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主　論　文　の　要　旨

論文題目

Simulation Analysis of Work-In-Process Inventory Control for Discrete Manufacturing Systems

(生産システムにおける仕掛品の在庫管理に関するシミュレーション分析)

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論　文　内　容　の　要　旨

1. Research Objective

Under the modern discrete manufacturing mode, the multi-variety and small-batch production system satisfies the requirements of the diversified demands of consumers, rapid responses to market needs and high core competitive advantages. Especially, in this production system, tightly coupled cells are widely applied to improve production flexibility and precision and reduce manufacturing costs. However, the complexities and randomness of manufacturing system can lead to the ineffective control of multiple tightly coupled cells, resulting in high WIP levels and a high “block”/“starvation” frequency. Moreover, unreasonable WIP management extends production cycle times, decreases market responsiveness and causes system instability. Additionally, green production and reducing environmental impacts have been increasingly considered part of sustainable development practices. However, in the current manufacturing mode, because of the complex nature and randomicity of WIP inventory control, high WIP levels can not only affect productivity but also cause environmental costs as a result of inefficient WIP control. Owing to high WIP levels, overstocks of unnecessary materials and intermediate products are often produced, causing huge material waste, idle energy consumption, idle processing cost and stock scraps, which have substantial negative environmental burdens. Two aspects above of production capacity control and production environmental impact analysis are emphasized. Specifically, important issues in developing a WIP control strategy are achieving a lower WIP inventory level, higher productivity and better environment-oriented eco-efficiency performance. Therefore, the final goals for this dissertation are as follows: production cycle time is reduced, system bottlenecks are eliminated, and the production operation capacity is improved while saving manufacturing resources and minimizing the negative environmental costs and burden by effectively controlling WIP inventory at a reasonable level. To overcome the urgent control issue, these eight chapters are structured to study the corresponding problems in detail.

2. Research Structure and Contents

This dissertation is organized as follows:

Chapter 1, after reviewing the development history and previous research background of the current discrete manufacturing system and inventory management and control, this chapter proposed two research problems regarding WIP inventory management: production capacity control and production environmental impact analysis. Aiming to resolve these two problems, two main objectives, four related sub-objectives and corresponding evaluation indexes are proposed to maximize economic efficiency and ecological environmental benefits that not only obtain production profits but also contribute to the environmental harmony of a sustainable eco-society. The relationship among objectives and sub-objectives are also illustrated, which are studied and achieved in the corresponding chapters. Additionally, a research structure involving different chapters of this dissertation is overviewed.

Chapter 2, this second chapter presents a general overview of some main issues and analytical approaches in WIP inventory control (i.e. Finite WIP Buffer Capacity and Block, Bottleneck Analysis, CONWIP, Production Lot-Sizes Determination, and Pull/Push System) and illustrating three main methods (i.e. Fuzzy Control, Material Flow Cost Account and Simulation Modelling) applied in this dissertation. The application principles and functions for these control issues and methods are also reviewed and improved to efficiently control WIP inventory level, shorten production cycle time, break existing production bottlenecks, strengthen productivity and improve the environmental effects of products and production processes.

Chapter 3, the related approaches and cases studies are generally reviewed which are aiming to resolve problems of WIP control policy using unreliable production systems and focus on various aspects of these systems. Based on the system operation characteristics, research objectives and control issues presented in chapter 2, two types of relative literature on WIP control is reviewed. First, the literature describing the aspects of system control and modeling strategy are discussed, which involves five parts: queue modeling, finite WIP buffer control, CONWIP control, production lot-size determination and environmental eco-control.

Second, the literature concerning optimization methods, specifically heuristic algorithms, fuzzy control methods and simulations, is considered. These two research areas comprise the literature reviewed in the corresponding sections of Chapter 3. These previous and current researches result many successful applications and provide beneficial suggestions for WIP control for this dissertation.

Chapter 4, this chapter, aiming to resolve problems in a multi-variety and small-batch production system with one tightly coupled production cell, has developed a distributed fuzzy controller. It is used to maintain the WIP inventory and cycle times at a low level by checking the inventory levels of distributed WIP buffers and dynamically adjusting the processing rate of each workstation. According to the surplus-based system, using correction factors makes the dynamic real-time WIP inventory level changes close to the hedging point and maintains system stability. The advantage of this two-dimensional fuzzy controller is that it can provide a supervisor group with a control policy based on simple representations and linguistic IF-THEN rules. A VBA module operates all fuzzy calculations for each distributed workstation in the simulation model. By analyzing a system bottleneck tightly coupled cell, a proposed optimized method, which integrates a “Pull”/“Push” mode and fuzzy method, is embedded into the discrete simulation model by fixing specific major stochastic factors. An AS-IS model joined with a TO-BE model provides remarkable control ability for WIP and enhanced cycle time. Noticeable performance improvements and robustness are achieved with this model. This fuzzy control policy thus represents a successful approach to reduce WIP and shorten cycle time for this modern production system. Consequently, it is also demonstrated that the Sub-objective 1-1 proposed in Chapter 1 is achieved.

Chapter 5, the present study, aiming to resolve production problems in a multi-tightly-coupled-cells production system, has developed a hybrid control method and a corresponding centralized hybrid controller. These tools are used to eliminate system bottlenecks and maintain the WIP level and cycle times at low levels by checking the inventory levels of WIP buffers and dynamically adjusting the processing rate of distributed workstations. To effectively resolve current problems caused by unreasonable control of tightly coupled cells in this case, by analyzing the system characteristics, the proposed optimized approach is designed as a hybrid control method with a mixed Pull and Push mode, which divides the system into multistage CONWIP cells and other production cells. It applies the JIT operation ideology and easily monitors the dynamic parts process in a production cell. To execute this optimized control idea, the corresponding centralized hybrid controller is developed, which include two parts: a switching control mode and a fuzzy control mode with a self-correction factor. According to the surplus-based system, this hybrid controller makes the dynamic real-time WIP level changes close to the hedging point and maintains the system stability. The merit is that this system utilizes the superiority of fuzzy control, satisfies multiple conflicting criteria, and has a rapid response ability to obtain a reasonable control policy. In the TO-BE simulation model, a VBA module operates all calculation processes for the optimized method. Compared with the AS-IS model, the simulation results presents that TO-BE model provides a remarkable control ability to reduce WIP and cycle times. As illustrated in previous sections, the present study improved the method used in a previous study in Chapter 4. By comparing the NM and OM models, noticeable performance improvements, rapid response and robustness are achieved with the optimized control method proposed in the present study. This approach thus more successfully improves production capacity, reduces WIP inventory and shortens cycle times for a modern production system. Consequently, it is also demonstrated that the Sub-objective 1-2 proposed in Chapter 1 is achieved.

Chapter 6, an AS-IS model is constructed to simulate the Pull production mode and back scheduling for a case study of a multi-variety and small-batch production system. By analyzing the simulation data from running the AS-IS model, substantial WIP overstocks and idle processing are traced in the production system owing to the current unreasonable production lot-size determination. Moreover, overdue WIP overstocks and defective WIP intermediate products are scrapped in abundance, causing a huge environmental burden that is ignored in conventional cost accounting. However, the effectiveness of a new environmental accounting method called MFCA is confirmed through the construction of an AS-IS-NC simulation model introducing the MFCA concepts. Based on MFCA, the abandonment of the dead WIP stocks, useless materials and idle processing are reflected as the generation of negative products cost in terms of monetary units, which are invisible during production. Additionally, as analyzed in section 6.3.1 and 6.3.2, after comparing the AS-IS-NC model and the AS-IS model, substantial WIP inventory level, huge negative products cost and environmental cost caused by the current production lot-size determination policy are identified. Moreover, through running several different simulation scenarios, two sensitivity analyses are obtained to analyze the changes in the negative products cost as a result of regulating the production lot-size. After observing the characteristics of similar cycle curves with gradually regulating the production lot-size, two regular changes in negative products cost and the corresponding percentages for the unit part are presented. These change trends provide production managers with effective and strategic knowledge or instructions for determining appropriate production lot-size to maintain a low WIP inventory level and for considering both economic and environmental benefits. Consequently, it is also demonstrated that the Sub-objective 2-1 proposed in Chapter 1 is achieved.

Chapter 7, a centralized fuzzy control methodology is used to control the change of WIP inventory level, and MFCA is adopted to calculate system environmental cost by adjusting production capacity. According to comparison results in section 7.4.3, it is easily seen that the centralized fuzzy control methodology can exactly simulate WIP control by on-site operators. Also, it can adjust production ratio according to the WIP inventory level to balance production line and increase production capacity. For the MFCA, this method can be used to calculate environmental cost hiding in the production processes by the simulation for each process. Additionally, through sensitivity analysis with regard to three factors, t, $g(y)$ and $F(X)$, it can be found that the fine increment or decrement change of each factor can lead a relative big change of R. Additionally, the sensitivity analysis can also make a fast search route to get the optimal solution by Optquest software package. These change laws of sensitivity analysis as well as the optimal solution give the managers and worker on-site an easy and effective control method of WIP inventory level to achieve a good performance considering production capacity and environmental cost. Comparing with three models (AS-IS model, TO-BE model and optimal model), a conclusion is made that the methods for controlling WIP applied in this Chapter really improve the production capacity as well as reduce green manufacturing cost that it is a scientific issue proposed in section 7.1 and have achieved the Sub-objective 2-2.

Finally, the contents of each chapter are reviewed respectively. The conclusions corresponding to the different main objectives and sub-objectives are presented in the chapter 8. The special performance evaluation indexes for different objectives proposed in chapter 1 are achieved. The academic contributions of this dissertation in the WIP control and management filed are also obtained. Additionally, implementation steps, principles and key points of the main applied methods, fuzzy control and MFCA, are discussed and developed. Furthermore, for the two aspects of production capacity control and production environmental impact, the suggestions and study directions for the corresponding further research are provided.

3. Academic Contributions

[1] Fuzzy control method is applied to study a classic discrete system and various stochastic factors are considered. However, in previous studies, the continuous system mode and only two random factors (machine failure/repair probability and demand change) are focused on. This dissertation thus expands the application field of fuzzy control in the production research, and also improves system complexity.

[2] A simulation method integrating hybrid control mode is structured to analyze the tightly coupled production cell. It can provide some new method to consider finite WIP buffer control and CONWIP management.

[3] In a multi-variety and small-batch production system, the environmental effect of WIP management is considered. MFCA method related to environmental protection has been developed to improve economic efficiency while reducing environmental burden. This study opens up a new vision angle for the WIP control.

4. Future Research

[1] For manufacturing system, the impacts on fuzzy control parameters coming from the various random production control factors will be considered in the future. Additionally,

for Fuzzy control method, simulation modeling integrating intelligent algorithm will be applied to study reasonable control parameters in the future researches.

[2] For manufacturing system, the determination of delivery time and dynamic order decomposition mechanism will be studied to provide a reasonable decision-making policy for environmental consideration. Furthermore, for MFCA method, future study will integrate other appropriate optimal methods to improve MFCA for resolving problems rather than indentifying problems.