3-D Design Process for Manufacturing and Assembly: Table Top Tools for Incremental Continuous Improvement (Kaizen)

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Abstract

This paper proposes a design for manufacturing washers, bolts, and nuts assemblies, which can be used to illustrate Kaizen as an incremental continuous improvement methodology. Kaizen accomplishes continuous improvement through waste elimination and cycle time minimization. In addition to a compact set of manufactured plastic steel assembly, the corresponding 3-D models are generated and presented to facilitate "non-destructive testing." The design for assembly is used as a prototype for several applications of Kaizen tools and techniques through multiple sizes of individual parts and multiple sequences of part arrangements. Incremental continuous improvement has been found as a value added to each step of the assembly process to minimize cycle time and eliminate waste. In addition, substantial and significant improvements were noted on the final model of each manufactured assembly .In conclusion, the paper demonstrates an incremental improvement in the assembly processing and explains the design process for manufacturing and assembly using 3-D visualizations and renderings.

Introduction

Design for manufacturing and assembly is an important technique used to validate incremental improvement through tabletop set of washers, bolts, and nuts assembly especially when the value-added improvement is minor and incremental to the work in process. Robert Sturges defines design for manufacturability as "designing a product to be produced in the most efficient manner possible (in terms of cost, resources, and time) taking into consideration how the product will be processed, utilizing the existing skill base (and avoiding the learning curve) to achieve the highest yields possible" [1]. The design for manufacturing and assembly is a very powerful tool that enhances the manufacturing process design and control through Kaizen, which is a common word in Japan. "Kaizen" means change for the better. Change is deeply ingrained in the mind and behaviour of the human being and it fluctuates among three states: change for better, change for worse, and change for a new paradigm. Leaders, managers, engineers, and workers do not always realize that the minor changes they introduce could affect the manufacturing process for better or worse until they face problems with the customers who feel the propagated variation of small changes. In many industries, Kaizen practices are used to eliminate waste and involve employees at minimal cost. Moreover, Kaizen permits industries to manufacture products at low cost, and

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with improved quality and quantity. It is a powerful tool that helps sustain success in a competitive environment [2].

Research Purpose

This paper is concerned with the impact of minor design changes of the manufacturing procedure for washers, bolts and nuts assembly on applying Kaizen. In addition, this paper suggests a design for manufacturing washers, bolts and nuts assembly that is used to illustrate Kaizen as an incremental continuous improvement methodology through waste elimination and cycle time minimization.

Earlier Work

The earliest known and recognized manufacturing paradigm was product design specification, which involved changing the requirements of the customers into engineering specifications. Later, design engineers used the customer information to introduce new engineering changes. Design for manufacturing and assembly was developed before the Second World War; it was used by Chrysler and Ford as a rigorous methodology in their design and manufacturing process of military equipment such as tanks, carts, and weapons. Prior to the 1970s, Boothroyd and Dewhurst developed a design for manufacturing and assembly where the product development was essentially done through the product design and/or the working prototype. After testing and approving the prototype, the manufacturing plan should be constructed along with the lists of required specifications, tools, labor, methods, and materials [3]. Many design for manufacturing and assembly paradigms are available. For example, the Lucas design for assembly divides the product design procedure into three steps: function, handing, and fitting analyses. The method has been integrated in the engineering analysis software “TeamSet,” which is the product of CCI [3]. CyberCut is another paradigm that relies on the knowledge-based planner to promote design for manufacturing [4]. The producibility measurement tool paradigm practices producibility assessment worksheets, which are dependent on the familiarity and proficiency of the evaluators. Mathematical/ numerical values are used to calculate the producibility factor for the constituent components of the process. The mean value of these provides an estimate of the probability of production success [3].Gupta and Nau’s paradigm involves estimating the manufacturing evaluation using a two-step process:

(1) Generation of all the possible features for the design element, wherein the feature elements correspond to a machining operation [5], and elimination of the non-machinable components/parts

(2) Creation of a feature base model without redundancy

After that, the same process is repeated. Eventually, the best plan is followed. The Genichi Taguchi paradigm is a statistical procedure intended for estimating the factorial design and experiment design to ascertain process unpredictability and to discover the optimal set of parameters or conditions in diverse manufacturing practices. The Taguchi method is a very successful technique for the manufacturing process stability and quality of their products. It is a well-established method for incremental continuous improvement (Kaizen).

Kaizen

The word “Kaizen” was coined in 1984, by Masaaki Imai in his book *Gemba Kaizen- A Common Sense Approach for Continuous Improvement Strategy* [5]. According to Imai, Kaizen is a continuous improvement process involving everyone, managers and workers alike. In general, Kaizen is typically defined as “a strategy that includes concepts, systems and tools within the larger picture of leadership involving and people culture, all driven by the customer” [6]. It is a comprehensive strategy that covers many continuous improvement techniques such as poke-yoke, lean manufacturing, cellular manufacturing, Kanban, total productive maintenance, six sigma, automation, just-in-time, suggestion system, and productivity improvement. Among the very important goals of Kaizen is reducing cost, improving quality, and providing on-time delivery. It is true that Kaizen will create money, but without people, there is no Kaizen and without improving people’s standards of work life, Kaizen is not sustained.

Method

Part One: Hands-on Design Manufacturing and Assembly

The authors have designed the washers, bolts, and nuts assembly to facilitate the application of Kaizen at the College of Engineering at the University of Hail. Design for manufacturing and assembly includes not only assembling the geometric shape of the washers, bolts, and nuts but also the entire tooling activity. Designing the assembly with different sizes of washers, bolts, and nuts requires knowledge about the tooling and materials involved. Since the assembly is designed with pre knowledge of the downstream manufacturing process, the assembly team will have to modify its practices based on the feedback provided by the manufacturing designer. The author designed the manufacturing assembly with a robust planned variability in the size of each washer, bolt, and nut to furnish the floor for the following Kaizen measurements:

1. Assembly time improvement
2. Assembly process variability
3. Manufacturing accuracy
4. Value stream mapping
5. Manufacturing flow
6. Human factor effect
7. Waste recognition
8. Waste elimination
9. Production system simulation

Materials

The assembly consists of the following materials:

1. 20x20x8 mm waterproof plastic junction box (see Figure 1)
2. 12 x120 mm steel bolt x 24 piece
3. 10 x120 mm steel screw x24 piece
4. 8 x120 mm steel screw x 24 piece
5. 6 x120 mm steel screw x 24 piece
6. 6mm steel nut x 2kg
7. 8mm steel nut x2kg
8. 10mm steel nut x 2kg
9. 12mm steel nut x 2kg
10. 6mm steel washer x 2kg
11. 8mm steel washer x 2kg
12. 10mm steel washer x 2kg
13. 12mm steel washer x 2kg
14. Multiple quantities of random size of washers, bolts and nuts (see Figure 2)
15. Adjustable wrench
16. Nose pliers
17. 12cm x12 cm marking square
18. Drill
19. Bits (6mm, 8mm, 10mm, and 12mm)

Figure 1. Waterproof plastic junction box

Figure 2. Random size of washers, bolts and nuts

Assembly Procedures

Each assembly consists of one plastic junction box with one piece of each size of the bolts, nuts, and washers. The process of manufacturing the assembly has the following steps:

1. Marking the drilling points for each bolt using the 12-cm x 12-cm marking square
2. Drilling the corners of the marked square with the appropriate bits starting with 6mm hole size
3. Continuing the drilling process clockwise ascending to 12-mm hole size (see Figure 3 below)

Figure 3. Junction Box prototype

4. Attaching each bolt to the appropriate hole as shown in Figure 4 below:

Figure 4. Basic assembly

5. Installing the appropriate washer to each bolt
6. Tightening each nut to the appropriate bolt
7. Repeating the above steps to manufacture 24 units

Kaizen Application

The authors have developed a set of models to apply Kaizen basics and rules using the washers, bolts, and nuts assembly. The main idea behind each model is to install extra washers and nuts to each unit according to the instructions, procedures, and measurements of each model in order to perform the planned tasks and goals for that model. Each model represents a real mimic of actual manufacturing processing and production paradigm such as push-pull system, lean manufacturing, visual workplace, inventory control, poke yoke, 5S, etc. The authors designed the Kaizen models based on a teamwork role to achieve the following:

1. Standardize the tasks for each model
2. Identify the value added/non-value added activities in each task
3. Allocate the bottleneck in sequential models
4. Determine the 8 types of waste
5. Evaluate teamwork performance
6. Develop organizational skills
7. Create the culture of working smarter not harder
8. Set high standards to achieve near perfection

Part Two: 3-D Design Visualization

Of late, visualization tools are being employed in a wide range of applications [7, 8]. Visualization has innumerable benefits especially in the areas of design, assembly, and manufacturing. One crucial advantage of visualization in the area of manufacturing design is the ability for 'non-destructive testing'. This refers to the ability to conceive industrial design, create the models in 3-D, and then inspect the various aspects of design and check them for criteria-satisfaction. This greatly reduces waste generation and is extremely time-saving. For instance, Figure 5 below shows the rendering of the 'bottom-view' of the model show in Figure 3.

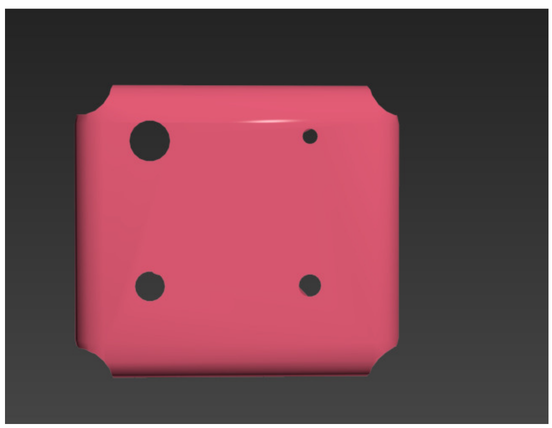

Figure 5. 3-D model rendering of the junction box prototype

By using 3-D visual scene renderings, manufacturing designers can identify desirable or undesirable elements within the design and make modifications before actual implementation. Chandramouli and Bertoline (2012) mention about some of the important advantages of such VR visualizations. Table 1 highlights few salient features provided by VR settings.

Virtual Environments with Interactive Capabilities

Interactivity is a very desirable functionality in virtual environments as they enable the user to interact with the scene components. This can also be useful in the case of teaching manufacturing design process to students via simulation. Such features allow students to visualization a pre-recorded simulation and with interactivity, they can interact with the tools to gain more experience working with them. The EAI (external authoring interface) serves as

Table 1. Important advantages of the VR scene visualization

Feature	Description of the Advantage
Point of View (POV)	The scene can be evaluated from innumerable points of view
Levels of Detail (LOD)	The same scene can be created and viewed using varying levels of detail.
Navigation	Different browser/plug-in combinations offer various methods of navigation such as study, flying, and walk-through.
Controlling Scene Attributes	The Scene attributes and the attributes of the VR scene objects such as Geometry and Appearance can be controlled in multiple ways

a channel to access the nodes making up the scene elements in a virtual scene. Typically, a VRML-based environment is constructed using scene elements that can be structured as nodes representing the basic shapes that make up the whole scene. Interaction, at the core, involves a change in the state of the scene objects. Two important functionalities used in this study, from a design perspective, include “sensors” and “EAI.” Sensors refer to the ability of a virtual environment to ‘sense’ and respond to user actions. Using sensors like visibility sensors, touch sensors etc. the objects in the scene can be programmed with these sensing elements to respond to user events like holding, dragging, etc.

Figure 6 shows the virtual elements such as bolts, nuts, and washers, which can be selected, grabbed, and moved to new locations. These can be re-positioned, rotated, and even scaled (larger or smaller). This also is useful in aesthetics, where users can try to map different textures and materials to these objects. Various shades of metals and paints can be applied to these objects before finalizing the manufacturing design.

Pilot Test –Kaizen Improvement Using 5S Model

The purpose of the 5S Model is to improve the assembly process by organizing the workplace through the following steps:

1. Sort
2. Set in order
3. Shine
4. Standardize
5. Sustain

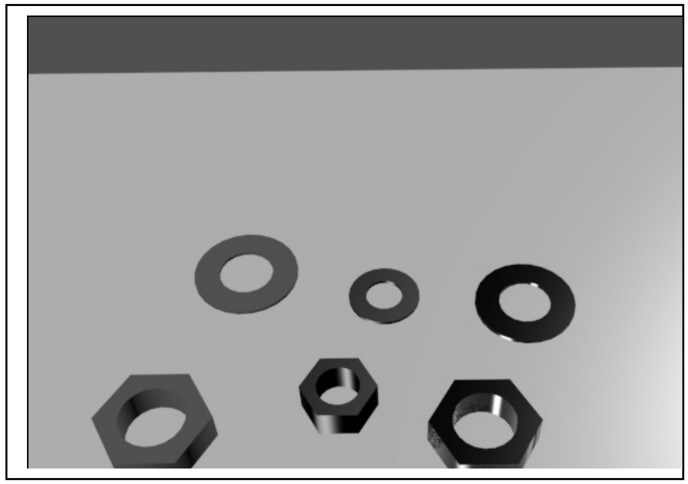

Figure 6. Virtual elements: Nuts, bolts, washers with changeable parameters

The model begins with a normal mode where the assembly process starts random. Then, an evaluation session for the count and waste identification is established according to following tables 2 and 3:

Table 2. Waste identification sheet

	Team 1	Team 2	Team 3	Team 4
Inventory				
Waiting				
Rework				
Motion				
Overproduction				
Over processing				
Transportation				
Unutilized skill				

Table 3. Parts count

	Team 1	Team 2	Team 3	Team 4
Washers				
Nuts				

Pilot Test Finding

The results of the pilot test are illustrated in Figures 7-9:

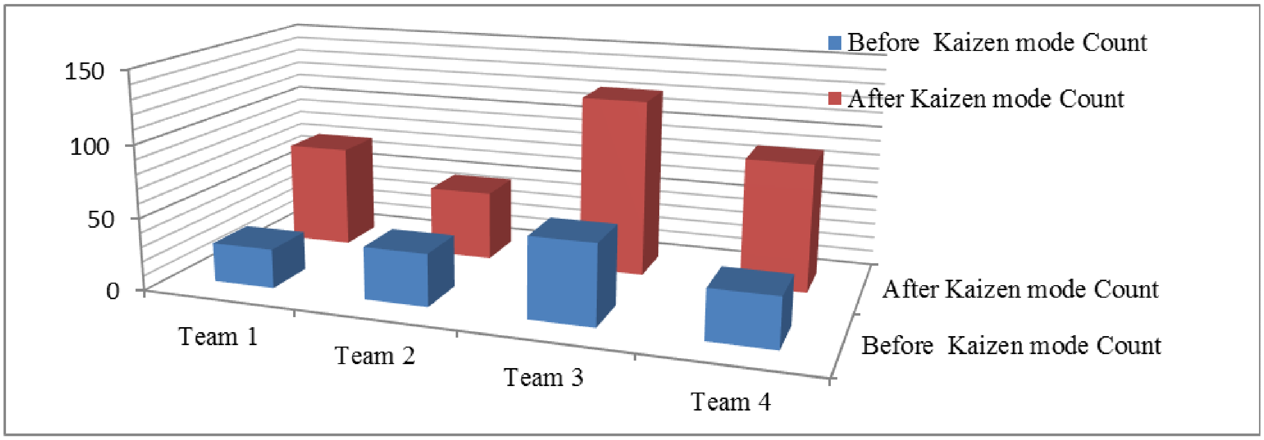

Figure 7. Before and after Kaizen mode washer and nuts count

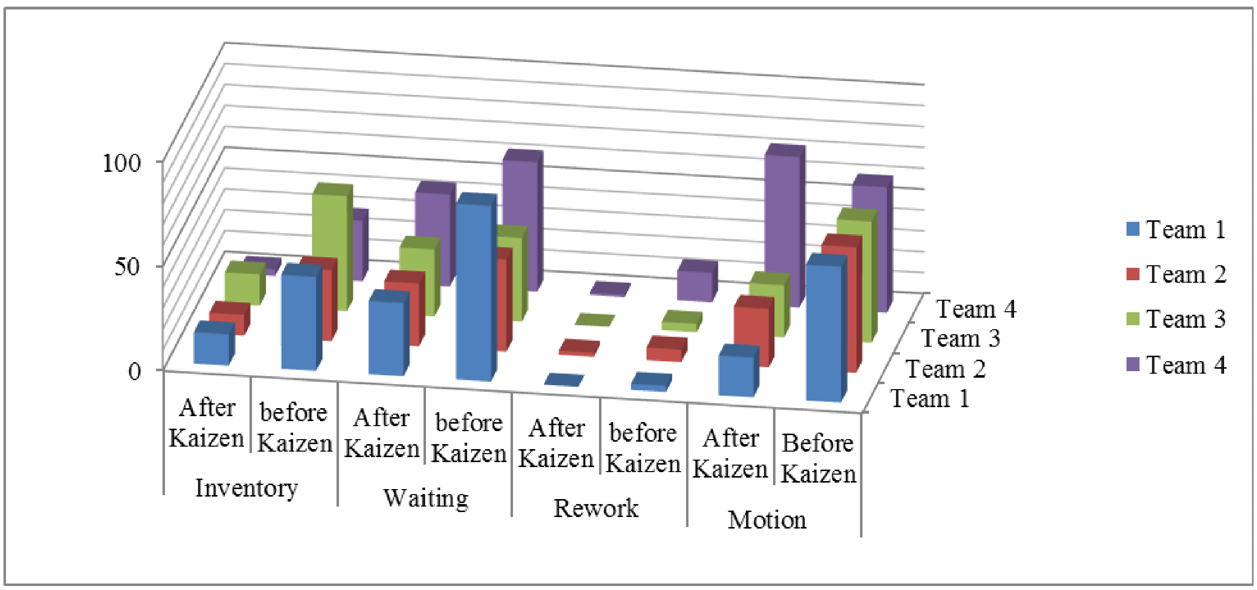

Figure 8. Before and after Kaizen mode waste identification

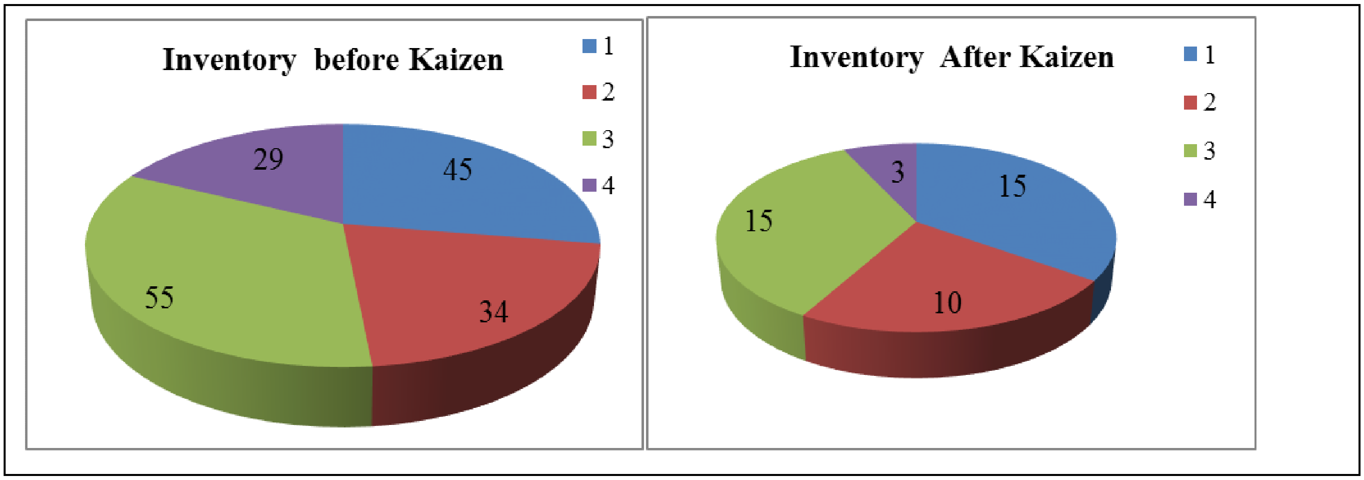

Figure 9. Before and after Kaizen inventory level

Pilot Test Results

Data collected from the pilot test shows an incremental improvement in the assembly processing as shown in Figure 7. The measurement during the pilot test was focusing on the cycle time of each assembly and counting the repetition of the non-value-added activities (waste). The differences of the measured values between the normal mode and the Kaizen mode are shown in Figures 8 and 9 illustrate the decreasing level of inventory in each team activity.

Conclusion

Design for manufacturing and assembly is a methodology that works well in facilitating Kaizen through waste elimination and cycle time minimization. The washers, bolts, and nuts assembly was found to be efficient and easy to use for Kaizen models to measure the level of improvement in manufacturing processing.

Recommendation

The authors recommend that each Kaizen model be visualized through VRML before hands-on practice. Also, they recommend team-based projects to perform each exercise, focusing on one type of waste, in order to be able to determine the incremental improvement that is associated with each model.

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