ratios while it was ignored in the referenced work.

In an article, Kastner et al. [4] adopted a mapping review approach to examine container terminals are selected and how to design the terminal layout. The principal issues tackled include the methodology used, the indicators of performance and the may which the terminal layout is made as well as the equipment selection. The mentioned parameters in the referred work are different from the current article. These include ecological factors, handling costs and travel distances. However, the present study examines the downtime optimisation problem and the concerned parameters are the aspect ratios of downtime, probability density function and the cumulative density function.

Okanminiwei and Oke [5] studied the attributes of some chosen maintenance downtime parameters extracted from the real operations of the container terminal in a Sub- Saharan container port terminal. While the detail in the article was analysed based on the downtime, probability density function and the cumulative density function, the present article diverged from this approach by considering the aspect ratios of these mentioned parameters to reveal the feasibility of using the aspect ratios of parameters in practical situations. The most important result was that when the Taguchi method was instituted, for the shape parameters of 0.5, 1 and 3 (i.e. β), the most significant parameter was downtime while the least significant parameter was the cumulative density function in all cases of the shape parameters. Nonetheless, the study concludes that the proposed approach is effective to control the port's downtime.

3. Method

The method used in this work is the Taguchi method. It works on the framework of factors and levels, orthogonal array, signal to noise ratios and the optimal parametric settings. To evaluate the signal to noise ratio a criterion should be chosen among smaller-the-better, nominal the best and the larger-the-better. However, the smaller the better criterion is used in the article, Equation (1) [5].

$$\text{S-N ratio} = -10\log_{10}\frac{1}{n}\sum_{i=1}^{n}y_i^2 \tag{1}$$

where S-N ratio is the short form of the signal-to-noise ratio, n represents the number of factors considered, which is six in this case and y_i is the value of the transformed orthogonal matrix element from the table of factors-levels.

4. The Case Study

In this article, the Taguchi method was proposed as an optimisation tool to enhance the downtime of the container ports with emphasis on the change to aspect ratios of parameters instead of the previously defined parameters of downtime (DTM), probability density function (PDF) and the cumulative density function (CDF) [5]. The data obtained from the literature on a container terminal operating in a sub-Saharan African port is used to demonstrate the effectiveness of the method. The case study referred to engages in port operations, which are a group of inter-model equipment such as the gantry cranes, straddle carriers and portainers. While the usage of data from these equipment groups reflects the real situation precisely, it was decided to limit the study to the gantry cranes alone due to the paucity of data available for analysis in the container terminal [5]. The industry of interest to the present investigators deals with the loading and discharging of container cargo, ro-ro, dry bulk, breakbulk and liquid bulk. Although port activities may be automated using robots for cargo handling (i.e. Kawasaki robot controllers) with enhanced conveyor tracking system, servo-motivated end-of-arm tooling and collision detection mechanism, the studied port still engages the manual system due to the large cost of automation. The container terminals are designed to handle, store and may load or unload cargo. They are afterwards picked up and dropped off from a mode of transport, for instance, vessel, to another mode, such as a barge, truck or rail. Now the analysis and discussion of the various parts of the paper are made specifically concerning β = 0.5, β = 1 and β = 3 [5].

Concerning β = 0.5

Table 1 is developed for the comparison of each of the downtime factors previous analysed in Table 1a of Okanminiwei and Oke [5]; where DTM, PDF and CDF were considered as the principal factors.

However, it was discovered that comparing these factors in proportional form could form strong measures that may serve as good controls for the performance of the mobile harbour crane. To create a factor, each

Expt. Trial	DTM/PDF	DTM/CDF	PDF/DTM	CDF/DTM	PDF/CDF	CDF/PDF
1	1608.33	29.38	0.0006	0.0340	0.0183	54.75
2	2757.14	25.77	0.0004	0.0388	0.0093	107.00
3	2412.50	27.22	0.0004	0.0367	0.0113	88.63
4	1754.55	27.41	0.0006	0.0365	0.0156	64.00
5	3216.67	25.13	0.0003	0.0398	0.0078	128.00
6	3720.00	59.60	0.0003	0.0168	0.0160	62.42
7	6377.14	62.96	0.0002	0.0159	0.0099	101.29
8	5580.00	63.41	0.0002	0.0158	0.0114	88.00
9	4058.18	58.13	0.0002	0.0172	0.0143	69.82
10	7440.00	67.95	0.0001	0.0147	0.0091	109.50
11	2006.67	33.96	0.0005	0.0294	0.0169	59.08
12	3440.00	34.20	0.0003	0.0292	0.0099	100.57
13	3010.00	31.35	0.0003	0.0319	0.0104	96.00
14	2189.09	36.65	0.0005	0.0273	0.0167	59.73
15	4013.33	32.15	0.0002	0.0311	0.0080	124.83
16	2439.17	41.58	0.0004	0.0241	0.0170	58.67
17	4181.43	38.11	0.0002	0.0262	0.0091	109.71
18	3658.75	44.55	0.0003	0.0224	0.0122	82.13
19	2660.91	39.08	0.0004	0.0256	0.0147	68.09
20	4878.33	41.28	0.0002	0.0242	0.0085	118.17
21	2966.67	46.35	0.0003	0.0216	0.0156	64.00
22	5085.71	54.19	0.0002	0.0185	0.0107	93.86
23	4450.00	47.53	0.0002	0.0210	0.0107	93.63
24	3236.36	50.21	0.0003	0.0199	0.0155	64.45
25	5933.33	50.57	0.0002	0.0198	0.0085	117.33

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

Table 1 Aspect ratios on the downtime of mobile harbour cranes (β = 0.5)

factor, for instance, DTM, is compared with the next, say the PDF, for instance, to form the ratio DTM/PDF. The DTM is also compared with the CDF to form the proportion, DTM/CDF. Hence all possible combinations of proportions are formed. But beyond these, the reciprocals of these developed ratios are also possible. Hence, they are considered as additional ratios such as the PDF/DTM and CDF/DTM for the examples stated. Thus in all, for the factors DTM, PDF, and CDF, the developed ratios are DTM/PDF, DTM/CDF, PDF/DTM, CDF/DTM and CDF/PDF. However, to obtain these aspect ratios, the experimental values of Table 1a from Okanminiwei and Oke [5] are revisited. The data consists of twenty-five experimental trials based on the L25 orthogonal array indicated in the previous work. To explain how the ratios were generated, say DTM/PDF for experimental trial1, the DTM value of 19.3 is divided by that of the PDF, which is 0.012 to yield 1608.33. Consider Table 1, which brings out the Table 2 of factors and levels, six factors, namely DTM/PDF, DTM/CDF, PDF/DTM, CDF/DTM, PDF/CDF and CDF/PDF are extracted.

Factor	DTM/PDF	DTM/CDF	PDF/DTM	CDF/DTM	PDF/CDF	CDF/PDF
Level 1	1706.50	21.96	0.0004	0.0292	0.0109	62.88
Level 2	4590.40	53.85	0.0002	0.0211	0.0119	89.90
Level 3	3617.15	40.82	0.0003	0.0265	0.0126	84.98
Level 4	3390.72	39.09	0.0003	0.0259	0.0122	88.69
Level 5	4123.42	47.91	0.0003	0.0210	0.0122	86.82

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

Table 2 Factor-level arrangement of downtime for mobile harbour crane (β=0.5)

It was decided to use five levels as it is a convenient scale. Furthermore, the five levels used for the aspect ratios and the decision was influenced by the way the levels were partitioned for the direct factors DTM, CDF and PDF used in the literature source adopted in this study [5]. However, in general, the aspect ratios could be separated into five levels by outlining five grids, placing the highest value for each aspect ratio in the topmost grid and the lowest value at the base grid. The values between are then spread evenly. Thus to obtain the values to be placed under each factor for the various levels, an average of five experimental trials each is considered. Thus, to compute for level 1 under DTM/PDF, the average of experimental trials 1 to 5, comprising of 60.31, 96.50, 87.73, 80.42 and 137.86 is used, which gives 92.56 (Table 2). For level 2, the next five experimental trials are averaged to yield 214.09. The procedure continues until all the entries in Table 2 are filled. Table 3 contains the orthogonal elements and the aspects ratios of factors impacting the downtime of the handling equipment in a container terminal.

The orthogonal arrays are decided from the factors and the levels specified for the downtime minimisation problem. As the number of factors considered is six, including DTM/PDF, DTM/CDF, PDF/CDF, PDF/DTM, CDF/DTM, CDF/DTM and CDF/PDF, and the number of levels is five, the 5-level design of 6 factors was chosen in Minitab 18, made the Taguchi design framework to yield L25 runs of 5^6 for the 5^columns and the Taguchi array of L25 (5^6) was extracted and used for further analysis.

Thus, an orthogonal array containing 25 experimental trials and six factors was produced by the Minitab 18 software. The elements of the orthogonal array are 1,2,3,4 and 5 for the problem under consideration. The orthogonal array is noticed as a matrix containing levels 1 to 5 with a structured distribution determined by containing mechanisms outside the discussion in this paper. Thus, two halves of almost similar information are contained in Table 3. The first half is the orthogonal matrix consisting of levels distributed in a matrix form. The second half is the transformed matrix elements into real values from the earlier obtained factor-level table. Consider the experimental trial 1, which has the first six elements as 1,1,1,1,1, and 1, which represents level 1. The last six elements in the row are actual values interpreted from the factor-level table, which are extracted from Table 1. Since level 1 is of concern to us, the intersection of DTM/PDF and level 1 is in Table 3. By doing the same interpretation from Table 2, the DTM/CDF with the intersection of level 1 yields 29.38 and it is therefore fixed in Table 3 where similar interpretations apply to all other entries concerned. Next, the computations proceed to the signal to noise ratios Table 4 where β = 0.5 represents the parameter of the Weibull considered in this work. To obtain the signal-to-noise ratio, a criterion needs to be chosen among three: smaller-the-better, nominal-the-best and the larger-the-better. However, since the lower values of these factors are desired, the smaller-the-better criterion is chosen for the signal-to-noise ratio analysis in this work. Thus, to achieve this, the formula in Equation (1) is used. By deploying this method where the squares of each of 1608.33, 29.38, 0.0006, 0.0340, 0.0183, and 54.75 are obtained, summed up and multiplied by 0.1667 (which is 1/6). The answer is further acted upon by logarithm and then multiplied by -10 to yield -56.3525. Similar evaluations are conducted throughout Table 4.

	Orthogonal elements						Orthogonal elements transformed into values					
Expt.	DTM/PDF	DTM/CDF	PDF/DTM	CDF/DTM	PDF/CDF	CDF/PDF	DTM/PDF	DTM/CDF	PDF/DTM	CDF/DTM	PDF/CDF	CDF/PDF
1	1	1	1	1	1	1	1608.33	29.38	0.0006	0.0340	0.0183	54.75
2	1	2	2	2	2	2	2757.14	25.77	0.0004	0.0388	0.0093	107.00
3	1	3	3	3	3	3	2412.50	27.22	0.0004	0.0367	0.0113	88.63
4	1	4	4	4	4	4	1754.55	27.41	0.0006	0.0365	0.0156	64.00
5	1	5	5	5	5	5	3216.67	25.13	0.0003	0.0398	0.0078	128.00
6	2	1	2	3	4	5	3720.00	59.60	0.0003	0.0168	0.0160	62.42
7	2	2	3	4	5	1	6377.14	62.96	0.0002	0.0159	0.0099	101.29
8	2	3	4	5	1	2	5580.00	63.41	0.0002	0.0158	0.0114	88.00
9	2	4	5	1	2	3	4058.18	58.13	0.0002	0.0172	0.0143	69.82
10	2	5	1	2	3	4	7440.00	67.95	0.0001	0.0147	0.0091	109.50
11	3	1	3	5	2	4	2006.67	33.96	0.0005	0.0294	0.0169	59.08
12	3	2	4	1	3	5	3440.00	34.20	0.0003	0.0292	0.0099	100.57
13	3	3	5	2	4	1	3010.00	31.35	0.0003	0.0319	0.0104	96.00
14	3	4	1	3	5	2	2189.09	36.65	0.0005	0.0273	0.0167	59.73
15	3	5	2	4	1	3	4013.33	32.15	0.0002	0.0311	0.0080	124.83
16	4	1	4	2	5	3	2439.17	41.58	0.0004	0.0241	0.0170	58.67
17	4	2	5	3	1	4	4181.43	38.11	0.0002	0.0262	0.0091	109.71
18	4	3	1	4	2	5	3658.75	44.55	0.0003	0.0224	0.0122	82.13
19	4	4	2	5	3	1	2660.91	39.08	0.0004	0.0256	0.0147	68.09
20	4	5	3	1	4	2	4878.33	41.28	0.0002	0.0242	0.0085	118.17
21	5	1	5	4	3	2	2966.67	46.35	0.0003	0.0216	0.0156	64.00
22	5	2	1	5	4	3	5085.71	54.19	0.0002	0.0185	0.0107	93.86
23	5	3	2	1	5	4	4450.00	47.53	0.0002	0.0210	0.0107	93.63
24	5	4	3	2	1	5	3236.36	50.21	0.0003	0.0199	0.0155	64.45
25	5	5	4	3	2	1	5933.33	50.57	0.0002	0.0198	0.0085	117.33

Table 3 Orthogonal elements and transformed orthogonal elements into values (β = 0.5)

Expt.	DTM/PDF	DTM/CDF	PDF/DTM	CDF/DTM	PDF/CDF	CDF/PDF	S-N ratio
1	1608.33	29.38	0.0006	0.0340	0.0183	54.75	-56.3525
2	2757.14	25.77	0.0004	0.0388	0.0093	107.00	-61.0346
3	2412.50	27.22	0.0004	0.0367	0.0113	88.63	-59.8742
4	1754.55	27.41	0.0006	0.0365	0.0156	64.00	-57.1086
5	3216.67	25.13	0.0003	0.0398	0.0078	128.00	-62.3738
6	3720.00	59.60	0.0003	0.0168	0.0160	62.42	-63.6317
7	6377.14	62.96	0.0002	0.0159	0.0099	101.29	-68.3125
8	5580.00	63.41	0.0002	0.0158	0.0114	88.00	-67.1528
9	4058.18	58.13	0.0002	0.0172	0.0143	69.82	-64.3873
10	7440.00	67.95	0.0001	0.0147	0.0091	109.50	-69.6512
11	2006.67	33.96	0.0005	0.0294	0.0169	59.08	-58.2730
12	3440.00	34.20	0.0003	0.0292	0.0099	100.57	-62.9538
13	3010.00	31.35	0.0003	0.0319	0.0104	96.00	-61.7947
14	2189.09	36.65	0.0005	0.0273	0.0167	59.73	-59.0282
15	4013.33	32.15	0.0002	0.0311	0.0080	124.83	-64.2931
16	2439.17	41.58	0.0004	0.0241	0.0170	58.67	-59.9671
17	4181.43	38.11	0.0002	0.0262	0.0091	109.71	-64.6483
18	3658.75	44.55	0.0003	0.0224	0.0122	82.13	-63.4880
19	2660.91	39.08	0.0004	0.0256	0.0147	68.09	-60.7229
20	4878.33	41.28	0.0002	0.0242	0.0085	118.17	-65.9868
21	2966.67	46.35	0.0003	0.0216	0.0156	64.00	-61.6670
22	5085.71	54.19	0.0002	0.0185	0.0107	93.86	-66.3475
23	4450.00	47.53	0.0002	0.0210	0.0107	93.63	-65.1881
24	3236.36	50.21	0.0003	0.0199	0.0155	64.45	-62.4224
25	5933.33	50.57	0.0002	0.0198	0.0085	117.33	-67.6865

Note: PDF – probability density function
CDF – cumulative density function
DTM – downtime
S/N ratio – signal-to-noise ratio
β – shape parameter for Weibull distribution
* S-N ratio (lower the better)

Table 4 Aspect ratios and S-N ratios (β = 0.5)

Factors	DTM/PDF	DTM/CDF	PDF/DTM	CDF/DTM	PDF/CDF	CDF/PDF
Level 1	-59.3487*	-59.9783*	-62.9735*	-62.9737*	-62.9738*	-62.9738*
Level 2	-66.6271	-64.6593	-62.9741	-62.9740	-62.9739	-62.9739
Level 3	-61.2686	-63.4996	-62.9738	-62.9738	-62.9738*	-62.9738*
Level 4	-62.9626	-60.7339	-62.9738	-62.9738	-62.9739	-62.9738*
Level 5	-64.6623	-65.9983	-62.9742	-62.9740	-62.9739	-62.9739
Delta	7.2784	6.0200	0.0007	0.0003	0.0001	0.0001
Ranks	1st	2nd	3rd	4th	5th	5th

*Optimal parametric setting

Table 5 S-N response table (β =0.5)

To compute the signal-to-noise response table, in Table 5, the orthogonal matrix is matched with computed S-N ratios. Consider Table 4 where the parameter β=0.5 is defined for the Weibull distribution used to control the downtime of the handing equipment. Of interest is the factor DTM/PDF, which has five levels 1, 2, 3 4 and 5. Along the column where DTM/PDF stands, there are 25 entries of which the first one is "1" for the first entry at the intersection of DTM/CDF and experimental trial 1. At the intersection of DTM/CDF and experimental trial 2 is the second orthogonal matrix element, "1". These matrix elements go along the column down to the experimental trial 25, which has an orthogonal matrix element "5" at the intersection of the DTM/PDF and the experimental trial 25. To compute the value to be inserted in the signal-to-noise ratio response table where the DTM/PDF factor intersects with level 1, all the matrix elements "1" along the column DTM/PDF in Table 3 (β=0.5) are noted and their corresponding S/N ratios on Table 4 are as well noted. These S/N values are averaged for level 1. For instance, the DTM/PDF factor yields an average of -59.3487 (Table 5), which is obtained by averaging the corresponding values to 1, 1, 1, 1, 1 (Experimental trails 1 to 5 under the DTM/PDF factor) for the S-N ratios, which are -56.3525, -61.0346, -59.8742, -57.1086 and -62.3738. This average value of -59.3487 is recorded in Table 5. By following the same interpretation, other values in Table 5 are computed. From the results of the Taguchi method while β=0.5 for the Weibull distribution's parameter, it was found that the downtime process, if conducted within the specified optimized group of process parameters of 1706.50hrs of DTM/PDF, 21.96hrs of DTM/CDF, 0.0004hr^{-1} of PDF/DTM, 0.0292 hr^{-1} of CDF/DTM, 0.0109 of PDF/CDF and 62.88 of CDF/PDF, an effective operational mobile harbour crane set will be maintained.

The delta values are determined as the difference between the highest and lowest values for each factor. These are established as 7.2784, 6.0200, 0.0007, 0.0003, 0.0001 and 0.0001 for the respective factors of $DTM/PDF_1DTM/CDF_1PDF/DTM_1CDF/DTM_1PDF/CDF_1CDF/PDF_{1,3,4}$. Accordingly, the ranks are allocated as 1^{st}, 2^{nd}, 3^{rd}, 4^{th}, 5^{th} and 5^{th} in the order of mentioning the factors above. In this article, the different optimal parametric settings were obtained based on the conditions that the container terminal is at the infant mortality (β=0.5), at a constant life (β=1) and a decaying situation (wear-out region) (β=3). These values of Beta as 0.5, 1 and 3 are used to determine at what stage of the lifecycle the container terminal fits in. It is thought that the best of these three options of Beta of 0.5, 1 and 3 is known by the best optimal parametric setting, which could be determined from the combination of parameters. Besides, ports experience infant mortality, useful life and wear out phases of their existence and these impact the maintenance activities in the plant. Infant mortality is an extremely expensive load for port operators and managers. Thus, the present authors introduced the Weibull function with $\beta = 0.5$, representing infant mortality to diagnose the port's maintenance system and then decide its lingering influence on the maintenance performance of the port using the aspect ratios. The three phases of $\beta = 0.5$, 1 and 3, representing the infant mortality, useful life as well as wear out stage of the port's maintenance operations were predicted such that proper actions to cope with these stages of maintenance will be implemented.

Furthermore, optimisation of the aspect ratios, including DTM/PDF, DTM/CDF, PDF/DTM, CDF/DTM, PDF/CDF and CDF/PDF was conducted based on the Taguchi method. All the experiments, obtained from Okanminiwei and Oke [5] were analysed at β = 0.5, β = 1 and β = 3 for the applied Weibull distribution. The finding of Okanminiwei and Oke [5] revealed that for β = 0.5, DTM ranked 1^{st}, PDF ranked 2^{nd} and CDF ranked 3^{rd}. However, compared to the present article where aspect ratios are considered, the number of factors analysed shifts from three to six. For the current work, DTM/PDF is ranked 1^{st}, DTM/CDF is ranked 2^{nd}, PDF/DTM is ranked 3^{rd}, CDF/DTM is ranked 4^{th} while PDF/CDF and CDF/PDF are ranked 5^{th}. Now, it is essential to analyse the case of β = 1, which is considered in the next sub-section.

Concerning β = 1

Table 6 is developed for the comparison of each of the downtime factors previous analysed in Table 1a of Okanminiwei and Oke [5] where DTM, PDF and CDF were considered as the principal factors.

Expt.	DTM/PDF	DTM/CDF	PDF/DTM	CDF/DTM	PDF/CDF	CDF/PDF
1	60.31	28.38	0.0166	0.0352	0.4706	2.13
2	96.50	24.13	0.0104	0.0415	0.2500	4.00
3	87.73	24.74	0.0114	0.0404	0.2821	3.55
4	80.42	25.39	0.0124	0.0394	0.3158	3.17
5	137.86	21.69	0.0073	0.0461	0.1573	6.36
6	139.50	55.80	0.0072	0.0179	0.4000	2.50
7	223.20	57.23	0.0045	0.0175	0.2564	3.90
8	202.91	58.74	0.0049	0.0170	0.2895	3.45
9	186.00	50.16	0.0054	0.0199	0.2697	3.71
10	318.86	65.65	0.0031	0.0152	0.2059	4.86
11	75.25	30.87	0.0133	0.0324	0.4103	2.44
12	120.40	31.68	0.0083	0.0316	0.2632	3.80
13	109.45	27.06	0.0091	0.0370	0.2472	4.05
14	100.33	35.41	0.0100	0.0282	0.3529	2.83
15	172.00	30.10	0.0058	0.0332	0.1750	5.71
16	91.47	38.51	0.0109	0.0260	0.4211	2.38
17	146.35	32.89	0.0068	0.0304	0.2247	4.45
18	133.05	43.04	0.0075	0.0232	0.3235	3.09
19	121.96	36.59	0.0082	0.0273	0.3000	3.33
20	209.07	37.53	0.0048	0.0266	0.1795	5.57
21	111.25	40.00	0.0090	0.0250	0.3596	2.78
22	178.00	52.35	0.0056	0.0191	0.2941	3.40
23	161.82	44.50	0.0062	0.0225	0.2750	3.64
24	148.33	45.64	0.0067	0.0219	0.3077	3.25
25	254.29	46.84	0.0039	0.0213	0.1842	5.43

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

Table 1 Aspect ratios on the downtime of mobile harbour cranes (β = 1)

The procedure followed to obtain values of the aspect ratios to be transformed into the factor-level arrangement for β = 0.5 is repeated here to obtain Table

7. Table 8 contains the orthogonal elements and the aspects ratios of factors impacting the downtime of the handling equipment in a container terminal.

Factor	DTM/PDF	DTM/CDF	PDF/DTM	CDF/DTM	PDF/CDF	CDF/PDF
Level 1	92.56	24.87	0.0116	0.0405	0.2951	3.84
Level 2	214.09	57.51	0.0050	0.0175	0.2843	3.68
Level 3	115.49	31.02	0.0093	0.0325	0.2897	3.77
Level 4	140.38	37.71	0.0077	0.0267	0.2898	3.76
Level 5	170.74	45.87	0.0063	0.0220	0.2841	3.70

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

Table 7 Factor-level arrangement of downtime for mobile harbour crane (β=1)

Next, the computations proceed to the signal to noise ratios (Table 9) where β = 1 represents the parameter of the Weibull considered in this work. To compute the signal-to-noise response table, Table 10, the orthogonal matrix is matched with computed S-N ratios. However, from Table 10, the delta values, ranks and the optimal parametric setting of the problem are indicated. The delta values calculated for the DTM/PDF, DTM/CDF, PDF/DTM, CDF/DTM, PDF/CDF and CDF/PDF are 7.2324, 3.6788, 0.1862, -0.0273, 0.0230 and 0.0098, respectively.

	Orthogonal elements						Orthogonal elements transformed into values					
Expt.	DTM/PDF	DTM/CDF	PDF/DTM	CDF/DTM	PDF/CDF	CDF/PDF	DTM/PDF	DTM/CDF	PDF/DTM	CDF/DTM	PDF/CDF	CDF/PDF
1	1	1	1	1	1	1	60.3125	28.38235	0.01658	0.035233	0.470588	2.125
2	1	2	2	2	2	2	96.5	24.125	0.010363	0.041451	0.25	4
3	1	3	3	3	3	3	87.72727	24.74359	0.011399	0.040415	0.282051	3.545455
4	1	4	4	4	4	4	80.41667	25.39474	0.012435	0.039378	0.315789	3.166667
5	1	5	5	5	5	5	137.8571	21.68539	0.007254	0.046114	0.157303	6.357143
6	2	1	2	3	4	5	139.5	55.8	0.007168	0.017921	0.4	2.5
7	2	2	3	4	5	1	223.2	57.23077	0.00448	0.017473	0.25641	3.9
8	2	3	4	5	1	2	202.9091	58.73684	0.004928	0.017025	0.289474	3.454545
9	2	4	5	1	2	3	186	50.1573	0.005376	0.019937	0.269663	3.708333
10	2	5	1	2	3	4	318.8571	65.64706	0.003136	0.015233	0.205882	4.857143
11	3	1	3	5	2	4	75.25	30.87179	0.013289	0.032392	0.410256	2.4375
12	3	2	4	1	3	5	120.4	31.68421	0.008306	0.031561	0.263158	3.8
13	3	3	5	2	4	1	109.4545	27.05618	0.009136	0.03696	0.247191	4.045455
14	3	4	1	3	5	2	100.3333	35.41176	0.009967	0.028239	0.352941	2.833333
15	3	5	2	4	1	3	172	30.1	0.005814	0.033223	0.175	5.714286
16	4	1	4	2	5	3	91.46875	38.51316	0.010933	0.025965	0.421053	2.375
17	4	2	5	3	1	4	146.35	32.88764	0.006833	0.030407	0.224719	4.45
18	4	3	1	4	2	5	133.0455	43.04412	0.007516	0.023232	0.323529	3.090909
19	4	4	2	5	3	1	121.9583	36.5875	0.0082	0.027332	0.3	3.333333
20	4	5	3	1	4	2	209.0714	37.52564	0.004783	0.026648	0.179487	5.571429
21	5	1	5	4	3	2	111.25	40	0.008989	0.025	0.359551	2.78125
22	5	2	1	5	4	3	178	52.35294	0.005618	0.019101	0.294118	3.4
23	5	3	2	1	5	4	161.8182	44.5	0.00618	0.022472	0.275	3.636364
24	5	4	3	2	1	5	148.3333	45.64103	0.006742	0.02191	0.307692	3.25
25	5	5	4	3	2	1	254.2857	46.84211	0.003933	0.021348	0.184211	5.428571

Table 8 Orthogonal elements and transformed orthogonal elements into values (β = 1)

Expt.	DTM/PDF	DTM/CDF	PDF/DTM	CDF/DTM	PDF/CDF	CDF/PDF	S-N ratio
1	60.3125	28.38235	0.01658	0.035233	0.470588	2.125	-28.7000
2	96.5	24.125	0.010363	0.041451	0.25	4	-32.1794
3	87.72727	24.74359	0.011399	0.040415	0.282051	3.545455	-31.4202
4	80.41667	25.39474	0.012435	0.039378	0.315789	3.166667	-30.7444
5	137.8571	21.68539	0.007254	0.046114	0.157303	6.357143	-35.1222
6	139.5	55.8	0.007168	0.017921	0.4	2.5	-35.7558
7	223.2	57.23077	0.00448	0.017473	0.25641	3.9	-39.4702
8	202.9091	58.73684	0.004928	0.017025	0.289474	3.454545	-38.7152
9	186	50.1573	0.005376	0.019937	0.269663	3.708333	-37.9152
10	318.8571	65.64706	0.003136	0.015233	0.205882	4.857143	-42.4717
11	75.25	30.87179	0.013289	0.032392	0.410256	2.4375	-30.4282
12	120.4	31.68421	0.008306	0.031561	0.263158	3.8	-34.1259
13	109.4545	27.05618	0.009136	0.03696	0.247191	4.045455	-33.2663
14	100.3333	35.41176	0.009967	0.028239	0.352941	2.833333	-32.7604
15	172	30.1	0.005814	0.033223	0.175	5.714286	-37.0647
16	91.46875	38.51316	0.010933	0.025965	0.421053	2.375	-32.1553
17	146.35	32.88764	0.006833	0.030407	0.224719	4.45	-35.7441
18	133.0455	43.04412	0.007516	0.023232	0.323529	3.090909	-35.1330
19	121.9583	36.5875	0.0082	0.027332	0.3	3.333333	-34.3200
20	209.0714	37.52564	0.004783	0.026648	0.179487	5.571429	-38.7651
21	111.25	40	0.008989	0.025	0.359551	2.78125	-33.6749
22	178	52.35294	0.005618	0.019101	0.294118	3.4	-37.5887
23	161.8182	44.5	0.00618	0.022472	0.275	3.636364	-36.7177
24	148.3333	45.64103	0.006742	0.02191	0.307692	3.25	-36.0380
25	254.2857	46.84211	0.003933	0.021348	0.184211	5.428571	-40.4718

Note: PDF – probability density function
CDF – cumulative density function
DTM – downtime
S/N ratio – signal-to-noise ratio
β – shape parameter for Weibull distribution
* S-N ratio (lower the better)

Table 9 Aspect ratios and S-N ratios (β = 1)

Factors	DTM/PDF	DTM/CDF	PDF/DTM	CDF/DTM	PDF/CDF	CDF/PDF
Level 1	-31.6332*	-32.1428*	-35.3308	-35.2448	-35.2524	-35.2457
Level 2	-38.8656	-35.8217	-35.2075	-35.2221	-35.2255	-35.2190*
Level 3	-33.5291	-35.0505	-35.2243	-35.2305	-35.2025*	-35.2288
Level 4	-35.2235	-34.3556	-35.2174	-35.2174*	-35.2241	-35.2212
Level 5	-36.8982	-38.7791	-35.1445*	-35.2349	-35.2452	-35.2350
Delta	7.2324	3.6788	0.1862	-0.0273	0.0230	0.0098
Ranks	1st	2nd	3rd	6th	4th	5th

*Optimal parametric setting

Table 10 S-N response table (β =1)

Besides, the ranks are DTM/PDF as 1st, DTM/CDF as 2nd, PDF/DTM as 3rd, PDF/CDF as 4th, CDF/PDF as 5th and CDF/DTM as 6th. Furthermore, as the highest average S-N ratio for each factor is observed as -31.6332, -32.1428, -35.1445, -35.2174, -35.2025 and -35.2190 for the respective factors of DTM/PDF, DTM/CDF, PDF/DTM, PDF/CDF, CDF/PDF and CDF/DTM. Thus, the optimal parametric setting for β=1 is DTM/PDF_1 DTM/CDF_1 PDF/DTM_5 CDF/DTM_4 PDF/CDF_3 CDF/PDF_2. This is interpreted as 92.56 hr of DTM/PDF, 24.87 hr of DTM/CDF, 0.0063 hr^{-1} of PDF/DTM, 0.0267 of CDF/DTM, 0.2897 of PDF/CDF and 3.68 of CDF/PDF. The next step is to analyse the case concerning $\beta = 3$.

Concerning $\beta = 3$

Table 11 is developed for the comparison of each of the downtime factors previous analysed in Table 1a of Okanminiwei and Oke [5] where DTM, PDF and CDF were considered as the principal factors.

The procedure followed to obtain values of the aspect ratios to be transformed into the factor-level arrangement for β = 1 is repeated here to obtain Table 12. Table 13 contains the orthogonal elements and the aspects ratios of factors impacting the downtime of the handling equipment in a container terminal.

Expt.	DTM/PDF	DTM/CDF	PDF/DTM	CDF/DTM	PDF/CDF	CDF/PDF
1	643.33333	28.38235	0.001554	0.035233	0.044118	22.66667
2	643.33333	22.44186	0.001554	0.04456	0.034884	28.66667
3	965	25.39474	0.001036	0.039378	0.026316	38
4	1930	27.57143	0.000518	0.036269	0.014286	70
5	1930	23.25301	0.000518	0.043005	0.012048	83
6	1488	51.90698	0.000672	0.019265	0.034884	28.66667
7	1488	58.73684	0.000672	0.017025	0.039474	25.33333
8	223.2	63.77143	0.00448	0.015681	0.285714	3.5
9	4464	54.43902	0.000224	0.018369	0.012195	82
10	4464	65.64706	0.000224	0.015233	0.014706	68
11	802.66667	31.68421	0.001246	0.031561	0.039474	25.33333
12	802.66667	34.4	0.001246	0.02907	0.042857	23.33333
13	1204	29.36585	0.000831	0.034053	0.02439	41
14	2408	35.41176	0.000415	0.028239	0.014706	68
15	2408	28	0.000415	0.035714	0.011628	86
16	975.66667	41.81429	0.001025	0.023915	0.042857	23.33333
17	975.66667	35.69512	0.001025	0.028015	0.036585	27.33333
18	1463.5	43.04412	0.000683	0.023232	0.029412	34
19	2927	34.03488	0.000342	0.029382	0.011628	86
20	2927	38.51316	0.000342	0.025965	0.013158	76
21	1186.6667	43.41463	0.000843	0.023034	0.036585	27.33333
22	1186.6667	52.35294	0.000843	0.019101	0.044118	22.66667
23	1780	41.39535	0.000562	0.024157	0.023256	43
24	3560	46.84211	0.000281	0.021348	0.013158	76
25	3560	50.85714	0.000281	0.019663	0.014286	70

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

Table 11 Aspect ratios on the downtime of mobile harbour cranes (β = 3)

Factors	DTM/PDF	DTM/CDF	PDF/DTM	CDF/DTM	PDF/CDF	CDF/PDF
Level 1	1222.33	25.41	0.0010	0.0397	0.0263	48.47
Level 2	2425.44	58.90	0.0013	0.0171	0.0774	41.50
Level 3	1525.07	31.77	0.0008	0.0317	0.0266	48.73
Level 4	1853.77	38.62	0.0007	0.0261	0.0267	49.33
Level 5	2254.67	46.97	0.0006	0.0215	0.0263	47.80

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

Table 12 Factor-level arrangement of downtime for mobile harbour crane (β=3)

	Orthogonal elements						Orthogonal elements transformed into values					
Expt.	DTM/PDF	DTM/CDF	PDF/DTM	CDF/DTM	PDF/CDF	CDF/PDF	DTM/PDF	DTM/CDF	PDF/DTM	CDF/DTM	PDF/CDF	CDF/PDF
1	1	1	1	1	1	1	643.33333	28.38235	0.001554	0.035233	0.044118	22.66667
2	1	2	2	2	2	2	643.33333	22.44186	0.001554	0.04456	0.034884	28.66667
3	1	3	3	3	3	3	965	25.39474	0.001036	0.039378	0.026316	38
4	1	4	4	4	4	4	1930	27.57143	0.000518	0.036269	0.014286	70
5	1	5	5	5	5	5	1930	23.25301	0.000518	0.043005	0.012048	83
6	2	1	2	3	4	5	1488	51.90698	0.000672	0.019265	0.034884	28.66667
7	2	2	3	4	5	1	1488	58.73684	0.000672	0.017025	0.039474	25.33333
8	2	3	4	5	1	2	223.2	63.77143	0.00448	0.015681	0.285714	3.5
9	2	4	5	1	2	3	4464	54.43902	0.000224	0.018369	0.012195	82
10	2	5	1	2	3	4	4464	65.64706	0.000224	0.015233	0.014706	68
11	3	1	3	5	2	4	802.66667	31.68421	0.001246	0.031561	0.039474	25.33333
12	3	2	4	1	3	5	802.66667	34.4	0.001246	0.02907	0.042857	23.33333
13	3	3	5	2	4	1	1204	29.36585	0.000831	0.034053	0.02439	41
14	3	4	1	3	5	2	2408	35.41176	0.000415	0.028239	0.014706	68
15	3	5	2	4	1	3	2408	28	0.000415	0.035714	0.011628	86
16	4	1	4	2	5	3	975.66667	41.81429	0.001025	0.023915	0.042857	23.33333
17	4	2	5	3	1	4	975.66667	35.69512	0.001025	0.028015	0.036585	27.33333
18	4	3	1	4	2	5	1463.5	43.04412	0.000683	0.023232	0.029412	34
19	4	4	2	5	3	1	2927	34.03488	0.000342	0.029382	0.011628	86
20	4	5	3	1	4	2	2927	38.51316	0.000342	0.025965	0.013158	76
21	5	1	5	4	3	2	1186.6667	43.41463	0.000843	0.023034	0.036585	27.33333
22	5	2	1	5	4	3	1186.6667	52.35294	0.000843	0.019101	0.044118	22.66667
23	5	3	2	1	5	4	1780	41.39535	0.000562	0.024157	0.023256	43
24	5	4	3	2	1	5	3560	46.84211	0.000281	0.021348	0.013158	76
25	5	5	4	3	2	1	3560	50.85714	0.000281	0.019663	0.014286	70

Table 13 Orthogonal elements and transformed orthogonal elements into values (β = 3)

Next, the computations proceed to the signal to noise ratios (Table 14) where β = 3 represents the parameter of the Weibull considered in this work. To compute the signal-to-noise response table, Table 15, the orthogonal matrix is matched with computed S-N ratios. Furthermore, from Table 15, the delta values, ranks and the optimal parametric settings of the problem are indicated. The delta values obtained are 5.3130, 9.9512, 0.0003, 3.9321, 3.9326 and 3.93299, respectively for DTM/PDF, DTM/CDF, PDF/DTM, CDF/DTM, PDF/CDF and CDF/PDF.

Expt.	DTM/PDF	DTM/CDF	PDF/DTM	CDF/DTM	PDF/CDF	CDF/PDF	S-N ratio
1	643.33333	28.38235	0.001554	0.035233	0.044118	22.66667	-48.4010
2	643.33333	22.44186	0.001554	0.04456	0.034884	28.66667	-48.4011
3	965	25.39474	0.001036	0.039378	0.026316	38	-51.9188
4	1930	27.57143	0.000518	0.036269	0.014286	70	-57.9362
5	1930	23.25301	0.000518	0.043005	0.012048	83	-57.9383
6	1488	51.90698	0.000672	0.019265	0.034884	28.66667	-55.6774
7	1488	58.73684	0.000672	0.017025	0.039474	25.33333	-55.6786
8	223.2	63.77143	0.00448	0.015681	0.285714	3.5	-39.5342
9	4464	54.43902	0.000224	0.018369	0.012195	82	-65.2151
10	4464	65.64706	0.000224	0.015233	0.014706	68	-65.2149
11	802.66667	31.68421	0.001246	0.031561	0.039474	25.33333	-50.3203
12	802.66667	34.4	0.001246	0.029070	0.042857	23.33333	-50.3208
13	1204	29.36585	0.000831	0.034053	0.024390	41	-53.8386
14	2408	35.41176	0.000415	0.028239	0.014706	68	-59.8560
15	2408	28	0.000415	0.035714	0.011628	86	-59.8577
16	975.66667	41.81429	0.001025	0.023915	0.042857	23.33333	-52.0150
17	975.66667	35.69512	0.001025	0.028015	0.036585	27.33333	-52.0137
18	1463.5	43.04412	0.000683	0.023232	0.029412	34	-55.5324
19	2927	34.03488	0.000342	0.029382	0.011628	86	-61.5513
20	2927	38.51316	0.000342	0.025965	0.013158	76	-61.5506
21	1186.6667	43.41463	0.000843	0.023034	0.036585	27.33333	-53.7132
22	1186.6667	52.35294	0.000843	0.019101	0.044118	22.66667	-53.7151
23	1780	41.39535	0.000562	0.024157	0.023256	43	-57.2318
24	3560	46.84211	0.000281	0.021348	0.013158	76	-63.2502
25	3560	50.85714	0.000281	0.019663	0.014286	70	-63.2501

Note: PDF – probability density function
CDF – cumulative density function
DTM – downtime
S/N ratio – signal-to-noise ratio
β – shape parameter for Weibull distribution
* S-N ratio (lower the better)

Table 14 Aspect ratios and S-N ratios (β = 3)

Factors	DTM/PDF	DTM/CDF	PDF/DTM	CDF/DTM	PDF/CDF	CDF/PDF
Level 1	-52.9191*	-52.0254	-56.5439	-56.5439	-52.6114*	-56.5439
Level 2	-56.264	-52.0259	-56.5439	-56.5440	-56.5438	-52.6110*
Level 3	-54.8387	-51.6112*	-56.5437	-56.5432	-56.5438	-56.5443
Level 4	-56.5326	-61.5618	-56.5436*	-56.5436	-56.5436	-56.5434
Level 5	-58.2321	-61.5623	-56.5438	-52.6118*	-56.5439	-56.5438
Delta	5.3130	9.9512	0.0003	3.9321	3.9326	3.9329
Ranks	2nd	1st	6th	5th	4th	3rd

*Optimal parametric setting

Table 15 S-N response table (β =3)

However, the ranks are DTM/CDF as 1st, DTM/PDF as 2nd, CDF/PDF as 3rd, PDF/CDF as 4th, PDF/CDF as 5th and PDF/DTM as 6th. Furthermore, the highest values of the average S/N ratios for each factor are -52.9191, -51.6112, -56.5436, -52.6118, -52.6118, -52.6114 and -52.6110, respectively (β=3). Thus, the optimal parametric setting is DTM/PDF_1 DTM/CDF_3 PDF/DTM_4 CDF/DTM_5 PDF/CDF_1 CDF/PDF_2. The interpretation is 1222.33 hr of DTM/PDF, 31.77 hr of DTM/CDF, 0.0007 hr^{-1} of PDF/DTM, 0.0215 hr^{-1} of CDF/DTM, 0.0263 of PDF/CDF and 41.50 of CDF/PDF.

How to implement the best parametric setting?

In this article, the β=3 shape parameter has been found to suit the condition of the container part terminal being at the wear-out stage. It thus produces the best parametric setting. However, for implementation, the decision-maker should set the optimal parametric settings for each aspect ratio as the target to be achieved while the actual performance at any stage is compared. This is synonymous with the installed and operating capacities of a plant. Here, the plant can achieve the optimal parametric settings but uncontrollable limitations prevent the work team to achieve this goal. Thus, the decision-maker can remove these constraints and then drive towards obtaining the optimal parametric settings.

5. Conclusions

In this paper, the previously considered three factors used to evaluate the downtime of critical handling equipment at the ports' container terminal are downtime (DTM), probability density function (PDF) and cumulative density function (CDF). However, it was argued that aspect ratios factors, which are not considered in the literature to date, may be useful factors to account for the precise performance measures of the container terminal. Consequently, six aspect ratio factors were developed after a critical analysis to ensure a comprehensive representation of the downtime factors. Therefore, the following aspect ratios were developed for each Weibull parameter of β = 0.5, β = 1 and β = 3. The factors are DTM/PDF, DTM/CDF, PDF/CDF, PDF/DTM, CDF/DTM and CDF/PDF. Consequently, the optimisation of the downtime process parameters, which resulted in multiple conclusions, are mentioned in the present section.

From the results of the Taguchi method while β=0.5 for the Weibull distribution's parameter, it was found that the downtime process, if conducted within the specified optimized group of process parameters of 1706.50hrs of DTM/PDF, 21.96hrs of DTM/CDF, 0.0004hr^{-1} of PDF/DTM, 0.0292 hr^{-1} of CDF/DTM, 0.0109 of PDF/CDF and 62.88 of CDF/PDF, an effective operational mobile harbour crane set will be maintained. Further, while β=1, for the Weibull distribution's parameter, it was also noticed that the downtime process, if implemented within the defined optimum group of process parameters of 92.56 hr of DTM/PDF, 24.87 hr of DTM/CDF, 0.0063 hr^{-1} of PDF/DTM, 0.0267 hr^{-1} of CDF/DTM, 0.2897 of PDF/CDF and 3.68 of CDF/PDF., an effective operational mobile harbour crane set shall be maintained. Besides, while β=3, for the Weibull distribution's parameter, it was observed that the downtime process, if monitored within the specified optimized group of process parameters of 1222.33 hr of DTM/PDF, 31.77 hr of DTM/CDF, 0.0007 hr^{-1} of PDF/DTM, 0.0215 hr^{-1} of CDF/DTM, 0.0263 of PDF/CDF and 41.50 of CDF/PDF, also, an effective operational system will emerge.

Further, it was found that the downtime factors obtained at β=1 had the lowest values, followed by those obtained by β=3 while β=0.5 has downtime values regarded as the worst case. For example, DTM/PDF of 1706.50hrs at β=0.5> DTM/PDF of 1222.33hrs at β=3> DTM/PDF of 92.56hrs at β=1. Hence, the Taguchi method focusing on the downtime process can be used to minimize the downtime of handling equipment in a container terminal with enhanced operational efficiency. The findings of this research reflect a high impact potential in that the straightforward approach presented here allows the possibility of enhancing the effectiveness of controlling the downtime process regarding the mobile harbour crane in a container terminal. Consequently, it may be employed in streamlining the downtime process and the schemes used for the controls in the ports container terminals.

There are a few interesting research that could be conducted on the study in the future. First, previous literature has shown the evaluation of downtime for container ports terminals using Taguchi-Pareto and Taguchi-ABC methods. However, none of these methods has considered the aspect ratios as factors considered. Hence, an appropriate direction of research is to consider these methods while incorporating the aspect ratios of factors instead of the three known methods of downtime, probability density function and cumulative density function. A further step could be taken to compare the results of the optimisation using these two methods of Taguchi-Pareto and Taguchi-ABC with and without the aspect ratios of factors. Furthermore, the literature has also defined the economic aspect of Taguchi optimisation with the possibility of merging the present worth factor with the Taguchi method. This can be done with and without the aspect ratios for both the Taguchi-Pareto and Taguchi-ABC methods. Besides, as mentioned in the introduction, the container terminal in the case study is run by manual operation. However, how about an automated terminal? Thus, the results obtained in this study may vary in an automated system where an organized downtime collection and analysis system has been installed. Hence, a future study area may be to compare the systems of manually-operated and automated ports regarding the downtime analysis.

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