Evaluation of project quality engineering problems in material handling plants using factorial designs[1]

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Abstract

Quality engineering is generally defined as conformance to specifications or fit for purpose. Production plants experience production downtimes due to material handling plants poor reliability and availability which relates very well with the project engineering quality management process. These problems are common to industries like power plant, mining, steel manufacturing, and cement manufacturing where large bulk material plants are used for material transportation purposes. This problem is worse where material transported have fine particle sizes, which if not handled well mechanically worsen the operating environment increasing the rate of equipment premature failures.

In strategic planning, there is a belief that the organization's future depends entirely on what is done now and management has no choice but to anticipate the future and attempt to mold it and to balance short-range and long-range goals. The decisions, actions, resource allocation, and work done now will create the future. The present and immediate short-range require strategic decisions as much as the long-range. In systems engineering, designing a balanced system is what every design engineer must strive to achieve. This must be done by first looking at how the system should look like in the operational state, followed by a detailed requirement of the system.

Project quality engineering consists of analysis methods and the development of systems to ensure products or services are designed, developed, and manufactured to meet or exceed the customer's requirements and expectations. Quality engineering encompasses all activities related to the analysis of a product's design, development, and manufacturing processes for improving the quality of the product and the production process while identifying and reducing waste in its many forms. This study aimed to investigate project quality engineering problems in material handling plants and how factorial design can be used to improve material handling plants performance.

Keywords: Factorial design, project quality engineering, plant performance

Introduction

"In the middle of difficulty lies opportunity" - Albert Einstein"

Goetsch and Davis (2013-5) argue that quality management is generally acknowledged as an approach to organizational management, which brings about enhanced performance

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(operational, technical, and financial). Oahland (2003-154) points out that over the past decades, organizations throughout the world have been antagonistically trailing project quality management since there is a commonly held view that high-quality products and services result in improved performance.

The lack of a definitive theory, which explains and substantiates how the quality management practices or dimensions are related to bring about improved organizational performance, has resulted in claims and counter-claims by advocates and opponents of quality management as its ability to deliver returns, explains Taylor (2009-157). Dolan (2000-252) indicates that it is important for every organization to identify quality management practices, which maximally contribute to organizational performance and how the quality management practices interact and influence each other to culminate in superior organizational performance.

Background of power plant ash handling plant (similar plant for mines, cement etc)

In thermal power plants, coal is burnt in the boiler to supply heat which is necessary to generate steam. During his process ash is released from the boiler into the boiler ash hopper, while other materials are taken up by the flue gases and released in the gas passage as fly ash. The ash-handling plant continuously removes ash from the power plant in the form of both fly ash and coarse ash. The coarse ash is removed from the bottom of the boiler by the submerged scraper conveyor (SSC) and conveyed to the transverse conveyor via the Japanese pipe conveyor (JPC). The fly ash is transported from precipitator hoppers by a hopper chain conveyor, through transfer conveyors to a bucket conveyor, moving ash to the fly ash bunker. The ash conditioning plant mixes dry fly ash from a fly ash bunker with water so that the resulting product can be handled mechanically without dust escaping to the atmosphere. The fly ash and coarse ash is transported by the same transverse conveyors onto the overland conveyors to the stacker via the extendable and shift-able conveyors. The ash stacker machine stacks the ash in the ash dump.

During normal operation, precipitator hoppers are to be kept empty at all times. This is necessary to prevent ash build-ups and cementing of ash in the hoppers when the ash temperature drops. During emergencies only, when the ash handling plant is unavailable or the fly ash bunker is full, fly ash can be stored for up to six hours in the precipitator hoppers. The submerged scraper conveyor (SSC) was designed to stop for one-hour maximum at full load and load reduction to half load required after stopping more than an hour to prevent the formation of ash clinkers inside the boiler.

Research hypothesis

The following are the hypothesis the research must respond to:

- H1: Project system design problems are the major contributor to poor plant reliability of material handling plants as a result of poor project quality management.
- H2: There is a relationship between project quality engineering management and plant performance through its life cycle.

Research proposition and objectives

The main proposition for this study is to investigate how quality processes can be used to ensure continuous improvement of material handling plant performance and how quality processes can be integrated into all business functions to ensure all functions performed to meet the needs for which they were undertaken. To test this proposition, this paper examines the performance of material plants using the factorial designs to identify variables that affect plant performance most, relating to project quality management. The study results have the potential to offer a means of improving material handling plants performance.

Literature review

Quality has evolved from inspection through QC and quality assurance (QA), to a system-based approach like TQM. The quality revolution has transformed organizations from inefficiency relying on inspections, autocratic leadership and hierarchical control, to a system of teamwork, paying attention to customer needs and satisfaction, getting quality right the first time, and continuously improving processes. Deming points out that quality has a sequence reaction of positive results: "Improving quality leads to costs decrease with less rework and fewer delays which improves productivity and captures the market with better quality and lower prices". QMS is shown through policies, procedures, processes, resources, and organizational structure required to implement quality management.

Common types of quality engineering problems

Smith (2000-44) indicates that interpreting or responding to situations, well-founded problem types, or categories must be used as an assurance of expert problem-solving. Problem types or categories help direct attention to relevant past experiences and pertinent problem-solving techniques. Three types of quality problems were differentiated by recognizing the need to fit a problem-solving response to the nature of the situation:

- Repair - to restore a malfunctioning system to its intended level of performance.
- Improve - to improve a system to achieve performance goals.
- Engineer - to design a new system or solution that will satisfy pertinent goals

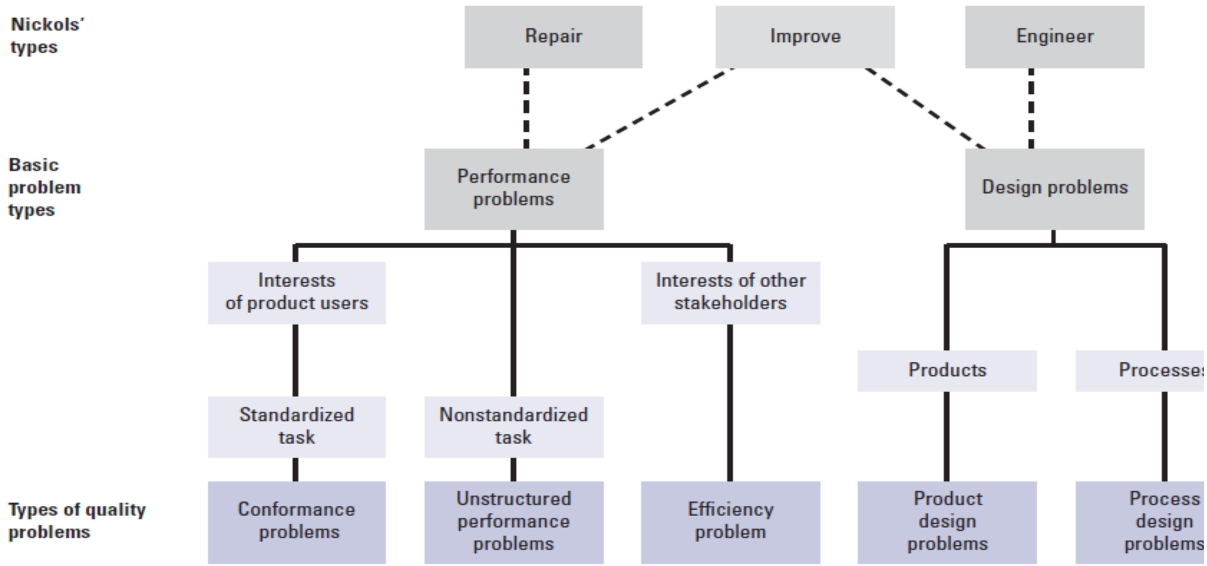

Figure 1: Types of quality engineering problems (Smith- 2000)

Quality and performance

Keller (2003-215) argues that quality improvement is the use of a deliberate and defined improvement process and the continuous ongoing effort to achieve measurable improvements in performance. Performance management uses data for decision-making, by setting objectives, measuring and reporting progress toward those objectives, and engaging in quality-improvement activities when desired progress toward those objectives is not being made. Figure 2 below shows the factors that constitute performance management.

Figure 2: Factors that constitute quality management (Evans and Lindsay, 2014)

Design experiment

According to Oahland (2003-337), quality improvement is most effective when it is an integral part of the service/product realization process. Oahland (2003-67) points out that design experiments are tests where purposeful changes are made to input variables of a process so that observations can be made to similar changes in the output. The process variables contain controllable factors and uncontrollable factors. Figure 3 below shows a general model of such a process. The objective in many cases is to develop a robust process minimally affected by external sources of variability. A well-designed experiment is important because the results and conclusions that can be drawn from the experiment depend to a large extent on how the data were collected. In general, experiments are used to study the performance of processes and systems. The objectives of the experiment may include the following:

- Determining which input variables are most influential in the output response.
- Determining where to set the influential input so that output is almost always near the desired nominal value.
- Determining where to set the influential input so that variability in output is small.
- Determining where to set the influential input so that the effects of the uncontrollable input variables are minimized.

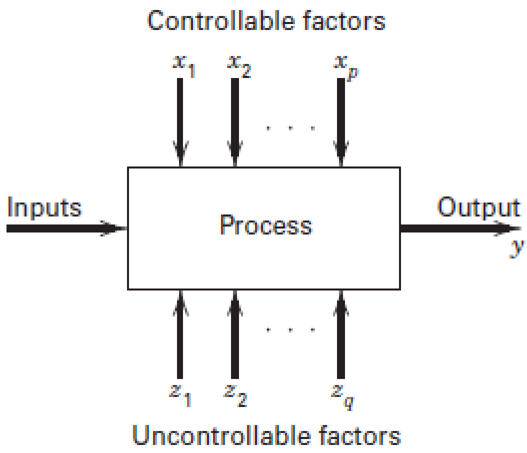

Figure 3: General model of a process (Oahland- 2003)

Research Methods

Factorial experiment

The objective was also to improve the process by identifying the best possible combination that would deliver a balanced material handling system capable of delivering the desired output carried out by varying controllable inputs and observing the impact on the output.

As a case study was done in a power plant ash material handling plant was used to experiment. The ashplant conveyor system is designed to operate at a minimum speed (X1) of 1 m/s and a maximum speed 2.87 m/s. The throughput time (X2) is the number of hours that the ash system runs without accumulating any ash backlog. The ash capacity (X3) is the number of tons that the system was transporting per hour which by design is a minimum of 650 t/h to a maximum of 2060 t/h. The formula below is used to calculate the output from each combination of factors.

Formula: $y_{ijk} = \mu + \alpha_i + \beta_j + \alpha\beta_{ij} + \varrho_{ijk}$

Where Y is responses, μ is an overall mean, α is row effects, βis Column effects, αβis interaction effects, ϱ is random errors. The three factorial experiments compare all possible combinations between minimums and maximums varying from one factor and recording the output response based on the input change. Figure 4 shows the research experimental design process.

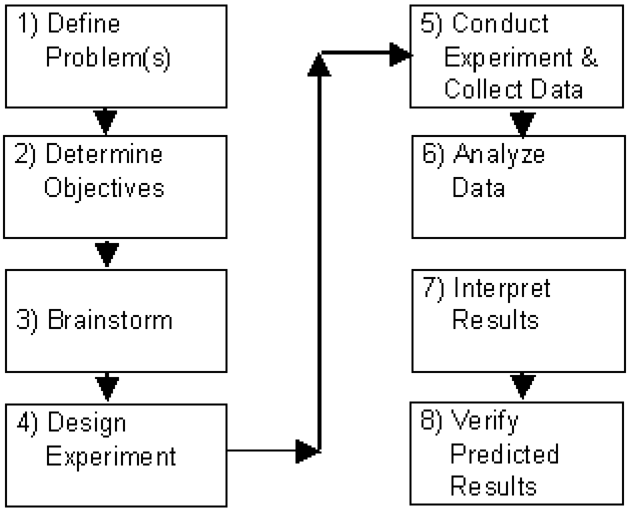

Figure 4: Experimental design processes (Montgomery, 2005)

Conduct experiment

The experiment was set up to measure the process parameters required to calculate the performance of the conveyor system over a certain period. The active factory (supervisory control and data acquisition) database was used to record and view plant real-time data including operating speeds, conveyer load, downtime, uptime, operating times, and breakdown rate per equipment. Relevant data tags were trended for the duration of the experiment. The three factorial experiments which contain three main effects and four interaction effects were carried out as follows:

1. The controllable input variable was varied to all treatment levels
2. Uncontrollable variables were fixed for the duration of the experiment
3. The output variables were measured to determine the output variability
4. Calculate probability values

5. Calculate the effects on output per change in the input variable
6. Calculate the sum of squares (SS) using formula
7. Calculate the analysis of variance (ANOVA)
8. Plot main effects and interacting effects then interpret results.

Experiment results

A factorial experiment was performed to measure the main factor effects and interacting (relationships) effects of the three factors at different levels to identify controllable inputs that have the most effects on the output. The controllable variable in the conveyor system identified were conveyor speed, operating hours (mean time between failures) and ash capacity (amount of ash transported)

Table 1: Process controllable factors

Name	Low level	Medium level	High level	Units
Speed (X1)	1	2.5	2.87	m/s
Time (X2)	7	15	24	H
Capacity (X3)	650	1300	2060	T/H

Controllable process input variables were varied as shown in the table below and the response output recorded. Online real-time process output data (percentage performance and throughput operating hours) was recorded.

Table 2: Experiment recorded data

Run order	Controllable variables	Column 1	Column 2	Performance	Throughput time
	***X_1* -speed**	***X_2* -Time**	***X_3* - capacity**	***Y1 (%)***	***Y2(H)***
1	-1	-1	-1	29.52333333	7.0856
2	1	-1	-1	94.85666667	22.7656
3	-1	1	-1	91.23666667	21.8968
4	1	1	-1	95.62	22.9488
5	-1	-1	1	44.09666667	10.5832
6	1	-1	1	94.57	22.6968
7	-1	1	1	66.57333333	15.9776
8	1	1	1	94.95333333	22.7888
Yields					

The table above indicates the value of the output plant performance (Y1) and operating hours (y2) which were recorded. The effects calculations were done using the formula:

$$Effects\ (Y1) = \left(SumX1 + \frac{1}{n}\right) - \left(SumX1 - \frac{1}{n}\right)$$

Table 3: Factorial design effect's results

	X1 (Speed)	X2 (Time)	X3 (Capacity)	X1X2	X1X3	X2X3	X1X2X2	Y1	Y2
1	-1	-1	-1	1	1	1	-1	**30**	**7**
2	1	-1	-1	-1	-1	1	1	**95**	**23**
3	-1	1	-1	-1	1	-1	1	**91**	**22**
4	1	1	-1	1	-1	-1	-1	**95**	**23**
5	-1	-1	1	1	-1	-1	1	**44**	**11**
6	1	-1	1	-1	1	-1	-1	**94**	**23**
7	-1	1	1	-1	-1	1	-1	**67**	**16**
8	1	1	1	1	1	1	1	**96**	**21**
Effect (Y1)	**37**	**21.5**	**-2.5**	**-20.5**	**2.5**	**-9**	**10**	**76.5**	
Effect (Y2)	**8.5**	**4.5**	**1**	**-5.5**	**0**	**-3**	**-2**		**18.25**

Table 4 below results when time is interacted with capacity by getting the average value of the two numbers.

Table 4: Average values for time and capacity interactions

Column 1	Column 2	Column 3	Column 4	Column 5
Standard	**X1 - Speed**	**X2 - Time**	**Y1 (Average)**	**Y2 (Average)**
1,2	-1	-1	77.5	15
3,4	1	-1	93	22.5
5,6	-1	1	69	17
7,8	1	1	81.5	18.5

The three largest effects on performance:

The effects calculations were done using the formula. The results are as shown in table 5

$$\text{The sum of squares (SS)or X1} = \text{Number of} \frac{\text{runs}}{4} (\text{effects})^2$$

Table 5: Analyses of variance for performance

Source	Sum of squares	DF	Mean squares	F value	Prob > F
SSmodel	4503	3	1501	2.0978	< 0.001
X1	2738	1	2738	3.8267	< 0.001
X2	925.5	1	925.5	1.2935	< 0.001
X1X2	840.5	1	840.5	1.1747	< 0.001
Residual	2862	4	715.5		
Core Total	7365	7			

The regression model that was used to represent this process:

$$y = \beta 0 + \beta 1x1 + \beta 2x2 + \beta 12x1x2$$

Table 6: Comparison between actual performance and predicted performance

Standard order	X1 (Speed)	X2 (Time)	X1X2	Performance actual	Performance predicted	Residual
1	-1	-1	1	30	37	-7
2	1	-1	-1	95	95.5	-0.5
3	-1	1	-1	91	79	12
4	1	1	1	95	95.5	-0.5
5	-1	-1	1	44	37	7
6	1	-1	-1	94	74	20
7	-1	1	-1	67	58.5	8.5
8	1	1	1	96	95.5	0.5

Table 7 below shows the results of actual operating hours and predicted operating hours and its residual values.

Table 7: Actual operating hours and predicted operating hours

Standard order	X1 (Speed)	X2 (Time)	X1X2	Operating hours actual	Operating predicted	Residual
1	-1	-1	1	7	16.75	-9.75
2	1	-1	-1	23	23	0
3	-1	1	-1	22	9	13
4	1	1	1	23	22	1
5	-1	-1	1	11	9	2
6	1	-1	-1	23	23	0
7	-1	1	-1	16	13.5	2.5
8	1	1	1	21	22	-1

Factorial experiments focused on analyzing the ash transportation process by comparing current performance levels with design requirements or desired performance. It became evident that the process results indicated that the material handling plant out of statistical control and not capable of delivering the process requirements. This can be seen by the amount of ash backlog that the system accumulated during the duration of the experiment

Results discussion

Input variability was measured by varying controllable variables while keeping constant uncontrollable variables focusing on how sensitive the effects on the output when input change.

Controllable variable and its interaction

1. Conveyor speed (X1)
2. Conveyor operating time (X2
3. Interaction effect between conveyor speed (X1) and conveyor operating time (X2)
4. Interaction effect between conveyor speed (X1), conveyor operating time (X2), and capacity (load in tons).

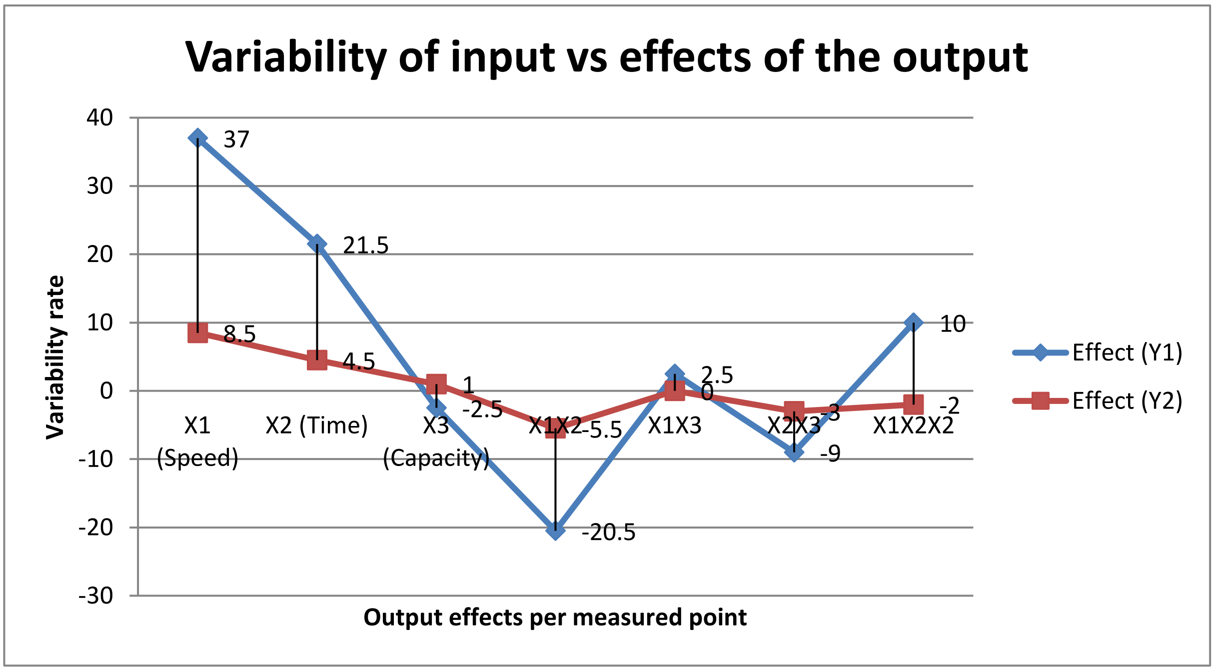

Figure 5: Input variability rate vs effects on the output

From the Figure 5 above, it is evident that throughput time is mainly affected by:

1. Conveyor speed (X1)
2. Interaction effect between conveyor speed (X1) and conveyor operating time (X2)
3. Conveyor operating time (X2)
4. Interaction conveyor operating time (X2) and capacity (X3)

Interaction effect between conveyor speed (X1), conveyor operating time (X2) and capacity (X3)

Half normal plots for effects and its Pareto chart

Before plotting the effects, it helps to convert them into absolute values to ensure the scale becomes more sensitive to detect significant outcomes. The absolute value is accommodated by half normal which is based on a positive half of a full normal curve.

As shown in Figure 6 below, the biggest three effects fall out on the tail of the normal curve to the right. These three effects are significant (X1, X2, X1X2) or most likely significant. We also observe a big gap before the next lowest effect. The four trivial effects (X3, X1X3, X2X3, X1X2X3) closer to zero will be used as an estimate for error in the ANOVA.

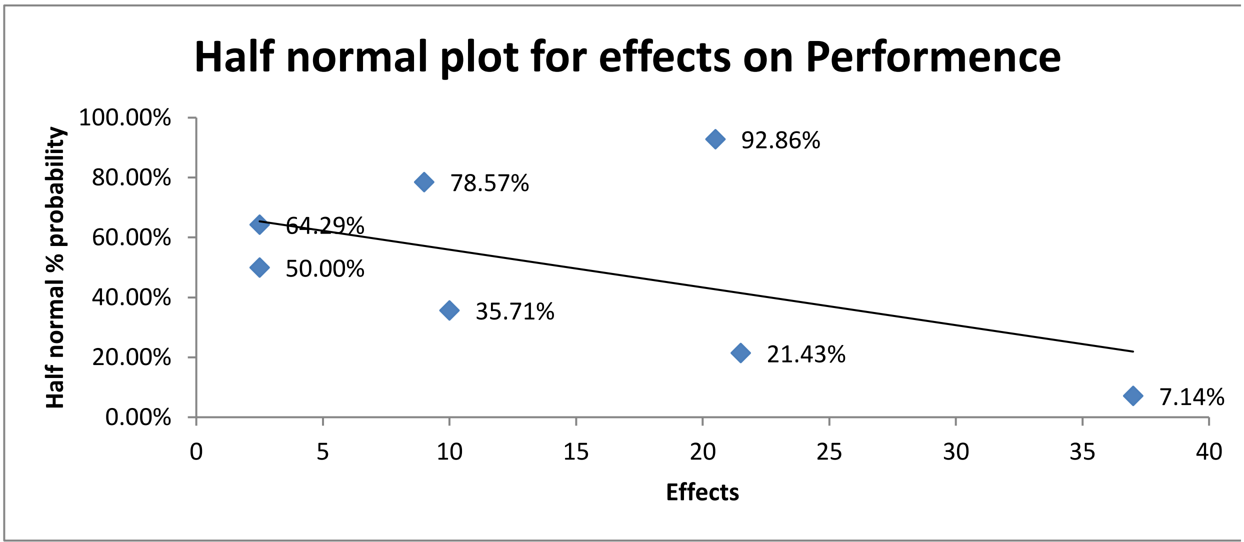

Figure 6: Half normal plot for effects on performance

The Pareto chart in the Figure below shows a simple view of the relative effects indicated above.

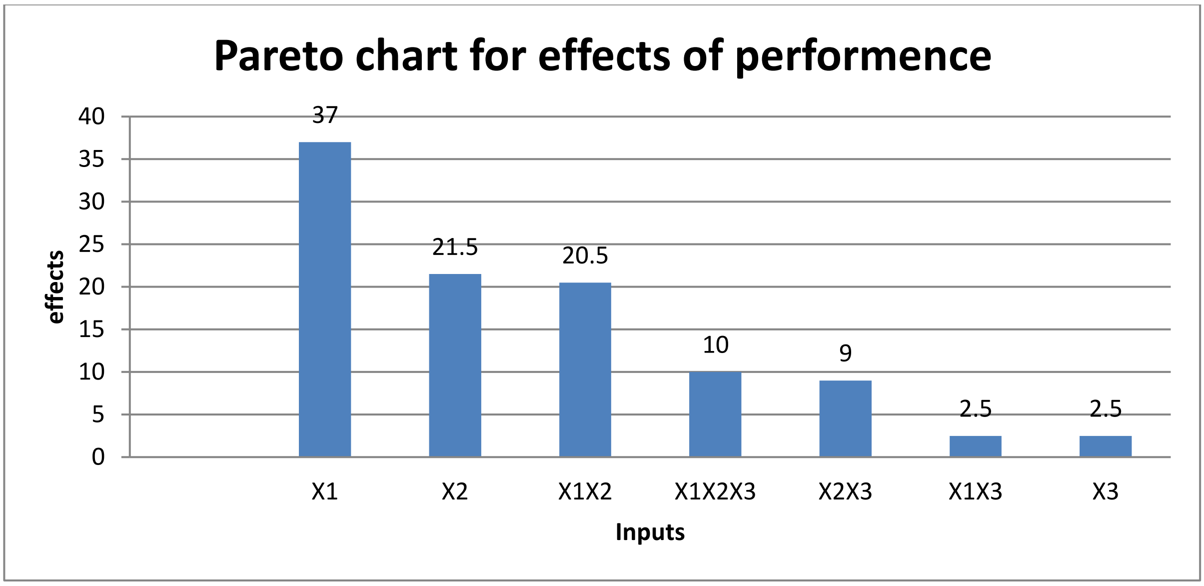

Figure 7: Pareto chart for effects on performance

Figure 8 below, shows that two of the effects fall to near zero (X3, X1X3), these effects only vary due to normal causes or may be due to the experiment marking it as insignificant. The effects of X1, X2, and X1X2 are bigger compared to other effects and are considered significant. These factors should be investigated to establish how they interact to affect the response of throughput time.

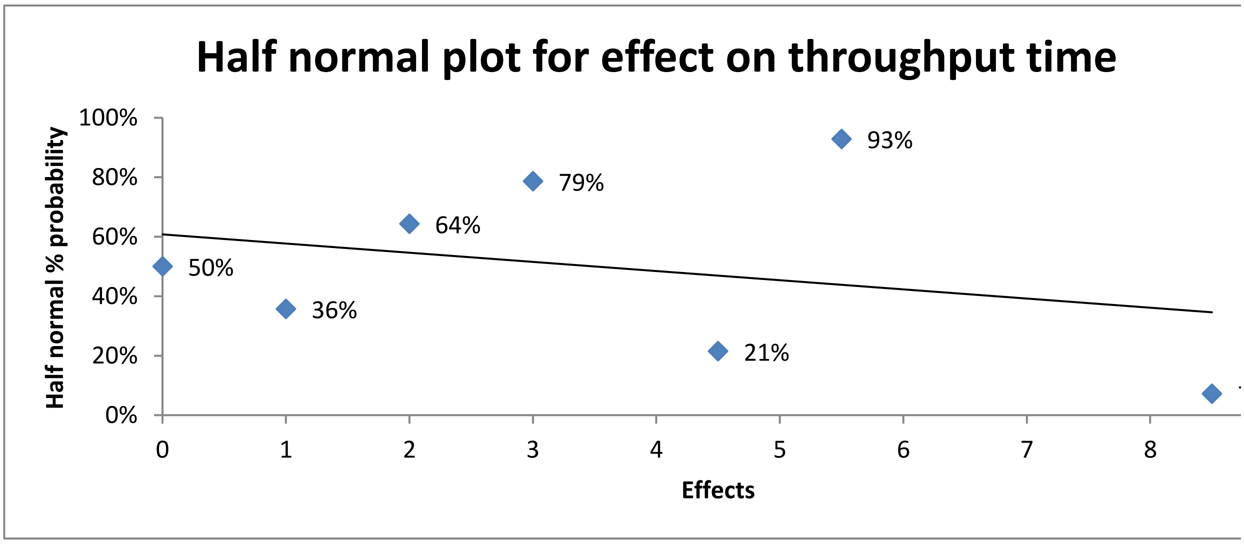

Figure 8: Half normal plots for effects in throughput time

The Pareto chart in Figure 9 below shows that the impact of X1, X1X2, and X2 on the left is the vital few (significant) and the rest on the right trivial many (insignificant).

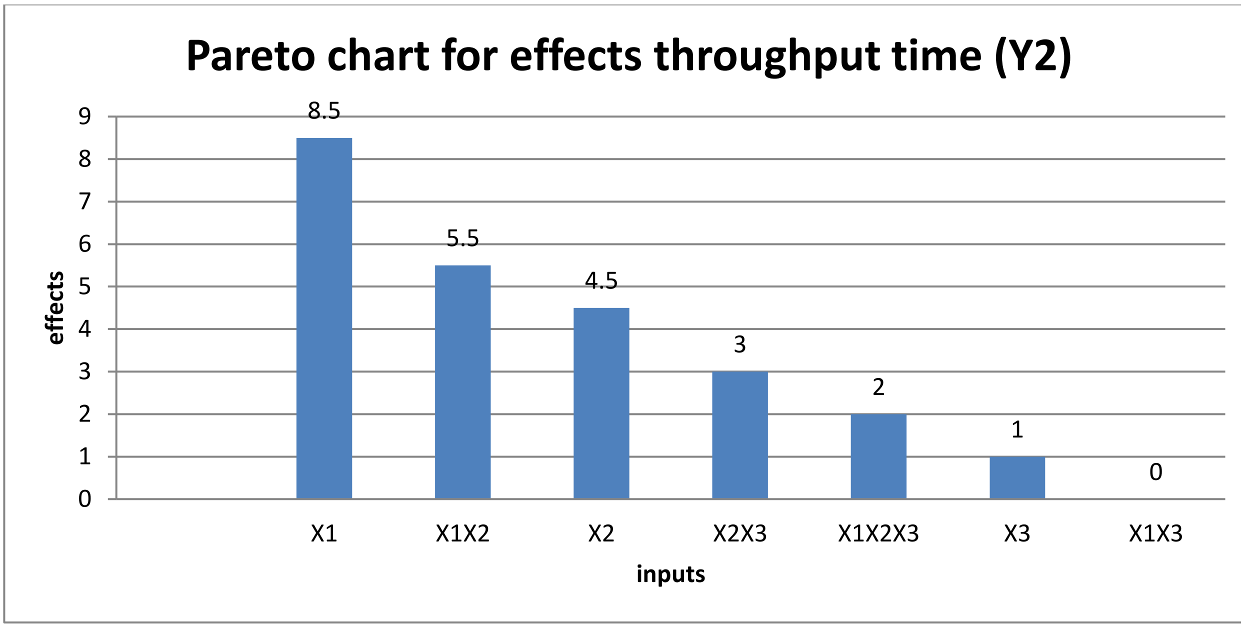

Figure 9: Pareto chart for effects on throughput time

Analysis of variance

To verify and validate the results above, the statistical validation was done by performing an analysis of variance (ANOVA). If the residual is normally distributed, it will fall in line. In this case deviations from the linear pattern are present. This is a completely non-linear pattern taking almost an "S" shape and requires a response transformation to be done. Figure 10 below shows the normal plot of the performance residual.

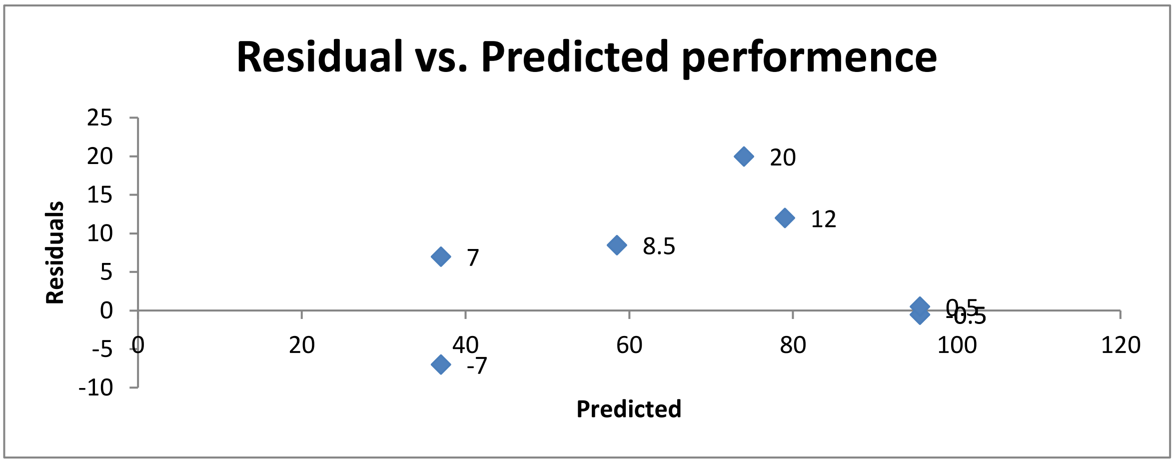

Figure 10: Residual vs predicted performance

Figure 11 below shows the normal plot of the throughput time residual.

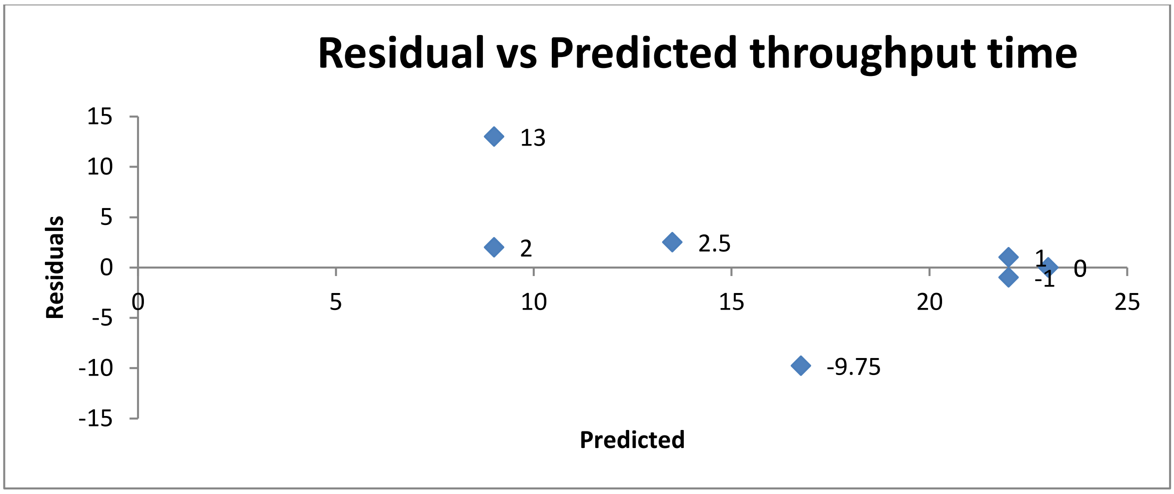

Figure 11: Residual vs predicted throughput time

Research findings

The following were research findings:

1. The material transportation process is observed to be out of statistical control (presence of special causes of variation) hence it is incapable of delivering the desired results. This was also caused by huge variations in loading conditions which mostly occurred when the plant was standing and material backlog accumulated. The qulity engineering inputs during system design must cater for system abnormality to be capable of delivering desired results.

2. It was evident that the percentage material handling plant performance (Y1) was more affected by: firstly, speed (X1); secondly, operating hours (X2); thirdly, the interaction between speed and operating hours (X1x2); fourthly, the interaction between speed, operating hours and loading capacity (X1X2X3). Speed and operating hours need to be maximized at all times to maximize plant efficiency.

3. It was evident that the throughput time (Y2) was more affected by speed (x1); secondly interaction between speed and operating hours (x1x2); thirdly, operating hours (X2); fourthly, interaction between operating hours and loading capacity (x2x3); and fourthly interaction between speed, operating hours and loading capacity (x1x2x3).

<u>Hypothesis 1</u>

<u>The null hypothesis and alternative hypothesis:</u>

- H_0 : Project system design problems are not a major contributor to poor plant reliability of material handling plants as a result of poor project quality management.
- H_1 : Project system design problems are the major contributor to poor plant reliability of material handling plants as a result of poor project quality management.

The success of projects is evaluated in two different aspects. The first part is that project completed on time, within budget, and scope (triple constraint) following the initially defined target. The second perspective is that if a project product (deliverable) has created the intended purpose, it is meant to deliver. This means that for the product to be successful, the project must be successful generally. Using the responsible, accountable, consulted and informed (RACI) framework to rank the importance of stakeholders, it is not that although both the success of a project and a product matters, most important stakeholders take consider product success a higher priority because it includes the creation of customer delights (Customer focus and product life cycle and apply measures such as the return on investment (ROE), net present value (NPV), cost and revenue (revenue and unmet needs). The half plot (Figure 6) and the Pareto (Figure 7) to the diagram, it is depicted that the design accuracy for the parameter which include operating speeds(X1), operating time (X2) and the interdependency between operating speed and operating time (X2) has more impact on the product performance (X).

From the above results H_1 : Is accepted - Project system design problems are the major contributor to poor plant reliability of material handling plants as a result of poor project quality management

Hypothesis 2

The null hypothesis and alternative hypothesis:

- H_0 : There is a relationship no between project quality engineering management and plant performance through its life cycle
- H_1 : There is a relationship between project quality engineering management and plant performance through its life cycle

To respond to the second hypothesis a distinction is made between the process and the product of design. Quality engineering focuses on making sure that goods and services are designed, developed to exceed consumers' expectations and requirements. The activities analysis of a good's design and development make sure that the manufacturer makes the goods according to specifications. Quality engineering is the analysis, management, development, and maintenance of different systems following high standards. As shown in half-normal plot effects on figure 8 which shows the absolute values of the standardized effects from the largest effect to the smallest effect. The standardized effects are t-statistics that test the null hypothesis that the effect is 0. In this plot (figure 9), the main effects for factors X1, X1X2 and X2 are statistically significant at the 0.05 level.

The half-normal probability plot of the effects displays the absolute value of the effects, we determined which effects are large but we could not determine which effects increase or decrease the response. We then use the normal probability plot of the standardized effects to see the magnitude and direction of the effects on figure 11. The normal probability plot of the effects shows the standardized effects relative to a distribution fit line for the case when all the effects are 0. The standardized effects are t-statistics that test the null hypothesis that the effect is 0. Positive effects increase the response when the settings change from the low value of the factor to the high value. Negative effects decrease the response when they settings change from the low value of the factor to the high value of the factor. The results in figure 11 show effects further from 0 on the x-axis indicating greater magnitude and are more statistically significant. Therefore, quality engineering directly influences performance in material handling plants.

From the above results H_1: There is a relationship between project quality engineering management and plant performance through its life cycle

Conclusion and recommendation

The key role is played by quality engineering is to implement and maintain systems used to control the quality of processes through a thorough understanding of all the technological activities and evaluation principles. Quality engineering main activities in project and products include analysis, testing, improvement, management, development, planning, data collection, and providing feedback. Poor quality material plant designs results in process overload, overloading the system for short periods (bad batch) of time causing more stress, wear, and tear, which resulted in premature failure of the weakest link in line with the theory of constraint "a chain is as weak as its weakest link". The material feeding system must be designed to ensure that the process must not allow overloads so that the plant can at all-time operates within its design parameters. The loading condition, therefore, was identified as the root cause of poor reliability and availability of material handling plants resulting in equipment performance deterioration in a short space of time. It is therefore recommended that material handling plant operates within statistical control at all times to avoid all secondary damages which will waste organizational resources.

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