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Original Article

Cost reduction of the head stack assembly process in the hard disk drive industry with simulation modeling and optimization: A case study

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Abstract

This research with the main goal of cost reduction in the hard disk drive industry focused on the head stack assembly process is action research between university research teams and industry. It aims to study the head stack assembly process and to investigate the problems that need to be solved in order to reduce costs by using computer simulations and optimizations. Steps in simulation methodology were applied starting from data collection, model building, model verification, model validation, experimentation, and optimization. Several factors and their effects were investigated that could lead to production improvement of 7.94% increase in numbers of assembled head stack or 7.32% decrease in production cycle time. This paper demonstrates simulation optimization methodology applied to problem solving. Also it illustrates the successful case of using simulation optimization in cost reduction.

Keywords: head stack assembly, cost reduction, simulation optimization

1. Introduction

Today, the hard disk drive industry is more dynamic and competitive than ever, and to be able to sustain its competitiveness, it is necessary for the companies to focus on long-term profit. Typically, approaches for increasing long-term profit are increasing revenues and reducing costs. Factors affecting revenue are sales price and sales volume; therefore long-term profit increment has to increase either price or sales volume. Raising the price can be made only its new products are unique from competitors, which can be fulfilled through company's research and development. Besides, increase in sales volume can be made by gaining vast market share, which is also difficult in the present-day situation due to market shrinkage.

About cost reduction approach, factors contributing to costs can be classified as three main categories, which are (1) non-value added (NVA) in processes, (2) product warranty and product liability, and (3) cycle time. Similar, the hard disk drive companies in this research have initiated a cost reduction program. In the past, the company started several programs in cost reduction such as Six Sigma for Operation, Zero Defect, etc. These programs were beneficial for the industry by uncovering the root causes in the processes that create nonconformity in the products. The processes can be improved by eliminating NVA, thus quality of products turns out to be better, and then costs will be reduced while product claims will also decline.

Still, the nature of the hard disk drive industry is remarkably dynamic; it can be evidently seen from shorter and shorter product life cycles. Thus, if any company has longer cycle time than competitors, it will take longer lead time in launching product to market. As a result, company will lose its competitiveness. Furthermore, utilization of machines in a factory will be low; as well depreciation cost

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will be high, which contribute to higher cost. So, decrease in production cycle time is a plausible approach in cost reduction. It is clear that a shorter the cycle time is, the greater is the throughput. Such, in this company throughput is measured by unit of products which are produced in an hour or "units per hour" (UPH) is applied to indicate the manufacturing performance. Hence, this research problem was defined as how the manufacturing process can be improved so as to increase the UPH.

Hard disk drive manufacturing system consists of a series of process, including slider fabrication process, head gimbal assembly (HGA) process, head stack assembly (HSA) process, and hard disk drive assembly (HDD) process, which are shown in Figure 1. Generally, goals of assembly line such as HSA process are both increasing throughput and decreasing resources. Thus, the common obstacles of any assembly production lines are how to improve the efficiency of lines.

However; under real world conditions of a manufacturing system, for the hard disk drive industry, which is very complex and inter-connected, it is quite difficult to conduct cost reduction project by running experiments on the real system. Hence, simulation was adopted as a tool in this research. Advantages of simulation have been widely known and applied in various circumstances. Yet the ability of simulation still has been questioned about finding the best answer. Fortunately, this disadvantage has been resolved in the form of simulation optimization technique.

Thus, the main objective of this research is to investigate the factors in the head stack assembly process improvement that can lead to enhance production throughput with the aim of cost reduction in hard disk drive manufacturer by using simulation optimization technique. This research can contribute in the field of simulation optimization applied to the real word industry, which are large scale manufacturing and complex characteristics. It was shown the successful practicality of simulation optimization as a decision support tool for manufacturing. It was also clearly illustrated how the simulation optimization technique can be accomplished under complicated manufacturing environment. Besides, similar or dissimilar industries can acquire knowledge and technique from this research if they are interested in problem solving applied with simulation optimization.

Methodology in conducting research is as follows. Manufacturing system of a hard disk drive company was studied and problems were identified under scope of this manufacturing system. Data were collected and analyzed. A computer simulation model was developed, and it needed to be verified and validated, and that model was used in conducting experiments in order to characterize the process behavior when the process parameters have been changed. So, the problem solving team can foresee the changing results without disturbing the real system. In this paper is divided into six sections, which can be summarized as follows, (1) Introduction, (2) Literature Review, (3) System Description, (4) Development of Computer Simulation Model, (5) Design of Experiment and Results, and (6) Conclusions.

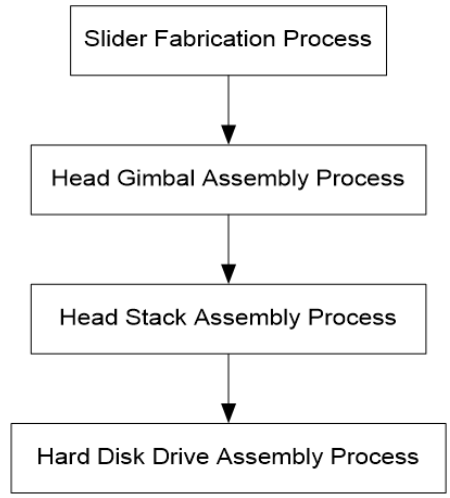

Figure 1. Hard disk drive manufacturing system.

2. Literature Review

Computer simulation and simulation optimization has increasingly become the attractiveness and frequently employed tool for problem solving and decision-making in the manufacturing environment. It has been commonly used to study behavior of real world manufacturing system to gain better understanding of underlying problems. There are numerous literatures discussing about simulation and simulation optimization. In this paper is only demonstrated some of the literatures concerning with simulation and simulation optimization that have been done in the past.

Beck (2011) studied and modeled the flows of passenger in Heathrow Airport. This paper described the situation that British Airways moved into their new terminal and simulation was applied to study in various aspects. Also, it represented the adoption and the usage of simulation. The developed model was used for explanation of infrastructure decisions, the number of desks required to service the passengers, the required staffs in a particular area, etc. Olhager and Persson (2006) studied the different production and inventory systems in a manufacturing system with simulation. They compared three different production and inventory control systems: reorder point system (ROP), material requirement planning (MRP), and cyclic production scheduling (CPS). They used discrete event simulation to conduct experiment and observed for the behavior and impact of each system. In addition, Qi *et al.* (2002) created a simulation model for wafer fabrication in the semiconductor industry. The developed model assisted the team in investigating the effect of different input variables on key manufacturing performance indicators such cycle time, work in process, equipment utilization rates, etc. Ólafsson and Kim (2002) defined simulation optimization as an optimization where the performance is the output of a simulation model, and the problem setting thus contains the usual optimization components, which are decision variables, objective function, and constraints. Fu (2002) presented a conceptual diagram of simulation optimization as shown in Figure 2. Besides, it can be denoted by the mathematical form of simulation optimization problem in the following.

Min or Max $E\left[f(X_1, X_2, ..., X_n)\right]$

Subject to $L_i \leq X_i \leq U_i$

where $X_1, X_2, ..., X_n$ are decision variables,

$E\left[f(X_1, X_2, ..., X_n)\right]$ is the expected system performance,

L_i, U_i are lower bound and upper bound, respectively, of each decision variable

In addition, optimization routines depicted in Figure 2 have various search methods, such as evolutionary algorithm, genetic algorithm, scatter search, Tabu search, neural networks, simulated annealing, etc. In this research, evolutionary algorithm (EA) was adopted. Harrell *et al.* (2012) explained EAs are a class of direct search techniques that are based on concepts from the theory of evolution. They mentioned that EAs are fitting with simulation optimization because EAs require no restrictive assumptions about the response surface being searched. Search techniques of EAs can be relied on and easily used. In addition, EAs are appropriate for response surfaces that are highly dimensional, multimodal, discontinuous, non-differentiable, and stochastic. It can be succinctly explained about the idea behind the theory of evolution that a population of solutions is manipulated in such a way that poor solutions fade away and good solutions continually evolve in their search for the optimal. EA's concept can be illustrated as a flow chart shown in Figure 3.

3. System Description

In this research was focused on HSA process, which HSA contains of a number of related parts such actuator magnetic flux, voice coil motor, actuator axis, actuator arm, head suspension arm, parking ramp, HSA connector, head preamplifier circuit. They are assembled into actuator pivot flex assembly (APFA) and then by mounting the components

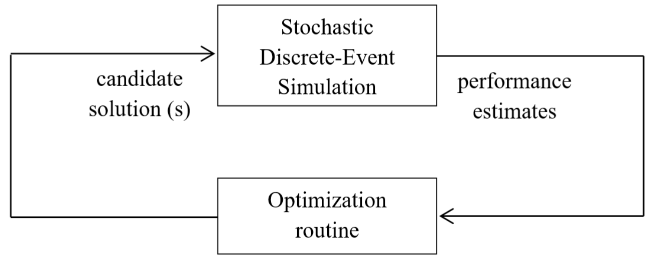

Figure 2. Optimization for Simulation (adapted from Fu, 2002).

between APFA and head gimbal assembly (HGA) together to become HSA. There are six stages to produce HSA, which outline process chart can be illustrated in Figure 4.

At first stage, loading operator will load APFA to shuttle and assemble HGA to the APFA, then move shuttle to unload stage in order to swage ball and unload HSA from shuttle, then load HSA to flow fixture. At the next stage, operator has to bond electrical circuit after that HSA on flow fixture will be transferred to coat stage in order to coat pad with epoxy glue and unload HSA from flow fixture. Then products are transferred to the downstream processes, which are visual mechanical inspection (VMI) and quasi static test (QST). Nonconforming products are detected at these stages.

In this research, system scope is focused mainly in the clean room of the head stack assembly process, containing about 250 manufacturing cells, which can be clustered into four groups, which are (1) Prime line, (2) Head rework center line, (3) Rewash line, and (4) Build back line. Each type of lines has slightly different in details.

4. Development of Computer Simulation Model

4.1 Data collection

The data were collected over a period of six months. These data mainly consisted of time between arrival,

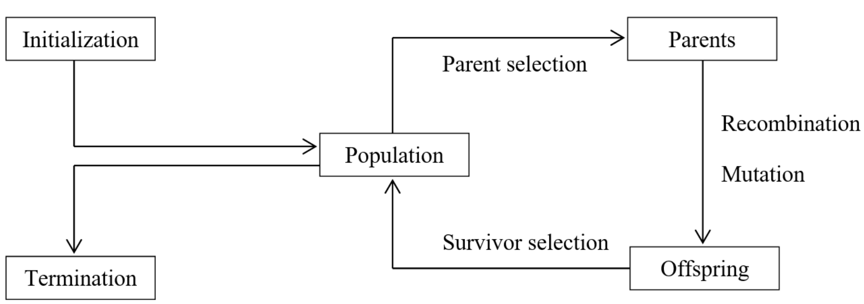

Figure 3. Evolutionary Algorithm's Concept (Eiben & Smith, 2003).

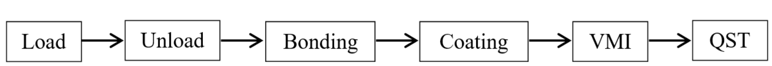

Figure 4. Head Stack Assembly Outline Process Chart.

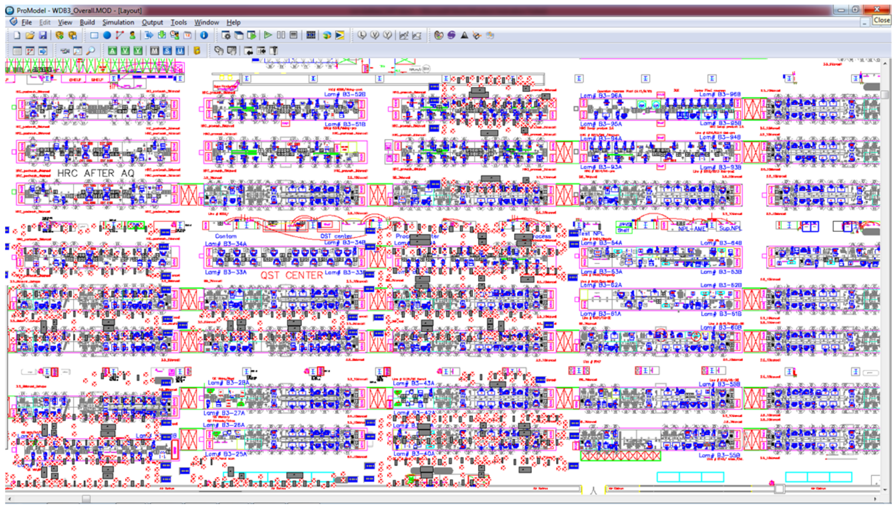

Figure 5. Example of Developed Simulation Model.

processing time in each stage, and routing time between each stage, etc. Subsequently, the data were explored and fitted to be input distributions for simulation model that were built in the next section.

4.2 Model building

The simulation model was built by ProModel® software package. A part of developed simulation model is illustrated in Figure 5. As it can be seen from Figure 5 that the clean room of head stack assembly process are too complicated to be modeled analytically.

4.3 Model verification and model validation

The verification of the model was determined in order to confirm that the computer simulation program, that was already built, performed as intended. Once the model was verified, the next step was to validate it. The validation is the process of justification whether the built simulation model can be represented the real system or not. According to the statistical tests were conducted. The results indicated that null hypothesis (H_0), stated as "*computer simulation model can represent the real production system*", was not rejected with a 5% significance level, which can be implied that the simulation model was valid.

5. Design of Experiment and Results

After the model was successfully built, the countermeasure was investigated by the research team and the company's problem solving team. To find the effective countermeasure, it basically relied on the problem solving process, especially in root cause analysis step. Two subprocesses were required: (1) to characterize the product and (2) to improve the process. In first part, product characterization is all about understanding the relationship between the set of manufacturing factors and response variable, which is UPH. It determines the significance of factors that contribute to UPH. In second part, process improvement is about setting the significant factors that will optimize UPH. Both parts were carried out by using the developed simulation model to conduct the experiments without disturbing the real system.

5.1 Product characterization

Product characterization stage can be illustrated in the following. UPH was considered as the "key process output variable" (KPOV), which was affected by various "key process input variables" (KPIVs) in the process. So, an investigation of the relationship between KPOV and KPIVs is indeed importance. KPIVs, brainstormed with the company's problem solving team, were number of handling tools, which were shuttle and flow fixture, used to capture parts in production cell, and number of workforces in clean room, who serve parts for load section and who collect finished products from pack section.

Design of experiment chosen is a four-factor factorial design where each factor has three levels. Mathematical model of experimental design can be illustrated in Equation 1:

$$y_{ijklm} =$$

$$\mu+\tau_i+\beta_j+\gamma_k+\delta_l+(\tau\beta)_{ij}+(\tau\gamma)_{ik}+(\tau\delta)_{il}+(\beta\gamma)_{jk}+(\beta\delta)_{jl}+ (\gamma\delta)_{kl}+(\tau\beta\gamma)_{ijk}+(\tau\beta\delta)_{ijl}+(\tau\gamma\delta)_{ikl}+(\beta\gamma\delta)_{jkl}+(\tau\beta\gamma\delta)_{ijkl}+\varepsilon_{ijklm} \tag{1}$$

and

$$i=1,2,3;\ j=1,2,3; k=1,2,3; l=1,2,3; m=1,2,..,n$$

where τ_i denotes number of shuttles, β_j denotes number of flow fixtures, denotes number of workforces for Load; δ_l denotes number of workforces for pack. In Equation 1, it can be seen that there are quite a few terms in the model, including main effects, two-order interaction effect, three-order interaction effect, and four-order interaction effect. These terms were investigated in the following experiment.

Experiments on computer simulation model were randomly run based on each experimental combination and data were collected. Before making a decision, a few steps were required. Firstly, experimental data from simulation were checked their adequacy before further analysis. It can be proved that no assumptions, such randomness, normality, and variance stability, were violated. Secondly, the 97.49% of R^2 value extremely clarified that most of variations in this experiment contributed from the controlled factors set up at the beginning of experiment. Finally results from analysis of variance were examined, as shown in Table 1. It is found that only four main effects, two-order interaction effect between number of shuttles and number of flow fixtures, and two-order interaction effect between number of workforces for Load and for Pack significantly contributed to UPH.

5.2 Process optimization

In searching for optimal level of UPH, not only number of shuttles and number of flow fixtures in production cell but also number of workforces for serving in Load Section and number of workforces for collecting in Pack Section in cleanroom were set in this experiment. In experiment 1, the number of shuttle and flow fixture quantities was set the boundary in searching for optimal level of UPH, while there were 7 shuttles and 11 flow fixtures in current manufacturing condition. The objective function and constraints of this problem can be written as follows in Equation 2, 3, and 4:

$$\text{Max Throughput} \quad (2)$$

$$\text{subject to } 5 \le X_1 \le 8 \quad (3)$$

$$7 \le X_2 \le 12 \quad (4)$$

where X_1 is number of shuttles, and X_2 is numbers of flow fixtures. From Equation 2, 3 and 4; there are two decision variables, which are number of shuttles and number of flow fixtures, while objective function is maximizing numbers of UPH, which is the output of computer simulation model developed. EA was a search technique applied in order to locate the optimal value of UPH within the range of X_1 and X_2. Searching through the region of possible solutions, the results show that the twelve conditions provided highest production of UPH of Head Stack Assembly, which is 201,600 pieces per day as shown in Table 2. So the selected condition, with the least resources, is the condition of 6 shuttles and 9 flow fixtures. The response surface of this experiment can be noticeably illustrated in Figure 6.

Table 1. Analysis of variance result from experiments.

Source	DF	SS	MS	F	P
Number of Shuttles	2	500,443	250,221.5	10,623.31	0.000
Number of Flow Fixtures	2	153027	76513.5	3248.43	0.000
Number of Workforces in Load	2	192482	96241.0	4085.97	0.000
Number of Workforces in Pack	2	361942	180971.0	7683.24	0.000
Shuttles Flow Fixtures	4	10440	2610.0	110.81	0.028
Shuttles Load	4	82	20.5	0.87	0.482
Shuttles Pack	4	80	20.0	0.85	0.484
Flow Fixtures Load	4	59	14.8	0.63	0.533
Flow Fixtures Pack	4	19	4.8	0.20	0.646
Load Pack	4	10306	2576.5	109.39	0.031

Remark: Values in this table are reported only main effect and two-order interaction effect.

Table 2. Experimental results on numbers of shuttle and flow fixture.

Trial	X_1	X_2	Y	Trial	X_1	X_2	Y	Trial	X_1	X_2	Y
1	6	10	201600	9	5	11	190400	17	5	10	190400
2	7	8	199200	10	7	12	201600	18	7	7	196800
3	6	9	201600	11	5	9	190400	19	8	10	201600
4	8	9	201600	12	8	12	201600	20	5	12	190400
5	6	7	196800	13	6	8	199200	21	8	7	196800
6	7	10	201600	14	7	9	201600	22	8	11	201600
7	7	11	201600	15	8	8	199200	23	5	8	189600
8	6	12	201600	16	6	11	201600	24	5	7	187800

Remark: X_1 is number of shuttles, X_2 is number of flow fixtures, and Y is throughput (unit in pieces).

Comparison of the number of handling tools between the current situation, which were 7 shuttles and 11 flow fixtures, and the proposed answer from experiment, discloses that three pieces of handling tools can be reduced in each manufacturing cell without affecting the production throughput. In addition, the price of handling tool which is about $1,000 per piece, the company can totally save $3,000 per each cell.

For experiment 2, the same method performed in Experiment 1 was repeated, while there are 19 persons for Pack and 21 persons for Load in current operating condition. The objective function and constraints of this problem can be shown in equation (5), (6), and (7).

$$Max\ Throughput \quad (5)$$

$$\text{subject to } 17 \le X_1 \le 26 \quad (6)$$

$$19 \le X_2 \le 26 \quad (7)$$

where X_1 is number of workforces for pack, and X_2 is number of workforces for load. The result illustrated in Figure 7, shows that the conditions with the highest production of UPH, which is 217,600 pieces per day, have 16 conditions. The selected condition with the least resources is 23 persons for Pack and 23 persons for Load. From the proposed solution, it apparently appears that number of workforces must be added 6 persons in clean room. Nevertheless, it will be paid off if it is compared with the increased number of UPH.

It can be concluded that the conditions with the optimal UPH are setting numbers of shuttles and flow fixtures to 6 and 9, respectively; and setting numbers of workforces for Pack and Load to 23 and 23, respectively. This condition will improve the amount of head stacks throughput from 201,600 to 217,600 pieces per day or 7.94% increase. Otherwise, regarding in terms of manufacturing cycle time, it will be reduced from 0.41 second per unit to 0.38 second per unit or 7.32% decrease. Conclusively, the company will have substantial benefit from the reduction of number of tools in production cell.

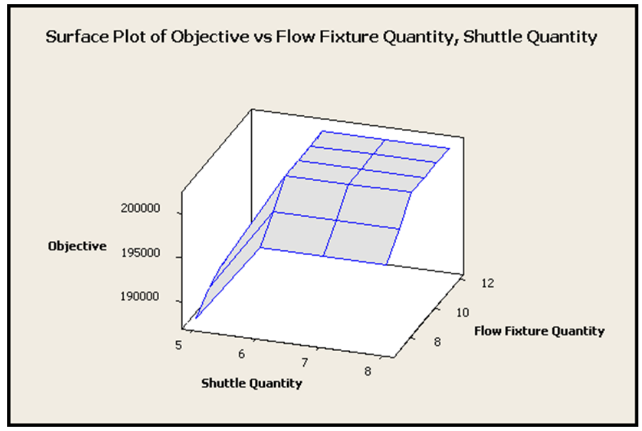

Figure 6. Response Surface of Experiment 1.

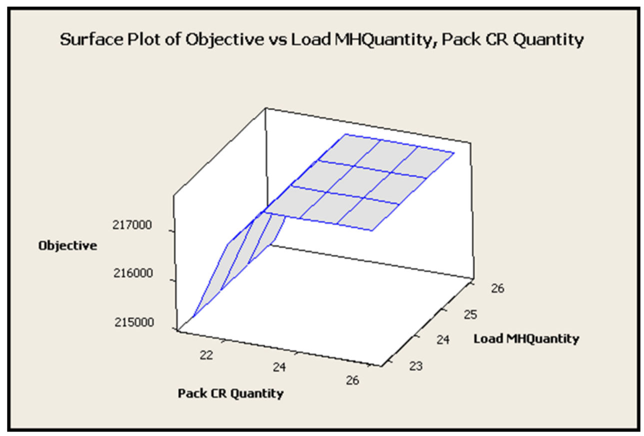

Figure 7. Response Surface of Sequential Experiment 2.

6. Conclusions

This manuscript presents simulation optimization technique applied to cost reduction in hard disk drive industry. The solution from research is worthwhile for industry in productivity improvement of the head stack assembly operation. Besides, this research is class of action research which researchers worked together with company's problem solving team. It also provides case studies which were successfully implemented in the industry. Simulation model was developed and used as a tool for conducting experiment, thus the problem solving team can make decisions without interfering in the manufacturing system. Understanding the performance of the large scale manufacturing is extremely arduous since lots of variables and their numerous interactions influence the results. It is always very challenging in developing model of such large and complicated system. Finally, simulation optimization has unquestionably exhibited its ability in applying with industry problem solving.

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