Ergonomic Evaluation of Manufacturing System Designs

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Abstract
Using high-level, 3-D computer graphics simulation and other engineering analysis tools, this research investigates the ergonomic advantages of one manufacturing system design over another. The designs compared are lean manufacturing (manufacturing cells) and the functional (job shop) design. Simulation models based on an actual manufacturing cell and its workers are used to generate corresponding functional workstations with identically modeled workers. Three ergonomic areas—kilocalorie expenditure, potential for harmful postures, and potential for repetitive motion disorders—are analyzed from simulated and monitored data on energy expenditure, postures, repetitive motion, and other processing functions, such as cycle time. Initial research indicates a substantially lower risk from work-related injuries when using the cellular manufacturing design rather than the functional job shop design; thus, the design of the manufacturing system may inherently reduce or eliminate physiological problems before they develop. In addition, 3-D simulation software with ergonomic analysis functions is shown to be an extremely effective tool for the manufacturing system designer and the ergonomist.

Keywords: Manufacturing System Design, Ergonomics, Lean Production, Cellular Manufacturing, Physiology, 3-D Simulation

Introduction
This research sought quantitative evidence that the design of a manufacturing system directly affects the physiological and ergonomic functions of workers and shows how manufacturing system design can be developed concurrently with ergonomic and safety considerations. Computer simulation was the primary tool for the three-dimensional simulation and ergonomic analysis of two manufacturing system designs: lean manufacturing (cellular manufacturing) and the functional job shop design. Other industrial and manufacturing engineering analysis tools supplemented the graphical 3-D simulation analysis.

Manufacturing systems are considered essential by most nations for the creation of wealth; however, manufacturing systems are complex and require careful and considered planning to maximize profits while minimizing risk. Ergonomics is the science of the relationship between man and work and is loosely defined as "making the job fit the worker." Computer simulation, in particular, 3-D and virtual reality simulation, is the science of generating digital images of products, processes, and systems to study the relationships between these elements. Often these programs have various analytical tools built in.

Functional Design (Job Shop)
The traditionally designed functional job shop has been in use since the beginning of the First Industrial Revolution; in that era, it was necessary for machine tools and processes to be grouped according to type because of the overhead power system in use. Thus, different departments emerged, such as the turning department, the milling department, and so forth. The normal operation of a job shop dictates one worker per process.
Typically, functional job shops can produce a variety of products because of the high skill level of employees and versatile processes; however, most job shops are run by the push methodology, which requires extra inventory to be carried by the system. These very common manufacturing systems are batch-and-queue operations driven by labor/machine availability and schedules.

Figure 1 shows a typical layout of a small traditional manufacturing system. Figure 2 shows the same traditional system transformed into a lean manufacturing system composed of three manufacturing cells.

Lean Manufacturing Systems
The newest manufacturing system is Lean Production, which is specifically designed to con-
In a manufacturing cell, workers typically go with the material flow and move from process to process exchanging parts; that is, after the worker initiates the machine, the machine automatically processes the part and then turns itself off at the end of the process cycle. The machine tools in the cell are in-house built or modified single-cycle automatics.

**Comparison of Systems**

The issue then arises as to which manufacturing system design can provide the workers—internal customers—with the safest and healthiest work environment while providing the manufacturing operation with a system that is robust, flexible, economical, and profitable. These are two sometimes-conflicting goals.

Lean production is a manufacturing philosophy determined to maximize the two most valuable non-depreciable resources of every manufacturing organization—people and materials. The four fundamental attributes of lean production are: lowest unit cost, 100% good quality, shortest throughput, and flexibility (Black 1991). The normal goal of the manufacturing cell design is job enlargement, not job simplification, and the processes and controllers reflect that philosophy. Job enlargement—adding additional work tasks to the worker—lends itself to beneficial ergonomic effects.

Simulation software is a tool for the manufacturing engineer to use to model, simulate, and analyze a production system before implementation. Manned cells are important because manual work is...
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