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QUALITY ENGINEERING IMPLEMENTATION IN AN ORGANIZATION: A BRIEF FINDING ON QE METHODOLOGY

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Abstract
As many research focused on robustness methodology, this paper discuss on how to implement these methodology concept from the management perspective. Guidelines and appropriate strategies are discussed on Quality Engineering (QE) implementation in an organization and experimentation. Firstly, the experience of a company implementing QE is presented. Secondly, the practical data of a laboratory experiment is discussed in order to relate between the experimental result and requirement in industry. The QE implementation is explained on the strategies used in tackling organization problems. Optimization of peel adhesion strength test is carried out to propose the feasibility of experimental design tools. QE methodology between the practical case and company's case study is compared. Finally, through the QE implementation in organization and method applied in experimental design, a framework is proposed for QE methodology. QE implementation is presented from two sources, from a company and practical case study point of view. It helps a researcher or engineer applies the management strategy and engineering tool to ensure product robustness.

Keywords
Quality Engineering, Taguchi method, Design of Experiments (DOE), T-peel test, product robustness.

Introduction

Fuji Xerox Co., Ltd. demonstrates how Quality Engineering (QE) can be introduced into an organization to minimize product development cost, reduce time to market (TTM) and increase product quality. Most of the quality problems come from technological development and designs which is before the production phase. Taguchi method is used to identify the relationship between customer requirements and design characteristics specifications. Based on Fuji Xerox's experience, QE implementation is classified into two sections, management strategy and engineering tool. QE methodology presented by practical case study done in a laboratory is compared with Fuji Xerox case study done in their research and technology and new product development. Finding from the comparison is used to establish a framework in QE methodology procedure. An overview is shown in Fig. 1 on how information is delivered in this paper:

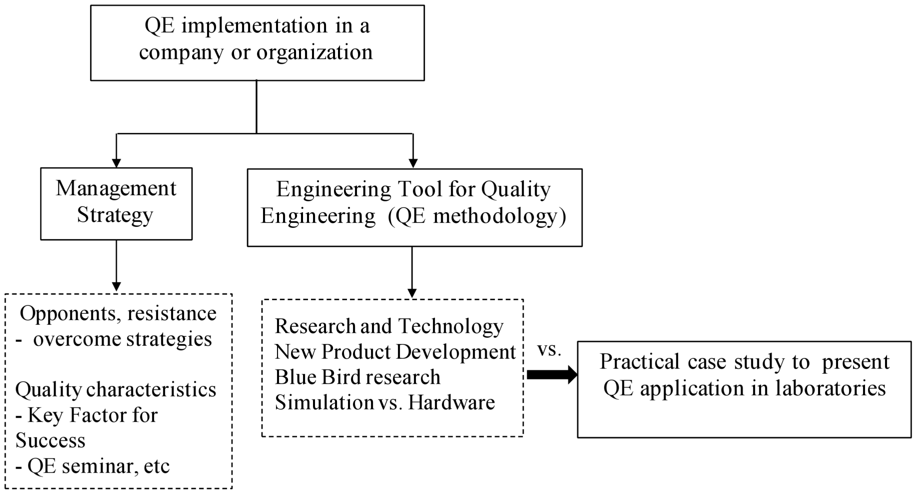


Fig. 1. Overview of information mapping [source: own work].

Methodology

QE Implementation in an Organization Management Strategy

At the initial stage of QE introduction, opposition from engineers made QE hard to deploy. This is due to the strong force from QE promoter and lack of understanding among the top management. Fuji Xerox overcomes the problem by training the problem solving teams via outside and in-house seminars. The skillful member will then train the engineers through many practices. Those engineers who have fully understanding of the robustness concept formed an internal study team and made text books with case studies. Those documents are established in internal seminar for Robust Design. It is concluded form this positive grow that the importance of management's role in supporting engineers to study voluntarily. In addition, continuous advice by trainers to current engineers and future trainers are given to ensure QE continuity. A revised internal QE seminar is held to focus on quality characteristic in technology development. Eight Key Factors for Success (KFS) as shown in Table 1is induced through Cause and Effect diagram.

Table 1
8 Key factors for success (KFS) [1].

1	Policy making by top management
2	Responsibility to promote QE
3	Promotion activities
4	QE training consistency
5	Themes clarification of QE status
6	Continuous meetings
7	Consultant and expert support
8	Result review and clarification

Support and interest in QE involvement from the top management members, activities for promoting QE will not show any progress although with a great effort by an eager promoter and engineers succeeded in implementing QE. Continuous training to engineers who are in need to be trained is more effective in activating the activity than training many engineers at once at the beginning of QE introduction period. As the top management support is crucial, engineer portrays the training as the manager's willingness to implement QE and the discontinuance of training is interpreted as loss of interest. Structural guidance to engineers by promoters are also important as leaving the usage up to engineers result inactive QE. Promotion committee has been established under top management's leading, so called a top-down approach. One of the functions of QE promotion system is establishing internal seminar (IQE). The objective is to train engineers' ability on QE application and train the future trainer to avoid the stagnation of QE. QE promotion on components supplier is done by the procurement department. An internal presentation forum is also held annually in June presented by the engineers regarding their achievement in QE and Design of Experiments (DOE) applications. QE is also incorporated in existent product development process and new concept of process innovation. The concept explained on applying QE at the earliest stage consisting of optimization and confirmation evaluation, followed by building the first prototype. In consequences, occurrence of quality problem is minimized before building the prototype. The new concept is vice versa from the conventional product development process which prototype is built first then followed by improving the quality of the next prototype. It is obviously described the concept of robust engineering which robustness is confirmed before any design is finalized. Research and Development center play a key role to provide matured technologies and new technologies corresponding to business environment changes. Utilization of computer simulation has speeds up the development process and reduces the prototypes cost.

Engineering Tool for QE Methodology

Annual QE forum is emphasizing on engineering tool that are QE and DOE. Fuji Xerox has differentiated the usage of QE tool based on process and purpose. DOE is utilized at the research stage to fix the themes of product and process and further verify the feasibility of the research. Taguchi method is used extensively to find the design parameters that result in the product or process robustness. It is an immensely useful tool for product development to establish the technology. Three main steps in technology development are preparing a strategy by setting the objective, selecting technology in the first development step and robust design in the second development step. Criterion in research and technology development process is defined. Objective of research is to find for "Blue Bird" [2], which means to create breakthrough technologies valuable to customers. In addition, DOE is used when problem occurs. The purpose of DOE in troubleshooting the problem is to find the factors that change the mean value of characteristics. The difference between DOE and Taguchi method is critical to understand ensuring the suitability of the tool based on purpose. In Fig. 2, a framework is made after analyzing the QE implementation in Fuji Xerox to explain some tools used in an organization. Notice that DOE and Taguchi method have been placed separately. Other tools which are useful in each process or stage is also highlighted.

QE Methodology in Practical Case Study

As explained by Fuji Xerox, Taguchi method had been used in research and technology development process to find the design parameters that minimize the variation. It is a QE tool to make the process or product insensitive to changes in the noise factor or variation. A case study, optimization of T-peel test using Taguchi method is done to propose the feasibility of QE in practical experimentation. Standardized test method of T-peel test in measuring peel strength is established by JIS K6854 [3] and ASTM D1876 [4]. The limitation of the standardized method is the test only fit for rigid materials and not capable to apply on flexible film. Big variation in peel strength measurement due to specimen failure to hold the T-shape during peeling is a significant problem when standardized method is used on flexible film. This problem statement has motivated the researcher to come up with a system that can satisfy the industry requirement, which in this case is flexible packaging film. Thus, a new testing apparatus had been established to overcome this problem for flexible film. The case study is discussed on T-peel test optimization of flexible packaging film using the new apparatus. The objective is to obtain the minimum variation of peel strength. The goal of research and the technology used to deliver the goal have been integrated by applying QE. Three main steps mentioned in the Fuji Xerox's strategy of implementing QE are followed [2], that are objective setting (to satisfy the testing capability), technology selection (new apparatus for flexible film instead of using established method) to enable the functionality and finally robust design (optimization of T-peel test for minimum variation in flexible film). The study was carried out to identify factor's level that would minimize the variation in peel strength.

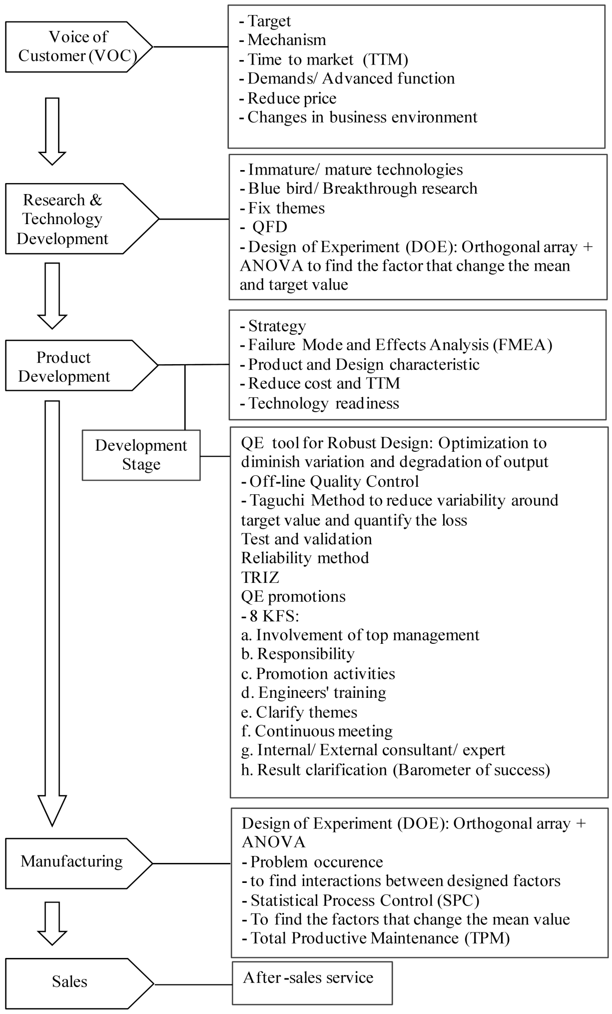
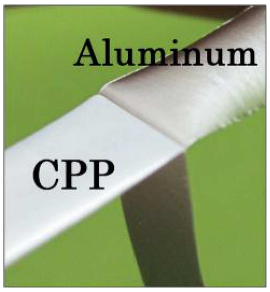


Fig. 2. Quality engineering implementation framework in an organization [source: own work].

The test apparatus system is described as in Fig. 3. The specimen is attached at the bottom of the drum, and a weight (paper clip) is fixed on the free-end of the film to hold the specimen in T-shape. The two drums peel the specimen.

a)



b)

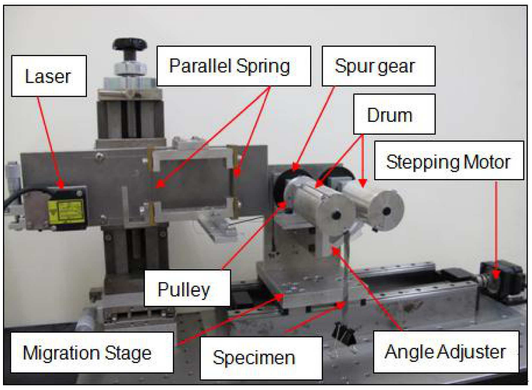


Fig. 3. Specimen in T-shape position (a) and test apparatus (b) [source: own work].

Ideal Function, P-diagram and Signal Strategy

A dynamic ideal function was identified in this study, based on various range of specimen width. Y is the output energy that is peel strength. M is the input of signal factor that is various size of specimen width since it is desirable to have robustness within each width. Beta, β, is the measurement sensitivity to different inputs; thus the slope must be steep. Therefore, the dynamic ideal function is Y = βM. P-diagram in Fig. 4 is constructed to give a whole picture on the parameters studied. The function of Al-CPP T-peel test is to measure peel strength. Thus, the response or output of T-peel test is peel strength, which measured in Newton (N). The input of T-peel test is known as signal factor. In the ideal function, the energy transformation occurs for three different specimen width that are 5 mm, 10 mm, and 15 mm. Signal factor, in this study, is specimen width is a controllable variable to actualize the intention (variation in peel strength) to achieve robust condition regardless of various width condition [5].

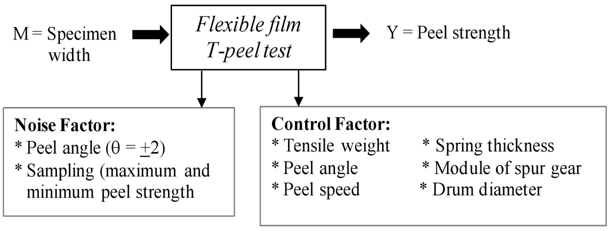


Fig. 4. P-diagram of practical case study [source: own work].

In P-diagram, robustness is optimized by evaluating the control factors and their levels. Noise factor condition is varied accordingly to minimize variation that influences the response. Signal-to-Noise ratio (SNR) with dynamic response (Eq. 1) is used in this study due to the signal factor existence. A dynamic signal-to-noise ratio (SNR) has been used in this study, where the specimen width of 5 mm, 10 mm and 15 mm as the signal factor is used to measure the peel strength linearity.

$$S/N \text{ ratio}, \eta = 10 \log(1/r)[(S_\beta - V_e)/V_N], \qquad (1)$$

where S_β – variation caused by the linear effect, V_e and V_N – error variance (error variance/DOF), r – total number of measurements under signal, (r is also the effective divisor due to level changes of signal factor), DOF is degree of freedom.

Noise Strategy

Noise factor is uncontrolled factor during normal production or use, but are controlled during the experiment. Noise factors are likely to produce variability in the response. For noise factor (outer array), historical data has proven that the peel angle would vary during exchanging the peel angle setting and during peeling process. Peel angle deviation will affect the peel strength; thus peel angle is considered as sources of variability. As shown in Fig. 5, noise in peel angle is defined as deterioration in $\pm 2°$ due to angle deviation during peeling caused by natural movement of the specimen. Maximum and minimum value of peel strength at $+2°$ and $-2°$ angle are taken for result.

Thus, there are two noise levels that are N1 and N2 under each signal factor level. The intended condition is N1 has higher peel strength than N2 (N1 > N2). N1 consists of peel angle with deviation$+2°$ and maximum peel strength is taken as a result. On the other hand, N2 level consists of peel angle deviation $-2°$ and minimum peel strength is taken as a result in outer array.

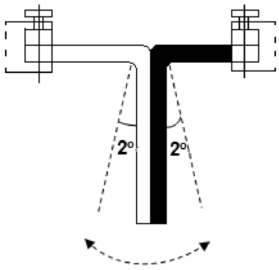


Fig. 5. Deviation in peel angle during peel test [source: own work].

Control Factor Selection

The objective of this T-peel test is to satisfy the industry requirement of getting the minimum variation for flexible film. Thus, select control factors that may affect variability in the response, and possibly the mean of the response. The controllable factors or inner array are chosen based on testing and design condition which possible to affect the variance. The controllable factor selection is also considered based on previous experiment result, preliminary test, theory and available knowledge, and expert's opinion. For example, previous experiment result in L9 orthogonal array uses tensile weight as noise factor. However, there is no significant trend in the peel strength based on 8 g and 4 g tensile weight. It is concluded tensile weight does not produce variability, but likely to affect the response. Thus, tensile weight is one of the control factors in L18. Tensile weight used for keeping the specimen in T-shape, peel angle, peel speed and peeling curve region are controllable factors considered based on testing condition. Parallel spring thickness, module of spur gears and drum diameter are considered based on design of apparatus condition.

The factor's level is decided based on objective. The level must not be so close to each other that the effect on the response is not observable or undetected. Level must also not very far apart that there is a region of unknown process behavior. Previous process knowledge is useful to determine the level. For example, three levels is chosen to observe the curvature effect on the response. Two levels are chosen to determine whether the factor has an effect on the response. More than three levels are suitable to observe significant trend or behavior, such as sudden rise or drop at certain levels.

Two-Step Optimization

Two-step optimization established by Taguchi method is essential in QE [6]. Step 1 is to reduce variability. This step focuses on seeking a design that maximizes the Signal-to-Noise ratio. Step 2 is to adjust sensitivity of the response to meet the target or requirement. It often referred to an adjustment factor that has high sensitivity and even SNR plot pattern. It is more difficult to reduce variation than to adjust the mean response to the target value. Thus, variation reduction is the first priority in QE followed by adjusting the mean.

Orthogonal Array Selection

The design space is large, and it needs a strategy to explore. After determining the control factors and factor's level, they are assigned into an orthogonal array. An orthogonal array is used for optimization to maximize the signal-to-noise ratio [7]. Balance set of experimentation runs is provided by orthogonal array. Design of experiments using orthogonal array.

L_{18} is utilized with one two-level factor (tensile weight) and six three-level factors (peel angle, peel speed, data region, spring thickness, module of spur gear and drum diameter) as shown in Table 2. In L_{18}, only 108 observations implied (18 runs ×3 signal level ×2 noise level).

Table 2
Experimental set up (a) and Orthogonal array (b) [source: own work].

a)

Control Factor	Unit	Level 1	Level 2	Level 3
A: Tensile weight	g	4	8	
B: Peel angle	°	60	90	120
C: Peel speed	mm/s	6	9	12
D: Data region	%	30	50	70
E: Spring thickness	mm	0.3	0.4	0.5
F: Module of spur gear		0.5	1.0	2.0
G: Drum diameter	mm	20	30	40
Signal Factor		Levels		
M: Specimen width	mm	5	10	15
Noise Factor		LevelN1	Level N2	
Peel Angle	θ	+2	−2	
Peel strength sampling	N	Maximum	Minimum	

b)

								5mm		10mm		15mm	
	A	B	C	D	E	F	G	N1	N2	N1	N2	N1	N2
1	1	1	1	1	1	1	1						
2	1	1	2	2	2	2	2						
3	1	1	3	3	3	3	3						
4	1	2	1	1	2	2	3						
5	1	2	2	2	3	3	1						
6	1	2	3	3	1	1	2						
7	1	3	1	2	1	3	2						
8	1	3	2	3	2	1	3						
9	1	3	3	1	3	2	1						
10	2	1	1	3	3	2	2						
11	2	1	2	1	1	3	3						
12	2	1	3	2	2	1	1						
13	2	2	1	2	3	1	3						
14	2	2	2	3	1	2	1						
15	2	2	3	1	2	3	2						
16	2	3	1	3	2	3	1						
17	2	3	2	1	3	1	2						
18	2	3	3	2	1	2	3						

Handling the Result of Experiment

There are two main plots for QE result that are SNR response plot and Sensitivity (beta) plot as shown in Fig. 6 and Fig. 7 respectively. SNR plot is obtained by computing the average SNR at each level of a process parameter. It explains the variation effect of each level of a factor. The maximum level of SNR value in each factor is taken as the optimum condition, implies the minimum variation as the signal is bigger than noise. Sensitivity response

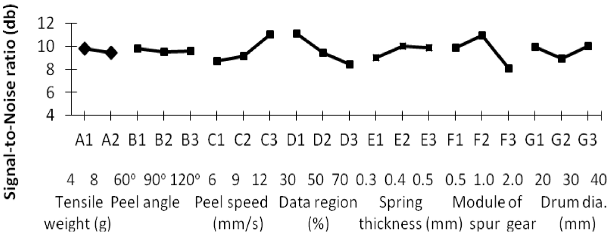


Fig. 6. SNR response plot [source: own work].

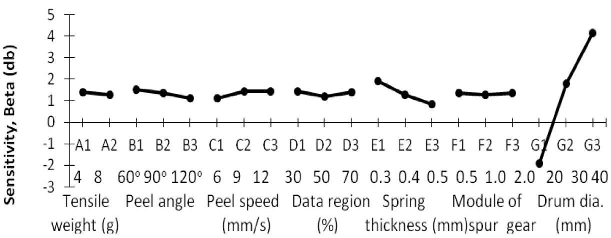


Fig. 7. Sensitivity (Beta) plot [source: own work].

plot, often called as Beta plot shows the sensitivity of response value at each level. It has no relation with variation, only focus on sensitiveness of response upon level's change. A confirmation run is done to check the reproducibility of the experiment. SNR in optimum condition is compared with worst condition. Db gain for confirmation SNR is differed by 2.86 db than estimated SNR. The db gain difference is caused by the worst condition as confirmation SNR deviates a little bit from the estimated SNR for worst condition. The repeatability of worst condition is not quite reasonable compared to optimum condition. As this confirmation experiment data is practical and actual, the dissimilarity of SNR in the worst condition is suspected due to testing condition and environment. Table 3 summarized the optimum and worst condition and db gain. Second step in two-step-optimization is to adjust the controllable factor to target value. The second step is done when certain target is desired. The best factor to adjust is drum diameter (factor G) because of high sensitivity, and SNR is roughly even. Thus, the variability in peel strength is not influenced by different level of that factor. Factors with even sensitivity and uneven SNR as C, D and F are particularly useful to improve variation because the value of peel strength has no change. As this experiment data is practical and actual, the db gain dissimilarity between estimated and confirmation result is suspected due to variation in experiment handling and environment.

Table 3
Optimum condition and SNR db gain
[source: own work].

Type	Condition	Estimated SNR (db)	Confirmation SNR (db)
Optimum	A1 B1 C3 D1 E2 F2 G3	14.91	14.82
Worst	A2 B2 C1 D3 E1 F3 G2	4.30	7.07
SNR db Gain		10.61	7.75

Results and Discussion

QE implementation in Fuji Xerox is explained from the beginning of the implementation. Engineering tool of some case studies given by Fuji Xerox is analyzed and compared with practical case study done in the laboratory. Figure 8 shows the comparison between QE methodology in laboratory case study (Fig. 8a) and Fuji Xerox case study (Fig. 8b). Fuji Xerox's flow is started by problem identification that motivates what kind of improvement to be done. Based on three case studies, problems can be coming from industry requirement, customer dissatisfaction [8], technology obsoleteness [9], cost reduction driven, system improvement [10] and such. Reference [8] emphasized on the relationship between output (Y) and problem statement to generate signal factor that transforms the energy. Optimization is conducted with the ideal function. In laboratory, problem is known from available standards and further optimization is done for the betterment of the new developed apparatus. Similarly, the output Y (peel strength) is related with the known problem (big variation) to generate the ideal function. Both flows focused on selection of quality characteristic which describe on the desired result. Quality characteristic is defined from the measured value of the objective, which referred to response, results or output [11]. Ideal function and P-diagram are identified after problem statement is done. Confirmation run in Fuji Xerox is done on trial manufacture while case study is done with laboratory scale. In Fuji Xerox, quality is monitored after-launch to society upon the in-house quality result is official.

The QE methodology flow is approximately similar between laboratory case study and Fuji Xerox. It is proven that QE engineering tool can be applied in any environment, be it industrial application or research field. Results from methodology comparison in Fig. 8a and 8b is used to produce a framework on how to apply QE methodology to obtain robustness of a product or process. The experience from L18 in selecting control and noise level is presented and need to be carefully done. The framework is shown in Fig. 9 and briefly described as follows:

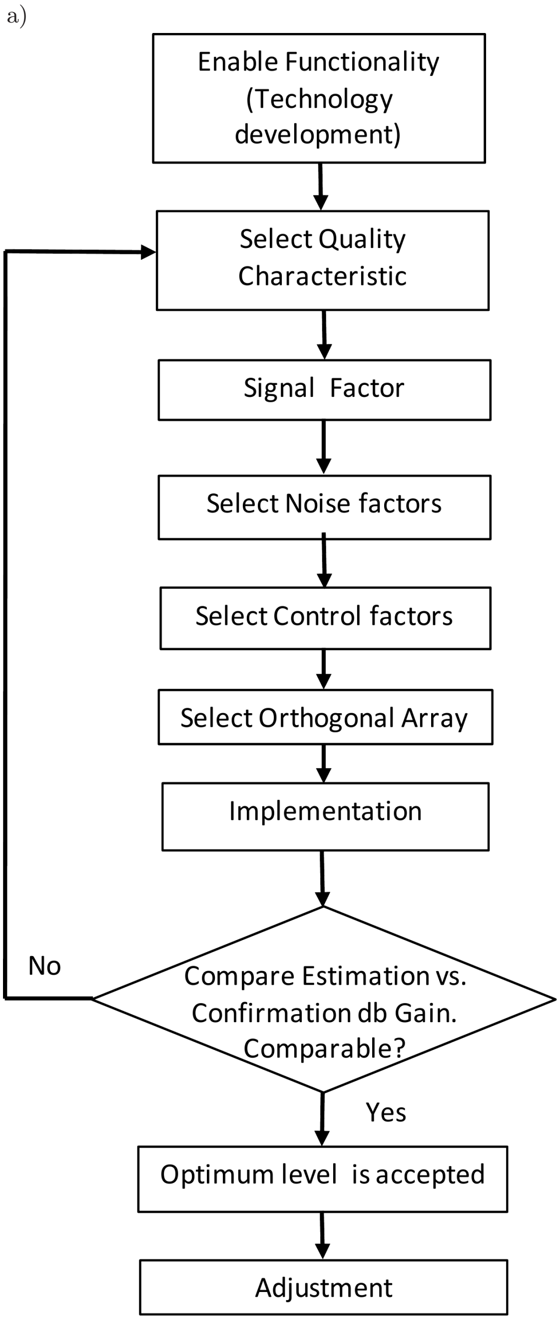


Fig. 8. a) Laboratory case study, b) Fuji Xerox case study [source: own work].

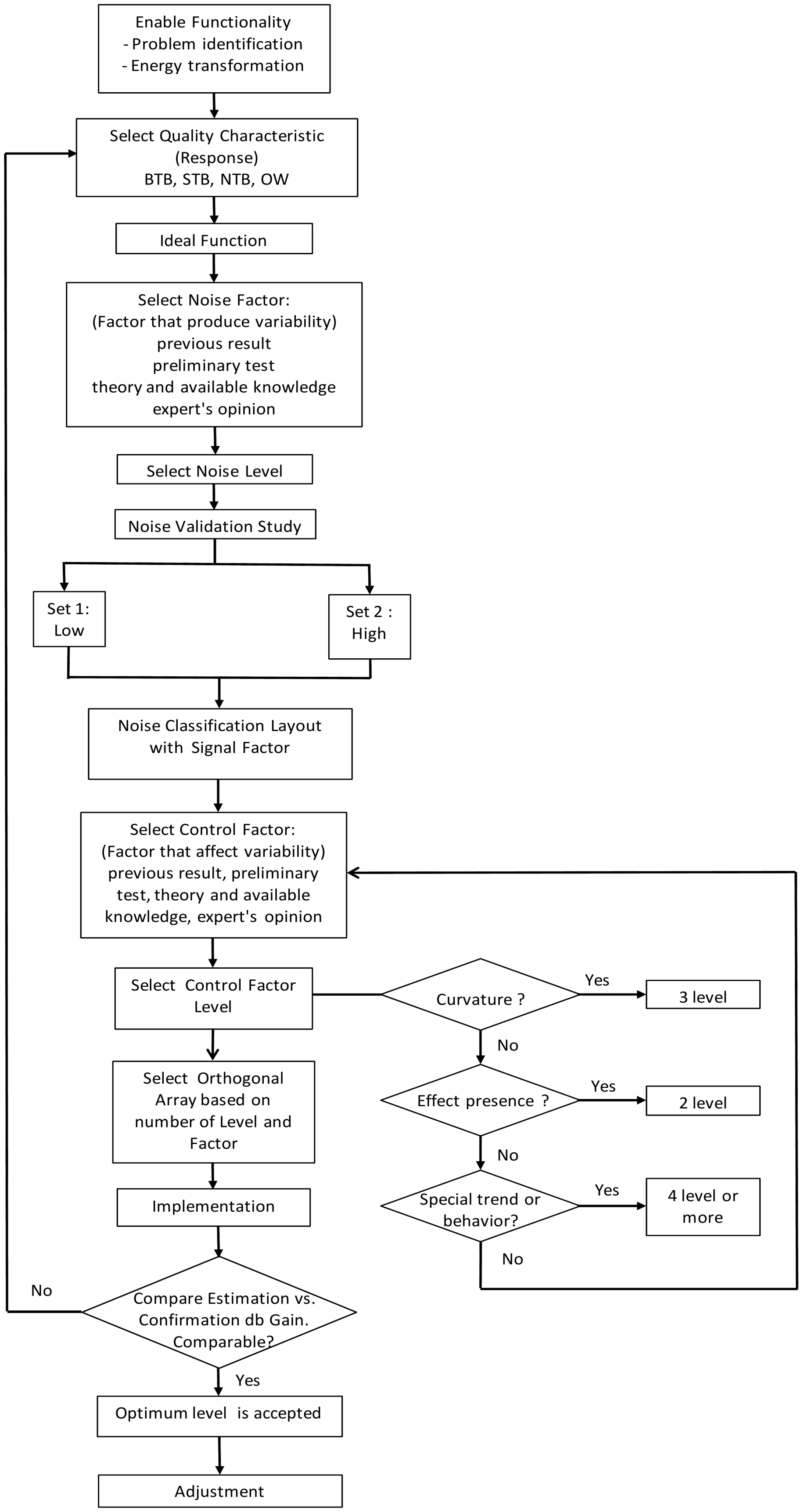


Fig. 9. Quality engineering methodology framework [source: own work].

Step 1: Enable functionality of the system. Carefully analyze the ideal function that transforms the energy into quality characteristic. Construct P-diagram to get a whole picture of the system.

Step 2: Identify the problem by selecting the response based on experiment's objective. The response may be maximized, minimized, or taken to a target value. The mean and variance of a response can be studied simultaneously. Construct an ideal function and P-diagram. Determine the input (signal factor) and output (response)of the experiment.

Step 3: Select noise factor and level for outer array. Relate with response objective, for example if the objective is to minimize variation of peel strength, make sure the noise factor can produce the variation in peel strength and the design space is covered as best as it can. Three noise layouts are decided to be done as the possibility of variation is satisfactorily covered.

Step 4: Select control factor and level for inner array. Consideration of factor level must in line with objective or intended effect on the response such as curvature, effect presence and other behavior or trend.

Step 5: Construct an orthogonal array based on number of factors and levels. Implement an experiment based on Taguchi method. SNR and sensitivity response plot are analyzed.

Step 6: Check on reproducibility. Estimation and confirmation db gain is compared. Rule of thumb of less than 3 db gain difference is preferable.

Step 7: Next step is adjustment. It is done if the intention is to move the mean to target. If there is no intention to move the mean to certain target, step 1 to 6 is sufficient enough.

Conclusions

This paper had presented an implementation of QE in an organization and QE application in process or product optimization through practical case study. QE has proven successful and is emphasized during the design stage before manufacturing or production to find the design parameters and ensure the product's robustness. Fuji Xerox hypothesis of Key Factors for Success has helped promoting QE in research, technology development and product development activities. QE promotion activities accelerate the implementation in an organization. Top-down approach is undeniably a driving force for a successful QE implementation. The case study represents on how QE is implemented in one of the product optimization.

Identifying the experiment's objective is crucial that affect the selection of noise and control factors. General guidelines are described step-by-step from selecting the response up to decision making on the optimum db gain. The engineering tool employs the engineering and statistic knowledge to obtain product robustness. A brief framework is presented for QE implementation in organization and procedures on QE methodology. Continuous research on improving the methodology will be done, not only focusing on one type of industry. In QE methodology, planning before implementation is a key element for performing a successful experimental design.

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