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Research Paper

OPTIMIZATION OF MANUFACTURING PROCESS PARAMETERS USING ARENA SIMULATION AND TAGUCHI METHOD

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This article presents a study in which an attempt has been made to figure out the optimal arrival parameters to reduce the cost of manufacturing submersible pumps. It mainly focuses on the idea to find the significance of arrival parameters such as entities per arrival, assembly batch size and inter arrival time on the response called cost of manufacturing. A proper combination of these factors must be established so as to get reduced manufacturing cost using the Taguchi method. The manufacturing cost for trial runswas obtained using ARENA simulation using data collection from a pump manufacturing industry. Mixed level design was considered with 4-level design for inter-arrival time and 2-level design for other two factors. Least manufacturing cost of INR 1046 was deduced with optimum combination of inter-arrival time of 5 min, entity per arrival of 1 and assembly batch size of 3. Another objective was to find significance of factors affecting the manufacturing cost. It was found that inter arrival time highly affects manufacturing cost. Thus significant factors along with their optimum combination were found using Taguchi techniques to arrive at the least manufacturing cost.

Keywords: Taguchi, Optimization, ARENA, Manufacturing cost, Simulation

INTRODUCTION

The establishment of optimum process parameters for reducing the manufacturing cost was achieved through Define, Measure, Analyse, Improve, Control (DMAIC) strategy (Clements, 1991). Rotary Machine Division (RMD) manufactures three different types of pump namely, Monoblock pumps, M-type and R-type submersible pumps. This division aims at reducing overall manufacturing cost of M-type submersible pump without having major changes in industry. So, the Define phase of

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this article was to investigate factors affecting cost at the place of manufacture of that particular model. After investigating significance of those factors, improved combination of factors must be suggested to reduce the manufacturing cost of the M-type submersible pump. Thus the primary objective was to find the significance of factors affecting the manufacturing cost of M-type submersible pump in RMD division and hence suggest improved combination of factors with least cost using Taguchi method. The relevant metrics for our study includes data collection related to process study, machining time and cost of every process involved in manufacturing. The strategic impact of this work is to improve factors affecting manufacturing cost with a major limitation that the result should not bring major changes to the industry. The major factors taken for consideration for the study are all the manufacturing process till packaging of the component and the entire process simulation. Also there are some factors neglected in the study. They are Monoblock pump, R-type submersible pump, in-process quality control and defects involved in all the processes.Thus, arrival parameters such as entities per arrival, assembly batch size and inter arrival times have been chosen as control factors for the study. Input of parts for corresponding operation at regular inter-arrival time corresponds to entities per arrival. After machining operation, quantity of machined sub-parts sent to assemble corresponds to batch size.The inter arrival time is the time interval between the arrival of Work In Progress (WIP) for manufacturing. Improvement in these factors results in less manufacturing cost which reduces cost of final product. This results in increased demand, lesser waiting times, lesser idle time of machines, thereby increasing machine utilization.

Taguchi Application in Manufacturing System

The Taguchi method (Taguchi *et al.*, 1989; and Roy, 2001); is a powerful tool for the design of high quality systems and is a well-established technique that provides a systematic and efficient methodology for process optimization. Taguchi approachto design of experiments is simple to adopt and apply for users with limited knowledge of statistics, hence obtained wide popularity in the engineering and scientific field (Roy and Ranjith, 1990; and Karthikeyan and Vignesh Shanmugam, 2013). This is considered as one of the engineering methodology for obtaining product and process condition, which are modestly sensitive to the different causes of variation, and which produce high-quality products with less development and cost of manufacturing. Signal to noise ratio and orthogonal array are the two major tools used in this design. The S/N ratio characteristics can be divided into three categories when the characteristic is continuous.They are “Nominal the best”, “Larger the better” and “Smaller the better”. For manufacturing cost, the solution is “Smaller is better” (Park, 1996). Using response curves, the influence of each and every control factors can be depicted easily. In order to achieve reliable and better results without increasing the experimental cost, parameter design is an important step in Taguchi method.

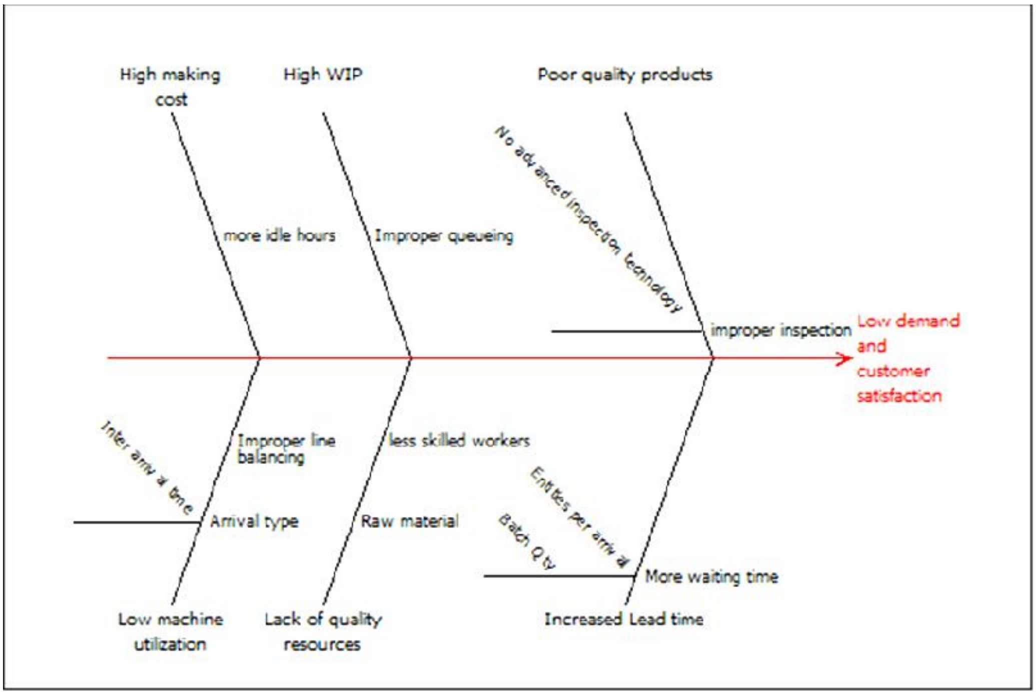
COST OF POOR QUALITY

The need for optimization includes financial impact of this study. Reduced customer satisfaction is a form of poor quality (Phadke, 1989; and Taguchi *et al.*, 2005) of the product. Increased idle hours increases the overall lead time of the component reducing customer satisfaction. Increased Average Waiting Time (AWT) and Work In Progress (WIP) leads to lowered lead time. Thus, Cost Of Poor Quality (COPQ) can be represented in terms of AWT and WIP in relation to lead time, poor quality (Lochner and Matar, 1990) and customer satisfaction (Motorcu, 2010). Optimal production management aims to minimize cost and WIP. WIP requires storage space and carries inherent risk of expiration. As minimization of cost is a primary goal, COPQ on cost basis is taken as machining cost per product. Thus, by minimizing manufacturing cost, we attempt to reduce COPQ, WIP and AWT increasing customer satisfaction. The causes for low customer satisfaction must be analyzed. The major causes for this response were generated using MINITAB 16 software (Rama and Padmanabhan, 2012) as shown in Figure 1. Out of these causes, manufacturing cost predominantly affects all other causes as explained earlier. Thus, the entire article revolves around minimizing cost.

DATA COLLECTION FOR FACTORS AND LEVELS

The Measure phase of this article involves selection of suitable factors and levels for simulation and optimization. One of the critical issues in selection of factors was that the changes in factors should not have major change in industry. Thus factors such as space optimization and shifting machines were ruled out. The factors satisfying these constraints were input arrival parameters such as entities per arrival, assembly batch size and inter arrival time. The significance

Figure 1: Cause Effect Diagram



of process arrival parameters were already discussed by Paul Savory (2008). These parameters were noted down while detailed process study. Time of operation was noted down in its optimistic, pessimistic and most likely form. This was done to take into account of uncertainties. Parameters such as cost and time were measured accurately using detailed process study. The same process was observed repeatedly to validate same time of operation. Cost parameters were enquired. Parameters such as worker wages were noted down accurately. Machining cost was calculated by a detailed process study and shown in Table 1. Operation cost involves space utilization, electricity consumption and maintenance per hour. Idle cost involves only space utilization per hour. Worker wages involves wages of trainee, permanent and contract worker per hour. Holding cost involves storage, input and output transport cost of component per hour. Operation time was calculated in its optimistic, pessimistic and most likely form. This was decided by observing same operation to approximately five times and its minimum, maximum and mean values were noted. Thus the simulation was run with triangular delay type (Fowlkes and Creveling, 1995).

The holding cost of the inventory was INR 0.2836/hour. The batch size is considered as a variable one and taken as 2 or 3 in this study.The scheduling rule followed was First In First Out (FIFO).

SIPOC TABLE

SIPOC (Supplier, Input, Process, Output and Customer) table represents any manufacturing process in sequential category. The detailed process study in the manufacture of M type submersible pump was shown in Table 2 in the form of SIPOC. As explained in the previous section, the major constraint was that factors to be optimized should not bring in major changes in the industry. And hence the factors such as inspection techniques and worker skills were not considered for the study. Factors such as lead time and queuing were indirectly analyzed using arrival parameters as they are dependent on the later. As several combinations are to be executed, simulation using ARENA® (Bobby John and Jenson Joseph, 2013) was chosen as a platform.

Table 1: Data Collection on Machining Cost

Machine	Operation Cost/hour (Rs.)	Idle Cost/hour (Rs.)	Worker Wages/hour (Rs.)
Broaching	3.9	1.5	36
Balancing	11.8	2.1	36
Drilling	15.75	2.4	36
Labor	51.75	0	0
Grinding	9.25	3.2	28.2
Milling	16.2	3.1	24
Lathe 1	40.5	1.2	60
Lathe 2	40.5	1.4	60
Lathe 3	40.5	2.4	60

Table 2: SIPOC table

Supplier	Input	Process	Output	Customer
Pressure die casting	Impeller	Broaching, Balancing	Impeller with key	Assembly
Foundry	Suction housing	Turning, Drilling	Suction housing (machined)	Assembly
Foundry	Stage casting	Turning, Drilling	Stage casting (machined)	Assembly
Foundry	NRV body	Turning, Drilling	NRV body (machined)	Assembly
Foundry	Distance sleeve	Grinding, Milling	Distance sleeve (milled)	Assembly
Upstream production line	Pump shaft	Facing, Milling, Grinding	Pump shaft (milled)	Assembly
Assembly	Assembly pump	Painting, Packing	M-type submersible pump	Dispatch

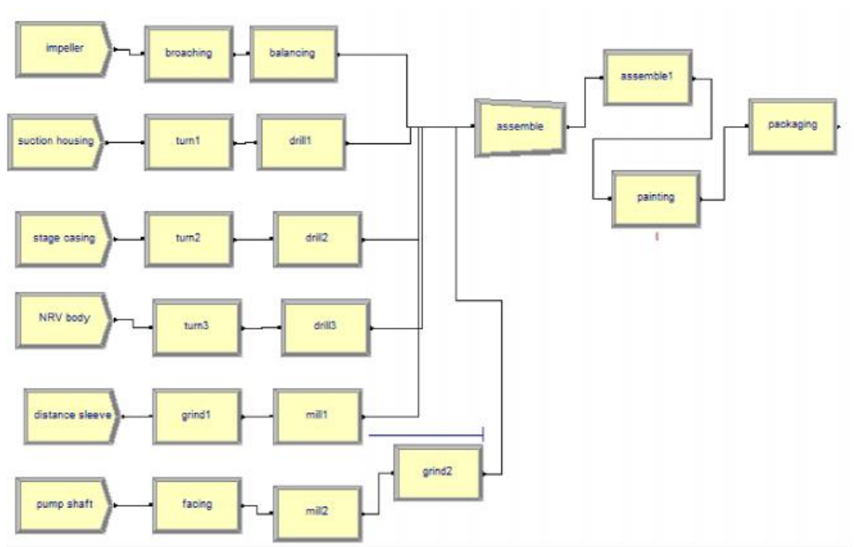
ARENA SIMULATION

The Analyze phase of this article was to find manufacturing cost of the above process using ARENA simulation. As this analysis deals with application of Taguchi in manufacturing, every trial cannot be performed by changing those selected factors. The main limitation was that it affects production. Numerical simulation (Vignesh Shanmugam *et al.*, 2013) helps to perform any research without actually affecting routine production. So, all data required for the simulation are collected and using which analysis was performed. Analysis becomes very flexible with the software. The steps involved in ARENA simulation are studying the entire manufacturing process, developing the process flow diagram as shown in the Figure 2 using ARENA, machining time and cost data entry, animating resources to facilitate simulation, running the simulation to get the manufacturing cost of M-type submersible pumps. The result of simulation was manufacturing cost.

OPTIMIZATION

The improve phase of this article involves optimization of process parameters to yield

Figure 2: Development of Process Chart for ARENA Simulation



least manufacturing cost. In order to study the combined effect of associated factors affecting the manufacturing cost of pump, all those factors with the selected levels in each are to be involved when formulating design of experiments. But, by doing this, the number of experiments is too high to perform each trial. Hence, in order to avoid this constrain, the Taguchi method can be used to reduce the number of experiments to a practically feasible level without leaving any factor or even any one of its level, leading to the formulation of a fractional factorial design of experiments (Liu *et al.*, 2010). This method can also be used to find the most optimum combination among the input parameters which will result in getting the minimum possible output, that is, minimum manufacturing cost of pump. For this analysis, mixed level design with three factors is performed. Mixed level involves 4-level design for one factor and 2-level design for other two factors. In full factorial design, it was found that 16 runs were to be performed to find the combined significance of each factor. But in Taguchi method, when L8 orthogonal array was used, significance of factors and optimum combination would be found in 8 runs itself. This explains the benefit of Taguchi application. The factors considered for this study were based on the past manufacturing history. The factors are inter-arrival time, entities per arrival and assembly batch size. Required levels were chosen as shown in Table 3.

Then the combinations of these levels were derived using MINITAB 16 software for standard L8 orthogonal array (Roy and Ranjith, 1990). Thus a complete manufacturing simulation with required factors and levels were performed with ARENA. Manufacturing costs of each trial were tabulated and analysed. Corresponding S/N ratios were found. The manufacturing costs and corresponding S/N ratios were shown in Table 4. S/N ratio was calculated using the formula $-10*\text{Log}_{10}(\text{sum}(C^2/n))$, where, where 'C' is the manufacturing cost.

The analysis was performed for "Smaller the Better" type since minimising manufacturing cost was the final goal. It was calculated by estimating mean of the S/N ratios of all the trials corresponding to that level of the factor. It is different for 4-level and 2-level design. For example, in case of 4-level design, mean of S/N ratio corresponding to 2 min of inter arrival time was calculated by taking mean of first two trials of L8 combinations, mean of S/N ratio corresponding to 5 min of inter arrival time was calculated by taking mean of last two trials of L8 combinations and so on for other levels. In case of 2-level design, mean of S/N ratio corresponding to entity per arrival of 1 was calculated by taking mean of 1, 3, 5, 7 trials of L8 combinations, mean of S/N ratio corresponding to entity per arrival of 2 was calculated by taking mean of 2, 4, 6,8 trials of L8 combinations and so on for other factor. In

Table 3: Selection of Factors and Levels

Factors	Units	Level 1	Level 2	Level 3	Level 4
Inter arrival time (A)	Min	2	3	4	5
Entities per arrival (B)	Nos.	1	2		
Batch size (C)	Nos.	2	3		

Table 4: Results of the Software and their S/N Ratio

Trial	Manufacturing Cost (INR)	S/N Ratio
1	1358	–62.6580
2	1317	–62.3917
3	1262	–62.0212
4	1317	–62.3917
5	1193	–61.5328
6	1358	–62.6580
7	1046	–60.3906
8	1353	–62.6260

other words, S/N ratio corresponding to that level of a factor was calculated by taking the mean value of all those trials containing that level. The mean of S/N ratios corresponding to their levels was shown in Table 5. The S/N ratio plot was deduced for the same and the level with maximum S/N ratio gives least manufacturing cost as the analysis is based on “Smaller the Better”.

As shown in the Figure 3, inter arrival time with level 4 gives has maximum S/N ratio. Thus, 5 min was considered to be the optimum inter-arrival time. It was clear from the figure that the effect of inter arrival time was also significant. Similarly for other two factors also, it was found that 1 entity per arrival and a batch size of 3 has highest S/N ratio. The next step was to rank factors according to their significance. The ranking was based on the delta value. Delta value was calculated as the difference of highest and lowest S/N ratio in the S/N plot. The factor with highest delta value

Table 5: Mean S/N Ratios for Each Level of Factors

Factors	Units	Level 1	Level 2	Level 3	Level 4
Inter-arrival time	Min	–62.5248	–62.2064	–62.0954	–61.0583
Entities per arrival	Nos.	–61.6506	–62.5168		
Batch size	Nos.	–62.4908	–61.6767		

Figure 3: S/N Ratio Plot for Considered Factors and Levels in L8 Array

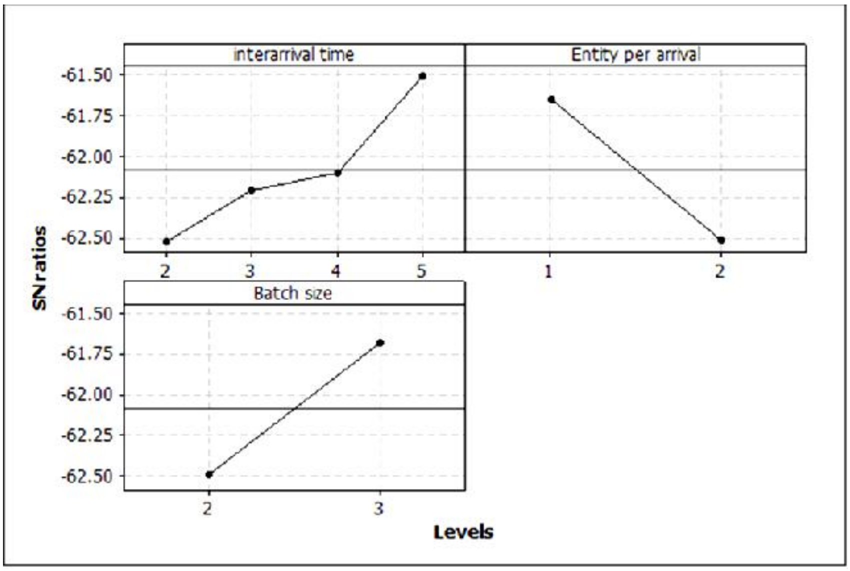


Table 6: Significance of Factors

Factors	Delta	Rank
Inter-arrival time	1.4665	1
Entities per arrival	0.8662	2
Batch size	0.8141	3

indicates higher significance. The delta values were shown in Table 6. It was found that inter arrival time was the predominant factor affecting manufacturing cost of simulation.

DETERMINATION OF LEAST MANUFACTURING COST

Least manufacturing cost was found using S/N ratio plot. The level with highest S/N ratio was considered to be optimum level. Thus, A4B2C2 was found to be optimum combination. The least manufacturing cost for this combination found using Taguchi calculation was INR 1017 as shown in Equation (1).

S/N ratio for least cost, $¦_{least} = ¦ + \Delta A_4 + \Delta B_2 + \Delta C_2$ ...(1)

(ΔA_4 corresponds to the difference of overall S/N ratio mean and S/N ratio mean corresponding to level 4 of factor A and so on; ¦ corresponds to overall mean of S/N ratio in Table 2).

$¦_{least} = -62.0837 + 1.0254 + 0.4331 + 0.407 = -60.2182 = -10*Log_{10}(sum(C_{min}^2/n))$, C_{min} = INR 1017

In order to validate this, manufacturing cost corresponding to this combination as tabulated earlier (result directly from simulation) was compared. Percentage of deviation was found to be 3%. This proves that simulation value and calculated value are in close agreement showing compatibility of Taguchi method for this application. Thus through this method, optimum combination for least manufacturing cost was found to be inter-arrival time of 5 min, entities of arrival of 2 and batch size of 3. This method yielded least manufacturing cost of INR 1046. Finally, control phase of this article suggests to maintain this optimum combination using suitable automation.

CONCLUSION

This article emphasizes the application and compatibility of Taguchi technique in the field of manufacturing simulations (Enzo Morosini *et al.*, 2013). Using DMAIC approach, It was proved that least manufacturing cost can be obtained using optimized factors by proper data collection and software simulations. This work creates a platform for research in the field of optimization of manufacturing process using software simulations and Taguchi method. The main advantage is that the research can be performed without actually affecting routine production using software simulations (Lukasz Rauch *et al.*, 2008; and Raska and Ulrych, 2012) and also time saving was achieved by performing experiments only for selected trials using Taguchi method. Also among selected factors, significance of factors was also found; so as to focus on those factors for productivity improvements.

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