Integrating Lean and Ergonomics to Improve Internal Transportation in a Manufacturing Environment

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Abstract

This paper presents a study that integrates lean manufacturing and ergonomic principles to redesign and improve the internal transportation process in a high-end server manufacturing environment. Transportation of electronic parts within the factories is an important issue. The current transportation carts present quality hazards to electronic parts and they were not designed to handle the right dimensions and quantities of the newly introduced products. Furthermore, the current flow of carts introduces waiting time for the carts in the assembly areas. Inefficient transportation not only increases the waiting times but also the transportation costs. The objective of this study is to improve the transportation process and redesign transportation carts that are currently used to transport parts between different areas in a high-end server manufacturing environment utilizing lean and ergonomic principles. A new lean-based flow of transportation carts is proposed to reduce the waiting time and transported distance by having separate carts for each area. The new design of the carts represents a Poke-Yoke that prevents the operators from stacking the cards. Ergonomic principles are also considered in the new design. The number of carts required is estimated based on historical demand, outcomes from containment actions, current processes, and inputs from the production-planning department. The new lean-based flow and design of carts have resulted in cost savings and cost avoidance.

Keywords
Internal transportation, cart design, lean manufacturing, ergonomics, digital human modeling, server manufacturing

1. Introduction

The focus on quality is one of the main concerns of lean production systems. Safe transport within (or outside) the factory has a direct impact on the quality of parts and products. Care must be taken that items are correctly handled during transportation to reduce the risk of damage. Conversely, the use of poorly designed transport equipment can seriously damage the transported items. Electronic products are more sensitive to transportation because they can be affected by shocks and electrical discharges. As a result, the requirements for safe packaging and the use of Electro Static Discharge (ESD) materials are becoming more stringent.

As one of the lean manufacturing wastes, transportation can also present safety hazards to both operators and parts. To improve the transportation process, lean manufacturing principles and ergonomic requirements should be
considered. According to [1], lean manufacturing activities and ergonomic assessment should be initiated synchronously because workplace ergonomics and lean manufacturing are highly inter-related.

High-end server manufacturing produces servers that contain expensive parts and components. These parts and components exist in different buildings of the company and they have to be transported from one area to another. For example, raw parts are transported from the crib to the Fab test area. The parts are tested and then returned back to the crib. The tested parts are then transported from the crib to the manufacturing floor using carts. These carts are pushed manually and they should have inserts made of ESD material to protect the parts against electric discharging.

Many movements of electronic parts at the current high-end server manufacturing plant are performed every day and quality problems can be caused by improper transportation. This study focuses on improving the process of transporting electronic parts by eliminating/reducing quality and ergonomic risks and reducing the waiting time. Quality problems are minimized by means of redesigning the carts in a way that prevent operators from stacking the cards. Ergonomic risks are reduced by proper placement of the inserts in the carts. Waiting time is reduced by having separate carts in each area and redesigning the flow of carts within the plant.

The rest of this paper is organized as follows: Section 2 presents the problem statement. Section 3 discusses the literature related to lean and ergonomics and their integration in manufacturing systems. Section 4 introduces the proposed methodology and how it is applied in a server manufacturing environment. Finally, conclusions and recommendations are discussed in Section 5.

2. Problem Statement

Quality problems can affect the performance of high-end server manufacturing. Many of these problems are due to the transportation of parts between different places within the factory. This study focuses on the transportation of kitting parts and logic cards, given that an incident happened in the past and cost the company thousands of dollars as a result of poor design of transportation carts. New products are introduced every two years. However, most of the current and future servers are, and will be, configured with a new style of logic cards. The current transportation carts were not designed to handle the dimensions and potential quantities that force the operators to stack more than four cards high (see picture 1 and 3 in Figure 1). Stacking cards while they are transported contradicts safety rules and could cause defects for the cards. Furthermore, the teardown and Fab test carts could present some quality hazards for the cards (see picture 2 in Figure 1). The current design of the carts requires the operators to bend that may cause lower back pain to them. To address these problems, this study provides new robust and safe carts for logic cards transportation.

![Figure 1: Current transportation carts that present quality hazards to the logic cards](image)

Four lean wastes were identified:

1. Defects that could occur as a result of stacking cards and tipping hazard of poorly designed carts. Furthermore, stacking the cards could cause bending of the cart’s shelves.
2. Waiting time in the kitting area for the carts to arrive from the crib area. In addition, fulfillment assembly operators wait for the carts before building the servers.
3. Motion that is related to moving the carts from the crib to the kitting area. This could lead to more frequent backfills of short cards.
4. Transportation of carts with or without the parts. Ergonomic hazards are caused by the poor design of the carts that requires the operators to bend and exert pushing force to move the carts.
3. Related Literature
Several studies have discussed the considerations of ergonomic design of transportation carts to avoid quality and safety hazards. Incorporating ergonomics into engineering design was discussed in [2]. A hospital meal cart was redesigned by incorporating ergonomic principles and data [3]. The old conventional carts presented many issues to the operators including difficulty in setting the cart in motion and postural discomfort in shoulders, neck, back, lower back, knees, and feet. To eliminate ergonomic hazards, recommendations were made for redesigning the carts which include proper placement of handles, reducing cart height, use of plastic material, and emergency brake. A study was performed to quantify the excreted push force, trunk inclination, and lower back loading when pushing a four-wheel cart [4]. It was found that for ergonomic evaluation of pushing tasks, magnitude and direction of pushing force and trunk inclination should be considered. Ergonomic risks related to moving transportation carts in a grocery store were studied in [5]. Their study showed that an ergonomically designed cart with adjustable height had some potential to reduce ergonomic risks. Evaluation of ergonomic adjustments on pushing forces was investigated in [6]. Their study focused on the effect of pushbar and castor design of transportation carts and provided an ergonomically designed prototype to reduce the pushing force.

Integrating lean manufacturing with ergonomics could effectively improve work environments by minimizing both lean wastes and ergonomic risks. To date, a limited numbers of studies have considered this integration. The relationship between job characteristics and motivational outcomes in lean production was explained in [7]. Their study indicated that lean production job design might engender worker intrinsic motivation. The impact of lean production on working conditions was discussed in [8]. An assessment of a harvester assembly line was conducted based on interviews and collected data. Their results concluded that working conditions improved after lean production had been introduced. A management system that integrated lean management principles with occupational safety was proposed for a worldwide automotive supplier firm [9]. This study integrates lean principles with ergonomics to redesign the internal transportation in a server-manufacturing environment.

4. Research Methodology and Implementation
The research methodology consists of the following steps: (1) changing the kitting flow to reduce the distance traveled and the waiting time in the kitting and assembly areas by having separate carts for kitting parts and logic cards, and (2) designing new robust and safe transportation carts. In the first step, lean tools are utilized to identify and eliminate/reduce lean wastes including transportation and waiting time. In the second step, ergonomic principles are utilized to redesign the new transportation carts to eliminate hazards to parts and employees. The following sections discuss the two steps and the calculations of the required number of carts.

4.1 Eliminating Lean Wastes
As discussed in Section 2, four lean wastes were identified: defects, waiting time, motion, and transportation. Lean tools and techniques were utilized to eliminate or reduce the lean wastes. Process flow was used to map the path of the transportation carts and the total traveled distance was then calculated. The path of the carts was changed to eliminate or reduce the transportation wastes. Figures 2 and 3 illustrate the current and improved kitting flows, respectively. In Figure 2, parts are kitted in three areas and are then transported to the assembly line. The_kitted parts in area 2 are transported in dedicated carts to the assembly line. For areas 1 and 3, carts are shared and there is waiting time in area 3 for the carts coming from area 1. Backfill is performed when there is a shortage of parts in the assembly line. To reduce the waiting time and the transportation (and motion) wastes, the kitting flow was redesigned (see Figure 3). Waiting time in both the assembly line and kitting areas along with the traveled distance were considered. The total distance traveled for current and improved scenarios are compared in Table 1. The new scenario will result in 6% reduction in the total transported distance.
Table 1: Comparing total distance traveled for current and improved scenarios

<table>
<thead>
<tr>
<th>From</th>
<th>To</th>
<th>Total Distance (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area 1</td>
<td>Area 3</td>
<td>540 x 2 = 1,080</td>
</tr>
<tr>
<td>Area 3</td>
<td>Assembly</td>
<td>618 x 2 = 1,236</td>
</tr>
<tr>
<td>Area 2</td>
<td>Assembly</td>
<td>490 x 2 = 980</td>
</tr>
<tr>
<td>Area 1</td>
<td>Assembly (backfill)</td>
<td>1,158 x 2 = 2,316</td>
</tr>
<tr>
<td><strong>Total Distance</strong></td>
<td></td>
<td><strong>5,612</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>From</th>
<th>To</th>
<th>Total Distance (ft)</th>
</tr>
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<tbody>
<tr>
<td>Areas 2 &amp; 3</td>
<td>Assembly</td>
<td>618 x 2 = 1,236</td>
</tr>
<tr>
<td>Area 1</td>
<td>Assembly</td>
<td>1,158 x 2 = 2,316</td>
</tr>
<tr>
<td>Area 1</td>
<td>Assembly (backfill)</td>
<td>1,158 x 2 = 2,316</td>
</tr>
<tr>
<td><strong>Total Distance</strong></td>
<td></td>
<td><strong>5,868 - 0.25 x 2,316 = 5,289</strong></td>
</tr>
</tbody>
</table>

* The improved scenario has resulted in 25% reduction in backfill

4.2 Minimizing Ergonomic Risks and Safety Hazards

To identify ergonomic risks, digital human modeling using the Jack® software was performed. Safety hazards were identified based on visual inspection of the current transportation carts and by reviewing historical incidents. Transportation carts were redesigned to minimize quality problems and ergonomic risks. To eliminate the safety hazards on the logic cards that were caused by the stacking of the cards by operators, the transportation carts were redesigned in a way that prevents the operators from stacking more than four cards. Furthermore, an ergonomic modeling was conducted to ensure that the new designs meet the ergonomic standards. The new design prototypes are shown in Figure 4 where cart 1 is used for kitting area 1 and carts 2 and 3 are used for kitting areas 2 and 3.

Figure 4: Redesigned transportation carts

The inserts for carts 1 and 3 were also designed for logic cards (cart 1) and power cards (cart 3). ESD material is selected for the inserts to avoid the discharge of cards during the transportation. The insert prototype for logic cards is shown in Figure 5. The required number of transportation carts for the new scenario was estimated based on historical data, current number of carts used, and outcomes from the containment action that was implemented during the design stage of the new scenario. A total number of 39 transportation carts was required. With this quantity of transportation carts, 116 ESD inserts were needed. The new transportation cart for logic cards is shown in Figure 6. The new cart is designed in a way that prevents operators from stacking cards and minimizes the ergonomic risks. The cart has four ESD inserts. The bottom insert is used for wider cards that are ordered less frequently to minimize the bending by the operator. The top and the third inserts are used to transport lighter cards where the heavier cards are put in the second insert from the top to minimize the lifting force and the potential of lower back pain to the operators (see Figure 6).
The main differences between the old and new designs are summarized below:

1. The old design of the carts allows the operators to stack more than four cards high which violates the safety rules for stacking logic cards. In the new design of the carts, the operators have to put the cards inside the inserts (vertically) and this prevents them from stacking the cards.

2. The old design of the carts is not stable and this is supported by the fact that some carts flipped over in the past and caused damages to the carts. In the new scenario, the design team was involved to assure the carts are stable and the hazard of flipping over of the carts is minimized.

3. Ergonomic requirements were not considered in the old designs (see Figure 1) where the cards are randomly distributed among the cart shelves. When designing the new carts, digital human modeling and ergonomic requirements were considered.

5. Conclusions

Preventing quality hazards before they happen tends to be easier and cost less than treating them after they happen. Transporting electronic parts is one of the factors that affect their quality because they are sensitive to damages and discharging. Effective design of transportation equipment for electronic parts is necessary to reduce quality problems. In this study, lean concepts and ergonomic considerations were utilized for redesigning the internal transportation of electronic parts in a high-end server manufacturing environment. Lean wastes and ergonomic risks were identified and analyzed. The old transportation carts presented safety hazards to the electronic parts and ergonomic risks to the operators as well as waiting time in the assembly and test processes. The transportation flow was redesigned to minimize the waiting time and the carts were redesigned to eliminate safety and ergonomic hazards. The new design serves as a Poke-Yoke that prevents the operators from stacking cards.
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References