

## 論文の内容の要旨

論文題目    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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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 buffer topology network layout problem that refers to obtain a buffer topology network of a production line with proper designed buffers to meet some specific objectives. The other one is buffer allocation problem that refers to allocating proper buffer size into the production line to satisfy some specific objectives. To evaluate the effectiveness of a buffer design solution, a performance evaluation methodology such as throughput analysis methodology is also developed.

Agile manufacturing is to respond quickly to customer and market needs. Agile design that serves for the agile manufacturing requires a quick buffer design process to estimate the potential success and values of a production line design plan. Former studies mainly focused on the solution quality that refers to closeness of the throughput measurements to a theoretical value 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 the 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 research that is 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 to analyze the throughput and buffer design of a production line. Therefore, solution applicability whose objective is to make the throughput analysis and buffer design applicable to production lines with serial, merging, splitting and recirculating topologies should be also improved for practical application.

The studies in the thesis can be divided into three parts: 1) efficient throughput analysis approach of production lines; 2) efficient buffer allocation approach of production lines; 3) buffer topology network layout of production lines.

1) 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 a 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, a 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 line with serial, merging, splitting and recirculating topologies until the throughput is obtained. Numerical examples show that the proposed throughput analysis approach calculates the throughput of production lines with merging, splitting, and recirculating topologies rapidly (completed in 600 s) with acceptable solution quality ( $\geq 90\%$ ). The contribution of the study is an efficient throughput evaluation methodology that can be used to rapidly estimate the throughput of production lines with various topologies.

2) This study addresses the challenging problem of efficient buffer allocation in a production line. To this end, I need to determine suitable locations for buffer allocation to satisfy the desired throughput while achieving a good balance between solution quality and computation time. I propose the extended active probability as a bottleneck indicator to rapidly detect suitable locations and increase the buffer size. This indicator is highly effective for production lines with serial, merging, splitting, and recirculating topologies. The variable neighborhood search algorithm is used to avoid local optimal solutions and maintain acceptable solution quality. Further, a throughput analysis approach is adopted to evaluate the effectiveness of the buffer allocation solution. Extensive numerical experiments demonstrate the efficacy of the proposed approach. In summary, the proposed buffer allocation approach can facilitate agile design of production lines in industry by rapidly estimating the topology and cost of a production line.

3) Buffer topology network layout is very important in buffer design. The study is to obtain a buffer topology network of a production line that can achieve the desired throughput with proper designed buffer size. A proper classification of candidate buffer topology networks can decrease the number of candidate

buffer topology networks and reduce computation time of the buffer design. 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. Based on the proposed throughput analysis approach and buffer allocation approach in the thesis, the best buffer topology network topology with the fewest designed buffers required to achieve the desired throughput can be obtained. In numerical examples, four kinds of candidate buffer topology networks were used and the best buffer topology network among them was detected. The results of numerical examples verify the feasibility of the layout approach of the buffer topology network in the thesis. The contribution of the study is to propose a layout approach of the buffer topology network based on the classification of the buffer topology network, which is useful to decrease the computation time of the buffer design.

The study in the thesis can be applied into rapid buffer design of production lines. The proposed throughput analysis approach can obtain the throughput of a production line 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 is 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 servers and buffer with acceptable solution quality. Compared to former methods, the proposed buffer allocation approach can keep the higher solution quality in a short computation time.