博士論文(要約)

Efficient Buffer Design of Production Lines Based on Modular Queues

(モジュラーキューに基づく効率的な
生産システムのバッファ設計)

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1 Introduction

1.1 Background

Buffer design is an important but very difficult research issue for the design, optimization and management of production lines. In the thesis, two problems are solved in the buffer design of production lines. One is the buffer topology network layout problem that refers to obtaining a buffer topology network of a production line with proper designed buffers required to meet some specific objectives. The other one is the buffer allocation problem that refers to allocating proper buffer size into the production line to satisfy some specific objectives. To evaluate the effectiveness of the buffer design solution, a performance evaluation methodology such as a throughput analysis methodology is also developed.

Agile manufacturing is to respond quickly to customer and market needs. Agile design that serves for agile manufacturing requires a quick buffer design process to estimate the potential success and values of a production line design plan. Therefore, it is necessary to decrease computation time of the throughput analysis and the buffer design of production lines.

1.2 Related research

Former studies mainly focused on the solution quality that refers to closeness of the throughput measurements to theoretical values for the throughput analysis and the number of design buffers required to realize a specific throughput value for the buffer allocation. The high solution quality is useful to reduce manufacturing costs of a production line while meeting design requirements. However, the high solution quality usually means a long computation time. In agile design, short computation time with acceptable solution quality is more important for the rapid estimation of a production line design plan. Few former researches are related to decreasing computation time of the throughput analysis and buffer allocation that can be used in the agile design. According to my best knowledge, there are no former researches that are similar to the buffer topology network layout in the thesis. An efficient buffer design methodology and an efficient throughput analysis methodology that achieve a good balance between solution quality and computation time have not been proposed. Moreover, different production line topologies increase the difficulty for the throughput analysis and the buffer design of a production line. Therefore, solution applicability whose objective is to make the throughput analysis and the buffer design be applicable to production lines with serial, merging, splitting and recirculating topologies should be also improved for practical application.

1.3 Research purpose

The study purpose of the thesis is to propose an efficient buffer design approach and an efficient throughput analysis approach that is used to evaluate the buffer design solution based on modular queues.

In the thesis, the following approaches are taken to solve the challenging points:

1) As for the efficient throughput analysis approach, I solve the efficient throughput analysis problem by a decomposition method. I define queue modules which are decomposition models with standardized structure and

the decomposition regulation based on the queue modules, which decreases the decomposition time and makes the decomposition applicable to production lines with various topologies involving serial, merging, splitting, and recirculating topologies. To decrease the manual calculation time of solution equations of the queue module state probabilities, I prepared a queue module database consist of solution equations of state probabilities of common queue modules in advance to automate the calculation process of the queue modules. An iterative approximation method is improved to iteratively calculate the state probabilities of the queue modules including not only serial but also merging and splitting structure until the throughput of a production line is obtained. The improved iterative approximation method can obtain the throughput of a production line quickly with acceptable solution quality.

2) As for the efficient buffer allocation approach, I propose a bottleneck indicator to predict the real bottlenecks as suitable buffer updating locations, which facilitates the rapid buffer allocation by avoiding invalid buffer allocation attempts. The proposed bottleneck indicator is applicable to serial, merging, splitting, and recirculating production line topologies. Moreover, the variable neighborhood search algorithm is used to avoid local optimal buffer allocation solutions and maintain acceptable solution quality. Finally, the proposed throughput analysis approach is adopted to evaluate the effectiveness of candidate buffer allocation solutions.

3) As for the layout approach of buffer topology networks, I propose the classification method based on principle of mutually exclusive and collectively exhaustive by which commonly used buffer topology networks are divided into four groups. Four buffer topology networks that represent the four groups are used as candidate buffer topology networks in the proposed layout approach. This decreases the number of candidate buffer topology networks and computation time of the layout. The best buffer topology in the four candidate buffer topology networks is detected based on the proposed throughput analysis approach and the proposed buffer allocation approach.

2 Throughput analysis approach of production lines

Analyzing throughput is very important for the performance evaluation of production lines. In this study, an efficient throughput analysis approach is presented for production lines with serial, merging, splitting, and recirculating topologies. In particular, I define queue modules that are decomposition models with standardized structure and the decomposition regulation based on the queue modules, which are used for the decomposition of various production line topologies. By the queue modules, the decomposition process of a production line model can be accelerated, and computation time is decreased. By iteratively calculating state probabilities of the queue modules, the throughput of production lines can be obtained. To decrease the computation time and automate the calculation process of the queue module state probabilities, the queue module database that includes the solution equations of common queue module state probabilities is built. Moreover, an iterative approximation method is improved for calculating and iterating the queue module state probabilities in production lines with serial, merging, splitting and recirculating topologies until the throughput is obtained. Numerical examples show that the proposed approach calculates the throughput of production lines with merging, splitting, and recirculating topologies rapidly (completed in 600 s) with acceptable solution quality (≥90%). The contribution of the study is the efficient throughput evaluation methodology that can be used to rapidly estimate the throughput of production lines with

various topologies in agile design.

3 Buffer allocation approach of production lines

The study presents the difficult problem of efficient buffer allocation in production lines. In this problem, I need to determine buffer updating locations to allocate proper buffer size into a production line to satisfy the desired throughput rapidly with acceptable solution quality. The extended active probability is proposed as a bottleneck indictor to detect proper buffer updating locations and increase buffers quickly. The effectiveness of the extended active probability keeps high for different production line topologies. The variable neighborhood search algorithm is used to avoid obtaining local optimal solution and keep acceptable solution quality of the proposed buffer allocation approach. The proposed throughput analysis approach based on queue modules is used to evaluate the effectiveness of buffer allocation solutions. Extensive numerical experiments demonstrated the efficacy of the proposed buffer allocation approach. The contribution of the study is the efficient buffer allocation approach that can be used to rapidly estimate the topology and cost of production lines with various topologies in agile design.

4 Layout approach of buffer topology networks of production lines

Buffer topology network layout is very important for the buffer design. The study is to obtain a buffer topology network that can achieve the desired throughput with proper designed buffers. In the study, not only buffer size and server size, but also their location relationships are designed. The layout problem of buffer topology network is very difficult and involves a lot of studies. Moreover, there are so many kinds of buffer topology networks that it is difficult to test all of them and obtain the best one. Therefore, it is a good choice to classify buffer topology networks into proper groups and test candidate buffer topology networks that represent the groups respectively to detect the best one. By the classification method based on principle of mutually exclusive and collectively exhaustive, commonly used buffer topology networks are classified into four groups according to different server arrangements and buffer topologies. Then, based on the proposed throughput analysis approach and the proposed buffer allocation approach before, candidate buffer topology networks are tested to select the best one. Numerical examples tested five experiments and show that the best buffer topology network changes with different desired throughputs and application conditions. Moreover, the numerical examples also verified the feasibility of the proposed layout approach of buffer topology networks. The contribution of the study is to propose a layout approach of buffer topology networks which is useful to decrease computation time.

5 Conclusion

In the thesis, an efficient buffer design methodology was proposed including an efficient buffer allocation approach and a layout approach of buffer topology networks so as to achieve agile design. In addition, an efficient throughput analysis approach to rapidly evaluate buffer design solutions was also developed.

The study in the thesis can be applied into rapid buffer design. The proposed throughput analysis approach can obtain the throughput of production lines with serial, merging, splitting and recirculating topologies in 600 s. The

relative errors between the throughput obtain by the proposed throughput analysis approach and simulation data obtained by a commercial simulator are lower than 10%. The proposed buffer allocation approach can achieve rapid buffer allocation to satisfy the desired throughput. The buffer allocation process can be finished in 28800 s even for a complex production line with 50 buffers and servers. Compared to former methods, the proposed buffer allocation approach decreases computation time and can achieves better solution quality within a short computation time.