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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-

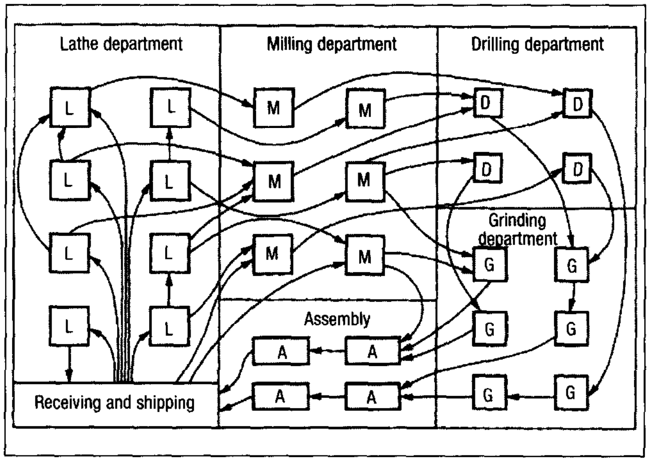

Figure 1
Traditional Functional Manufacturing System (Black 1991)

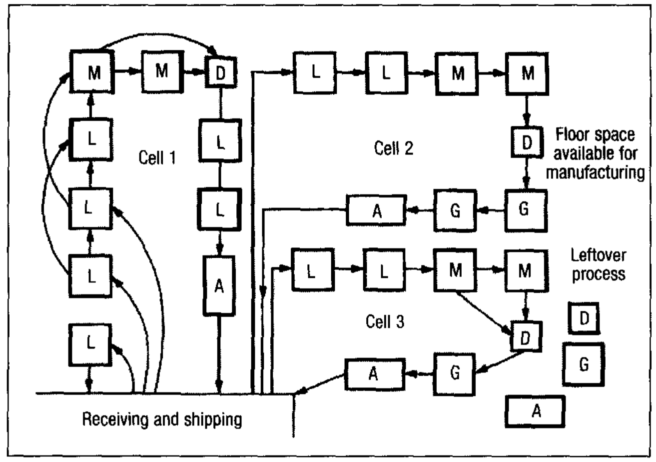

Figure 2
Three-Cell Manufacturing System (Black 1991)

tend in today's highly competitive manufacturing arena. Lean production is "lean" because the manufacturing system uses less of everything compared to traditional manufacturing system designs such as the traditional functional (job shop) design. Lean production uses less human effort, less manufacturing space, and less tooling, and less engineering time is required to develop a new product in half the usual time. The lean manufacturer keeps less than half of the needed inventory on hand and has much fewer defects while producing a greater variety of goods (Womack, Jones, Roos 1991).

The transformation from the Second Industrial Revolution, the era of mass production, circa 1913, to the Third Industrial Revolution started with the design and implementation of the manufacturing cell—the basic building block in the lean production scheme. A manufacturing cell is composed of dissimilar processes grouped together and operated by multifunctional workers who use the cell to process a family of parts. Manufacturing cells are typically laid out in a "U" shape. This configuration is best for a short walking distance for the standing, walking cell workers. This shape also encourages communication and conserves floor space. Material flow is downstream and information flow is upstream—the cell is designed as a pull system. The cell incorporates inventory and production control, quality assurance, continuous improvement, and preventive maintenance functions. The manufacturing cell has economy of scope; that is, the manufacturing cell has the ability to produce a wide variety of products at low cost (Black 1991).

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