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Simulation optimization-based decision support tool for steel manufacturing

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ABSTRACT

To buffer against increasing global competition and variability in the price of raw materials, steel manufacturers continuously strive to improve operations and lower costs. In this research, we employ a simulation optimization approach to develop a decision support tool to aid in strategic and operational decision-making. Specifically, we investigate work-in-process inventory levels and potential manufacturing process modifications to reduce utilization costs. A simulation model captures the complex nature of the system while an optimizer searches the solution space and sends trial solutions to the simulation for evaluation. Experimentation suggests that significant daily cost savings are possible by modifying current inventory practices and production process capabilities. Overall, the work demonstrates the ability of the solution approach to analyze complex industrial systems and identify potential improvements in a short time frame.

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1. Introduction

Fueled by changes in government policies, labor relations, and industry structure, the steel industry has emerged with renewed vitality in the new millennium. Although growth has slowed due to the economic conditions of recent years, Bekaert et al. (2009) suggest strength of global steel intensity (the amount of steel needed per dollar of global GDP) will likely fuel growing demand for years to come. To remain competitive in the industry, which is subject to large amounts of variability in raw material prices and increasing global competition, manufacturers must continuously improve operations and lower costs. In such efforts, many firms implement lean practices and minimize work-in-process (WIP) inventories. While this approach may be beneficial with respect to reducing inventory holding costs, it can lead to production downtime if sufficient "buffer" stock is not available to shield against upstream variability in the manufacturing process. Thus, it is critical that manufacturing firms do not ignore the cost trade-offs which exist between holding inventory and process downtime.

Our research focuses on the development of a simulation optimization-based support tool to aid in operational decision-making in complex industrial environments. To illustrate the utility of the solution approach, we work with a steel manufacturing firm to investigate production strategies aimed at cutting costs. While we perform experimentation based on the facility under consideration, this work demonstrates that the general solution approach is likely applicable to other complex industrial environments; assisting firms to make strategic and operational decisions in reasonable time while accurately accounting for inherent system uncertainties.

Many researchers agree that simulation-based solution approaches are superior to analytic models for investigating complex stochastic systems (Wang and Chatwin, 2005). However, a review by Taylor et al. (2009) reveals that only 10% of simulation-based papers published from 2000 to 2005 address real-world applications. Furthermore, a survey by Semini et al. (2006) shows that very few simulation studies related to manufacturing system decision-making focus on primary metal industries. Thus, using the steel manufacturing facility under consideration as a testbed, we address this deficiency by employing a simulation optimization solution approach to investigate the impact of varying inventory policies on system performance as well as the impact of manufacturing process improvements in a steel manufacturing environment. Specifically, we determine key work-in-process inventory levels to buffer against upstream process variability while minimizing costs related to inventory holding and production downtime.

In this solution approach, a computer simulation model works in concert with a separate optimization component to search for high quality solutions. The simulation model represents the manufacturing process including structural, material/information flow, and logical considerations. The optimization component searches the solution space and dictates trial solutions for the simulation model to evaluate so as to measure solution quality. Moreover, the solution approach provides high quality solutions in a very short time with respect to the performance period.

The remainder of this paper is organized as follows. Section 2 reviews the literature pertaining to the use of simulation in manufacturing environments. Section 3 describes the production process and the objectives of the work. Section 4 details the

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simulation optimization approach used for the investigation. Section 5 presents experimental results and offers managerial insights. Finally, Section 6 summarizes the work and its utility.

2. Literature review

This research presents a real world application of simulation in the steelmaking industry as well as a solution approach applicable to other manufacturing environments. With very few works addressing simulation in primary metal industries (Semini et al., 2006), the conducted review focuses on the general use of simulation in manufacturing. Research addressing the application of simulation in manufacturing environments dates back to the 1960s. Most works fall into one of two categories based on the area of focus: manufacturing system design or manufacturing system operation. We now discuss relevant works in each category.

2.1. Manufacturing system design

System design typically involves making long-term decisions such as facility configuration or capacity. Models designed for such application are commonly developed for a single design exercise versus ongoing decision support (Smith, 2003). With respect to facility layout/design, Nandkelyar and Christy (1989) present a computer simulation model interfaced with an implementation of the Hooke–Jeeves algorithm to determine an optimum design of a flexible manufacturing system. Cash and Wilhelm (1988) develop a simulation model to assess the performance impacts of tool operating speeds, robot travel speeds, sensor capabilities, cell layout, and number of tools provided in a robotic assembly cell. Williams and Gevaert (1997) presents a discrete-process simulation analysis of proposed design modifications for the production system of an automotive supply company. The study unveiled several unforeseen dynamics that would result in less than desirable results and a decision not to proceed was made. Conway et al. (1988) uses simulation to investigate the effects that buffer size has on production rates in serial systems with stochastic processing times and machine breakdowns.

Aside from design of the physical system, simulation has been extensively used in investigating the effects of varying resource and logistic capacity. A SIMAN model was used in Park et al. (1999) to verify that sufficient production capacity existed at a recently built "All Activity Vehicle" (AAV) facility to meet a target output. Weston et al. (1999) presents an applied simulation study in which a Micro Saint model is used in conjunction with OptQuest^{TM} to answer "what-if" capacity questions posed by a microbrewery. A discrete event simulation is used in Chen et al. (2002) to determine the required capacity of logistics operations to allow continuous operations of a chemical manufacturing plant. Papanagnou and Halikias (2011) present techniques for simulation modeling of an aluminum coils production plant using Matlab software. Testing was performed with actual production data and used to predict the impacts of various resource levels on utilization and throughput. In Rajotia et al. (1998), simulation is used to validate the results of mathematical models for determining optimal fleet sizes of AGV's for a flexible manufacturing system. In Yücesan et al. (2002), a simulation model is integrated with a genetic algorithm heuristic to determine a resource configuration in a wood processing facility that minimizes cycle time. A solution yielding a cycle time reduction of 18% was obtained after evaluating less than 2% of the solution space.

2.2. Manufacturing system operation

System operation models consider short term aspects of a manufacturing system such as production planning, scheduling, and operating policies. In contrast to system design models, operation models are typically developed to provide ongoing decision support (Smith, 2003). Works within this area are typically further classified into planning tools, real-time control applications, and performance analysis applications. Pegels and Narayan (1976) presents a simulation study of a machine shop consisting of 69 work centers to be used as a short-term planning tool to evaluate various scheduling rules. More recently, Greasley (2005) presents a discrete-event simulation study of a gas cylinder manufacturing process to assist in production sequencing decisions. The use of simulation as a planning tool for reassigning varying skill personnel to tasks in a manufacturing system is discussed in Zülch et al. (2004). Mjema (2002) construct a SIMPLE++ simulation to study personnel utilization in a maintenance department of a steel product manufacturing company. The model incorporated work orders with different throughput times, personnel with varying skills, and different job priorities.

Real-time control applications seek to aid near term decision making in complex manufacturing environments. Son et al. (2003) present a structure and architecture of a simulation-based real-time shop floor control system for a discrete part manufacturing system. A component of the system is an Automatic Simulation Model Generator (ASMG) which generates an Arena simulation model based on a resource model and a shop level execution model. Perrone et al. (2006) describe an Arena-based simulation tool constructed for a steel making firm integrated with Excel which produces reports projecting system parameters such as queue lengths given inputs including open orders, and product/process characteristics. Rosen and Harmonosky (2005) proposes a discrete variable simulation optimization method which incorporates statistical knowledge of the response surface into a traditional simulated annealing algorithm. Testing of the method is based on a semi-conductor manufacturing process and obtains solutions equivalent to or superior to traditional simulated annealing in fewer iterations. In Sharda and Bury (2010), a simulation model of a chemical processing facility is developed and used for bottleneck detection under a current product mix. Generic construction allows easy modification to assess system changes as the product mix evolves. Quintero et al. (2010) details a hypothetical simulation model that integrates with other information systems in a printed circuit board manufacturing operation to assist in detection and elimination of quality defects. Greenwood et al. (2005) present a decision support system for production scheduling at a ship panel shop. Given a current workload and capacity, incoming orders are simulated in sequences following a set of common dispatching orders (e.g., shortest processing time). The best performing sequence with respect to a weighted multi-criteria objective is suggested for use. Chang et al. (2007) describe an application where a manufacturing system is simulated whenever a state change occurs such as a machine breakdown. Using current data, the system is simulated under the current state, and the output is used to suggest the best recourse action.

In Mendes et al. (2005), solutions of a simulated annealing heuristic seeking to establish demand dependent line configurations for a camera assembly process are passed to a simulation model. The simulation model is used to verify the performance of the solution with respect to flow time and utilization when system variability is considered. In Chin-Wen and Moodie (1989), a SLAM simulation model is used to verify the solution of analytical and heuristic solution approaches for production planning in a generic steel manufacturing setting. Caprihan and Wadhwa (2005) use simulation to study the impacts of information delays on the performance of a hypothetical semi-automated flexible manufacturing systems. Mehra et al. (2006) use simulation to determine the effects of batch size reductions in process industries. Results suggest that process industries can reap the

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