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Manufacturing System Improvement through Measurement and Redesign: A case study.

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Abstract:
Systematic improvement is a buzz word in the manufacturing world. Companies want to hear or know about how they can do one or all of the following three things: a) Produce more by keeping input at the same level, b) produce at the same level with a reduced input, or c) do both; that is, produce more with less input. The question often faced is whether this is possible. The answer to this question depends on the extent to which the company is willing to go to achieve its goal. In any of (a) through (c), many alternatives can be explored. These include productivity improvement through time study, ergonomics, and investment in new technology, worker's motivation, and attitude of the management towards productivity. All of these alternatives are not the same but they can be implemented individually or collectively.

This paper discusses how a student used the combination of time study and redesign to help a mid-size company improve its manufacturing processes. This effort ultimately resulted in improved quality and increased productivity of workers in a section of the company. It also reduced the amount of personal, delay and fatigue allowances of the workers.

Introduction
In the last decade, we have witnessed increasingly growing awareness of large-range planning in all sectors. Companies are more than ever concerned with long-term stability and profitability. In order to remain competitive, manufacturing facilities must be designed with enough flexibility to withstand significant changes in their operating requirements.

Productivity improvement means elimination of wastes and its precondition is the proper pursuit of goals. Manufacturing system improvement includes productivity improvement, work system improvement and work measurement with special elements of safety, health and comfort of the workers (see Figure 1).

There is absolutely no compromise among safety, health and comfort. They must all complement each other to achieve optimum productivity (see Figure 1). Safety and health deal with the work environment and comfort deals with work station. Human factors have been known to enhance long-term performance of workers and prevent them from being overly overwhelmed or fatigued. It is therefore highly imperative that men as well as machines be recognized as essential components of the system.

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As part of an effort to increase students hands-on experience in our engineering technology programs, this study at a mid-size company started as a basic class exercise for a student. The Initial assignment for the student was to spend a week with a manufacturing engineer at the

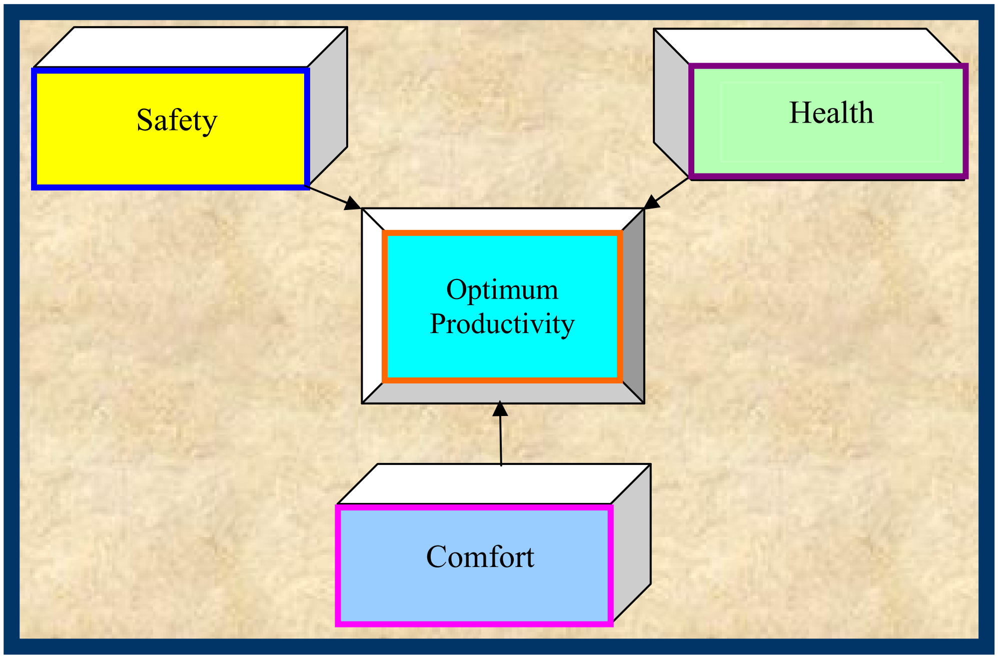

Figure 1: Productivity Elements

company to understand human performance at work. After the completion of the assignment, the student reported his findings. He noticed that the company was faced with the problem of reduced productivity, increased worker fatigue and absenteeism in a certain section of the company. The operation in this section of the company is a manual assembly that has shown significant inconsistencies in quality, and is plagued with persistent problems of bottleneck on a daily-basis. Historical data for the manual assembly unit showed significant inconsistency in the quantity of production on a daily basis. Also the workstation was inappropriately designed for productivity.

A proposal was presented to the company and was gladly accepted. The proposal was for the student to work on finding a solution to the problem. The company decided to ascertain the bottlenecks and develop solutions to minimize the problems that hinder productivity of the workers. Their goal is to find the most efficient way to meet certain daily production quota with the currently available resources. It wants to be able to produce 2,500 units in 7.66 hours. The objective of this study is to analyze and evaluate the system and then develop a better and a more efficient method of achieving this goal at the assembly unit with current resources. Other factors that are considered in this study are quality, reliability, longer life of the tools and ergonomics.

The student went back and worked full-time during the months of June to August. During this time he performed some time study of the operations in the section and obtained the anthropometric measurement of workers. By the end of August, he has collected enough data needed to develop a system improvement at the section. After August, he started working part-time on the problem redesigning and testing the design for effectiveness. In order that others may learn from the process, the student was constantly present the report of his process and findings as he went along.

It has been construed by some that the only way to achieve manufacturing improvement is to make things easier, better, faster and cheaper. While some of these may still be true, it should not be forgotten that cheaper does not always necessarily mean better. The question is:

- Can we achieve any or all of these multi-objectives without compromising the other? Or
- Can we assume that if the system is designed to achieve one of the objectives, it will or should ultimately achieve the others?

In the above situation, a combination of a little improvement in each of the elements provides better overall system improvement than a 100% improvement in one element.

In order to effectively develop or improve on any system, it is imperative that we are able to measure its current status. Identification of the basic technologies that determine all the manufacturing conditions necessary to produce all involved parts is also important. After understanding the current status and basic technologies, we must develop strategies that consider the fundamental improvement. This improvement must reduce things like setup times, distance traveled, amount of human intervention with the system, etc.

In designing and laying out workstations, efforts have been made in the past to define the relationship between ergonomics and work station design that provides optimum efficiency. Meyers and Stephens[3] refer to this relationship in terms of a golden rule that is to design the workstation to fit the person rather than an attempt to force the human body or psyche to fit the job. They assert that in order to achieve this simple, yet extremely important principle, one area of ergonomics (anthropometry) must be employed. When cost is considered, Meyers and Steward[4] explain that motion study can save a larger percentage of manufacturing costs than anything else we can do in manufacturing plant. However, the statement assumes the introduction of automatic machines with no consideration given to a manufacturing plant's ability or inability to afford the initial investment.

Chapanis[1] explains the use of link analysis which uses data from activity, task analyses, and observations of functional system. Their study addresses arranging physical layout of work areas to meet certain objectives. The method includes the increase of accessibility and reduction of total amount of movement. Wickens et al.[8] introduce and discuss the general principles for workplace design for standing and seated work areas where human variability is recognized. The method concentrates on the use of anthropometrics data to efficiently design and layout a workstation that enhances human-system interaction.

Analysis of Original layout

At the manual assembly station1 (see Figure 2), it is required to process the product from the empty-stage to a stage where it is moved through a conveyor to station2 for further assembly. More often the productivity has been observed to be unpredictable for various reasons ranging from the daily target set for the stator to technical and maintenance issues. Figure 2 shows the original layout of the workstation and the flow of parts within the work area.

The magnetic feeder feeds the turn table and jigs that has four fixtures. Assembler1 retrieves part from the turn table and assembles. From this point, the product moves one way from assembler1 along a conveyor in the direction of the arrow and goes to assembler2. Assembler2 in turn manually performs some assembly operations and sends it down to another process area (not shown in diagram).

During an initial analysis of the system, the following two problems became imminent; 1) excessive time was spent on handling and fatigue, 2) work area layout was not conducive to productivity. The layout violated the fundamental rule of productivity which states that a workstation design must consider the safety, the health and the comfort of the worker and sometimes the material or product being handled.

The space between and around the equipment, the height and width of passageways, the feet and the head are some of the problems often encountered in design. As can be seen from Figure 3, the operator remains in a standing position through out the entire process. There was no sufficient space to bend or move freely around. In the layout, some workers were unable to conveniently access the work area due to this lack of enough clearance. Therefore they have to assume awkward posture that has inadvertently led to discomfort and safety concerns. This has created a lot of stress and fatigue and hence less productivity.

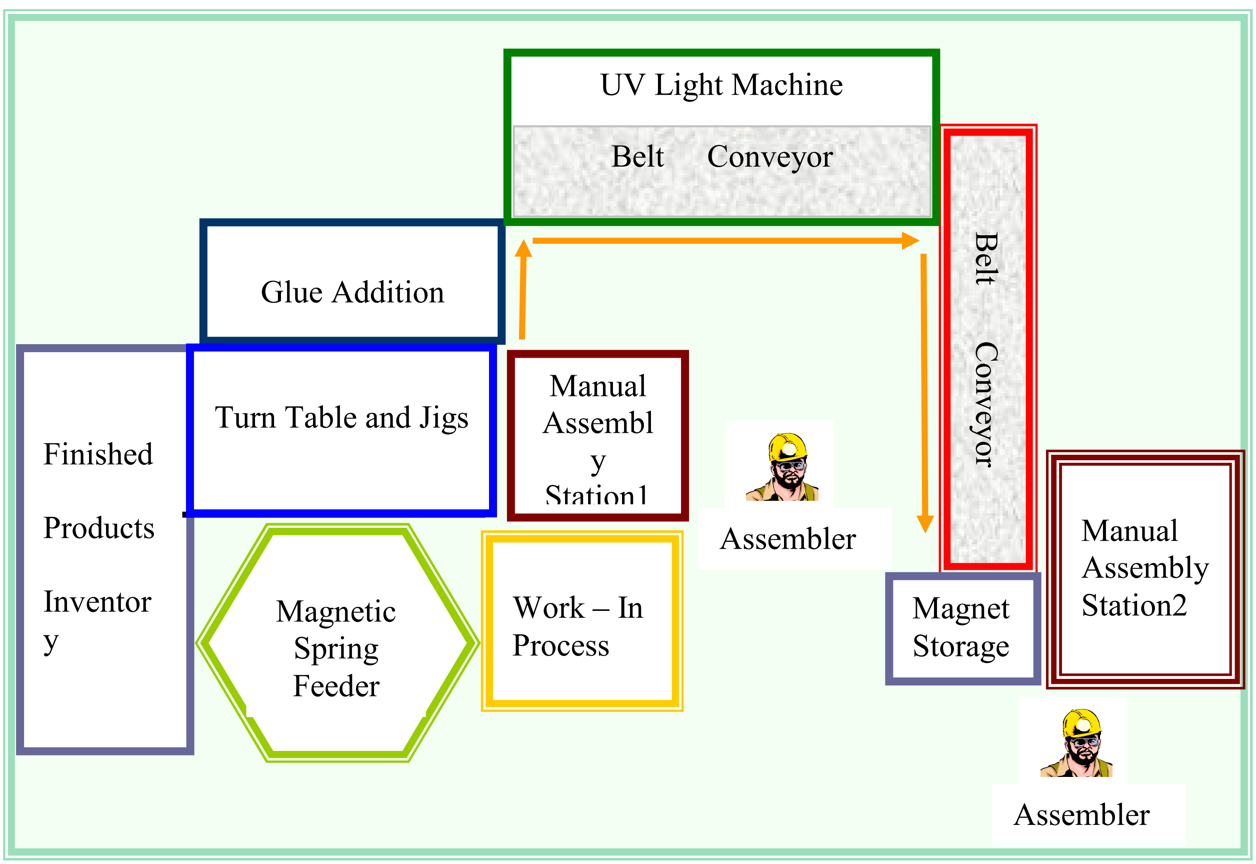

Figure 2: Original workstation layout

Figure 3: Pictorial view of original

In order to relieve the workers of some of the effects of the stress, they have to be moved out of the task every two hours. The reason for this movement was to reduce lower back pain and possible carpal tunnel syndrome. During the time study, it was discovered that not all the workers were equally qualified to work in the section. Sometimes a replacement was less experienced and thus and thus lowered productivity.

Solution Approach

In the study, the number of workers affected, and the kind of work being performed were considered. Also to achieve the company's objective, the following actions were taken.

Determining the standard time for an operator to perform a task.
Obtaining the expected quality requirements from consumer log book.
Taking the Anthropometric measurement of all personnel working in the area.

In addition, the following were also identified and documented.

- Number and sequence of operations leading to the final product for possible elimination of unnecessary steps (or combine some steps when elimination is not feasible) that will reduce handling.
- Delays, alarms, and bottlenecks. These will help in modifying or repositioning the available conveyor system.
- Maintenance activities and patterns of failure. This is for possible suggestions for a better maintenance system.

One big misconception that normally creates problem in workstation design is believing that the variability in human beings is so great that it cannot possibly be well addressed in any design.

Due to this believe, variability in humans has been of less interest for design purposes. In this study, the quantification of human variability was considered as an effective means of designing efficient workstation. The statistical mean of anthropometric data of all workers in the section was determined, and used as a predictor for people variables. Designing for clearances, reach, and strength using this statistical mean for the appropriate variable will result in accommodating workers in the section and many workers in other sections.

In order to achieve a proper design and layout that will address safety, health and comfort, all possible users were identified. Secondly, in order for safety concerns to be addressed effectively, they have to be transformed into tangible elements. These tangible elements were referred to as hazards. Several hazards scenarios were generated with different design options using the workers as the design appraisals. This is to enhance user involvement in the design and to effect user-centered design. Once all these were done, the final step was generating design specifications which must be met in order to eliminate the hazards.

Horizontal work surfaces are normally used by seated and sit-stand workers providing manual activities that are within convenient arm's reach. To design these work surfaces, knowledge of anthropometric measurement is imperative. Anthropometric data were used to develop design guidelines for height, clearance, and reaches of the workplace. It is also used for equipment so as to accommodate the body dimensions of current workers. Normal distribution was used with the dimensions based on one standard deviation below and above the mean measurement to accommodate any further variability among potential workers in the section. This sample mean is given by

$$\bar{H} = \frac{1}{n}\sum_{i=1}^{n} h_i \qquad (1)$$

where h_i is the height of the i^{th} worker and n is is the number of workers used in the sample. The standard deviation is given by

$$s = \sqrt{\frac{\sum_{i=1}^{n}(h_i - \bar{H})^2}{n-1}} \qquad (2)$$

The design layout involved the use of the sample mean in equation 1 and sample standard deviation, equation 2. The mean and standard deviation were determined for each of the variables height, grips and reaches. Other variables included in the design are the weight and body surface area. The weight and body surface area were used respectively to determine the type of flooring and clearances at the workstation.

A sample of 13 workers was used and some of the data collected is shown in table 1. Reach is determined by the farthest distance the operator can reach with only about 20^{o} of bending (see Figure 4) while standing comfortably in front of the machine and assembly table.

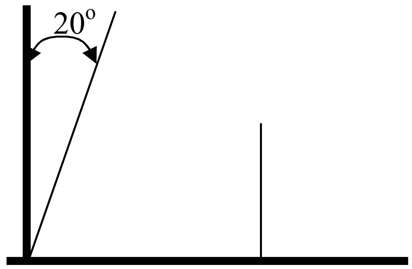

Figure 4: Degree of Maximum bend

Table 1: Anthropometric Measurement of workers

#	Height (Feet)	Reach (Inches)	
		Front	Side
1	5.58	18	24
2	5.67	18	24
3	5.8	20	23
4	5.83	21	24
5	6.00	21	26
6	6.17	19	26
7	5.67	17	23
8	5.92	17	24
9	6.00	20	22
10	5.83	20	22
11	6.17	21	23
12	5.75	18	22
13	5.70	17	22

The weight of the workers ranged from 159lbs to 321lbs. The height and the weight were used to determine the body surface area in equation 3 that accounts for clearance allowance of each worker around the workstation. The surface area from the DuBois formulas (Konz and Stephens)[2] is given by:

$$DBSA = .007184(HT)^{.725}\,(WT)^{.425} \qquad (3)$$

where

DBSA is the DuBois surface area in m^2
HT is the Height in cm
WT is the Weight in kg

Also, the "reach" element was incorporated by making the stator assembly station movable and the flooring adjustable for shorter workers. That is, it can be moved left and right (see Figure 5) to provide enough clearance for those with surface area larger than the one standard deviation below and above the mean. In the new design, an aisle by the section was reduced in order to maximize space utilization. The robotic arm on the machine was modified to pick four parts at a time. Four small tubes feed the product to the automatic gluing process at assembly1 station. The products are then moved onto the UV belt by the robotic arms. The belt moves to expose the glued part to UV radiation. The products are then collected by the robotic arm at the end of the glue belt and transferred onto a belt conveyor. The belt conveyor is situated at right angle with the UV belt connected to another work unit.

Unlike the old layout, the improved layout is laid out in a logical sequence where the part moves from one operation to the other automatically once it is fed into the jigs. In the old layout, crates were situated in an aisle towards the wall. The crates were brought to the workstation. About six crates were always fitted in the work area with parts stacked next to the operator. Depending on the operator, one, two or three parts are picked at a time. The magnets are stacked in front of the jigs. These are also simultaneously picked up by the operator.

One of the constraints and the problems with the old layout is the occasional overcrowding of the workstation with unnecessary tools. Another is the equipment that makes it difficult for the operators to work comfortably. This was remedied by reducing the space W_ I _ P bin and providing a storage rack in the area for tools. The clearance provided around the operator permits the installation of a swivel and an adjustable seat. The seat enables the operators to maintain sit-stand condition around the workstation and reduce lower back problems and carpal tunnel syndrome. Flooring at the place was made with flexible height by using adjustable platforms that operators can adjust to fit their needs in any given situation (sitting or standing).

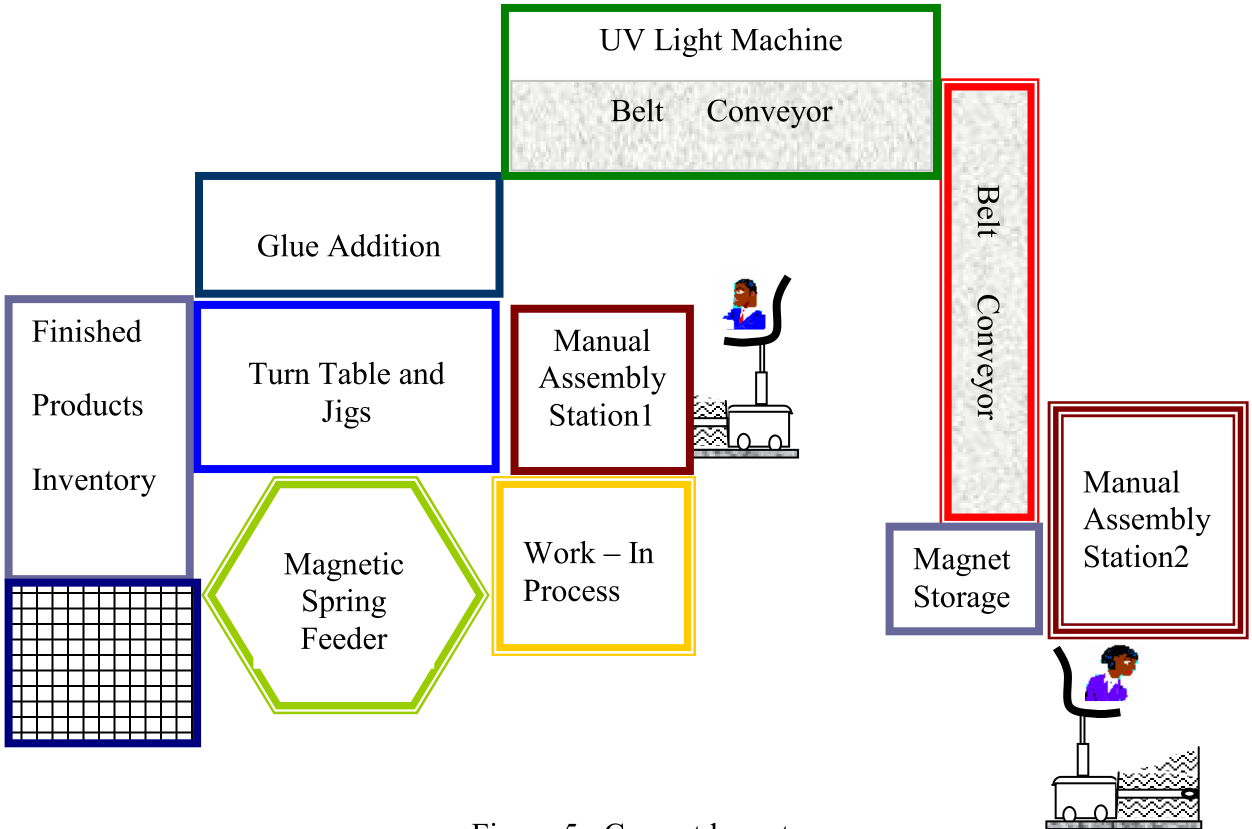

Figure 5: Current layout

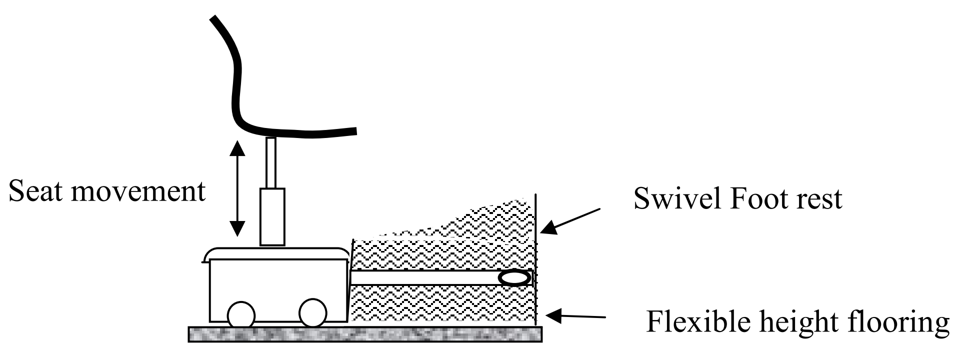

Figure 6: Adjustable operator station

Conclusion

In this study, instead of concentrating on only the reduction of the time to complete a process, the redesigning of the workstation became the focal point. Through this redesign of the workstation, the company has been able to achieve the required daily production goal of 2500 units in less than 7.3 hours. This was achieved with a reduction in the original standard time with no added resources.

The process was developed, implemented and monitored for a period of four months during which period all bugs were removed. This time study along with the analysis of the bottlenecks in the process helped in understanding the reasons behind the unpredictability of the process. In the original design, an operator works for two full hours in one position, standing and moving his/her hands in a preset motion. In the new (redesigned) workstation, an operator can work for as long as necessary without being overly fatigued.

The new work environment is safer than the original environment because of more clearance that allows the operator to move freely in the area. Also, before the redesign, the direction of the relative height for which the operation tables were designed was part of the problem. This has now been eliminated in the redesign and hence provided better reach. Flooring at the area was designed to be adjustable. This flexibility is designed to accommodate shorter workers and reduce cumulative trauma disorder.

Overall, the work ethics have improved and workers are more productive. Quality of product that was neglected in the past because of efforts to meet daily production quota has now improved. Workers do not have to exert additional effort to achieve this goal and they don't have to be shoveled between jobs.

A progress report of the project was constantly presented in the class together with a final presentation at the end. During each of these presentations, other students were given the opportunity to contribute by offering suggestions and criticisms. At the completion of the project, all the students in the class were transported to the plant to see the implementation of the actual improvement. The students were also challenged to present an improvement of yet this improvement. Each student presented their improvement on the last day of class for the semester. This exercise has made the students conscious of design environment and has increased their level of enthusiasm towards their own learning. It has also increased their creativity cognitive function, level of human relations and first hand experience with resistance to change, as well as how to make a constructive criticism.

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