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Optimal approaches to robust design for industrial wastes

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Abstract

This paper focuses on the analysis of Industrial production wastes applying robust design approaches. Past literatures on Optimum Manufacturing Strategy and Taguchi robust design were reviewed and applied to case study the Innoson Vehicle Manufacturing Company (IVM). Taguchi Robust design was implemented to optimize wastes in the Innoson vehicle manufacturing company while factorial design was implemented to establish the effects of interaction of factors at two levels (low and high). The half normal effects plot of Taguchi robust design with the design Layout show that the overproduction and excess inventory are the major wastes, with overproduction ranking highest. A detailed analysis of the firm's production processes showed that defects, excess inventory, over-production, and over-processing are the four major wastes that are impeding IVM progress and profitability. Apart from establishing the optimum parameter setting that will ultimately lead to waste elimination in IVM, the work showed that when excess inventory is 7 the optimization is 82.3. The factorial analysis model established was found to be significant with P-value of 0.012 at 95% confidence interval. Finally this study optimized the quality characteristics using minitab 16 and design expert 8 software and established optimum parameter combinations for the control of IVM wastes.

Keywords: Limitation; optimize; overproduction; over-processing; excess inventory; defects; quality characteristics

1. Introduction

For the modern industry practice, an excellent design of any product aims to shift resources to the creative design process rather than relying on inspection to ensure quality. A quality characteristic is identified, and quality is achieved by minimizing deviation from its target rather than mere conformance to specification. A design is said to be robust when the product performance is minimum sensitive to variations.The Robust Design system simultaneously yields significantly improved quality, reliability, and durability, as well as the reduction of design cycle times, and manufacturing costs.

Robust design enables engineers to develop products and processes which perform consistently as intended under a wide range of user's conditions throughout their life cycle (durable and reliable), maximize robustness-improve the intended function of the product by developing and increasing insensitivity to noise factors which tend to degrade performance, develop or change product formulas and process settings to achieve desired performance at the lowest cost and in the shortest time, and also simplify designs and processes to reduce cost (Dieter,2000). As a type of robust design Taguchi achieves the above objectives by first performing parameter design, and subsequently performing tolerance design if the conditions are not optimum (Shinkel etal,2004). Taguchi method involves reducing the variation in a process through robust design of experiments, as the overall objective of the method is to produce high quality product at low cost to the manufacturer (Schonberger, 2000). Denis, 2002, Burns and Weisman, 2006, Womack et al., 1990, Dale 2003 and Michael, 2005 also worked on optimum manufacturing while a programmed software for applying parameter design be downloaded (Reliasoft.com).

2.1. Overview of Taguchi robust design method

The Taguchi robust design is a method for designing experiments to investigate how different parameters affect the mean and variance of a process performance characteristic that defines how well the process is functioning.

As a scientifically disciplined mechanism for evaluating and implementing improvements in products, processes, materials, equipment, and facilities, Taguchi's methods of improvements are aimed at improving the desired characteristics and simultaneously reducing the number of defects by studying the key variables controlling the process and optimizing the procedures or design to yield the best results (Fraley, 2011). The standard procedures of robust design are as depicted in figure 1 as in (Fraley, 2011).

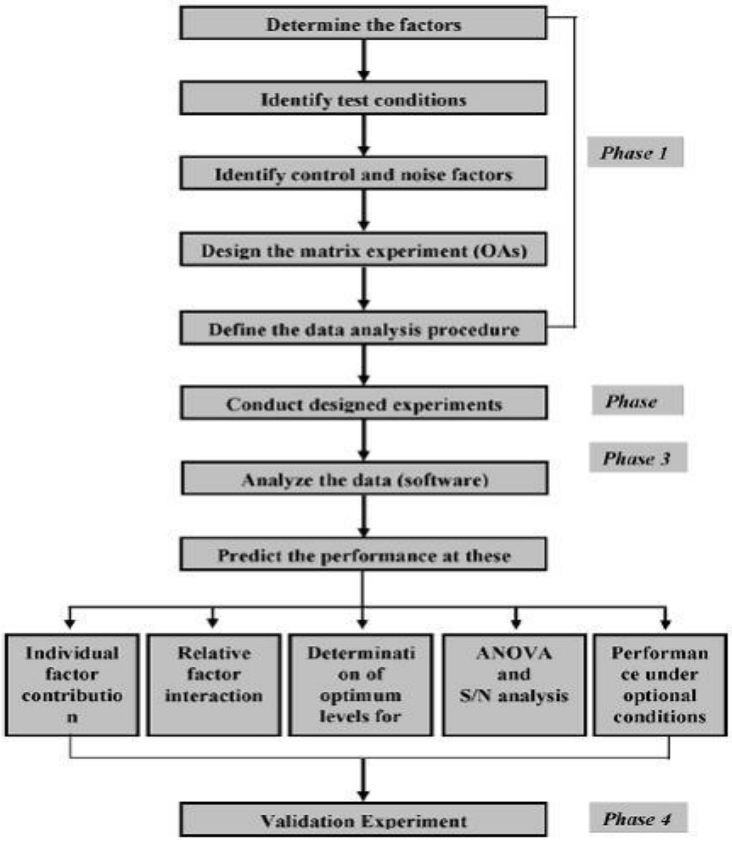


Fig. 1. Taguchi procedures.

Taguchi's philosophy is based on the fact that any decrease in the quality of a system leads to customer dissatisfaction. This occurs even if the departure in quality lies within the specified limits of the system and is considered acceptable to the customer.

2.2. Theoretical models for Taguch robust design

Taguchi established a quadratic function also called loss function used to assess the level of performance of process or product as well as the influence of design factors on product performance as

$$L(y) = k_c(y - m)^2 \tag{1}$$

Using the depictions of Fig. 1 and Eq. 1, various states of a process or product performance are established. Equation (1) depicts the nominal-the –best situation with Fig. 1a where the target value m must vary with the measured value, Fig. 1b depicts the smaller-the – better where the target value m is set to zero, Fig. 1c depicts the larger-the–better where the quality characteristics is continuous and nonnegative and the quality characteristics is expected to be as large as possible. This describes the situation where y = 0 is the worst case and as y increases the quality loss becomes progressively smaller. A situation where strength is the performance characteristics is a good example. These conditions are expressed from Eq. (1) in monetary terms in Dieter (2000), so that for nominal- the- better, smaller –the- better and the larger -the -better we have respectively:

$$L(y) = \frac{A}{\Delta^2}(y - m)^2 \tag{2}$$

$$L(y) = \frac{A}{\Delta^2} y^2 \tag{3}$$

$$L(y) = A\Delta^2 \frac{1}{y^2} \tag{4}$$

This loss function defines the difference between the target value of the performance characteristic of a process,m_2 and the measured value y (Dieter, 2000). where A is the money value of the loss to the society and m+ Δ and m - Δ are the tolerance limits, ie the product or process is unsatisfactory when y is outside this interval. Taguchi uses the signal-to-nose ratio SN as the objective function to be optimized in many situations leading to various versions of Taguchi robust models for the evaluation of performance characteristics based on (1) as follows:

For the case of minimising(smaller-the-better) the performance characteristic(cost of wastes), the following definition of the $S/_N$ ratio should be calculated :

$$SN_i = -10 \log\left(\sum \frac{y_i^2}{n}\right) \tag{5}$$

In this case the SN is a constant value aimed at making y =0 . For the case of maximising(larger-the-better) the performance characteristic, the following definition of the definition of the SN ratio should be calculated:

$$SN_i = -10 \log\left(\frac{1}{n} \sum \frac{1}{y_i^2}\right) \tag{6}$$

This is a situation in which we expect y to be large in order to minimize the cost of the loss to the society. This is also a case to apply when investigating the properties we expect to be high like when investigating the strength of material.
where n = the number of outer noise observation combinations used for each design parameter matrix (inner array) combination. This is also equivalent to the number of trials of each experiment of control matrix.

After calculating the SN ratio for each experiment, the average SN value is calculated for each factor and level [. Once these SN ratio values are calculated for each factor and level, they will be tabulated and the range R (R = high SN - low SN) of the SN for each parameter is calculated. The larger the R value for a parameter, the larger the effect the variable has on the process. This is because the same change in signal causes a larger effect on the output variable being measured. Equations (3) and (4) are programmed in many analytical software such as Design expert 8 and minitab16 which are also employed in this work.

2.3. Overview of Innoson vehicle manufacturing company

The Innoson Vehicle Manufacturing Company is a motor manufacturing factory in Nigeria, their experience with Optimum Manufacturing Strategy dated back to few months before they began production, when an expatriate staff from Japan introduced Lean Production System (LPS) to them. The management reviewed its merits and demerits and subsequently approved the organisations of workshops and seminars on the topic for the members of its staff. However, after the lectures the company did not immediately adopt the manufacturing strategy in its first month of production due to the seemingly high set up cost.

Faced with the problem of high inventory, defects, over-production, and over-processing in their first month of production, the management realised that the company will not be able to compete favourable in its market by continuing with the implementation of mass manufacturing, this therefore explained why they took the wise decision of adopting OMS in their second month of production.

Having used Just-in-time, value stream mapping, Five-S, and other important tools and techniques as curriculum while training its workforce on the new manufacturing approach coupled with the management's support, the expatriates were able to convince the employees that the manufacturing strategy will effectively overhaul their production processes when strictly adhered to.

Although they are still at the early stage of OMS implementation, with determination and continuous improvement in all its manufacturing processes, the company has been making lots of progress which has reduced the number of their wastes.

With a wide knowledge of all the tools and techniques of OMS, IVM has been using a variety of the tools and techniques to improve productivity in its organisation, it considers Just-in-time, and Five S as the two most common ones it has been using due to the numerous benefits they offer them in terms of meeting the needs of the customer and cleaning the surroundings.

Other common tools and techniques of OMS being used by the company include: Kaizen, Single Minute Exchange of Dies, and Visual Management, while it observed that single-piece-flow is the least commonly OMS tool and technique in the establishment. Ensuring the acceptance and active participation of its employees to OMS is considered by the company as the most important success criteria of OMS implementation, while others include: Management participation, cultural change, and organisational infrastructure.

The company explained that it has been able to achieve between 15 and 25% improvement in waste reduction with its introduction of OMS, but however classified its overall OMS implementation result as average. Believing that the manufacturing strategy will continue to grow in importance in the company, IVM pointed out that its OMS results will continue to improve as it targets involving its entire workforce.

From its experience, the company listed the major strengths of Optimum Manufacturing Strategy as waste reduction, increase in profitability, lead time and cycle time reduction, as well as increase in throughput. It noted that the major obstacles of the manufacturing method are irregular power supply, and employees' resistance to change. While others include: inexperienced workforce, financial constraints, and supplier's failures.

The management's decision to implement OMS has been very rewarding due to the numerous benefits that have been achieved by the company. On financial benefits, the company is optimistic that they will make considerable profit after the introduction of OMS, as a lot of money will be saved from the decreased number of defects; it has also reduced its overall inventory to 10%, achieved first time pass rate of 5.5%, and 20% increase in delivery performance.

2.4. Application of Taguchi robust design to IVM

The seven wastes that OMS aims to eliminate which bedevils manufacturing companies and reduces their profitability and throughput are transport, inventory, movement, waiting, over-production, over-processing, and defects. However, after a detailed research on IVM manufacturing activities and processes, it was observed that the company's successes are being impeded by four wastes: defects (A), excess inventory (B), over-production(C), and over-processing (D) as presented in table 1.

Table 1
IVM six monthly production chart

Months	Available Inventory	Manuf. Vehicles	Sold Vehicles	Defects	Excess Inventory	Over Production	Over Processing
Dec. 2010	60	50	31	7	10	19	5
Jan. 2011	59	52	37	3	7	15	1
Feb. 2011	45	41	40	1	4	7	4
Mar. 2011	47	43	38	2	4	9	3
April 2011	44	42	39	1	2	3	0
May 2011	45	42	40	1	3	2	1
June 2011	30	28	41	0	2	0	4

Table 1b
IVM monthly production chart for setting levels

Months	Available Inventory	Manuf. Vehicles	Sold Vehicles	Defects(A)	Excess Inventory(B)	Over Production(C)	Over Processing(D)
Dec. 2010	60	50	31	7	10	19	5
Jan. 2011	59	52	37	3	7	15	1
Feb. 2011	45	41	40	1	4	7	4

2.4. Array determination

This is done using 3 levels of factors as found from table 2 and knowing the number of factors as 4 also from table 1b and applying table to obtain L9 as depicted in table2.

Table 2
Array Selector

Number of Levels	Number of Parameters (P): 2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
2	L4	L4	L8	L8	L8	L8	L12	L12	L12	L12	L16	L16	L16	L16	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32	L32
3	L9	L9	L9	L18	L18	L18	L18	L27	L27	L27	L27	L27	L36	L36	L36	L36	L36	L36	L36	L36	L36	L36								
4	L'16	L'16	L'16	L'16	L'32	L'32	L'32	L'32	L'32																					
5	L25	L25	L25	L25	L25	L50	L50	L50	L50	L50	L50																			

Table 3 is used to establish tables 4 and 5 for IVM waste design matrix.

Table 3
Taguchi L9 orthogonal array

Experiment	P1	P2	P3	P4
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Table 4
The Taguchi L9 orthogonal array for 3levels 4parameters selected for experimentation

Experiment Number	Parameter 1:A	Parameter 2:B	Parameter 3:C	Parameter 4:D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Table 5
The L9 orthogonal array for the wastes in IVM: inner array (control matrix)

Experiment Number	Defects A	Excess Inventory B	Over-production C	Over-processing D
1	7	10	19	5
2	7	7	15	1
3	7	4	7	4
4	3	10	15	4
5	3	7	7	5
6	3	4	19	1
7	1	10	7	1
8	1	7	19	4
9	1	4	15	5

3.1. Analysis with traditional method

Analysis with traditional method following the methods of Dieter (2000) is shown in table 6 and figure 2 using average of SN ratios computed for the 9 experiments performed with table 5.

Table 6
The Response Table

Level	A	B	C	D
1	-35.13	-35.82	-37.56	-35.86
2	-35.85	-35.99	-35.30	-35.32
3	-35.80	-35.50	-33.84	-35.58
Range Δ	0.72	0.73	3.72	0.54
Rank	3	2	1	4

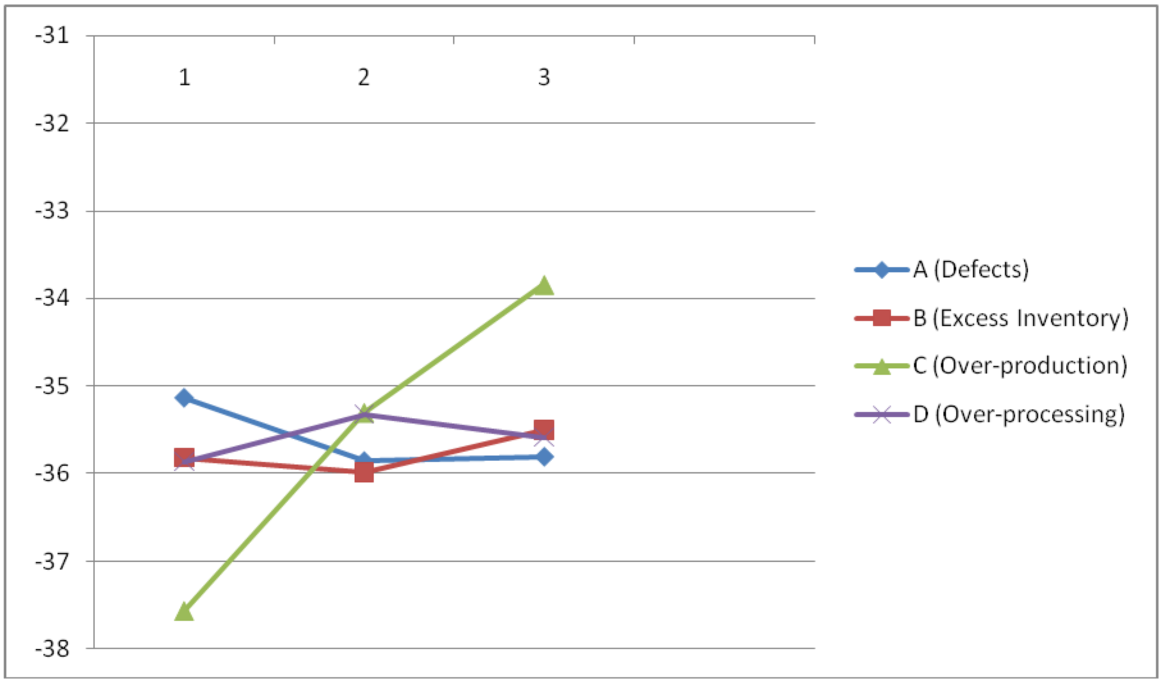


Fig. 2. Main effects plot of level factors.

Table 7
Optimum parameter setting

Control parameter	Optimum level	Parameter setting
A	1	1
B	3	10
C	3	19
D	2	4

3.2. Analysis with minitab16 software

Three levels of factors from table 2 are used with minitab16 to perform Taguchi 9 experiments and each of the experiments were performed 3 times and average responses recorded for smaller the better performance measure and presented as follows in figure 3, while table 8 is used for optimum setting of table 9.

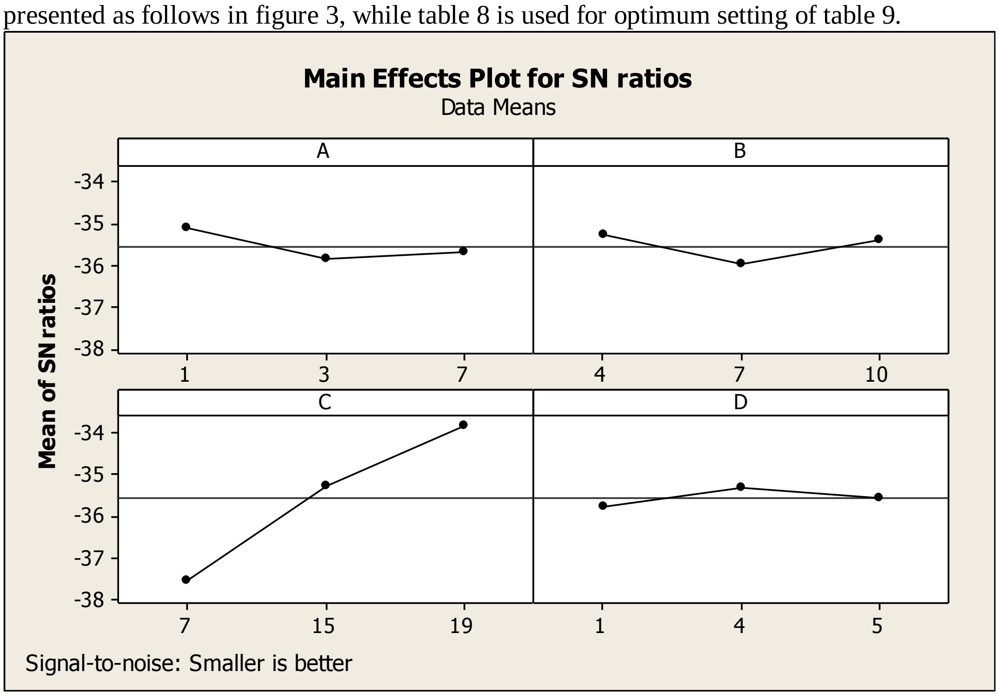


Fig. 3. Main effects plots for minitab analysis.

Table 8
Response table for signal to noise ratios smaller is better

Level	A	B	C	D
1	-35.13	-35.28	-37.56	-35.78
2	-35.85	-35.99	-35.29	-35.32
3	-35.70	-35.41	-33.83	-35.58
Delta	0.72	0.71	3.72	0.45
Rank	2	3	1	4

The ranking of the factors A,B,C and D in figure 8 show that overproduction C is ranked highest in IVM.

Table 9
Optimum parameter setting using mean minitab response table based on highest SN ratios

Control parameter	Optimum level	Parameter setting
A	1	1
B	1	4
C	3	19
D	2	4

Table 10
The Design layout

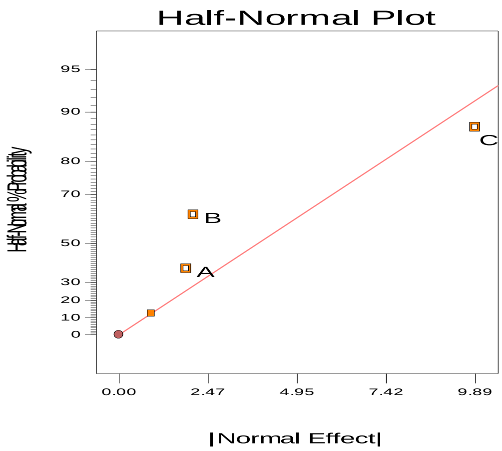
Standard	Run	Factor 1 A:Defects (No. of vehicles)	Factor 2 B:Excess Inventory (No.of vehicles)	Factor 3 C:Over-production (No.of vehicles)	Factor 4 D:Over-processing (No. of vehicles)	Response 1 Optimize (Cost of Wastes)
1	5	7	10	19	5	74.6
2	3	7	7	15	1	60.3
3	8	7	4	7	4	49.7
4	4	3	10	15	4	62.9
5	2	3	7	7	5	61.4
6	6	3	4	19	1	77.8
7	7	1	10	7	1	50.1
8	9	1	7	19	4	83.5
9	1	1	4	15	5	62.3

Half-Normal plot of wastes in IVM

3.3. Analysis with design expert8 software

The Design Expert (DX8) software is applied to model the wastes in the production processes of Innoson Vehicle Manufacturing Company (IVM).
The design expert and the Taguchi orthogonal array, $L9(3^4)$ is used with the values of table 1 to generate the design layout of table 10.

Figure 4 can be used to choose significant effects. Large and significant values appear at the upper section of the graph. The effects plot of figure 4 show that over-production C is followed by excess inventory B, followed by defects A and lastly the over- processing D in significant terms.



Design-Expert® Software
A: Defects
B: Excess Inventory
C: Over-production
D: Over-processing

Fig. 4. Half-Normal plot showing the major wastes in IVM.
Analysis of Variance (ANOVA) on Design expert software
The ANOVA results are as shown in table11.

Table 11
ANOVA Results

Source	Sum of Squares	Df	Mean Square	F value	p-value	
					Prob > F	
Model	1029.17	4	257.29	14.44	0.0120	Significant
B – Excess Inventory	61.31	2	30.65	1.72	0.2891	
C – Over-production	967.86	2	483.93	27.15	0.0047	
Residual	71.29	4	17.82			
Cor Total	1100.46	8				

Model graphs and interaction effects

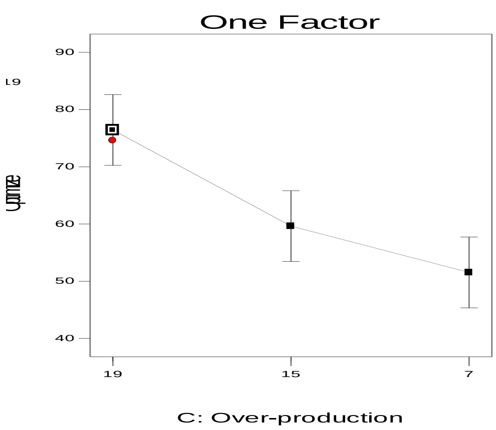


Fig. 5. Model Graph for Over-production (When Over-production is 19).

Design-Expert® Software
Optimize
Optimize = 76.4333
LSD: 12.3556
Design Points
X1 = C: Over-Production = 19
Actual Factors
A: Defects = 7
B: Excess Inventory = 10
D: Over-processing = 5

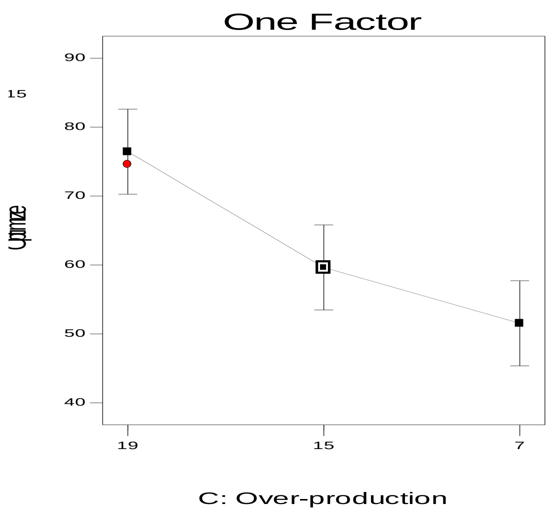


Fig. 6. Model Graph for Over-production (When Over-production is 15).
Design-Expert® Software
Optimize
Optimize = 59.6333
LSD. 12.3556
Design Points
X1 = C: Over-Production = 15
Actual Factors
A: Defects = 7
B: Excess Inventory = 10
D: Over-processing = 5

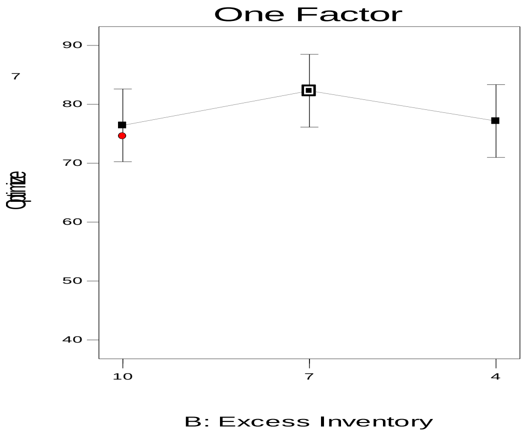


Fig. 7. Model graph for excess inventory
Design-Expert® Software.
Optimize
Optimize = 82.3
LSD. 12.3556
Design Points
X1 = B: Over-Production = 7
Actual Factors
A: Defects = 7
B: Excess Inventory = 19
D: Over-processing = 5

3. Discussion of results

Since the largest value of SN ratio (least negative) is preferred for all forms of SN ratios (Dieter, 2000), the optimum setting of IVM wastes are obtained as 1, 4, 19 and 1 for A, B, C and D wastes. Minitab 16 main effect plots of Fig. 3 and table 12 also shows that over product wastes as 19, while over processing has least effect in IVM production. Fig. 8 and table 11 show that the most significant wastes of IVM is over production.
Also the factorial model of Eq. 10 showed by factorial indexes, that the most significant factor is overproduction followed by excess inventory. Also the value P – value of 0.012 of table 11 reports that the model of this study is significant and over- production with P – value of 0.0047 constitute the most significant wastes of IVM.

The interaction effects of four factors were handled by design experts 8 software. By performing one factor interaction optimization, Figs. 7 and 8 show that the optimum setting of level for overproduction is at waste level of 19 giving optimize value (quality characteristics) as 76.4333. For excess inventory B, figure 7 shows that when excess inventory is set at 7 with other factors as shown graphically the optimize value is 82.3.

The factorial analysis based on two factors B and D and on two level of factors (high and low) using design expert gave a predictive model for optimizing the performance characteristics as

Optimize = +64.73-2.2 B [1] +3.67B [2] +13.9C [1]-2.90C [2] (7)

The factorial indices associated with the two factors shows that overproduction has the most significant influence in IVM process for manufacturing. Though, over production contributes to the major source of wastes, IVM can not go below the optimum setting of 19, what this values of waste means is that it is production that leads to other forms of wastes. This is validated by Fig. 8. The company can then adjust the setting of the other wastes low to obtain her optimum yield. This can be achieved by maintaining minimum inventory level, reducing over processing which sometimes may lead to more defective products. Even table 9 clearly shows the right combination of factor levels for desired optimization level, also interpreted is that production should be set at high level for a desired maximum.

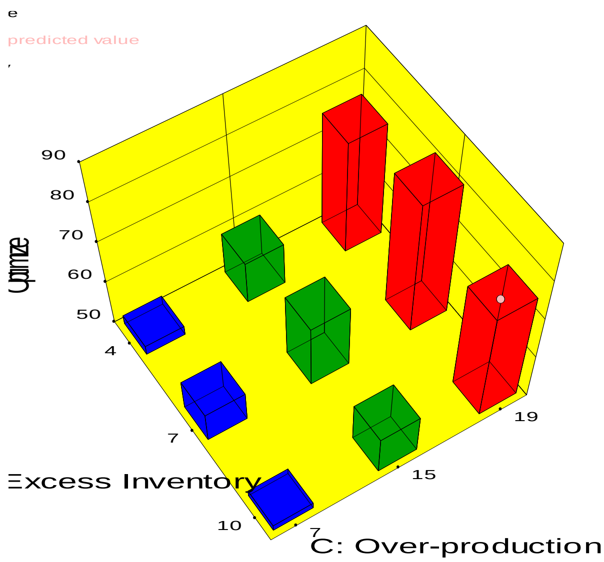


Fig. 8. 3D plot of factor levels effects.
Design-Expert® Software
Optimize
Design Points below predicted value
X1 = B: Excess Inventory
X2 = C: Over-production
Actual Factors
A: Defects = 7
D: Over-processing = 5

The 3D plot of factors of figure 8 also shows that optimization is highest when production is set at its highest
level 3(19)

4. Conclusion

Having identified the wastes as well as the optimization values for the production, the application of Just-in-time tool and technique of OMS will ensure the reduction and subsequent elimination of the wastes.
The findings of the work are very interesting and encouraging as it has revealed that Optimum Manufacturing System is the best approach to

manufacturing due to its numerous advantages over craft and mass production systems, also the application of Robust Design to OMS will ensure immediate identification and elimination of all wastes.

This unique approach to achieving quality assurance and robustness during the design phase utilizes identification of the ideal function of a product or process, as opposed to traditional methods which focus on inspection as a basis for improvement. The application will simultaneously yield significantly improved quality, reliability, and durability, as well as the reduction of design cycle times, and manufacturing costs.

Finally this study optimized the quality characteristics using minitab 16 and design expert 8 software and established optimum parameter combinations for the control of IVM wastes.

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