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Implement Industrial 4.0 into process improvement: A Case Study in Zero Defect Manufacturing

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Abstract

This study describes in detail step-by-step implementation of quality improvement activities in mechanical processing plants. Describe how to implement quality 4.0 technologies in DMAIC (Define-Measure-Analysis-Improve-Control) phases. As well as using statistical formulas, experimental design in data analysis at each phase of DMAIC. This study proposes to use Quality 4.0 Technology in product quality improvement activities in mechanical product processing factories with the aim of becoming zero defect manufacturing. The results of the research found are repair rate reduced from 600 PPM monthly to 0 PPM, processing capacity increased from Cpk1.02 to Cpk2.56, reduce time for inspection product from 702 hours per year (calculated to save USD 2106 per year), reduce the amount of repair products by 196 products per year (calculated in terms of money is reduced by 917 USD per year) and reduce 1 roughing stage (calculated in terms of cost reduction about 171288 USD per year). The roughness dimension has reduced measurement time by about 364 hours per year (save 1092 USD per year). Processing digital signals from sensors in an oily environment is a big challenge for researchers. Improving the security of digital data is also a limitation of this study. This study proposes a model to apply statistical hypothesis testing methods to analyze real data collected from each machining stage and perform each job according to each corresponding DMAIC phase of the model. In addition, digital processing techniques and computer vision techniques are also deployed in the improve phase to complete the goal of improving the semiautomatic production stage to the automatic production stage.

1. Introduction

Currently, manufacturing innovation requires everyone to change the current situation. Every employee working on their innovation lifts the whole morale in the workplace and encourages product innovation. Types of waste at the workplace are categorized into two areas. One is wastes of objects and the other one is wastes of motion and transportation. Improve redundancy operations at each stage executing machine with the necessary functions will bring you a great effect (Titmarsh, Assad, and Harrison). The flow of product movement between stages is interrupted. Specifically, there are bottle neck stages. The lines with WIP (work in process) stacked up and unidentified where "disturbed flow". Since such lines tend to cause defects and lengthen lead time (LT) make the flow while laying out each line. Furthermore, moving the lines closer to each other (which is called “efficient lay-out”) eliminates stagnation and creates more useful spaces. Procedures of machine improvements are to separate humans from the machines, and separate human’s functions from machine’s functions (Deeb et al.). Meeting production capacity, improving capacity at each stage is necessary (J. P. Costa, Lopes, and Brito). To diversify the production capacity of each processing machine, improvement activities applying quality 4.0 technology are necessary. Mechanical manufacturing plants need to apply this new technique to production control activities, which is considered a new step in the application of information technology in production (Yury et al.). Information in production is classified into main functions, and it is closely linked by a system connected by information technology. Manage, operate well, and bring high value to production operation. Data needs of departmental functions are stored in real-time and with data centralization in a common system, manufacturing companies have always turned to big data (Noori, Sadegheih, and Lotfi). My models of industrial system engineering and management show the overall linkage of functions and data, the information on the functions is concentrated on the total function of production management (PM).The production control information system in the company is implemented with the main goal of maximizing profits and minimizing costs (Rasay, Fallahnezhad, and &zaremehrjerdi). Production data is well collected, well managed, and well analyzed, helping managers make decisions easily and accurately. However, the collection of product data in the field, data of product dimensions, data of visual inspection, is still limited, requiring researchers to find ways to suitable methods to improve the quality of input data for information systems in a production. There are many studies on the application of information technology to production activities (Khlie and &abouabdellah), but there are many limitations such as managing operators with the layout they are assigned, people with no skills or poor skills. They operate the machine will easily cause occupational accidents. Quality control of products after completing processing at each stage has not been closely linked, or data is still recorded by hand and requires additional data entry into the computer for analysis and wasteful manipulation, which generates processing costs (Mishra and Jainb). The machining condition data at each line is disconnected and fragmented, the method of collecting the machining conditions is fully manual or semi-automatic, leading to under maximization of the machining step, causing many operations do not bring added value and take many operations, making the operator unsatisfied. In addition, research and application of image analysis technology are product appearance inspection activities. Mostly, at the processing stages in the process, the product is visually inspected by the operator (Michal and Vladimira Tamer et al.).

Eliminate operations that do not add value, which means more business profits. Managers are always looking for methods to optimize production, apply industrial 4.0 technology to process automation, shorten machining time, eliminate waste, improve productivity, and save data in processing according to the needs of customers. Real-time machining data analysis, and data visualization. In this study, the application of computer vision technology to control the operator of the stage with the machining layout by face recognition method and set up a product inspection system at each processing line, collect and process data management into a real-time online measurement system. Redesigned machining jigs and implemented a system to control machining conditions such as dimensions, the position of product racks into machining jigs, and apply a barcode management system, automatically calling machining programs, eliminating the dependency on people. This study has the following implications: (1) Optimizing the machining process at the mechanical factory by applying industrial 4.0 technology. (2) Automating product visual inspection using computer vision technology and collecting data over time. (3) Automating the collection of machining conditions at each stage by applying information technology to the measurement and data collection system over time. (4) Re-engineering tool design, simplifying machining operations, improving operator satisfaction. (5) Automating the calling of outsourcing programs by applying barcode technology and information technology systems, eliminating dependence on humans. (6) Develop an enterprise resource integration system by developing technology systems in production control, data visualization, and support for managers to make accurate decisions. (7) Improve labor safety control activities in production by applying computer vision technology, facial recognition technology to control people with assigned stages and improve safety in operation. (8) Analyze production data by applying statistics and visualize data with graphs in statistics, applying statistical software such as minitab18.0, SPSS (Statistical Package for the Social Sciences) 20, Matlab2019a. (9) Eliminating the distance from the research environment and the practical environment, creating a close connection by applying research results to production activities.

The research paper has the following organizational structure: Section 2 presents literature review. Section 3 presents methodology and result of experience. Section 4 presents discussion and conclusion.

2. Literature review

The model of continuous improvement is applied by Japanese companies in the real world. The improvement department brings together members of departments such as engineering, production, quality, and information technology (Lizarelli, Toledo, and De). Each employee performs different jobs, but with the common goal of improving, eliminating waste, improving the company's competitiveness in terms of productivity, and quality, and ensuring safety for operating staff. Approaching the process of improving product quality, improving the quality of the machining process by applying statistical tools to quantitative and qualitative analysis of the factors affecting the product processing process eliminating waste products, eliminating factors that do not add value, and improving products to improve the customer-oriented spirit of the system and organization. J. P. Costa et al., (2019) proposed to use the DMAIC cycle to control the machining process, identify and qualitatively measure the factors affecting the process to eliminate variations in the process, and not produce irregularities or changes in machining (T. Costa, Silva, and Ferreira). T. Costa et al., (2017) proposed using the DMAIC cycle in Six sigma to improve product quality and process quality (Barot et al.). S. K. Priya et al., (2020) applied the DMAIC & RCA (Root Cause Analysis) tools cycle in lean manufacturing to improve the quality of the manufacturing process products to optimize the machining process (Saravanakumar et al.) , eliminate activities that do not bring added value as well as measure (Priya et al.), check and confirm the factors that cause the failure of the product and make improvements. P. B. Ranade et al., (2021) used the DMAIC cycle in six sigma, in process quality improvement activities to control the generation of fluctuating parameters during operation (Ranade et al.). R. S. Barot et al., (2020) suggested using six-sigma tool with DMAIC cycle to continuously improve process quality performing waste data analysis, find root cause and find ways to improve process. the process of eliminating waste products, eliminating unnecessary problems due to errors in waste generation (Talapatra and Gaine).

N. Nandakumar et al., (2020) proposed to apply a combination of tools such as DMAIC, SIPOC (Supplier-Input-Process-Output-Customer), VSM (Value Stream Mapping), ANOVA (Analysis of Variance) (Pravin et al.) , and 5S methods to process quality improvement activities to determine process quality (Nandakumar, Saleeshya, and Harikumar). Identify and Improve the bottleneck stages in the machining process, improve equipment efficiency, improve productivity, and reduce product processing fluctuations. In the product processing process, the fluctuation in the output of the process is the top concern, enterprises apply six-sigma to the machining cycle to minimize the fluctuations in the output, which is realized through the processing cycle. DMAIC process and at each cycle is used quantitative and qualitative statistical tools to determine the variable factors (Ranjith et al.) and evaluate the process according to the six-sigma standard. However, in small and medium-sized companies, there is a lack of resources for six-sigma awareness, making it very difficult to implement six-sigma implementation. K. Srinivasan et al., (2014) used a combination of tools such as the critical to quality (CTQ), the voice of the customer (VOC) and Pareto chart along with six - sigma activities. C. V. V de M. Castro (2020) conducted interviews with 24 experts in outsourcing organizations including mechanical technicians, electrical technicians, and leaders (Deeb et al.) , interviewing contents such as the reduction of waste, the training of the workforce, and the translation of corporate goals into tangible goals for the plant, the results show that the key points in the implementation of continuous improvement are the satisfaction level of employees in the organization who are afraid to change the implementation process, not want to change what you're doing. M. H. Nguyen (2018) conducted a survey of many companies with many types of processing for many different types of products on the relationship between quality control activities and the efficiency of the machining process, the results obtained 144 survey results and empirical analysis show a necessary relationship between quality control activities and process machining efficiency and continuous improvement activities in the production process (Nguyen, Phan, and Matsui). J. d. Mast et al., (2012) provided an in-depth analysis of the DMAIC cycle in aspects such as domain specificity of methods, problem structure, generic problem-solving tasks, diagnostic problem solving, and remedial problem solving and the results show that quantitatively, powerful data systems support the DMAIC cycle, on the other hand, the DMAIC cycle still has limitations such as methodical generality (Koumas, Dossou, and Didier Talapatra and Gaine). The underlying cause finding methodology and weak data aggregation techniques (De Mast and Lokkerbol). A. B Sin et al., (2015) conducted an expert opinion survey on the relationship between the implementation of six - sigma operations and the performance of the operational process (Kregel et al.). A. Pugna et al., (2016) proposed the application of lean six-sigma tool to improve product quality, eliminate waste and improve productivity, as well as enhance competitive advantages for manufacturing enterprises by methods such as applying DMAIC cycle into stages and processes. currently need to improve and cycle DMADV (D-Define, M-Measure, A-Analyze, D-Design, V-Verify) into the product design process (Soliman and Why), (Zaman and Zerin Arafeh Jevgeni, Eduard, and Roman Krzysztof Tamer et al.).

3. Methodology and Result of Experience

The activities in the research are: (1) Detected the stage to be researched, test, confirm, and evaluate the entire production process from start to finish by video recording method and direct observation. (2) Evaluate each processing stage, the details of processing operations on each production. (3) Identify wasteful factors and activities arising in the processing line. The main job of improvement activities is to implement improvement activities to eliminate waste, reduce inefficiencies, eliminate downtime, reduce waste, and eliminate repair work. Continuous improvement activities follow the PDCA cycle along with positive thinking about the manufacturing process redesign through poka-yoke theory. Specifically, designing tools and processes to replace human manipulation and automating operations in production activities, The actual results delivered at the machining line after improved process reengineering, re-engineering of automatic measurement data collection models, and re-engineering are post-machining repair rates down from 600 ppm monthly 0 ppm, process capacity increased from Cpk1.02 to Cpk2.13, measuring time reduced by 702 hours per year (calculated into savings of USD 2106 per year), reducing the amount of post-processing repair products by 917 USD per year (calculated in cash is a reduction of 917 USD per year) and shortens 1 roughing stage (in terms of money reduction in roughing costs is 171288 USD per year.

The lean six sigma technique consists of 5 phases that use the heart to integrate into the PDCA cycle to implement continuous improvement operations. Phase 1 (define) defines the overall status where the problem arises and establishes goals to work towards solving the problem. Phase 2 (measure) examines all data related to the problem, evaluates the impact of the problem on the quality requirements of the production process, the quality of the work and the quality of the product. Phase 3 (analysis) applies statistical hypothesis testing tools and empirical analysis to evaluate the real process based on data from phase 2 (measure). Phase 4 (improve) redesigns production tools, applying numerical control techniques to advanced design of production tools. Phase 5 (control) deploys an automatic control system to control the stability of the process, applies computer vision techniques using artificial intelligence (AI) techniques to identify objects to control stability in the process.

Define phase

Analysis of working methods according to model 1 (table 1) is as follows.

The results of processing line data collection for the period from Jan 2020 to March 2020, groove processing remain corrected for the highest rate of 36 ppm. In the histogram of 100 test samples, the

TABLE 1. Model 1 about analysis working methods

Step	Methods of analysis	Items of analysis of working
Step 1:	Workflow diagram	Visualize the movement of operators or materials in the operating process
Step 2:	Process flow chart	Specifying the workflow in the process such as machining, assembly, moving, testing, waiting, and storage is represented by symbols
Step 3:	Human - machine activity chart	Analyze the correlation between human - machine activities, identify operations that do not bring added value. For example, take a video of the process and analyze the man-machine operation and determine the time of each operation.
Step 4:	Hand operation chart or hand operation chart	Analyze the operator's right-hand and right-hand actions with machining, assembly, moving, waiting, and checking operations. Identify redundant operations, causing waste in the operating process

capacity of the H1 size process is Cpk1.16, the W1 size is Cpk1.11. Using a tool to analyze the correlation over time of operator and machine operations (operating stages) through video recording. Determine the completion time of each worker's operation at each stage, confirm the cycle time on each stage, determine the valid time and the time of the invalid operation at each stage, set value chain flowchart for the production stage at the block product line processing line. The results show that the current time of the machining line is as follows, total lead-time is 1001 minutes, total cycle time is 879 minutes, value add time is 401 minutes. Applying the relation chart to analyze the causes of repair goods in the block line processing process, perform 5 steps to set up the relationship chart. (1) The product to fix the free size is too much. (2) The cause of the product that needs to be repaired at the fine grinding stage. (3) List the cause of the error at the previous stage. (4) Have an expert check and re-evaluate the reasons listed above. (5) Re-evaluate and determine the main cause of the excessive amount of trench repair in the process. The analysis results show that there are 2 main reasons for the high production of repair goods on the processing line. (1) Measuring instruments and measuring methods are not guaranteed. (2) The product dimensions are changed (larger and smaller) due to the heat process.

The pLCC qualitative statistical model clearly identifies the subject that is causing the bad results and redefines it from the np chart and control chart results. The qualitative variable used in the pLCC statistical model is the language variable V centered by the language value T: $T = (L_i,\ i = 1 \div t\}$, where t is the number of linguistic values in the set of language values T. Linguistic values such as Good-T, Fair-K, Moderate-B, Slightly Bad-H and Bad-X. The steps to make the pLCC statistical chart are:

Step 1: Build the sample mean fuzzy variable $\bar{X}_i$

$$\bar{X}_1 = \frac{\left(L_1 k_{1j} + \bar{L}_2 k_{2j} + \cdots + L_t k_{tj}\right)}{n, j} = 1 \div m \quad (1)$$

Step 2: Determine the mean fuzzy variable of the sample mean.

Step 3: Determine the centreline.

Step 4: Determine the standard deviation of the mean fuzzy variable of the sample mean.

$$\sigma_{\bar{\bar{X}} = (B+C) \times} \frac{1}{2} = \frac{(B+C)}{2} \quad (2)$$

Step 5: Determine the control limit for the pLCC statistical chart.

Step 6: Determine the sample point on the pLCC statistical chart.

Reducing the repair goods in the grinding process, improving the processing capacity to Cpk1.47, and the scrap rate in the process down to 10 ppm are the goals that need to be considered in this research project. Take 30 samples and each sample take 10 products, all cashew products are being produced on the processing line. Samples state has table like results. From pLCC statistical chart the average quality level of 30 samples is calculated as CL = 0.385, the UCL standard = 0.584 and the LCL = 0.216. The results show that out of 10 products, there are 4 bad products (X), 4 slightly bad products (H), 2 average products (B) and no pretty good (K) or good (T) products. The quality level of this sample was calculated to be 0.2 which is lower than the lower limit of LCL = 0.216.

Measuring H1, and W1 is time-consuming, skill-dependent, and manual re-measurement slows down the completion time. The left-hand fixes the product on the map table, and the right hand adjusts the measuring tool. The impact of hand vibration due to the human mechanism that depends on the heart rate makes it inaccurate. The un-reasonable face machining method is the result of industrial tools analysis on human-machine interaction.

Measure phase

Think about what is causing the gap, repeat ”why” 5 times, the real cause is hidden in many factors and use a fishbone diagram to the analysis root cause. The statistical hypothesis is used in the analysis to determine the classification activity, to determine the estimation of the problem that may occur in the operation. Hypothesis testing of expected deviation when variance is unknown with large sample size is used to evaluate a problem that is performed on two different conditions, determining whether the problem is indeed an anomaly. The statistical function of the standard deviation of the sample mean, with a unit normal distribution. Hypothesis rejection area H0

$$R = \left(\left(\bar{X}_1 - \bar{X}_2\right) < -Z_{\frac{\alpha}{2}} \sqrt{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}}, \left(\bar{X}_1 - \bar{X}_2\right) > Z_{\frac{\alpha}{2}} \sqrt{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}} \right)$$

Take 50 samples of product running on machine 1 and take 60 samples of the same product running on machine 2. To test the expected deviation of the quality setting of products manufactured on two different machines, calculate sample mean and sample variance. Apply Eq. (3), mean standard deviation: $D = \bar{X}_1 - \bar{X}_2 = 0.96$,the rejection region can be calculated $(H_0)R = (D < -0.678,\ D > 0.678]$, establish a statistical hypothesis. HO: The quality of products processed by machine no. 1 is like the quality of products processed by machine no. 2. H1: The quality of products processed by machine no. 1 is completely different like the quality of products processed by machine no. 2. The sample mean deviation falls in the rejection region R, so H0 is rejected, the expected product quality product in the two processing machines is different. This proves that the processing machines in the production line of size W1, H1 of block products are unstable and need to improve the processing method for block products. This proves that the processing machines in the production line of size W1, H1 of block products are unstable and need to improve the processing method for block products.

An expectation test when knowing variance was used to re-evaluate problem determination on the same routine conditions used with the same agents. For X with a normal distribution with a large sample size, the normalized sample mean with a unit normal distribution, hypothesis rejection area H_0, Eq. (4)

$$\left(\bar{X} < \mu_0 - Z_\alpha/\sqrt{n}\right] \quad (4)$$

Re-check the stability of the W1, H1 size machining of the block product on the same machine. Take 50 samples of block products and process them on 1 machine. The mean value of 50 samples is calculated as 34.45. Hypothesis setting H0: Quality of dimensions W1, H1 processed on machine no. 1 for stable quality. Hypothesis H1: Quality of dimensions W1, H1 processed on machine no. 1 for completely unstable quality. According to Eq. (4) to calculate the value of the null hypothesis H0. $R = \left(\bar{X} > 33.96\right]$, the sample mean falls in the rejection region R, so H0 is rejected. Expectations set the quality product are not stable. This proves that the size W1 and H1 of the block product, although processed on the same machine, give unstable results need to rethink and improve the processing method.

Statistical test ANOVA applied to determine whether a condition affects an object or not and tests the degree of influence of that impact condition, Eq.

(5).

$$F_0 = \frac{MS_T}{MS_E} = \frac{\frac{SS_T}{(a-1)}}{\frac{SS_E}{(a-1)(b-1)}} \tag{5}$$

Check and evaluate measurement methods for sizes W1, H1 that have an impact on quality instability. The experimental number is converted by subtracting the actual number by 9.5, then multiplying the result by 10, resulting. Establish statistical hypothesis H0: The accuracy of the measuring instrument responds well to the dimensions W1, H1. Hypothesis H1: The measuring instrument accuracy does not respond well to the dimensions W1, H1. Following Eq. (5), analysis of Variance ANOVA, result P=0.0009, H0 will be rejected with any $\alpha > 0.0009$. With α = 0.05 > 0.0009, H0 is rejected, or the type of measuring instrument affects the expected result of size measurement W1, H1. This proves that the measuring tools W1, H1 are not suitable for measuring size, it is necessary to research and improve the measuring tools.

Hypothesis testing "factor influence test and factor interaction test" uses the assessment of objects affected by a condition in two different directions, testing the interaction of activities in process, determine influencing factors and non-affecting factors. To test the effect of factor A, it is assumed that the data model is suitable and that the experimental error is normally distributed with constant variance (σ^2), Eq. (6).

$$F_0 = \frac{MS_A}{MS_E} \sim F_{(a-1),\, ab(n-1)} \tag{6}$$

Test the interaction between factor A and factor B, it is assumed that the data model is suitable and that the experimental error is normally distributed with constant variance (σ^2), Eq. (7)

$$F_0 = \frac{MS_{AB}}{MS_E} \sim F_{(a-1)(b-1),\, ab(n-1)} \tag{7}$$

Continue to analyze the impact level of the processing of block products, on the same processing time for W1 size, and H1 size, to determine the interaction between W1 size and H1 size, see table 2.

Consider the influence of the W1 size processing factor. We see that p value = 0.0020, so the W1 factor influences the response for all $\alpha >$ 0.0020. It affects the generation of rows that need to be corrected. Consider the influence of the H1-size machining factor. We see, P value = 0.0001, so the H1-size machining factor responds to the output with all $\alpha >$ 0.0001. The machining factor of the H1 dimension has an impact on the row that requires the H1 dimension correction. Consider the influence factor between the W1 and H1 machining factors. We see, P value = 0.0186, so the interaction of the W1 and H1 sizes influences the output response for all $\alpha >$ 0.0186. With α = 0.01, the machining factors acting on the W1 size and the machining factors acting on the H1 jack are both responsive to the output results what affects the generation of repair goods. However, the W1, H1 interaction was not influential.

ANOVA analysis of variance with hypothesis testing aims to evaluate the influence of the tested factor levels of the hypothesis on the expectations with the factor levels. Instead of compare the statistic with the percentile. We can compare the α error probability and the p-value corresponding to the statistic found and recheck the machining method at machining center by changing 5 machining conditions, running 5 times each, assessing whether the W1, H1 jacking method has an impact on the output resulting in repair goods. See table 2. The results from the ANOVA analysis of variance show that the P value < 0.01. Setting up statistical hypothesis H0: Machining conditions at machining center (MC) for dimensioning W1, H1. Hypothesis H1: The machining conditions at the machining center (MC) are completely unstable in the W1, H1 dimensions. Hypothesis H0 is rejected for all $\alpha >$ 0.01, with F0 = 14.76 we see the same P value. So, with error probability α = 0.05, we conclude that there is a difference between the treatments or impacts in the process that affect the output of the process. In particular, the process of affecting the sizes W1, H1 generates corrections.

Statistical hypothesis testing is applied to measuring the process of interaction between man and machine, between machine and machining jig, between product and machining jig and between machining jigs and machining machines. The results show that the size W1 and H1 of the block product completely do not meet the quality requirements.

Analysis phase

TABLE 2. Analysis of variance ANOVA empirical 2 variables

Source of variance	Sum of square	Degree of freedom	Mean square	F_0	P-value
W1 size	10.68	2	5.34	7.91	0.0020
H1 size	39.11	2	19.56	28.97	0.0001
Interaction between W1H1	9.61	4	2.40	3.56	0.0186
Due to measurement error	18.23	27	675.2		
Total	77.65	35			

TABLE 3. The results of analysis variance ANOVA

Source of variance	Sum of square	Degree of freedom	Mean square	F_0	P-value
Due to handling	475.76	4	118.94	14.76	<0.01
Due to measurement error	161.2	20	8.06		
Total	636.96	24			

Design experimental simulation models from commercial software and determine experimental parameters to create verification of the design model before implementing it into the actual operating model. Software used like solid work, Minitab18.0. From the system diagram, the cause of the problem is identified, and corrective actions are suggested. However, to choose the corrective action that achieves good results and optimizes costs is essential for managers. Making decisions knowing the probability distribution, under random conditions with an objective function of cost or profit, the expected utility function is a reasonable basis for comparing alternatives, expected utility when choosing the option a_j, Eq. (8).

$$E\left(u_j\right) = \sum_{i=1}^{m} u_{ij} p\left(S_i\right) \tag{8}$$

Maximum expected utility, Eq. (9).

$$E\left(u^*\right) = maxE\left(u_j\right) \tag{9}$$

There are 4 proposed options to improve the production process of block products. Option 1, reengineer the measuring tool jigs. Option 2, improve the processing step of W1, H1 size by redesigning the jigs (machining mold). Option 3 is to apply computer vision system at the processing line and supervise the measurement operation as well as monitor the condition of the processing line to ensure the right person, to ensure that the person is skilled enough to perform at the specified section, but not the right person. The other step is to replace the fixed staff at each processing line and Option 4 is to change the roughing dimensional tolerances to reduce the impact caused by heat work. The 4 proposed solutions above, with the utility of current value PW, probability of non-positive current value P(PW≤0), expectation and variance of present value E(PW), V(PW) is calculated and shown in the following table 4. The results are calculated from Eq. (8), Eq. (9). According to the expected standard E(PW), option 4 (Change the roughing dimensional tolerances) is the best, options 1, option 2 and option 3 are the same. According to the probability standard P(PW≤0), the option 3 is the best, followed by the option 2, the option 4, and the option 3. According to the standard of variance V(PW) option 3 is the best option., followed by option 2, option 4 and option 1.

Evaluation of improvement implementation for case 3 and case 4, it is necessary to perform a reassessment to see if improvement needs to be made and how to implement improvement. Consider option 4 (Re-engineering the measuring tool jigs). This is simply renovating the measuring instrument and deciding to make the improvement immediately. However, the redesign of the processing step for sizes W1, H1 needs to be considered in more detail before deciding to implement option 3, it is necessary to redesign the machining mold, redesign the entire machining process.

Decision making when knowing the probability distribution is applied Bayesian decision making for the purpose of selecting an improved investment plan or not, whether to collect information about the system state before making decision.

Conditional information verification −.

$$p(x\_k|s\_i\ ) = (p(x\_k|s\_i\ ))/p(x\_k\ )\ \times p(s\_i\ ) \tag{10}$$

TABLE 4. Analysis of 4 proposed alternatives

Option No.	P (PW≤0)	E(PW)	V(PW)(x 10^9)
No.1. Change the roughing dimensional tolerances	0.2	60000	5
No.2. Computer vision system at the processing line	0.1	60000	3
No.3. Improve the processing step of W1, H1 size	0.0	60000	2.5
No.4. Re-engineering the measuring tool jigs	0.1	65000	3.85

The probability of variation of information $p\left(x_k\right)$.

$$p(x_k) = \sum_{i=1}^{n} p(x_k \mid s_i) \times p(s_i) \quad (11)$$

Expected utility with information x_k.

$$E(u\_j|x\_k\ ) = \sum \_(i=1)\hat{}m\ u\_ij\ p(x\_k|s\_i\ ) \quad (12)$$

Maximum expected utility with information x_k.

$$E(u^* \mid x_k) = \max E(u_j \mid x_k) \quad (13)$$

Maximum expected utility with information X.

$$E(u_x^*) = \sum_k E(u^* \mid x_k) p(x_k) \quad (14)$$

With complete X_p information, maximum expected utility.

$$(u_{xp}^*) = \sum_k E(u_{xp}^* | x_k) \times p(x_k) \quad (15)$$

$$V\left(x_p\right) = E\left(u_{xp}^*\right) - E\left(u^*\right) \quad (16)$$

This work greatly affects the entire processing line of block products. The company has 2 decisions, to make improvements under option 3 (a1) and not to make improvements under option 3 (a2), We have the utility matrix. Eq. (10) to Eq. (16) can calculate the result, the expected utility when choosing option a1 is E(a1) = 1, the expected utility when choosing option a2 is E (a2) = 0.5. So, the choice is a1 and the maximum expected utility is E(u*) = E(a1) =1. Specifically, option 4 is allowed to implement improvements. To proceed with the improvement of option 3, improve the processing step of the W1, H1 size of the block line. We conduct 8 simulations of machining steps on solid work software, utility expectation with incomplete information E (u_x^*) = 1.875, incomplete information value V(x) = 0.875, expected utility with complete information E (u_{xp}^*) = 3 and complete information value V(xp) = 2. Implement the design to improve the machining step according to option 3.

Implement option 4, by redesigning the tool to size W1, H1. Improve inspection capacity for employees, buy precision measuring instruments for W1 and H1, and change in material or thermal conditions that 3 actions are selected to perform the improvement because the score is less than 12 points. Design a tool to automatically measure dimensions W1, H1 by changing the measuring instrument with a high accuracy class of deviation (0.005mm) compared with the current measuring instrument with a deviation accuracy class (0.010mm), improve the measurement operation from manual to semi-automatic and automatically save the measurement results to the measuring system through the signal transmission cable, the measurement data is saved to the database of the SQL (Structured Query Language) system. The kit is simulated on solid work software. Simulate the connection of measurement data from the integrated measuring tool for sizes H1, and W1 into the system and verifying the results with a control chart. Improve option 3 Improve the processing step of W1, H1 size. Rebuild the shelf sequence of product processing steps at the MC stage to stabilize the plane dimensions and eliminate post-processing burrs. Simulate machining steps from 1 to 8 on solid word software change the machining step at the position of machining the surface of the product by re-fabricating the machining jig on the MC machine, shortening the increments from 8 steps to 7 steps. The product quality is still guaranteed to meet the size requirements and the required processing capacity is C_{pk} greater than 1.33. Improve the fixture at the step of creating the standard face machining with a flatness of 0.002mm, then take the reference face as a fulcrum on the MC jig to machine the groove size and the remaining dimensions. The dimensioning data from the W1, H1 dimension combination gauge is set at the MC, surface grinding stage, and groove grinding stage and feedback connection to the machining machine re-measurement data was shown in Figure. 1 & 2. DNC (Direct Numerical Control) program takes measurement data from the combined gauge W1, H1 and updates over time the parameters in the respective machining program.

Dimensional values H1 and W1 are transmitted by the navigation system to the DNC system and compared with the standard set of size parameters of the H1, and W1 dimensions preset in the system taken from the customer drawing table. DNC system will compare the actual size and the standard size and take out the error parameter and update the machining residual parameter of the automatic machining machine. This loop is performed throughout the machining process without depending on the machining staff. In case the measured size does not meet the standards required by the customer, the system displays red and emits a warning sound.

Improve phase

Deploy the improved system from the simulation environment into the live machining environment. The integrated measuring system is designed and connected to the navigation system and linked to the machine program through the DNC program. Use the same test before improvement. Take 10 products, 3 employees, and each employee measures 3 times on each of the H1 and W1 dimensions on each individual product. Using the measuring instrument, the same master set to zero the measuring instrument, the same temperature and humidity in the measuring area are applied throughout the evaluation. The MSA (Measurement System Analysis) chart is used to analyze the measurement results, showing the loss of stability in the measurement, as shown in table 5.The reproducibility Appraiser Variation (AV) value is 1.13%, which proves that the correlation between the measured data of the employees is similar, no deviation arises. The repeatability & reproducibility (R&R) value is 6.81%, proving that the correlation of measured data of the instrument is similar, no deviation arises. The total Variation (TV) value is 20.66, which proves that the measuring system responds strongly in relation to the measurement data of the instrument with the measurer, the repeatability of the measurement ensures the response for sizes H1, W1. Specifically, this combined measuring set ensures stable results, and enough capacity to meet the measurement of sizes H1, and W1 at each stage. Use 30 products, 1 employee, measuring kits that combine sizes H1, W1, and the same temperature, humidity. Histogram in Minitab 18.0 software analyses process capacity after step improvement, machining jig improvement, and measuring tool set improvement. As a result, the processing capacity of H1 size is Cpk2.56 and the capacity of W1 size is Cpk2.62 to achieve the set goal.

The data performed in this study were collected from employees at ABC company. Specifically, employees of the technical maintenance department, automatic and semi-automatic lathe processing machines, and management staff from the leader level up to the factory manager of departments such as production and engineering, maintenance, improvement, safety, and quality management, order management, warehouse management. Implement a random draw method as it is easy for the survey participants. Most of the surveyed people have operated automatic and semi-automatic processing machines at least once. Criteria for survey sampling is that all of them have the perception that the improvement of tools and tools used in production is beneficial. The survey questionnaire is referenced from previous studies by domestic and foreign authors in Vietnam and reports that have been made from previous improvement activities in ABC company. Each research variable is implemented through at least three measurement indicators. The survey questionnaire was made in Vietnamese, replacing the client 5 scale to conduct the data collection survey. To ensure that the survey questionnaire was designed appropriately, the questionnaire was sent to 3 heads (head of the pro-

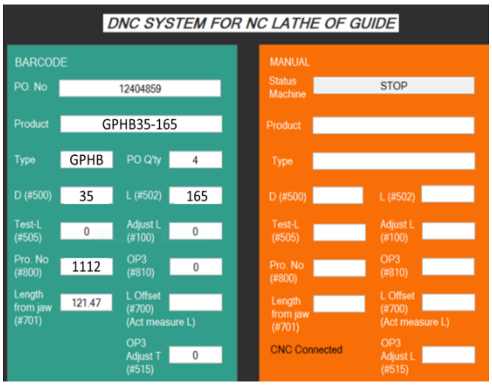

FIGURE 1. **DNC program screen**

FIGURE 2. **Real-time DNC program in process**

duction department, head of the technical department, and quality control department) for comments. The author has completed the survey questionnaire according to the opinions of the above three department heads.

A total of 300 questions were surveyed, 45 questionnaires were rejected, and the survey results were incorrect or answered with incorrect content because these people did not read the required content of the table carefully survey questions. Two hundred fifty five questionnaire samples gave valid results in the PLS-SEM (Partial Least Squares Structural Equation Modeling) analysis model. Smart PLS 3.0 and SPSS 20 (Statistical Package for the Social Sciences) software were used for data analysis. The data collection results showed that 75.5% were male and 24.5% female. Their qualifications are mainly 12, accounting for about 80%; for details, see table 6.

To assess the reliability and validity of the salary scale, we use the Composite Reliability index (CR) and the value of the Cronbach's Alpha index to assess the reliability of different factors. The CR and Cronbach's Alpha criteria must both be more significant than 0.8. Only then will the survey results be assessed as reasonable, and the PLS-SEM model analysis will begin. From Table 5, the analytical results of CR and Cronbach's Alpha indexes are both greater than 0.8, and AVE (Average) is also greater than 0.5, which proves that the analytical values of the scale are valid and have a high level of confidence to accept the research model. Table 7 shows that the analysis results of the research data's AVE square root value index are more significant than the correlation coefficient, which proves the validity of the data.

While the convenience factor and the useful factor are completely satisfied to loyalty using the results of this case improvement activity, was shown in table 8.The usefulness factor of the improved system affects the user's loyalty with a p-value of 0.001 and the convenience factor of the post-improvement system affects the loyalty of the valuable users p-value = 0.03. Prove that the usability factor and the convenience factor have a beneficial effect on user loyalty. However, the technical factor of the improved system on loyalty has a p-value = 0.64. Prove that the technical aspects of the post-improvement system need further improvement to improve the user's loyalty to use the post-improvement system.

Control phase

Update the processing sequence of similar processing machines on the operation of the improved results, conduct training for machining staff at each respective stage, check the understanding level and operation level of employees by OJT (On Job Training) form. Update the control plan sheet, perform a full stage reassessment based on the control plan sheet and P-FMEA (Process-Failure Mode and Effect Analysis) sheet, and reassess the Risk Priority Number (RPN).

Computer vision uses artificial intelligence (AI) technology to recognize face objects, deploying a system to control the layout of operator positions according to machine operation skills. Each employee is allowed to take 100 photos with many aspects and for the system to learn, other employees will operate, the system recognizes and sends out a warning signal for the whole system and integration in process inspection system, see figure. 3.The measurement system uses digital numerical control (DNC) technique deployed at each stage, measures the product size 100% of the data saved into the system and determines the pass or not pass result by the measurement system (Figure. 3). Measurement data is displayed on a control chart in real time on the computer screen at each stage.

4. Discussion and Conclusion

Reconstructing the future value stream map, the results show that, after the improvement, the total lead time is 928 minutes, less than the total lead time before the improvement is 1001 minutes. Total cycle time is 848 minutes, less than total cycle time before improvement is 879 minutes and value add time is 388 minutes, smaller than before improvement is 401 minutes and especially, after improving the machining step of W1, H1 size, by redesigning the machining mold and developing the DNC system, together with the measuring system, it has shortened 1 job machining stage, eliminating a source of using electrical energy in the machining process and bringing very practical profits.

The activity of connecting from research to practice, applied to the continuous improvement department at a mechanical processing company, is the successful step of this research project. The research model is easy to use, commercial software is readily available and easy to install on common computers, simple to operate, anyone can use it because of its simplicity, software such as following: (1) Minitab 18.0 statistical analysis software. (2) Solid word design and simulation software. (3) Path model analysis software, structural model of quantitative survey results. Use smart PLS software 3. The research model is made in combination with the technical department and the operator at the mechanical product line, and the research model is strongly responded by the operators at the line to deploy for other improvement activities in the future.

The research model is practical in nature, performed at the mechanical processing line. The improvement team consists of technical staff, machining operators, and information technology staff who participate in model research with the team leader who is an employee of the quality management department. PDCA model is applied by quality management staff to monitor and control the process of implementing improvement activities, verifying results of product quality before and after improvement. The quality manager uses the control plan sheet and the P-FMEA sheet which is used in

TABLE 5. Before – After measurement system analysis result

Measurement Unit Analysis	% Total Variation (TV) (Before)	% Total Variation (TV) (After)
Repeatability−Equipment Variation (EV)	37.06	6.71
Reproducibility−Appraiser Variation (AV)	8.81	1.13
Repeatability & Reproducibility (R&R)	38.09	6.81
Part Variation (PV)	92.46	99.77
Total Variation (TV)	3.42 (number)	20.66 (number)

TABLE 6. Sample characteristics

Variable	Item	Freq.	Percent
Gender	Male	239	75.5%
	Female	16	24.5%
Age	20-30	102	40%
	30-40	107	42%
	Over 50	15	6%
Academic degree	Upper University	30	1%
	University	23	9%
	College	26	10%
	High school	203	80%

TABLE 7. Convergent validity and reliability

Construct	Indi	Factor load	AVE	CR	Cronbach's Alpha
Useful	Use 1	0.731	0.551	0.801	0.852
	Use 2	0.741			
	Use 3	0.699			
	Use 4	0.752			
Convenience	Con 1	0.812	0.603	0.831	0.802
	Con 2	0.803			
	Con 3	0.799			
	Con 4	0.821			
Technology	Tech 1	0.912	0.599	0.813	0.852
	Tech 2	0.789			
	Tech 3	0.803			
	Tech 4	0.821			

TABLE 8. Path coefficient, t-value and p-value of PLS estimation

Path	Path Coefficient	t-value	p-value	Comments
Useful -> Loyalty	0.43	2.34	0.001	Supported
Convenience -> Loyalty	0.23	2.82	0.03	Supported
Technology -> Loyalty	0.09	0.51	0.64	**Not supported**

the whole production line assessment and machining line status analysis by taking video on each job and together with the improvement team to analyze the relationship. Correlating man-machine operation to find activities that do not add value such as inappropriate measurement methods, causing waste, and machining tools at the MC line that are not suitable for machining steps. Minitab 18.0 soft-

FIGURE 3. **Realtime process inspection system**

TABLE 9. **Efficiency after improvement**

Effective items after improvement	Efficiency after improvement
Quality improvement	Precision machined products. There are no more out-of-spec products, The repair rate for free defects is zero ppm. Specifically, down from 660 ppm to zero ppm.
Stage capacity	The capacity of the whole production line is guaranteed. Specifically, the processing capacity of H1 size is Cpk2.56 and the processing capacity of W1 size is Cpk2.62.
Improved measurement operation	Simple installation and measurement operation, low error. Staff training time reduced from 1 week to $\frac{1}{2}$ hour.
Productivity Improvement	Product inspection time is reduced by 702 hours per year, in terms of money, saving USD 2106 per year. The cost of repairing goods in terms of quantity reduced by 196 products per year, in terms of money, it saved 917 USD per year.
Rough stage	Machining accuracy is increased. Some dimensions can be unchecked after machining inspection time reduced by 364 hours per year. Calculated in money, saving 1092 USD per year.
Finished stage	Roughing is reduced by changing the machining process from re-engineering the MC jig. Calculated in savings is 171288 USD per year.

ware is used by the quality management staff to analyze the C_{pk} process capacity by the histogram, to evaluate the capacity of measuring instruments, the quality management staff uses the formula in measurement system analysis to analyze and evaluate. Technical staff uses solid word software to redesign the entire improved model and simulate the results before being processed and assembled into practice. Purpose of eliminate waste arising in the design process. Information technology staff connect the measurement data from the measuring system to the machining program of the automatic machining machine through the DNC model and check the connection, a model called navigation system. The DNC system has the function of receiving measurement data from the H1, W1 size combination gauge and updating the measurement data into the standard parameter set of the H1, W1 dimension machining program to adjust the machining parameters according to the quantity suitable machining allowance. The PLS-SEM model is used by the staff of the quality management department to analyze the results of the user survey, the results of improved operations with smart PLS 3 software. The results after apply the improved system to the processing line. The block product line is very practical. The effectiveness of the result after applying the improved model to the stage is shown in table 9.

Calling the machining program from the barcode on the machining order with the DNC program has not been completed and needs to be further improved on the response time of the measuring signal from the meter and updating the machining program parameters are these 2 contents. This is a limitation of the research model. Improve hole machining accuracy and improve hole of center size measurement accuracy, perform external setup for new MC jigs to save time on handle time are the content of future research by the improvement team.

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