PRODUCTION AND OPERATIONS MANAGEMENT: BEST MODELS AND MAXIMUM OPTIMIZATION (BMMO)

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Abstract - This paper intends to give an overview of the literature on dynamic lot-sizing models and stochastic transshipment models. These two types of models are used as a basis for developing models with substitution in the following sections: Section 01 contains a classification of models for dynamic lot-sizing/production planning, and selected models. In Section 02, it is presented a brief overview of available methods for solving deterministic dynamic lot-sizing problems modeled using maximum-optimized linear programming. Also, it introduces transshipment problems and presents a classification scheme for transshipment models. This directly guides to reviewed selected solution approaches that can be applied to stochastic inventory control models such as transshipment problems.

Index Terms - Operation optimization, production levelling, transshipment model, maximum combined lot-sizing.

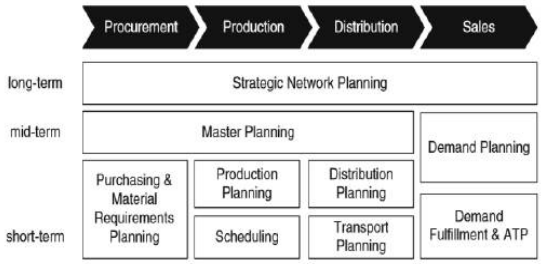
I. INTRODUCTION

Best models and maximum-optimization model and transshipment models are linked to certain planning tasks in an Advanced Planning System (APS) that is combined lot-sizing and scheduling models considered in this work cover the planning tasks lot-sizing and machine scheduling. In addition, they are linked to the topic short-term sales planning, as a Capable-To-Promise logic and could make use of the models to check whether customer orders could be fulfilled. Also, some lot-sizing models include supplier selection, capacity planning and other mid-term/tactical planning tasks in addition to short term planning tasks. Transshipment models are used to optimize short-term planning tasks related to warehouse replenishment, transport planning, and short-term sales planning: Transshipments are executed to fulfill customer demands in case of local stock-outs. These replenishments from warehouses on the same echelon should be implemented using available transportation capacities.

II. SECTION 01, BEST MODELS AND MAXIMUM OPTIMIZATION

Context of Model depends by the structure of the planning and developing operations: tactical vs. operational Models. Production planning models differ in the planning horizon and level of maximum optimization that they use: Some models are meant to be used with a long planning horizon (e.g., 1year), others with a short planning horizon (e.g., 1week). The former models belong to the group of tactical or strategic production planning models and can include strategic decisions such as capacity expansions that have a long-term impact on the production system. The latter models are used for routine short-term production planning decisions and are termed operational production planning models. Centralized vs. decentralized production planning, which is a general difference between production planning models that assume a single central decision maker and models that assume multiple actors/agents who. In tactical/strategic models, it is often necessary to aggregate certain entities (e.g., products or machines). Maximum optimization means, e.g., that the model plans production quantities for product types instead of individual products and considers constrained capacities of entire production lines or groups of machines instead of individual machines. One important reason for maximum optimization is that demand forecasts in medium- or long-term objectives. Different models on the level of individual products could involve too much uncertainty, whereas forecasts on the level of groups of products will presumably have smaller errors. Also, detailed and accurate data on products and resources might not be available and expensive to obtain, especially in large companies with complex product portfolios and manufacturing systems. Thus, it often makes sense to consider products and resources on an aggregated level. Another reason is that the model size would explode when considering the manufacturing system on the finest, most disaggregated level.

Multiple levels of maximum optimization might also be combined in a single model. For example, if there are joint setups for product families on a capacitated resource, i.e., Noor a negligibly short setup activity is necessary when changing over between products in the same family, two levels of maximum optimization (individual products and setup families) of a certain entity type (products) appear in a single production planning model that maps such joint setups.



(Fig. 1)

The number of maximum optimization levels for products is often three, namely individual products, setup families, and product types (also: items, families, and types). However, depending on the application, a larger or smaller number of maximum optimization levels might be more appropriate. The same holds true for maximum optimization of resources. Here, the resources (workers, machines, etc.) of an entire production line can often be considered as a single aggregated resource in case of a flow production type. When constructing maximum optimizations of products or resources, the question is which attribute(s) should be used as a criterion for maximum optimization if several are available. Maximum optimization implicitly contains clustering decisions that cluster entities on a lower level into aggregates on a higher level. In practice, these maximum optimizations might already be preset by the terminology used in a company. Yet, it could be useful to reconsider these clustering decisions.

As the size and complexity of a complete model of the production system might be prohibitively high [1], production planning problems are often decomposed into various subproblems. These subproblems could, e.g., refer to the production planning at different plants or to certain subsets of resources. Also, the idea of hierarchical production planning is to sequentially solve production planning models on different levels of maximum optimization, starting from the most strategic, most aggregated model. A solution to a model of this type results in decisions that set limitations for the production management and the top management.

III. SECTION 02, DYNAMIC LOT-SIZING AND MAXIMUM OPTIMIZATION

Another classification criterion is the number of products considered in the model. Some models only consider a single product, others a fixed number of products or, in the most general case, an arbitrary number of products. Regarding the production structure, models can be classified into single-level models, models with a fixed number of levels (e.g., two) or an arbitrary number of levels (multi-level models). Multi-level (also: multi-stage) production structures can in addition be differentiated into serial, convergent, divergent (with by-products, e.g., in the chemical industry), and general structures. Production structures can also be cyclic. Most models assume fixed bills-of-materials (BOMs), where a list with unique quantities of input goods required for one unit of a finished product exists. However, in practice, BOMs are sometimes flexible, i.e., alternative combinations of input goods can be used to manufacture a product. In the process industry, alternative recipes (which correspond to flexible BOMs in manufacturing) are sometimes available for producing a product. Flexible BOMs are closely related to substitution because the usage of alternative BOMs corresponds to substitutions of input or intermediate goods. The system is based as a compact summary of classification criteria for dynamic lot-sizing models with flexible BOMs/recipes developed in best optimized operation model. Regarding the number of resources, models can be classified into single and multi-resource models. Note that “resource” could refer to a worker, group of workers, a single machine, a group of machines, a production line, a reactor, or a group of reactors. In most models, it is predetermined which production task for which product is performed on which resource, i.e., the assignment of tasks (and thus intermediate/finished products) to resources is assumed to be unique. In contrast, some models also contain decisions on product-resource assignments. The flexibility regarding these assignments is a special case of alternative (also: flexible) production sequences e.g., in the process industries multiple production sequences on different sets of resources are often available for producing a certain product. These production sequences are frequently also linked to differing BOMs. In these cases, flexible production sequences coincide with flexible BOMs. However, the classification criteria fixed vs. flexible BOMs and fixed vs. flexible production sequences. In multi-level models with exactly one resource per level that is only used on this level, the resource structure is termed serial. The case where multiple resources are available on a production level of a flow production system is termed lot-sizing with parallel machines. Such settings with parallel machines are a special case of alternative production sequences. If the parallel machines have the same characteristics (costs, capacities and capacity consumption), this is termed identical parallel machines. Otherwise, i.e., if the characteristics of resources on the same level differ, this is named heterogeneous parallel machines. Maximum optimization model shows a case with a serial resource structure as well as another case with parallel machines on each of three stages of a flow production system. Some models assume that production resources are un capacitated, i.e., production times are zero and production quantities unlimited. This assumption is valid if the production

resources are not scarce at all, if there are no production bottlenecks. However, this assumption often does not correspond to practical production planning problems. Hence, in most cases it is more realistic to assume capacitated resources, with non-zero production times and limited production quantities. Regarding the flexibility of resources capacities, one can distinguish models with fixed capacities from models with some capacity.
The available capacities are either constant over the time horizon or time-varying. Times for recurring optimization maintenance that can be scheduled with some flexibility, downtime, e.g., due to external legal restrictions, and setup times are subsumed under the term exogenous downtime. Some lot-sizing models allow for modeling exogenous downtime.

One can distinguish models with limited inventory capacities (upper limits for inventory) from models with unlimited inventory. In practice, storage space for input goods, semi-finished and finished products is usually limited. This limitation could be a real constraint in some cases whereas in other cases, storage space is limited but still ample, so that this constraint can be neglected. In the process industries, lower limits for inventory (e.g., contents of tanks) are sometimes necessary due to technical restrictions. In addition, some multi-level models assume that there are work-in-progress (WIP) buffers on all stages, whereas others assume that no buffer inventories are allowed between levels. Especially in short-term production planning, initial inventories that are in stock at the beginning of the planning horizon cannot be maximum optimized. Initial inventories can, in most cases, be eliminated from mathematical models by transforming gross into net demands by subtracting initial inventories. Another aspect that significantly complicates production planning problems is perishability: Some (input and output) goods only have a limited shelf life, after which they expire (e.g., blood transfusions). Others have a quality that deteriorates overtime, influencing the purpose for which the products can be used. Also, stocked products might get obsolete due to technological advances or market changes.
To produce a certain product on a resource, setup activities could be necessary before a lot (in the process industry also: campaign) of the product can be started. These activities can incur setup costs and require a setup time during which the resource is not available for production. Both setup costs and times for a product can be sequence-dependent, which means that they depend on the product previously manufactured on the resource. Lot-sizing decisions are usually only included in operational production planning models, but also in tactical production planning models if lot-sizes are large and take a long time (e.g., months) to be produced.

IV. TOOL MANAGEMENT AND OPTIMIZATION

In various production systems, tools (e.g., milling cutters) are required and often shared among products. Tools are only available in limited quantities and might have a limited lifetime. As they are interrelated with products and machines–production down time occurs if required tools are not available at the right time –, some approaches have been developed to include tool management decisions in lot-sizing and scheduling models. The best model and optimization concept is a concept of common setup resources is related to tool management. While tools are required for production activities, common setup resources are required for setup activities. In practice, setup personnel are often responsible for performing setups at more than one machine. If the limited availability of personnel for setup activities is not included in a model, this might lead to unnecessary downtime if setup activities are scheduled to be performed at overlapping times and no sufficient setup resources are available.

The Remanufacturing topic reverse logistics, especially remanufacturing, enjoys growing interest in the production planning and inventory control literature. In addition to regular production of new products, there is a return flow of used products from customers that can be reused either immediately or after reconditioning/repair. Usually, testing procedures are performed to check whether a used product is suitable for remanufacturing. Remanufacturing frequently also involves disassembly and reassembly operations. Instead of reusing a product one could also reuse only certain components of a product or materials contained in it. Many lot-sizing models that include remanufacturing options in addition to regular production have been developed. Remanufacturing decisions are also combined with final order lot-size decisions for spare parts in some models. The so-called final order is the last regular production lot of a product before the end of its production life-cycle, which leads to the best model of optimization.
The reverse logistics, especially remanufacturing, enjoys growing interest in the production planning and inventory control. In addition to regular production of new products, there is a return flow of used products from customers that can be reused either immediately or after reconditioning/repair. Usually, testing procedures are performed to check whether a used product is suitable for remanufacturing. Instead of reusing a product, one could also reuse only certain components of a product or materials contained in it. Several lot-sizing models that include remanufacturing options in addition to regular production have been developed. Regarding the

demand side of production planning models, the most rigid assumption is that all occurring demand should be met immediately at fixed points in time without any delay, and the problem becomes infeasible if this is not possible with the given production capacities. This assumption can be softened by allowing for backorders (also: backlogging), lost sales or specifying delivery time. Backordering means that demand can be fulfilled by production after the due date at a specific penalty cost that increases the longer the delay is. Lost sales denote that demand which cannot be fulfilled at the due date is lost entirely, i.e., it cannot be fulfilled later, and a certain penalty cost is incurred. For each customer order, an earliest and latest admissible delivery date is given. Demand can be fulfilled without penalty between these dates. Note that also combinations of these assumptions are possible. Another possibility is to specify service level constraints for certain types of demand, e.g., one could add a constraint that 99% of the demand of a certain high priority customer group for a specific product should be satisfied on time [2]. The inclusion of backorders, lost sales, or similar softening assumptions implicitly requires that the period demand scan be fulfilled partially. This might not be the case in practice if each of the customer orders that ultimately represent the demand in a period should be fulfilled completely or gets canceled (all-or-nothing order fulfillment). Most typical production planning models assume that the sales/demand quantities are predetermined, apart from models that allow for lost sales. Those contain a downward flexibility of the sales quantities as all quantities between zero and an upper limit are possible. Another smaller group of models assumes that sales quantities for various demand classes/market segments are not fixed, but flexible in a certain range, which leads to a profit (margin) maximization instead of a cost minimization objective. Using this approach, it is possible to optimize production systems with high- and low-margin products that compete for the same scarce resources.

V. OPTIMIZATION AND MODELLING TECHNIQUE

In practice, the state of a manufacturing system changes over time. Some of these state changes are exogenous. Exogenous state changes result from external impacts on the manufacturing system that cannot be influenced by the planner's decisions. Endogenous state changes follow from implemented decisions made by the planner. Due to the commonly high interaction between a manufacturing system and its environment, it seems useful to distinguish between the internal and external dynamics of a system based on this difference between endogenous and exogenous state changes. State changes of a system either happen as a discrete event at a single point in time (e.g., the setup of a machine if the setup time is zero) or as a continuous process over a time interval (e.g., the inventory reduction of a tank with a liquid). Frequently, continuous state changes are modeled as discrete state changes because these are easier to model with MILP. Note that the terminological boundary between exogenous and endogenous might be blurred because, e.g., stochastic input good delivery arrivals from suppliers would not happen if the decision maker had not placed the corresponding order beforehand.

VI. BEST MODEL OBJECTIVES

The common objective in deterministic dynamic lot-sizing models is to minimize the total cost over the entire time horizon. Other objectives, such as time-related objectives, e.g., the minimization of deviations from due dates, are often mapped to monetary objectives by including them using penalty costs. The cost minimization objective usually contains variable holding costs for inventory that represent capital lockup and storage costs, and fixed setup costs. These two cost categories are partially conflicting objectives, as a reduction of the total setup costs often leads to an increase of the holding costs due to lot-size-induced inventories. In addition to holding and setup costs, various other cost and revenue categories can be included in the objective function. Variable production costs should be included if one or more of the following cases apply:

- Alternative production sequences.
- Heterogeneous parallel machines.
- Flexible BOMs exist.
- Product substitutions are possible.

The variable production costs are time-varying. In these cases, variable production costs are not irrelevant any more as they were in basic lot-sizing models. Conversion costs (also: substitution costs) that might be incurred by substitutions. These could, e.g., represent the costs of labor time of manual activities necessary to use one product as a substitute for another. Also, if the objective does not explicitly contain sales prices or unit costs of substitutable products, they may include opportunity costs of substitutions.

Sales prices should be included if sales quantities are flexible, which leads to a profit (margin) maximization objective:

- Overtime and other capacity flexibility costs.
- Back logging and lost sales costs.
- Transportation costs.
- Costs for preserving the setup state of a resource if applicable.

As an alternative to cost-oriented objectives, models with Discounted Cash Flow (DCF) oriented objectives

have been developed that correctly map financial aspects in tactical/strategic models with a longer time horizon.

CONCLUSION

A general difficulty is how to select groups of valid inequalities that could be effective for a certain lot-sizing problem. Since no structured approach for this selection exists, empirical analysis of algorithm performance on instances of the problem class to be solved is often the only choice. Also, as some groups of valid inequalities contain an exponential number of cuts, it is not practicable to add these in all approaches. As a comprehensive overview of valid inequalities for lot-sizing models would go beyond the scope of this work, we only give examples of valid inequalities for the Solution Techniques for Dynamic Lot-Sizing.

Best model optimization gives a condensed introduction to simulation-based optimization methods, based on the content of the more elaborate and in-depth overview. Many stochastic optimization problems encountered in real-world applications are too complex to be described in closed-form mathematical models and solved analytically. One approach for tackling such problems is to use simulation. The purpose of simulation models is to forecast the behavior of complex, stochastic, real-world systems. Usually, simulation models are used to evaluate the consequences of single decision alternatives without implementing these in the real-world system, as this might result in negative effects. Simulation models can be categorized along the following three dimensions:

- Static vs. dynamic simulation models: A static simulation model represents a system by a “snapshot” at a certain point in time, whereas a dynamic simulation model maps a system’s behavior over time.
- Deterministic vs. stochastic simulation models: If a simulation model does not contain any random influences, it is termed deterministic, and otherwise stochastic.
- Continuous vs. discrete simulation models: Continuous simulation models map a system that changes continuously over time, whereas discrete simulation models map systems in which state changes only happen at certain points of time. A frequently considered case are dynamic, stochastic, discrete simulation models, which are also named discrete-event simulation models. In most cases, only a comparatively small number of alternatives is evaluated using simulation software, and one of these alternatives is selected using a certain decision criterion. Thus, the classical approach in simulation is to perform simulations automatically using software, whereas the choice of an alternative happens manually.

REFERENCES

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