REVISITATION OF THE SIMULATION METHODOLOGIES AND APPLICATIONS IN MANUFACTURING

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ABSTRACT

Manufacturing is one of the largest application areas of simulation. For the purpose of understanding where, how and why the simulation is used in the manufacturing, this survey classifies the manufacturing system into two broad areas viz. manufacturing system design and manufacturing system operations. The two broad areas are further subdivided for this study. The survey discusses the evolution of the subdivisions before detailing the need of simulation in each of the sub divisions of the manufacturing systems. Finally, a discussion is made in order to understand where the research is heading for and identifying the future directions.

Keywords: simulation, manufacturing system design, manufacturing system operations

1. INTRODUCTION

Simulation involves the development of descriptive computer models of a system and exercising those models to predict the operational performance of the underlying system being modeled. Simulation has been one of the most widely used tools for manufacturing (Banks *et al.* 2005).

The basic components of manufacturing include product design, manufacturing/production, planning and control. The product design functions include, conceptualization, function identification, modeling and CAD, material selection, design for manufacturing and dimension and tolerance setting. The manufacturing operation includes processing, assembly, material handling, inspection and test. The planning function includes material requirement planning, capacity planning, process planning. The control function includes production scheduling, inventory control and tool management. For the sake of convenience, in this paper we consider the production, planning and control components all together as manufacturing operations.

Exact solutions are available for most of the manufacturing systems. In spite of it, simulation remains as a widely used tool in finding a solution to a problem. This paper focuses on the application of simulation technology to *manufacturing system design and manufacturing system operations.* System design generally involves making long term decisions such as facility layout and system capacity/configuration. As such, models are typically created and used for single design exercise, and model run time is not a significant factor during the simulation process (Smith, 2003). On the other hand *manufacturing system operations* focus on day-to-day activities within the company and are typically made by lower-level managers. Decisions made at this level help to ensure that daily activities proceed smoothly and therefore help to move the

2. MANUFACTURING SYSTEM DESIGN

In general, manufacturing system design problem (MSDP) encompasses the problem of facility location, plant layout, materials handling system design, assembly line balancing, and other ancillary functions necessary for the production of products. We discuss below the above sub divisions in detail.

2.1 Location Problems

The generic term of facility is used to denote a large variety of entities such as warehouses, plants, antennas, hospitals and other industrial or public structures. The problem is to choose a set of points where these facilities are located so that the sum of location costs and transportation costs are minimized and satisfy the needs of all or part of the customers. The complexity stems from a multitude of qualitative and quantitative factors influencing location decisions as well as the intrinsic difficulty of making trade-offs among those factors. In general, the location problems are formulated as un-capacitated facilities location problem or simple facility location problem and capacitated facility location problem.

The optimization problems defined above are mainly handled by deterministic and static approaches and these studies resulted in a number of valuable contributions to the area.There are a few studies such as, Hidaka and Okano (1997), Kurt and Scott (2007) that utilize simulation to investigate these trade offs. In general, the researchers employ the simulation tool to understand what if scenario. Simulation is used here either because data are not available or because of interactions that exist among many variables, such as customers, warehouse location, delivery time, transportation cost, fixed costs etc. involved in the decision making process.

2.2 Facility / plant Layout

Facility/plant design applications may involve modeling many different aspects of the production facility, including equipment selection/layout, control strategies (Push pull logic), material handling design, buffer sizing, etc. In general, the overall objective of facilities design is to get the inputs (material, supplies, etc.) into, through and out of each facility in the shortest time practicable, at acceptable cost. The material flow pattern becomes the basis for an effective arrangement of physical facilities. The facility layout problem is either formulated as a static layout problem or dynamic layout problems with optimizing the transportation or material handling cost as the primary objective. With this objective in mind different mathematical models have been proposed in the literature (Amine et al. 2007 and Balakrishnan and Cheng,1998). Simulation has found a large number of applications in the facility layout problems. Specifically, it is used for better understanding and visualizing the complexity of the problems as well as evaluating the system performance for alternative layouts. The complexity increases with increasing number of planning periods, stochastic flow patterns, stochastic demand patterns, unequal size of facility, different product mixes, etc. Some of the simulation studies that are found in the literature are Greasely (2008) and Harrell and Gladwin (2007). In these studies simulation is predominantly used as an interactive modeling and analysis tool to measure the performance of the system in terms of the work-in-process, bottlenecks, routing complexity, the machine setup, machine down time, capacity etc.

2.3 Material handling System Design

The material handling system includes two highly inter-related sub-problems: (i) design of the material flow network that provides the resource interconnections; (ii) sizing of the transporter fleet, and allocation of the inter-group moves to these transporters. Sub-problem (ii) vehicle routing problem.

The stochastic nature of some of the input factors such as demand, processing time, material flow, production schedules, travelling time, etc does not only increase the complexity of the problem but also necessitates a need for simulation or other stochastic optimization tools. Thus the material handling system design offers wide scope for simulation to test the different variables playing crucial role in the design of material handling systems and their interaction effect. The input factors (or variables) required for simulation of the material handling systems may be, the type of material flow, the type of material handling equipment, level of automation, machine schedules, shift patterns, the travelling distance, demand rate, desired throughput rate. Thus the material handling design offers wide scope for simulation to test the different variables playing an important role in the design of material handling system and also its interaction effects.

2.4 Assembly Line Balancing

Assembly lines consist of successive workstations at which products are processed. Workstations are defined as places where some tasks (operations) on products are performed. Products stay at each workstation for the cycle time, which corresponds to the time interval between successively completed units. There are a large number of methods proposed to solve these problems in practice. Bhattacharjee and Sahu (1990) discuss the complexity of the assembly line balancing problem. Some of the factors, such as, work content, cycle time, standard deviation of elemental times, TF-ratio, etc., which are responsible for the complexity of the line balancing problem, are identified and their effect on the complexity of the problem is discussed. Since the problem is NP hard, a number of heuristics are proposed to solve this problem (Sabuncuoglu, Erel and Tanyer (2000)). Boysen, Fliedner and Scholl (2008) provide a classification of ALB problems.

While the ALB problems are generally formulated by static and deterministic models, the stochastic nature of demand, the transport times, processing times, set up times etc. necessitates the tools such as simulation. Su and Lu (2007), Mendes et al. (2005), Bukchin et al. (2002), Hsieh (2002) propose simulation to obtain optimum results for ALB problems. The researchers predominantly use simulation packages to evaluate the performance of the system and identify bottlenecks.

3. MANUFACTURING SYSTEM OPERATION

Operational decisions focus on day-to-day activities within the company and are typically made by lower-level managers. Decisions made at this level help to ensure that daily activities proceed smoothly and therefore help to move the company toward reaching the strategic goals. Examples of operational decisions include scheduling, handling employee conflicts, and purchasing raw materials needed for production. System operation involves making decisions on a much shorter time schedule. As such, the model is generally used much more frequently, and simulation run time is a more significant factor in the software / package selection and model design process. The classifications made here for the purpose of study are operations scheduling, lot-sizing and operating policies such as push/pull systems.

3.1 Scheduling

Scheduling is the allocation of resources to tasks in order to ensure the completion these tasks in a reasonable amount of time.

The objective of scheduling is to determine the job schedules that minimize (or maximize) a measure (or multiple measures) of performance. Literature has shown that only a few instances of the scheduling problems as polynomially solvable. The majority of the problems are NP hard. Some of the recent literatures (Mejtsky (2007), Metan and Sabuncuoglu (2010)) are reviewed to understand the need of simulation in scheduling. The roles of simulation in these applications are: to test the proposed heuristics in different scenarios or operating conditions, estimate the performance of schedules, identify bottlenecks or critical resources in the schedules, and generate input data for other heuristic or meta-heuristic algorithms to arrive at an optimized objective function values. As stated by Sabuncuoglu and Goren (2009), the future applications of simulation in scheduling still lie in the area of estimation and testing alternative solutions or schedules generated by scheduling algorithms in stochastic and dynamic environments. Simulation will also be used to determine appropriate scheduling or dispatching policies for manufacturing systems. In the recent years, robust optimization and scheduling have become very popular. Simulation has a potential to be used as a surrogate measure in these applications.

3.2 Lot-sizing

The lot size is the amount produced for each machine set up or the aggregate order size. Two very important dimensions of performance relate to inventory levels and customer delivery performance. The objective is to minimize total costs for the planning horizon while satisfying all demands, without backlogging. The literature is replete with a lot of mathematical models right from linear programming, integer programming, branch and bound procedures, dynamic programming, exact formulations like Wagner and Whitin algorithm.

Karimi, Fatemi, and Wilson (2003) describe the eight characteristics that affect the complexity of the lot sizing problems. There are a number of review papers that study the lot-sizing under different classifications.

The roles of simulation in lot-sizing are: to develop the inputs for the heuristics, understand the bottlenecks, understand the different operating conditions, impact of scheduling, understanding the capacity constraints etc. The complexity is sought to be modeled and a robust approach is made to minimize the impact of uncertainties using simulation. Researchers in the future will concentrate more on doing robust design of the demand and integrating the lot sizing with scheduling as the work in this area is also limited, but the need is highlighted by many researchers.

3.3 Control Logic

In a typical manufacturing system a job moves from workstation to workstation. The control logic for managing this movement through the system can be based on push logic, pull logic or some combination. Special modeling features are required to accommodate each class, additional flexible constructs are required to represent the specific details and exceptions of the lower level control logic.

There are no known available mathematical formulations for the control logic. Simulation seems to be the best way forward to evaluate the performance of the system. The input variables for control logic required may be the set up time, the number of transporters, demand rate etc and depend on the model construct. Enns and Suwanruji (2006) have summarized one group of recent simulation studies comparing replenishment strategies. Time-phased planning, implemented using DRP and MRP logic, continuous-review reorder point and single-card Kanban systems. There are at least two types of performance measure of interest, one related to the inventory level and the other to delivery performance. A tradeoff between these two types of measure exists. Therefore the problem is one of obtaining the desired performance across multiple performance measures (such as inventory level and delivery performance) through the selection of multiple interacting decision variables (such as lot size, reorder point)

Some of the simulation studies that are found are Enns (2007), Jula and Zschocke (2005), Krishnamurthy and Claudio (2005), Treadwell and Herrmann (2005). Simulation is used here to understand the system performances with respect to capacity, storage space, number of transporters and simultaneously collect data for decision making such as prioritizing and routing depending on the replenishment rate based on delivery performance.

Loading of a facility requires complete tracking of all the resources and facilities, tracking of the schedule of the events to occur, the operator allocation and subsequent delivery of the material. Owing to its complexity of many interacting factor no results can be claimed as optimal. Optimizing a control logic phase of the manufacturing operations has immense scope of future research

4. Discussions and Future Directions

In this paper, the simulation studies in the manufacturing area are analyzed. A fairly comprehensive review is presented for the design and operational problems. The recent developments and applications of simulation are also discussed by identifying the future research directions.

This survey indicates that manufacturing is one of the prime application areas of simulation. At the same time, simulation is one of the indispensible tools for manufacturing. Design problems are usually viewed as tactical or strategic decision problems that contain lots of randomness. Hence, stochastic simulation with appropriate output data analysis is generally required to estimate the long term or steady state performance of the systems. The general purpose simulation languages available in the market place today are quite sufficient to answer the design questions. In these applications, simulation is mostly used in the off-line mode as a stand-alone decision tool to enforce the decisions made by analytical or other models. Since the time is not the main constraint in this decision making environment, computationally demanding simulation optimization procedures can be used to make better decisions. Because the implication of false or incorrect conclusions from a simulation study can be disaster for a firm which has to make long-term design decisions.

In contrast, operational issues span relatively short time horizons. Hence, deterministic simulation (or stochastic simulation with a few random variables) is normally sufficient. Output data analysis and other statistical issues are not the main concern in these applications.

Since for the operational problems, simulation is used as an on-line tool, its integration to the existing decision support system is an important issue. Depending on the type of the application, web-based and/or distributed simulations may also be employed to improve the effectiveness of simulation studies. Virtual reality is also a challenge for the real-time applications of simulation in future studies.

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