IFAC MCPL 2007
The 4th International Federation of Automatic Control Conference on Management and Control of Production and Logistics
September 27-30, Sibiu - Romania

OPERATIONS RESEARCH TECHNIQUES FOR DESIGN AND ANALYSIS OF LEAN MANUFACTURING SYSTEMS

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Abstract: The paper focuses on Lean Manufacturing. The aim is to position Operations Research techniques from the perspective of optimal design of lean manufacturing processes. The developed methodology is based upon advanced line balancing methods and their coupling with process planning and equipment selection. An example of such a decision aid system is presented for the design of machining systems.

Keywords: Machining systems, Lean Manufacturing, Process planning, Line balancing, Operations Research methods.

1. INTRODUCTION

Lean manufacturing is a comprehensive process design and management paradigm developed by Toyota (Liker, 2003). Making a manufacturing system lean consists in cutting the "waste" in the manufacturing processes. Here, waste is anything that does not add value for the customers. Lean Manufacturing reflects a set of tools and methodologies that aims at the continuous elimination of all *waste*. The main benefits deal with decreasing production costs, increasing output and shorting production lead times.

Most of publications on Lean Manufacturing concern the management aspects (Imai, 1997; Pyzdek, 2001; Dennis, 2002; Dinero, 2005; Santos et al., 2006; Flinchbaugh et al., 2006; Hirano and Makota, 2006): 5S, Kaisen, Just-in-time (JIT), Total productive maintenance (TPM), the Six Sigma method, etc. Only few publications concern the design of lean manufacturing processes. Nevertheless, this is a crucial aspect for the success of a lean approach. Indeed, most of the waste can be eliminated at this step of manufacturing system life cycle by revealing & solving problems before production.

The literature mentions several types of wastes which can be reduced at the stage of the process design (Dolgui and Proth, 2006): *Over-production* which consists in manufacturing more than needed. *Waiting times* which includes the time semi-finished products are attending the next operation or the time that machines and / or workers incur waiting for the next work to carry out. Processing, if not carefully designed, may include *operations that* may be *too time consuming* or *excessively complicated*. Lack of processing efficiency refers to preliminary manufacturing design. *Excess of inventory* is expensive. *Unnecessary* worker *motion* leads to undue stresses that may result in product defects and workers' injuries.

Several paths are available to obtain a lean manufacturing system. The most important are: Eliminate activities that do not add value to the products; Reduce the manufacturing cycle; Improve the product flows by reducing the variability of flows and congestion on the shop floor.

Limiting the variability of flows can be achieved by:

- Reducing set up times and times required for maintenance while maintaining efficiency.
- Choosing a layout according to product flow in order to reduce transportation and handling.
- Decreasing shop floor congestion requires:
- Launching the production by taking into account the capacity of the bottleneck resource.

An efficient element of lean manufacturing is line balancing (Dolgui, 2006). The assignment of operations to stations and within these stations, to pieces of equipment, workers or robots should be done in such a way that all resources have the same workload. This guarantees a minimum of total idle time and a smooth flow of items through the manufacturing system. The payoffs are elimination of waste, reduction of WIP and floor-space, shorter manufacturing cycle times and lower production costs.

The remainder of the paper is organized as follows. Section 2 presents the general approach and principle steps of a lean manufacturing process design. The objective and methods of "Takt time" calculation are discussed. A process planning optimization procedure is suggested. Section 3 deals with a survey of Line Balancing approaches, some key approaches and challenging perspectives are explained. Section 4 provides an example of application lean techniques for machining environments. A decision aid system for the design of transfer machines (dedicated or reconfigurable) is used to illustrate these concepts. Finally, in Section 5 some concluding remarks are given.

2. DESIGN OF A LEAN PROCESS

The following schema for the design of a lean manufacturing process is suggested:

1. Takt time calculation
2. Definition of tasks (operations)
3. Choice of process plan
4. Line balancing (assignment of tasks to workstations)
5. Equipment selection
6. Simulation of flows
7. Cost calculation

"*Takt Time*" imposes the cadence of fabrication needed to meet customer demand. It is equal to the available work time divided by the customer demand.

$$\text{"Takt Time"} = \frac{\text{Operating time}}{\text{Customer demand}}$$

$$\text{Operating Time} = \text{Shifts} \times \text{Effective Time}$$

"Effective time" takes into account the shifts worked and making allowances for stoppages, for predetermined maintenance, and planned team briefings, breaks, etc. The customer demand includes anticipated average sales rate plus any extras such as spare parts, anticipated rework and defective pieces.

Definition of tasks (operations) is the next step. The operations that should be kept, are those with added value, i.e. the operation where the product value after the operation is greater than the product value before. For example holding and transport operations have no added value and should be reduced (or eliminated if possible). Of course, stocks are necessary, but stocks should be minimised.

Choice of a process plan consists in analysing several possible process plans and choosing the one which minimises cost and production cycle. Remember that a process plan is defined by a set of operations, their sequence and corresponding tools necessary to execute these operations. Usually, there are a great number of possible process plans. Graph theory approach can help the manufacturers to analyse the possible plans and optimise a given criterion.

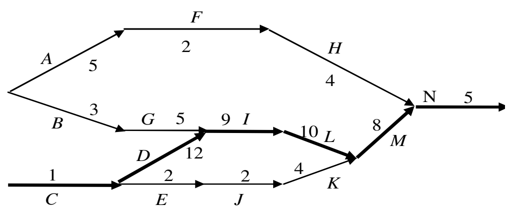

Figure 1: *An example of graph for manufacturing process analysis* (Dolgui and Proth, 2006)

Figure 1 illustrates an example of graph approach. In this graph the arc represents the operations and vertices the precedence constraints. The letters represent the names of the operations and the numbers are the operation durations. So to calculate the total production cycle, it is necessary to search for the critical path in this graph. To reduce the total *production cycle*, an aforementioned objective of the lean approach, it is necessary to diminish the durations of the tasks on this *critical path* (or even eliminate some of these tasks). Note that after the