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The Operations-Time Chart: A graphical tool to evaluate the performance of production systems – From batch-and-queue to lean manufacturing

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ABSTRACT

In this paper, we describe the spreadsheet modeling of manufacturing systems by means of the Operations-Time Chart (hereafter, OT-Chart), a graphical tool for an automatic time-phased representation and measurement of the operation of production systems, developed by the authors. In order to improve the design of a production system, it is necessary to know the key performance metrics of the system (productivity, lead-time, inventories, downtimes and wait times) and identify the effects of design parameters on system performance. Calculating some of these magnitudes can be very complicated, especially for production systems involving multiple and confluent processes, with different cycle times and lot sizes. The OT-Chart permits a visual tracking of the aforementioned parameters throughout each process, and like a simulation tool, the program calculates and displays the effects of changing input parameters. A special version of the Chart has been designed for lean manufacturing environments, where visual tools are much appreciated. The OT-Chart provides tracking of different types of waste and supports inventory supermarkets and pull scheduling. The paper includes a case study: a plant is redesigned from a conventional batch-and-queue production system into a lean manufacturing system with the help of the OT-Chart (it is used to test the performance of each layout) allowing managers to evaluate and refine their designs.

1. Introduction

For many companies, the key aspects of current competitiveness in order to raise customer satisfaction focus on delivery time, quality and cost. To attain and sustain competitive advantage, some companies have implemented manufacturing practices such as mass customization or lean manufacturing in search of more flexibility or agility (Fullerton, Cheryl, & McWatters, 2001). Lean manufacturing is known as the production of the necessary items in the necessary quantities at the necessary time (Womack, Jones, & Ross, 1990). Shah and Ward (2003) associate lean philosophy to improvements in "operational performance measures" that encompass the key aspects of competitiveness.

Ben Naylor, Naim, and Berry (1999) state that "leanness" means developing a value chain to eliminate all kinds of waste (activities that do not add value to the product). In consequence, lean thinking leads to the minimization of inefficiencies or *muda* as they are known in Japanese.

According to the philosophy of lean manufacturing, a major source of waste is work-in-process (WIP). Therefore the primary goal of a lean production system is to reduce manufacturing costs by cutting down the in-process inventory (Watanabe & Hiraki, 1997). In conventional production processes, inventories serve as a protective shield against the effects of many types of failures (machine breakdown, lack of quality, long machine setup time, etc.), and therefore inventories conceal such problems.

White and Prybutok (2000) state that although the high levels of inventory present in traditional production plants (as a result of large-lot manufacturing methods) allow greater flexibility for a wide array of products, this comes at the cost of efficiency because inventory covers up problems but does not solve them. Inventories imply an additional consumption of resources because they have to be managed, stored and manufactured. For this reason, lean manufacturing aims at efficient, well designed processes – with no imbalance or waste, with a minimized cycle-time, that operate with minimal transfer batches in order to achieve minimized inventories (Oliver, Delbridge, & Lowe, 1996). Besides, when inefficient activities are removed from the production process, WIP inventories originated by such activities are significantly reduced (Fullerton et al., 2001).

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2. The Operations-Time Chart: a methodology for the evaluation of process design

In the initial stage of manufacturing planning, different alternatives are examined. Manufacturing system modeling enables managers to predict the performance of the system and test how sensitive it is to design parameters (Koo, Moodie, & Talavage, 1994). According to Huettner and Steudel (1992) there are three possible approaches: Simulation, analytical methods (i.e. queuing models) and spreadsheet models. In this paper we describe a spreadsheet based graphical model.

The Operation-Time Chart developed by the authors (Fig. 1) is a graphical evaluation tool used in the design and improvement of production systems and related processes that allows companies to ask "what-if" questions about their systems without actually implementing, changing or disrupting the systems themselves. Thus, due to the complexity of most production systems, simulation analysis becomes a valuable tool for studying the system dynamics and its behavior (Denzig & Akbay, 2000).

The main objective of simulation tools is to observe the behavior of temporary entities (elements of a modeled system – i.e. manufactured parts in a production plant) and collect information on them. The authors designed the OT-Chart to represent the operation over time of complete production systems made up of parallel and confluent processes as a sort of simulation tool with a different approach than those of usual techniques such as discrete event simulation.

The OT-Chart displays the key parameters of a repetitive single product manufacturing system in response to a specific schedule under a push strategy (an MRP or EOQ-based system, where products are produced according to a schedule derived from estimated demand).

Since excessive inventory is considered to be a waste, work-in-process inventories are related to the efficiency of the entire system and therefore they must be taken into account in order to improve the design of the system or to compare two alternative configurations. For this reason, the OT-Chart calculates and displays the instant, average and maximum levels of work-in-process inventories.

After the basic OT-Chart, we also present a version especially designed for lean manufacturing systems under pull production scheduling strategies, since pull production planning is one of the cornerstones of lean management, where production is demand driven (Sakakibara, Flynn, Schroeder, & Morris, 1997). As one of the enablers of lean manufacturing is to decrease the time needed to change equipment for different production runs, users of the OT-Chart can choose the one-touch machine setup (OTED) option.

Finally, the OT-Chart for lean environments includes "supermarkets" or buffers of limited capacity that supply specific processes in order to control and level production when continuous flow from raw material to customers is not possible.

Although the OT-Chart is not a discrete event simulation package, as a time-phased analysis tool, it is used to test the performance of a process design, regardless of the complexity of its parallel and assembly tasks. Users may see and read where inventories build up and where and when workstations are idle. Users can trace the evolution of process metrics, since the development of the process is on the screen. This information helps them to evaluate new scenarios and implement processes that are more efficient.

Methodologies to optimize design, balancing and scheduling of production systems have been widely explored from the point of view of operational research by means of both analytical and heuristic procedures (Becker & Scholl, 2006; Ghosh & Gagnon, 1989; Linn & Zhang, 1999; Rekiek, Dolgui, Delchambre, & Bratcu, 2002; Scholl & Becker, 2006). The OT-Chart, like a simulation tool, may help researchers evaluate the goodness of their analytical/heuristic

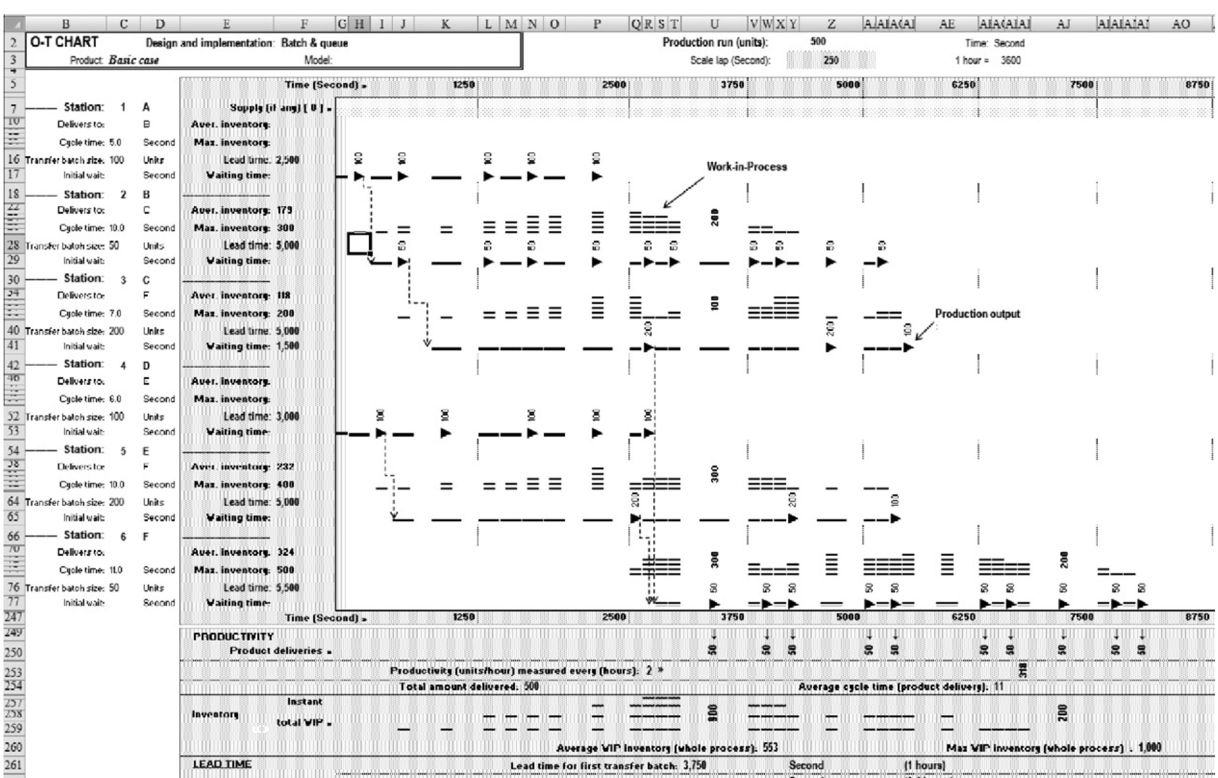

Fig. 1. OT chart applied to a set of simultaneous, sequential processes.