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DEVELOPMENT OF MATHEMATICAL MODELS FOR INTEGRATION OF LOT SIZING AND FLOW SHOP SCHEDULING WITH LOT STREAMING

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By

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DEVELOPMENT OF MATHEMATICAL MODELS FOR INTEGRATION OF LOT SIZING AND FLOW SHOP SCHEDULING WITH LOT STREAMING

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October 2015

Chair: **Norzima Zulkifli, PhD**
Faculty: **Engineering**

In manufacturing industries, production planning and scheduling strategy usually flow in a hierarchical direction. In this direction, the production planning problem is solved first; then the scheduling problem is solved to meet the production targets. This often generates an infeasible production plan because of not considering the details of scheduling. Therefore, it is necessary to develop models that can integrate production planning and scheduling. For manufacturing companies that have identical units of single products and are often grouped in production batches (lots), lot streaming can be used as a scheduling technique. However, there has been no model to integrate production planning (lot sizing) and scheduling, using lot streaming technique which can accelerate production. The main objective of this research is to develop mixed-integer mathematical models for integration of lot sizing and flowshop lot streaming problems such as variable sublots, consistent and equal sublots, scheduling with learning effects and the possibility of preventive maintenance tasks. The objective of these mathematical models is minimization of total costs and also, five goals of problem can simultaneously be solved, namely: determining the sequence among sublots, optimal number of sublots for each lot, size of each lot, inventory levels and size of individual sublots.

The second objective of this research is to propose a solution procedure for problems when data are fuzzy. Finally, the third research objective is to validate the proposed model through a case study. Three software are used to extract the results of mathematical models and validate the solution procedure. The name of these software are: LINGO, MINITAB and MATLAB. In this research, the author proposes the first mixed-integer mathematical models for integration of lot sizing and lot streaming problems. By these proposed models, not only sequencing and timing decisions of multiple products are calculated but also lot size of each product, work-in-process and inventory levels of finished products are calculated when lots can be split into smaller sublots. To get the results of mathematical models, in three examples, 70 randomly-generated problems are solved by LINGO solver. Moreover, a two-way ANOVA test as a statistical method is applied to validate the mathematical model, using four examples consisting sixteen problems, by MINITAB software. The NDM Company is used as a case study. The mathematical models are used to solve NDM company's problems by LINGO solver. The results showed 32 percent (77.66 hours) reduction in makespan compared to non-integrated mathematical model. Validation of the proposed solution procedure is achieved by comparison of results with max-min method results,

using Shahab Shishe company data. The results of using the proposed mathematical models in this research are first to reduce cost by using these proposed models. Secondly is greater marginal benefits were obtained by intermingled sublot cases than non-intermingled sublot cases. It is concluded that better makespans were obtained by intermingled sublot cases than non-intermingled sublot case.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PEMBANGUNAN MODEL-MODEL MATEMATIK UNTUK INTEGRASI PENSAIZAN LOT DAN PENJADUALAN PENGARUSAN LOT

By

NAVID MORTEZAEI

Oktober 2015

Pengerusi: **Norzima Zulkifli, PhD**
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Dalam industri pengeluaran, strategi perancangan pengeluaran dan penjadualan selalunya dilaksankan mengikut arah hiraki. Dalam keadaan ini, masalah perancangan pengeluaran akan diselesaikan terlebih dahulu kemudian penjadualan ditentukan untuk memenuhi sasaran pengeluara. Keadaan ini mengakibatkan perancangan pengeluaran yang tidak tepat kerana penjadualan adalah tidak terperinci. Oleh itu, adalah perlu untuk membangunkan model-model yang boleh mencantumkan perancangan pengeluaran dan penjadualan. Untuk syarikat pengeluaran yang mempunyai unit produk, yang sama, satu jenis produk biasanya akan dikumpulkan dalam lot dan lot arus boleh menggunakan teknik penjadualan. Walau bagaimanapun, tiada model yang menggabungkan perancangan pengeluaran (pensaizan lot) dan penjadualan, menggunakan teknik arus yang boleh mempercepatkan pengeluaran. Objektif utama kajian ini ialah untuk membangunkan model matematik integer campuran yang menggabungkan pensaizan lot dan lot arus bagi bengkel aliran seperti sublot boleh ubah, sublot yang konsisten dan sama, penjadualan dengan pengaruh pembelajaran dan kemungkinan untuk aktiviti penyenggaraan pengelakan. Objektif-objektif model ini ialah untuk mengurangkan kos dan juga penyelesaian lima masalah utama iaitu mengenalpasti jujukan sublot, bilangan optimum sublot untuk setiap lot, saiz lot dan tahap inventori dan saiz sublot secara individu.

Objektif kedua kajian ini ialah untuk mencadangkan prosedur penyelesaian bagi data yang ‘fuzzy’. Dan akhir sekali, objektif ketiga kajian ini adalah mengesahkan model melalui kajian kes. Tiga perisian telah digunakan untuk menjana keputusan dari model –model matematik tersebut bagi mengesahkan prosedur penyelesaian. Perisian tersebut adalah LINGO, MINITAB dan MATLAB. Dalam kajian ini, pengarang telah mencadangkan model pertama campuran integer untuk menggabungkan pensaizan lot dan lot arus. Dengan cadangan model-model ini, bukan sahaja keputusan jujukan dan pemasaan untuk produk pelbagai dapat ditentukan, tetapi juga saiz lot untuk setiap produk, ‘work-in-process’ dan tahap inventori untuk produk siap dapat dikenalpasti jika lot dipisahkan menjadi sublot yang lebih kecil. Bagi mendapatkan keputusan model-model, tiga contoh telah diambil dengan 70 masalah rawak telah diselesaikan dengan menggunakan penyelesai LINGO. Tambahan, uian dua arah ANOVA telah digunakan bagi menguji secara statistic dan mengesahkan model menggunakan empat contoh yang mengandungi enam belas permasalahan, dengan menggunakan perisian MINITAB. Syarikat ND telah digunakan sebagai kajian kes. Model-model matematik telah digunakan untuk menyelesaikan masalah perancangan dan penjadualan dengan menggunakan penyelesai LINGO. Keputusan menunjukkan 32 peratus (77.66 jam)

pengurangan dalam jangkamasa pembuatan dapat dicapai dibandingkan dengan menggunakan model tidak bergabung. Validasi untuk cadangan prosedur penyelesaian telah dicapai melalui perbandingan keputusan melalui kaedah maks-min melalui data dari syarikat Shahab Shishe. Keputusan melalui cadangan model matematik dalam kajian ini adalah pertamanya untuk mengurangkan kos. Sebagai rumusan, ianya dapat meningkatkan keuntungan melalui pencampuran sublot berbanding sublot yang tidak bercampur.

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I certify that a Thesis Examination Committee has met on 2 October 2015 to conduct the final examination of Navid Mortezaei on his thesis entitled "Development of Mathematical Models for Integration of Lot Sizing and Flow Shop Scheduling with Lot Streaming" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

The main goal of each manufacturing enterprise is to utilize the resources available in order to satisfy market demand in the most efficient manner possible. Production planning is crucial to achieve this goal. The process of planning of manufacturing in any company or industry called production planning. It uses company resources including machines, workers, materials and production capacity in order to serve different customers.

On the other hand, scheduling is considered as short-term decision planning. The process of assigning operations to a set of resources in the course of time with the objective of optimizing a criterion is defined as scheduling. With regards to the requirements of real-life production planning and scheduling problems, the main objective is to discover a proper schedule that generates a diminished inventory level, high plant efficiency that help to accelerate the production. Plant efficiency means high machine and labour utilization. To achieve the feasible production plan and schedule, these two topics should be integrated. Figure1-1 illustrates integration between production planning and scheduling.

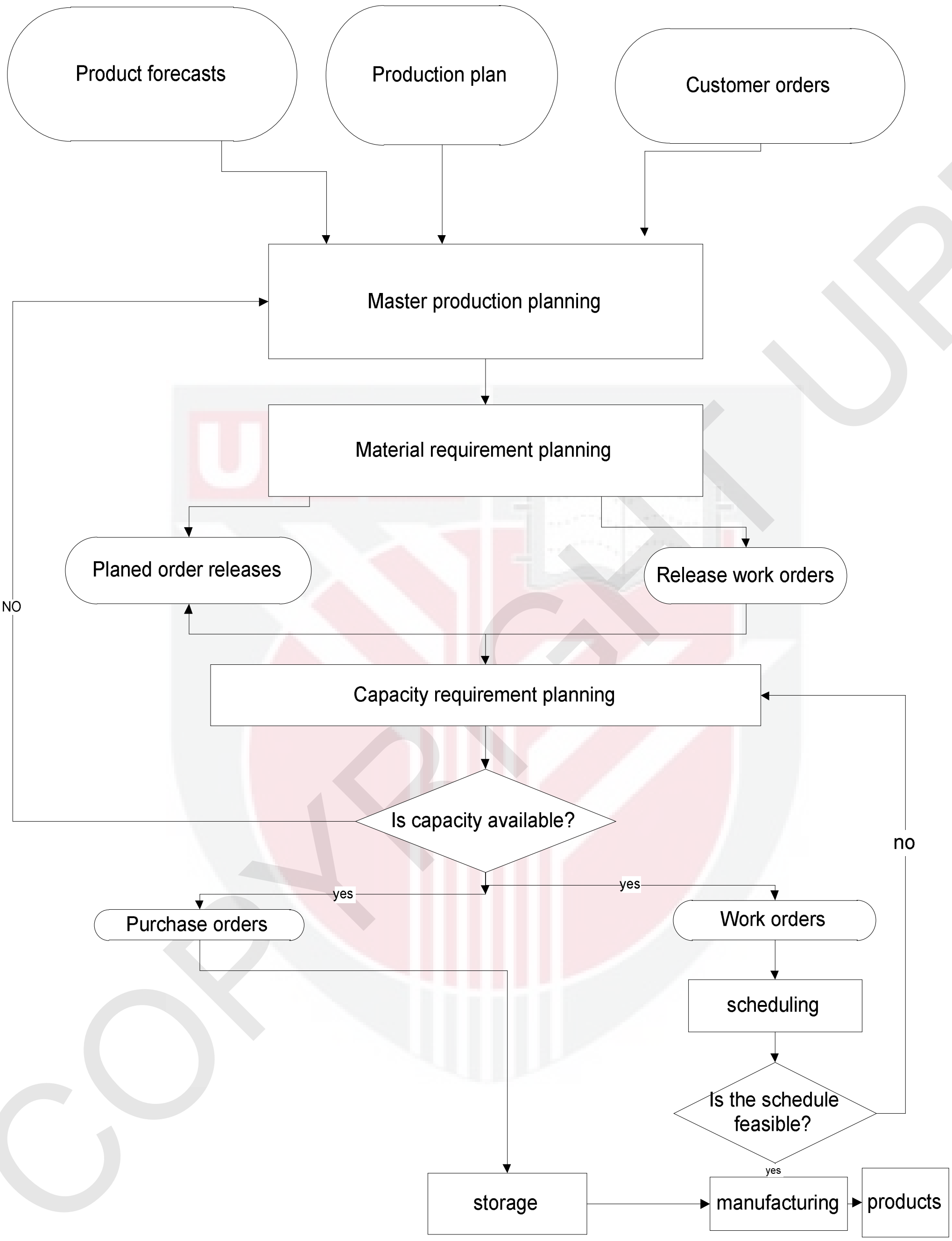

Figure 1.1 A closed-loop integrated production planning and scheduling system (Riane et al. 2001).

1.2 Problem statement

In this research, production systems are considered in a flow shop configuration. In the manufacturing industry, the commonly used planning and scheduling decision-making strategy generally follows a hierarchical approach, in which the planning problem is solved first to define the production targets and then the scheduling problem is solved next to meet those targets; however, there are some disadvantages to this traditional strategy since, there is no interaction between the two decision levels and no integration between production planning and scheduling. Those disadvantages and problems of non-integrated planning are (Zukui and Lerapetritou, 2010):

1) The generated production planning may cause infeasible scheduling sub-problems.

2) At the planning level, the effects of changeovers and daily inventories are neglected.

3) The neglect of those effects tends to produce optimistic estimates of production plans that cannot be realized at the scheduling level.

4) It causes over production or under production

Therefore, it is essential to develop methodologies that can effectively integrate production planning (lot sizing) and scheduling. On the other hand, in this research, lot streaming technique is added within the model as a scheduling technique. Without lot streaming two main problems are detected which are long lead times and high average work-in-process inventory. For the production of medium to high-volume products, identical units of a single product are often grouped into production batch (lot). In traditional batch production systems, a lot is transferred from one machine to the next only when all items of the lot have been completed. This reduces the time lost to setup. However, it also results in long lead times and high average work-in-process inventory (Hall et al., 2003). The lot streaming is a scheduling technique used to reduce makespan time. Lot streaming is a scheduling technique for splitting jobs, each consisting of identical items, into sublots to allow them to overlap on consecutive machines in multi-stage production systems (Chang and Chiu, 2005). Through lot streaming, production can be accelerated and a significant decrease of makespan can be achieved (Kalir and Sarin, 2000; Zhang et al., 2005; Sarin and Jaiprakash, 2007; Feldmann and Biskup, 2008). However, all lot streaming research assumes that the number of identical items of the product on each machine is given in advance. In other words, the lot sizing (production planning) problem is not integrated into the lot streaming problem. Moreover, all lot streaming research assumes that machines are always available, in other words; no breakdowns or scheduled maintenance are allowed which this is unrealistic. In addition, variable sublot type seldom is considered in previous studies. In this research, the author develops mixed-integer linear mathematical models for the integration of lot sizing (production planning) and lot streaming (scheduling) problems where machines are unavailable because they are undergoing preventive maintenance. All sublot types (equal, consistent, and variable) and scheduling with learning effects are considered in the proposed models.

In regard to second objective a solution procedure for problems when data are fuzzy is proposed. In reality, the demands of products are determined based on customer needs. The demand of a product fluctuates especially when demand is seasonal. There are two ways to deal with matter of fluctuations of demand (uncertainty) 1) uncertain demand is stochastic and follows a probability distribution function (i.e. normal distribution) 2) Uncertain demand is fuzzy. Fuzzy numbers can be allocated in order to solve demand fuzziness. Fuzzy number can be trapezoidal or triangular. In this research fuzzy numbers is supposed to be triangular. Each machine has its own capacity in a flow line. In practice, many circumstances can effect on machine capacity. Unforeseen circumstances such as machine break down, tool failure. These events can cause fluctuations in the use of machine capacity. It shows machine capacity is also uncertain. In this research two situations of company will be considered 1) stable situation 2) unstable situation. Input data of stable situation are crisp and unstable situation are fuzzy. Mixed integer mathematical models for integration of lot sizing and lot streaming proposed in this research can be used for both stable and unstable situations. Examples of instability in a company are old machines, unreliable supplier who deliver poor quality materials and poor quality management. Production costs, machine capacities, processing times and demands of finished products are fuzzy in these situations. Input data of proposed model are devoted fuzzy by managers to deal with these instabilities and get optimal results.

1.3 Research aims and objectives

The main objective is to develop a mathematical model for the integration of production planning (lot sizing) and lot streaming in a flow shop that generates a low inventory level, high plant efficiency and in which machines capacities are respected. The inputs of the model are forecasted demand in a finite planning horizon and detailed loads and schedules for the plant will be found. Research objectives are as follows.

(1) To develop mathematical models for integration of lot sizing and flow shop lot streaming problems under deterministic data.

(2) To propose a solution procedure for multi-objective aggregate production planning with fuzzy parameters and integration of lot sizing and lot streaming under fuzzy data.

(3) To verify the model with a case study.

1.4 Scope of study

There are five machine configurations in literature as follows: flow shop, job shop, open shop, hybrid flow shop, and hybrid job shop. Flow shop configuration is studied in this research. In repetitive manufacturing and cellular production systems flow shop configuration found that a set of jobs should be processed on several sequential machines, each job need to be processed on all machines, and the processing routes of all jobs are exactly the same (i.e., the operations of any job are processed in exactly the same order). If an operation did not require a certain machine, then the processing time of the operation on that machine would be zero (Ziaee and sadjadi (2007)). In the flow shop manufacturing environment the amount of operations of each job is equal to amount of machines and no two machines are capable of doing the same operation. Flow shop and lot streaming technique can be seen and used in medium to high volume systems, such as autos, personal computers, radios and televisions, and furniture. Mathematical modeling and mixed-integer programing will be applied by author to model and solve problems under consideration. Three following software will be used to find solutions 1) LINGO 2) MINITAB 3) MATLAB. LINGO and MATLAB are two software for solving mathematical models. MINITAB is a software will be used to verify results via statistical methods. As a case study the researcher uses a tape industry that produces three kinds of tapes that have same process and same routine) or produces in the flow shop configuration. Two case studies are used to verify proposed models as follows: 1) Tape industry for integration of lot sizing and scheduling models; 2) Light industry (shahab Shishe Company) for lot sizing model. To solve proposed models, Lingo software for small and medium-scale problem is used.

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