# Production Planning and Scheduling for Lot Processing

# Production Planning and Scheduling for Lot Processing

By

Larysa Burtseva,
Frank Werner,
Rainier Romero,
Carmen L. Garcia-Mata,
Brenda L. Flores-Rios,
Victor Yaurima,
Eddy M. Delgado-Arana,
Felix F. Gonzalez-Navarro
and Gabriel A. Lopez-Morteo

**Cambridge Scholars**
Publishing

Production Planning and Scheduling for Lot Processing

By Larysa Burtseva, Frank Werner, Rainier Romero,
Carmen L. Garcia-Mata, Brenda L. Flores-Rios, Victor Yaurima,
Eddy M. Delgado-Arana, Felix F. Gonzalez-Navarro
and Gabriel A. Lopez-Morteo

This book first published 2022

Cambridge Scholars Publishing

Lady Stephenson Library, Newcastle upon Tyne, NE6 2PA, UK

British Library Cataloguing in Publication Data
A catalogue record for this book is available from the British Library



ISBN (10): 1-5275-8502-6
ISBN (13): 978-1-5275-8502-7

To the Memory of

*Anatoliy Panishev*

Scientist, Teacher, Person

# TABLE OF CONTENTS

# LIST OF FIGURES

# LIST OF TABLES

# PREFACE

Advanced plants with High Mix and High Volume of the production have a common characteristic: the manufacturing process is organized by lots and batches to reach a maximal productivity maintaining a high flexibility to react on challenges provoked by world market changes and unexpected complications of the business, such as, e.g., effects of the consequences of a pandemic. Manufacturing with lot processing has two evident planning aspects: organization of the production and the modeling of the plant operations.

The organization of the production involves the production philosophy and culture, integrating a variety of paradigms and concepts. The goal of modeling the plant operations is the optimization of the planning and scheduling. Both these features are discussed in the book.

The planning systems have been changed since the creation of the Toyota production system, which gave rise to new production paradigms, such as Just-In-Time and Single Minute Exchange of Die, which reduced drastically the inventory and setup times, respectively. In parallel, the methodologies considering the Group Technology, lot processing and batching were introduced into scheduling methods, both in practice and the approaches.

Scheduling theory is a rather new discipline. It started in the 1950s, and since then it attracted the attention of planners due to the high applicability of the results and of researchers due to the high computational complexity of the problems. This theory has been mainly written in the recent years. It is not yet completed, and the models considering production lots issues might be currently one of the most active research directions.

New perspectives appear by the challenges of the practice and the actual state of science in general. Therefore, the main idea of the book is to highlight the main topics of scheduling theory, which are related to lot processing, starting with its effect on the planning system, and making the principal accent on the optimization of the scheduling process in the shop floor.

This book is an intention to present a general landscape of the related theory in its actual state, remembering the pioneering works, giving historical sketches, and then describing the principal results and showing some directions for future research. The book does not include all algorithms and methods developed, but gives a general state-of-the-art and references to investigate every mentioned topic more in detail.

The book consists of ten chapters.

Chapter 1 introduces production planning systems. The general model of the planning in a plant and its components are explained. A classification of production planning problems into strategic, tactical and operational planning levels as well as principal planning challenges are described, and an introduction into lean manufacturing, which has a wide application in manufacturing plants with lot processing, is given.

Chapters 2-4 describe general topics of planning and scheduling, but with an accent to special features when the production is realized in lots and batches of identical items.

Chapter 2 is dedicated to the inventory management in plants with serial manufacturing. Various related concepts are introduced. The principal components of the inventory are described: raw material, WIP and finished goods. A formula to calculate the average inventory level is given together with an example. The Push/Pull policies, which are used to control the inventory level, are explained. A big part of this chapter is dedicated to Material Requirements Planning, which is a computer-based production planning and inventory control system for the production and scheduling in the plant. A historical sketch of its development is given, also some features and extensions. Some aspects of the Japanese Toyota production system are described, namely, the "zero concept", CONWIP, the paradigms Just-In-Time and Just-In-Sequence. The kanban method is described in detail. The next concept is the Optimized Production Technology, and then the Drum-Buffer-Rope method, which can be used for its implementation, is described. An analysis of the available methods of inventory optimization finishes the chapter.

In Chapter 3, the standard notations and the basic scheduling models, which are used in the book, are described. A survey of problems and solutions, which consider lot processing, is given for the principal machine environments and shop conditions.

In Chapter 4, machine setup times are considered. The reduction of setup times is the main purpose of processing the items in batches and lots. The basic structure and a classification of setup times are explained. Then it is shown how lot scheduling problems are formulated for different environment configurations and different kinds of setups. The problems with sequence-dependent setup times are considered in most detail. This kind of setup is typical for modern industries, where effect of setups is substantial. New directions in this research area are described, such as machine/resource-dependent setup times: time-dependent setup times, pastsequence-dependent (p-s-d) setup times, including learning/deteriorating effects. Specially, there were considered family/batch setup times. Then a systematic classification of changeovers and setup/changeover reduction schemes are described. Finally, the SMED/OTED method is explained.

Chapter 5 takes the most attention in the book, due to numerous methods and approaches. The chapter begins with explaining the history, the first authors and the philosophy of the Group Technology, which is interesting by itself. This theory started in between 1920 and 1930 and looks complete at the moment, nevertheless, one can note a continuous interest of researchers in this methodology due to its big potential. First, the part family concept is introduced which is followed by grouping methods. The famous Opitz classification system is explained in detail. There is also given a resume of the most famous classification systems used, including the developers and accessible references for a consultation. Then the Burbidge production flow analysis is explained. The next basic approach of Group Technology is the cluster analysis. It is used for the formation of the production cells, which causes frequently difficulties in the plant. Various methodologies are illustrated by examples. This chapter is finished with a description of the cellular manufacturing approach and an explanation of the cell formation problem.

Chapter 6 is dedicated to batch scheduling. The difference and similarity between batch and lot terms is explained at the beginning. Then batching is studied by an example of semiconductor manufacturing, where batching appears with different features, and the burn-in operation gives rise to basic batching concepts, such as batch machine. Possible batching models for different environments are described. Computational approaches to form the cell architecture finish the chapter.

Lot streaming and lot sizing are approaches, which are directly dedicated to the modeling of the problems that consider lot processing. In Chapter 7, the concepts and problems of lot streaming and job splitting are explained, and the effect of these phenomena on the scheduling models is shown. Lot splitting problems require a special system of notations. It is described in this chapter, and an analysis of the corresponding models is given for different environments.

In Chapter 8, the background of the lot sizing problem is explained. It started in 1913 after the paper “How Many Parts to Make at Once” published by Eng. Ford Whitman Harris, where the famous Harris' square-root formula for the order quantity was introduced.  It inspired a family of lot sizing models, which is not complete yet.

Rescheduling is a hot topic in modern scheduling theory due to the required high computational effort in connection with modeling and special theories, which appeared recently. Chapter 9 describes these theories and possible approaches to the problem modeling.

Chapter 10 concludes the book. It is dedicated to three practical problems on different aspects of lot processing, which were solved by the book authors for big corporations of the region.

All chapters are finished by some concluding remarks, which contain a brief analysis of the state-of-the-art, references to available surveys, and some recommendations for future researches.

The group of authors jointly worked on research issues and participated in postgraduate and editorial projects in the lot scheduling area, referring to affiliations in Mexico: the Universidad Autónoma de Baja California (UABC), Universidad Politécnica de Baja California (UPBC), Tecnológico Nacional de México-Instituto Tecnológico de Chihuahua (TecNM/ITCH), Universidad Estatal de Sonora (UES), Skyworks Solutions, Inc., and the Faculty of Mathematics of the Otto-von-Guericke University Magdeburg (OVGU) in Germany.

The authors are grateful to the administration of the Instituto de Ingeniería of the UABC for the support of our research projects, to many people from the corporations COTO and Skyworks, who dedicated their time and interest to reach a result following our recommendations, and to the UABC students Paola Velazquez, Jaqueline Contreras, Laura Bravo, and Luis Martinez, who helped in the design of this book.

The book contains a wide collection of theories, methods and approaches, which are developed at the date, and it is directed to production planners for practical use. This book can be used by beginners and for a deep study because it considers not only algorithmic aspects but also the problem philosophy and history. It can also be useful for students of all university levels, which are interested in studying this subject. We hope that it will also find the interest of researchers in this area due to the wide analysis of the state-of-the-art of the studied subjects, which is systematized according to the book structure.

*Authors*

# CHAPTER ONE

# INTRODUCTION

In big manufacturing plants with lot processing, planning and scheduling activities play nowadays a key role to provide an efficient functioning of these complex organisms from a machine to an entire business operation. In this area, one can meet plenty of new and traditional theories, models and paradigms. The researcher and planner communities are interested in identifying the actual state-of-the-art to maintain an advanced production corresponding to the challenges of a modern competition level. In the following, some relevant concepts and their place in an entire planning system of a modern plant are presented and studied as production programming subjects. A general view onto such a system is given at the beginning. Scheduling is considered as an extension of the planning activities. This area belongs to the hot topics of modern science. Therefore, various concepts and notations still require commonly accepted definitions.

## 1.1 Planning and scheduling for manufacturing plants with lot processing

In advanced production systems, such as semiconductor and electronic components industries, as well as at diverse assembly lines, where the manufactured products have the characteristics of *high volume and high mixture* (HV/HM) of nomenclatures, the product components are processed by *lots* (pallets, containers, boxes) of many identical items. Another immanent characteristic of such systems is a *multi-stage production process* with parallel machines or workstations at each stage. Typically, a High Tech (HT) company with characteristics HV/HM has dozens and even hundreds of machines of different years and brands at several stages. The lot processing and the use of *batch machines* for parallel working are typical for modern manufacturing systems with mass production. The complexity of the production process organization is characterized by a *high frequency of changes* in the nomenclature of the ready products and components. This consideration together with the occurrence of unexpected events and priority changes, require a *flexibility* of the planning and a high level of its automation to support the decision-making.

In such an environment, the operation by lots has an effect on various aspects of planning and scheduling, such as the system of production and inventory control, which reflects the *philosophy of planning* as a leading mode of the manufacturing organization.

Processing by lots also implies other typical features. The lot processing machines require a *setup* service, which is necessary to handle the next lot. It includes an adjustment and preparation of the recourses. When adjacent lots have a big technological difference (size, shape, row material, machine programming, etc.), a setup takes a considerable time while similar products may have a minimal setup time, which can be insignificant, even negligible. The majority of scheduling problems, which involve intermediate setups, have a high computational complexity and represent an interest for the researchers since the 1960s until now, especially when lot processing is considered. The setup duration has a direct connection with *lot batching*, which is a usual practice in the plants. The lots of the same or similar products are coupled for processing to eliminate or reduce the setup times used for the adjustment of the machines.

A theoretical and practical interest on this issue can be met in those models, where *lot splitting* is permitted, i.e., one lot is allowed to be split into sublots to be processed in parallel on a batch machine or on various parallel machines, to accelerate the lot output time. In many models, the *sublot size* is not evident and must be optimized. When a sublot requires a considerable setup time on a machine, the complexity of the problem increases. Merging of sublots is another important aspect of lot processing. The scheduling theory offers two principal concepts to describe and solve problems that involve the treatment of lots: *lot streaming* and *job batching*. These commonly appear together in problems, where the jobs are allowed to be split.

A typical situation in many plants is *reworking* and *rescheduling* of those items, which did not pass the testing stage. This fact and the existence of scrap, which usually is not considered in theoretical studies or is taken as a constant percentage of the plant output, is still an open research area.

The models, which contemplate lot processing, have differences in comparison with traditional job scheduling. The job notation depends on the problem assumptions and requires an explicit interpretation. One lot, one work order or the whole customer's demand may be treated as a job. The typical scheduling notations, e.g. those introduced by Pinedo (2008, 56), are insufficient for a formal description of such problems and therefore, they must be revised and updated according to the lot processing assumptions.

The planning problem in the plant includes the management and control of inventory, in particular the so-called Work-In-Process (WIP). Sometimes, the term work in progress is used with the same abbreviation. The last one describes the costs of unfinished goods that remain in the manufacturing process while work-in-process refers to materials that are turned into goods within a short period. The terms *Work-In-Progress* and *Work-In-Process* are used interchangeably referring to products midway through the plant or assembly lines.[1]

From the one side, an excessive WIP requires an additional shop floor space to be stocked up. This delays also the output of finished goods and elevates the production costs. Nevertheless, some quantity of WIP is necessary to balance the capacities of the stages and to equilibrate unexpected situations. The size of the WIP and the intermediate buffers between the production stages require also the attention of the planner.

The planning and scheduling activities in the companies with lot processing are subjects of intensive research due to the diversity of the problems and the high cost of a decision taken. Actually, one can observe a growing interest in the industries to the results of theoretical researches and the stimulation of such researches in the companies. Big companies employ specialists in solving the planning problems and dedicate a considerable attention to the preparation of proper planners in high-level education schools.

The enumerated subjects and relevant problems are discussed below in detail. This book pretends to analyze the available literature with the goal to extract the basic topics and approaches used for the production management in manufacturing plants with lot processing. In this way, it tries to reduce the gap between theory and practical necessities.

## 1.2 Production chain

The production process represents the transformation of the raw materials into the final products, usually through a series of steps producing and consuming intermediate products and components. Raw materials, intermediate products and finished goods are often inventoried, allowing the production and consumption in different sizes and production stages. Each transformation requires several input components and products and has one or more outputs. The raw materials are acquired by suppliers, and the final products are sold to external customers. Sometimes, intermediate products

[1] Investopedia.com: Work in Progress vs. Work in Process: What's the Difference? Accessed 09.06.2020.

are also sold (spare parts, etc.). This general definition of the production as a transformation process is shown in Fig. 1-1. The material inventory is drawn by triangles, the transformation activities are denoted by circles, and the flow of the materials through the process is indicated by arrows as the inputs or outputs during the transformation).

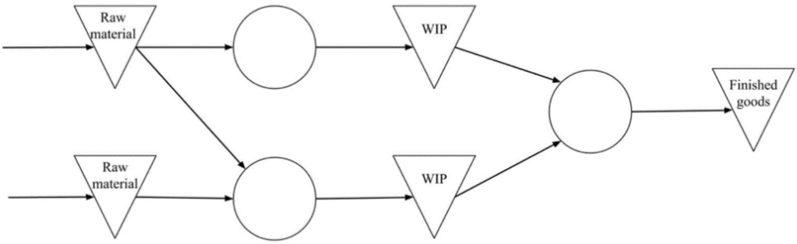


Fig. 1-1. Production process.

## 1.3 Production planning challenges

Production planning in plants is a process, by which the manufacturing departments organize the machinery resources over time in order to optimize their use and thus to achieve the highest possible productivity. Although the planning is a common problem for any company, it has not been systematically solved given the large number of variables that affect the decisions, which must be made. Therefore, the formalization of these activities is very difficult.

The production planning includes the management of the resources, which are necessary for the transformation of the raw material into the final products, in order to satisfy the customers in a most efficient or economical way. In other words, the decisions made during the planning are typically made for seeking a best balance between the financial objectives and the customer service objectives. The financial objectives are usually represented by the production costs for the machines, materials, labor, start-up costs, overhead, insurance, inventory costs, opportunity costs of the capital invested in the shares, etc. The objectives of the customer service are represented by the ability to offer the right product in the requested quantity, on the date and at the place promised.

When unexpected events occur, such as a quality problem, a process out of control, a change of priority, bad weather, road traffic, among many others, the exact fulfillment of the plan is prevented and its adjustment is required. Despite unexpected events and setbacks, which are usually out of control and surely always appear, the plan must be done in detail. Therefore, the main challenge of a planner is not only carrying out the planning itself. He must also be able to react to unexpected events without losing the control over the production process and follow with continuous planning. The main challenge of the production planning is the possibility to discover the weak points in the plant.

There exist conflicting goals when choosing the best way to arrange the jobs:

- If a good use of the resources is sought, the completion time becomes worse; the cost of stocks and delays is increased;
- If the delivery time of the products is minimized, the current stock is less, but the use of resources is worse.

The final objective of a detailed production planning is to take decisions about the sequence of the jobs that each resource of the company processes in a smallest possible planning horizon. This activity is referred to as production programming, or scheduling, as it is shown in Fig. 1-2.

In addition, planning has other objectives:

- On-time delivery;
- Minimizing the completion time;
- Minimizing the production cost;
- Minimizing the WIP;
- Maximizing the overall effectiveness of the equipment;
- Minimizing the lead time.

*Machine scheduling* is a central component and the heart of the production planning responsibility. It is a base for shop loading, the management of the supply chain and the row material requirements, demand forecasting, project planning, etc. Therefore, the scheduling decisions take the main attention in the planning optimization. The main goal of production scheduling is the possibility of discovering the *bottleneck*s or the *capacity constraints* in the plant processes. Scheduling is considered a source of improvement projects, which try to eliminate the restrictions that hinder the search for the best job sequence.

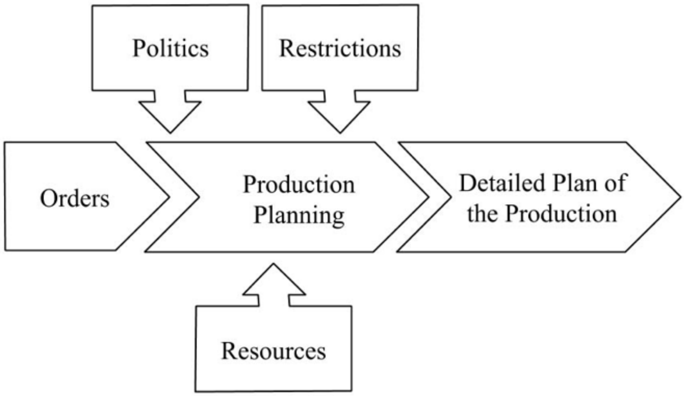


Fig. 1-2. General model of the planning.

A production schedule defines when the customer orders will be completed. Sometimes, it is necessary to fix a delivery date to the customer when a demand is fulfilled. In some cases, a too late or too optimistic date spoils the customer relationship or leads to penalties.

## 1.4 General scheme of the production planning

The production planning problems are classified into strategic, tactical, and operational planning levels.

*Strategic problems* deal with the management of changes in the production process and the acquisition of the resources needed to produce in the *long term*. This includes, for example, a combination of products, a perspective plan development, as well as the location, the supply chain design, and the investment decisions. The objective pursued in the solution of these strategic problems is to maintain an advantage and a competitive capacity in order to keep a growing rhythm. For this, it is necessary to propose long-term decisions using consolidated volumes of demand.

*Tactical planning problems* analyze the use of the resources in the *medium term*. The solutions are based on the information from the consolidated volumes. It consists, for example, in making decisions about the flow of materials, the size of the inventory, the capacity for use, the maintenance planning by the operational management. The usual objective at this stage is to improve the cost efficiency and the customer satisfaction.

*Manufacturing Planning and Control* (MPC) systems have been developed to address these complex planning environments, and they integrate these multi-term (multi-level) planning problems into a management system. In these systems, the medium-term production planning is the decision on how to use the capacity and aggregated levels of the inventory to meet the projected medium-term demand during approximately one year.

The *Master Production Schedule* (MPS) represents a detailed short-term plan of the manufacturing of the final products in order to meet an expected demand and an aggregate customer order, taking into account the use of the capacity and the global inventory level obtained at the processing stage.

An MPS is a document that answers the following questions in detail:

- *What* products will be produced?
- *In what quantities* will they be produced?
- *When* will they be produced?

In an MPS, the time is usually expressed in weeks and corresponds to the duration of the production cycle. With the *Material Requirements Planning* (MRP, also referred to as MRP-I) system, short-term plans are established for all components (intermediate products and raw materials) of the final products considered in the MPS phase and in the database of the product structure, forming the *Bill of Materials* (BOM). A BOM represents a list of all materials, subassemblies, and other components needed to make all product nomenclature of the plant. It also contains the inventory data.

An MPS has an important function regardless of whether the MRP system is used or not. It accomplishes a coordinating function between manufacturing, marketing, finance, and sometimes engineering. Master scheduling is a decision-making process that can be considered as both a threat and an opportunity.

Then the plant control systems (for the component manufacturing) and the supplier monitoring systems (for the purchase of the components) are developed in the MRP-I phase for the *very short-term* execution activities of the plans. The time in this last stage takes usually a few days.

The MPS and MPR-I determine the weekly commitments of the delivery of each order to the customer, but not the day or a sequence, in which these orders will be processed in the plant facilities. The definition of the priorities of the items to be processed follows some optimization criteria, such as the cost, the time to change tools, or the importance of the customer. An MRP-1 diagram is presented in Fig. 1-3.

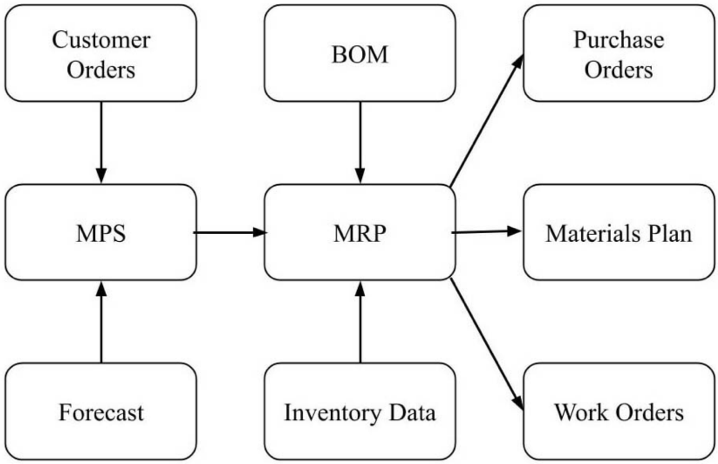


Fig. 1-3. Diagram of an MRP-I system.

The *Manufacturing Resource Planning* system, referred to as MRP-II, incorporates the original MRP-I system, defined by Orlicky in 1975, and follows the principles of *Hierarchical Production Planning* (HPP) defined by Hax and Meal in 1973 (Ptak and Smith 2016, 356). Other aspects of the MPR system are described in Section 2.4. Fig. 1-4 explains how tactical and operational planning problems are integrated into a classic MRP-II system. Other well-known production planning concepts and systems are adapted to this general scheme.

## 1.5 Lean manufacturing

Under the conditions of high competitiveness, a modern planning system tends to follow the lean manufacturing philosophy. *Lean manufacturing* is known as a production practice that considers the expenditure of resources for any goal different from the creation of a value for the end customer to be wasteful and thus, a target for elimination (Motwani 2003, 340–41; Ulutas 2011, 1194; Ptak and Smith 2016, 70). Practically, it is a set of tools that assist in the identification and steady elimination of waste (*muda*). Table 1-1 summarizes the typical seven prominent waste groups in the lean context. The main tools of a manufacturing program are a setup reduction system, such as the Single Minute Exchange of Die (SMED) approach, a visual control and fast intervention strategy, called the Total Productivity Maintenance (TPM) system, 5S, 5W+2H, Six Sigma.