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Implementing a hybrid simulation model for a Kanban-based material handling system

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Abstract

Plant floor material handling is a loose loop in most assembly plants. Simulation offers a quick, controllable and tunable approach for prototyping complex material handling processes in manufacturing environments. This paper proposes a hybrid simulation approach, using both discrete event and agent-based technologies, to model complex material handling processes in an assembly line. A prototype system is implemented using a commercial multi-paradigm modeling tool. In this prototype, JIT principles are applied to both the production and the material handling processes. The system performance is evaluated and system optimization directions are suggested. The proposed hybrid modeling approach facilitates the implementation of a responsive and adaptive environment in that various "what-if" scenarios can be simulated under different simulation configurations and real-time situations.

Keywords: Agent-based systems; Material handling; Discrete event simulation; JIT; Kanban

1. Introduction

Manufacturing enterprises are facing a substantially more complex situation than ever before because of the unpredictable market demands, growing product customizations, and fluctuating production environments. In order to stay competitive in the market, the decision making processes need to have the ability to adapt to the changing environment and to handle the system complexity. The ability to make use of the system flexibility and to retain flexibility itself is a primary requirement for the decision tools to be effective [1].

Material handling deals with material-flow related processes, including material requirement planning (MRP), scheduling and control of transportation resources (including AGVs, forklifts, and personnel), delivery of materials, buffering, and optimization of materials. Material handling problem is easily neglected because most people think it is only an auxiliary process to production. From our observation, even in a well designed assembly line, when the whole line is optimized, including its layout, processes, batching, scheduling, and operations, material handling is still laid outside of the scope of control. In certain industrial sectors, material handling has been the major barrier that results in production breakdowns, low efficiency, and low performance of a production system.

As we all know the optimization of work-in-process (WIP) is a critical objective for a production system since it represents saving of money in the product flow. In similar views, the flow of parts supply, resource allocation, and buffer arrangement are also critical issues to be addressed before launching a production line. Kanban mechanism in the inventory management is applicable in this area since JIT principles in this scenario emphasize the delivery of right materials to the right place at the right time. Minimum and optimized material buffers are to be designed for individual assembly stations. Optimization of a production system, by itself, is a complex NP-Hard problem that is difficult to be solved using pure analytical/mathematical approaches. The targeted material handling system, which must be built on the basis of production, adds more unpredictable factors to the problem. Therefore,

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simulation has been by far the methodologies of choice in the majority of studies reported in the literature under the material handling topic [2].

Intelligent agent technology has recently been applied to material handling system simulations [3]. Since its emergence, agent technology has been widely recognized as a promising paradigm for the next generation of design and manufacturing systems [3]. Agent technology makes a perfect fit for modeling dynamic and adaptive manufacturing systems. In the past 8 years, we have developed agent-based technologies for manufacturing process planning and scheduling [4], shop floor control [5], collaborative product development [6], and inter-enterprise collaboration [7,8]. We have also completed an updated literature review on applications of agent technology to manufacturing in general [9].

In this paper, we propose a hybrid simulation approach to implement the material handling system simulation that combines both the discrete event (DES) and agent modeling approaches. To demonstrate the feasibility of applying agent technology to the simulation prototype, we constructed a discrete event model of a simplified pull production line and a Kanban based material handling system using AnyLogic^{TM} [10]. Taking advantages of this multi-paradigm modeling tool, we build agent models for a number of components (either moving or stationary) in the discrete event model. As a result, the intelligence, controllability, and adaptiveness of the whole material handling system are greatly improved through agent-based technologies. For example, the vehicle agent hooking on its vehicle entity in the discrete event simulation (DES) environment controls the routing, breakdown, and repair activities, no matter whether the vehicle is moving around in the plant floor or it is idle in the parking lot. Moreover, the scheduling of transportation Kanbans is accomplished though the negotiation between the Kanban scheduling agent and a number of vehicle agents. With such capabilities, the system is able to simulate various dynamic situations and get more accurate information of transportation resources in general.

The rest of this paper is organized as follows: Section 2 provides a literature review on Kanban systems simulation and hybrid simulation technologies. Section 3 describes specifications of the material handling system and identifies the need of a hybrid modeling approach and a flexible modeling tool. Section 4 presents a prototype DES simulation environment created for a simplified pull assembly line and a Kanban based material handling system with an emphasis on the agent-based modeling implemented on top of the discrete event models. Finally, Section 5 draws conclusions and suggests some future research directions.

2. Literature review

From the application point of view, in most manufacturing plants, material handling processes deal with material supplies in a supply chain or material inventories in an enterprise. The material handling problem we intend to address in this paper refers to material and parts supply and delivery accompanying with the main production line. This section presents a brief research literature review on Kanban systems modeling and hybrid simulation technologies.

2.1. Kanban systems and simulation

There are two types of production control systems, namely *push* and *pull*. MRP systems and Kanban control systems are the two most popular implementations of the push and pull strategies, respectively. Pull is essentially a *replenishment* strategy that was initially designed for manufacturing environments producing repetitive products with high volumes [11].

According to Köchel et al., Kanban research can be divided into two directions: *synthesis* and *analysis* [12]. The synthesis approach aims at designing a new Kanban system that fulfills predefined conditions. Analytical mathematical models are commonly used to make such decisions [13,14]. Various analytical, mathematical, or experimental models were proposed in the literature to address the Kanban allocation, planning, and control issues. On the other hand, analysis approaches deal with performance analysis of Kanban systems under different structural deviations. Typical measurements employed in analysis are throughput, WIP, buffer size, and average flow time.

Most searchable papers can be classified into the second category. Simulation has been by far the methodologies of choice in the majority of studies reported in the research literature of JIT systems [15]. Various simulations were done on Kanban-related topics targeting different purposes [16]. For example:

1. To study Kanban allocation problems, either for a fixed allocation of Kanbans [17–19] or a flexible Kanban allocation strategy [2,15].
2. To look at Kanban control issues in a Kanban-based system, such as Kanban sequencing [20,21], buffer capacity [22], control, and maintenance policies [23,24].
3. To conduct performance analysis studies of Kanban-based systems [25,26].
4. To compare the Kanban control mechanism with others, i.e. traditional push systems [11,27].
5. To combine the simulation with optimization approaches, such as analytical models [2], neural networks [28,29], and evolutionary algorithms [12,30].

However, the models used in the above Kanban simulation researches are all quite simple and far from reality. Different simulation experiments lead to different conclusions because of constrained experimental assumptions. From our investigation, we also found a few relatively complete developments toward realistic Kanban simulation systems. Early development includes a simulation