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Knowledge-based support for simulation analysis of manufacturing cells

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Abstract

Simulation is a widely used approach for assisting design and improvement of manufacturing systems. It is a complex activity and needs a great deal of human expertise. Since the knowledge of analyzing simulation output for decision making is not inherently captured in the simulation modeling methodology, a framework that integrates simulation and knowledge-based decision analysis is needed. In this paper, we develop a knowledge-based system that cooperates with simulation for improving the performance of manufacturing cells. Using Axiomatic Design as a guideline, a hierarchical knowledge base structure that corresponds to the decision process is built. Our proposed knowledge-based system consists of a set of facts and three levels of rules in a hierarchy that is consistent with the manufacturing cell system configuration. The system demonstrates the effectiveness of utilizing Axiomatic Design concept when developing a knowledge-based system. The results of an industrial study show that our method contributes to improving the performance of manufacturing cells.

Keywords: Axiomatic Design; Simulation; Knowledge-based system; Manufacturing cells

1. Introduction

A manufacturing cell is a cluster of machines or processes in close proximity and dedicated to the manufacturing of certain identified part families that share similar manufacturing requirements. To improve design and performance of manufacturing cells, simulation has become an effective method for its versatility in modeling complex and dynamic operations. Nevertheless, improving the performance of a manufacturing cell is still a complex activity that not only is time consuming but also demands much human expertise in its decision making. In addition, the skills required to conduct simulation studies correctly and accurately are not widespread [13]. By using knowledge-based system techniques, these skills and knowledge for the simulation analysis process can be captured in a computer. This calls for the need of a framework that integrates simulation and knowledge-based decision analysis. According to the simulation outcome, the knowledge-based system will assist the decision process for the improvement of the manufacturing cell performance. However, since human experts typically do not express their knowledge in a well-structured manner during system development, knowledge-based systems often suffer from

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the problems of poor structure, redundancy, and difficulty in maintenance [6,8,16]. To develop such a decision support system, a well-organized knowledge base structure that reflects how the human experts solve problems is essential.

To meet this critical need, our research aims at the following objectives:

1. To develop a knowledge-based system that cooperates with simulation to support decision making for manufacturing cell performance improvement.
2. To construct a knowledge base structure in assisting the systematic development of our proposed knowledge-based decision support system.
3. To demonstrate the effectiveness of the knowledge base for decision support of manufacturing cell performance improvement.

The research focuses on flow-line type manufacturing cells where parts travel from upstream to downstream workstations sequentially in a fixed route. Every workstation consists of machines, loaders (i.e. operators or robots), and a conveyor. The proposed knowledge-based system analyzes outputs from a simulation model of a manufacturing cell, determines whether the specified objectives are achieved, and identifies opportunities for improvement.

2. Related literature review

2.1. Simulation and knowledge-based systems

An effective approach for improving manufacturing cell performance is to develop a simulation model for testing and selecting the configuration that meets the desired objectives [2,18]. The primary objective faced by engineers is to obtain a superior solution by analyzing manufacturing cell simulation outputs that include throughput, utilization, time/number in queue, and time/number in system [9]. Based on this analysis, engineers would improve the initial system by changing certain parameters, such as number of machines, speed of robots or conveyers. This process repeats until satisfactory results are obtained. However, even the procedure of analyzing simulation results could rely on various guidelines and rules, the decision making still requires significant human expertise and computer resources. To use simulation efficiently in the decision process, the integration of knowledge-based systems (also termed as expert systems) with simulation has been emphasized [4,9,10,13].

O'Keefe developed a taxonomy for combining simulation models and knowledge-based systems [10]:

1. *Embedded model*: The simulation may be embedded within a knowledge-based system, or vice versa. A knowledge-based system sometimes needs to run a simulation to obtain results for the users. On the other hand, a simulation model may need heuristics for choosing parameters during the execution.
2. *Intelligent-front-end model*: A knowledge-based system functions as an intelligent interface between the user and a simulation package. It generates necessary instructions, executes the simulation, and interprets the results to the user.
3. *Parallel model*: The simulation and the knowledge-based system are designed, developed, and implemented as separate software in parallel. Additional links are built for their communications.
4. *Cooperative model*: The simulation and the knowledge-based system cooperate in performing the task and sharing the data. The user is able to access both the simulation and the knowledge-based system sequentially or concurrently.

In the first three models (embedded, intelligent-front-end, and parallel models), the user interacts with only one tool (either simulation model or knowledge-based system). For instance, Ford and Schroer [4] developed a system that combines a knowledge-based system with a commercial simulation language for simulating an electronics manufacturing plant. Their efforts focused on providing a natural language interface so that decision-makers do not have to learn the simulation language. However, natural language interface is not necessary for the engineers if they could acquire knowledge and skills in simulation.

In the cooperative model, the user could interact with both simulation and the knowledge-based system. Sagi and Chen [11] proposed a framework that integrates simulation, neural networks, and knowledge-based system tools for manufacturing cell