Analysis and improvement of production planning within small-batch make-to-order production

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Abstract. This paper examines manufacturing planning within small-batch make-to-order. Electronic equipment manufacturing companies face challenges caused by increasing numbers of product variants as the demand for individualized products rises. Enterprises have to provide more individualized products instead of standardized ones. Cause of high variation in volumes and high mix of products it is difficult to use common planning tools. Known manufacturing planning methods cannot quickly realize adaptation for efficient use of enterprise capacities. This problem became big challenge for production planners. The purpose of this paper is to understand the requirements on enterprises to use planning and scheduling in small batch make-to-order production. We explore challenges associated with planning strategies. Finally, we consider a functional model of developing a planning system.

1. Introduction
Customer-oriented production is a key concept of the plant of the future. In the world of production, companies are facing the challenge of making customized products in a large number of variants in a very small batch [1]. The extreme case of Make-To-Order (MTO) production is a One-Of-A-Kind manufacturing when the product ordered by customer and it is produced only once. A more common case when a wide range of products with customer specifications and designs are made from a combination of standard materials and components [2]. Production is carried out only when the order is received from customers. MTO production needs realistic and flexible operational plans to easily track the progress of the order to ensure a reliable delivery date [3]. Most electronic equipment manufacturing companies are small or medium size enterprises working exclusively with small series. A constant change in production volumes and components leads to the inefficient use of enterprise capacities. Since production planning is the link between product development and production, it is a key factor in reducing costs and accelerating the market entry. It is not enough to use common planning tools to get effective small batch production.

This paper explores the importance of production planning within small-batch MTO production. Despite a large number of planning tools, we find no robust evidence of their effective use for make-to-order production. This study indicates that classic approaches of scheduling cannot be efficiently applied to the experimental small-batch production. In section 2, challenges of the make-to–order production planning are described. The relevance of different information tools to the MTO sector is assessed in section 3. In section 4 we consider a functional model of developing a planning system. The conclusion and further work follow in section 5.
2. Production planning levels and strategies

Planning is the process of developing production plans based on existing constraints. The purpose of production planning is to satisfy consumer demand at the lowest cost [4]. Production capacity is the ability to produce goods and services and it depends on the efficient use of equipment, labor and financial resources, as well as on the ability to timely receive materials and components from suppliers. A balance between demand and production capacity is achieved through effective planning.

Production planning is carried out at three levels such as strategic planning, tactical planning and operational scheduling [5]. Each level has its own task, duration and level of detail (Figure 1). As you move from strategic planning to operational scheduling, the task changes from determining the general direction to specific detailed planning, the duration decreases from years to days, and the level of detail increases from general categories to conveyors and equipment. A strategic plan is the statement of the main goals and objectives that the company expects to accomplish in a period of two to ten years or longer. It is based on long-term forecasts and is developed by marketing, finance, production and technical departments. Based on the tasks set in the strategic plan, the production plan is calculated. Decision-maker specialists should develop a production plan that would satisfy market demand based on the company’s capacities [6]. Master production schedule (MPS) reflects the nomenclature positions of products that the company plans to produce. Capacity requirement planning (CRP) is intended for planning the need for production capacities necessary for the implementation of the master production schedule. The main task of material requirement planning (MRP) is that each element of production, each component part, should be in the production at the right time in the right quantity. However, MRP/MPS/CRP methods are only effective for Make-To-Stock (MTS) production.

![Figure 1. Levels of production planning](image)

Production strategies can be different and depend on the type of product that the company produces. There are two fundamentally different concepts: Make-To-Order (MTO) and Make-To-Stock (MTS). The MTS manufacturing usually takes place without specific customer orders based on existing forecasts, and orders are satisfied with stocks of finished products [7]. The MTO is the occurrence of an order from a customer that starts a production order. Companies manufacturing at the
warehouse most often produce standard products without any specific customer influence. When making to order, the customer’s influence on the product is significant and this ultimately leads to a greater number of product ranges and variations. At the same time, the volume of products per unit of an item is much less than in MTS strategy [8]. While MTS sector is more predictable, MTO company product parameters are unknown until the order is approved. Features of MTO production lead to inefficient using of standard MRP/MPS/CRP systems [9].

Companies with MTS strategy often produce standard or module products without any specific influence of the customer. In MTO the customer's influence on the product is significant, resulting in more product range and variation [10]. At the same time, the volume of output per unit of the nomenclature is significantly less than in the MTS production. Among MTO companies most are small or medium sized. The average quantity for small-batch production can be around 50 products (devices, kits) per batch, which are produced less than 12 times a year. There is an intermediate strategy known as Assemble-To-Order (ATO). In such manufacturing, products are assembled with components after receiving an order from the customer. Key components are produced in advance and stored while waiting for the customer's order and receiving the order initiates the assembly of an individual product [12]. This strategy can be applied when there are large number of end products with differ in options and accessories, and can be assembled from common components. In the case when the products are too complex or consumer demand is unpredictable, manufacturers prefer to keep the products in semi-finished products [13]. With this strategy, manufacturers cannot produce products as fast as they do in stock, because additional time is required to complete the final assembly. In an enlarged form, the ATO strategy is close to the MTO, the main difference is the inventory level for each strategy. Special cases of MTO policies is Engineer-To-Order (ETO) [14]. The ETO strategy is the most complicated and it is not provided properly organized production planning system based on the provisions of the theory of schedules, lean production methods, optimization theory and computational methods. Although there are many more narrow production strategies, such as Build-To-Order, Design-To-Order, Finish-To-Order, but in our study we consider only MTO in a broad sense.

The first stage of planning is to receive an order or request from the customer. When a customer invites potential suppliers to participate in a tender for a specific product, requiring a specific price and delivery date. For MTO production strategy, planning should start here, since each order can be different and decisions made here affect all subsequent stages. Next comes the design stage, where detailed design and engineering planning takes place for accepted orders. When designing a unique product, which happens in ETO production, each customer order leads to a unique set of parts, specifications, and production routes [15]. The ETO strategy is the slowest to complete, taking time not only to create a product, but also to custom design to meet the customer's unique requirements. The next stage is planned to produce a confirmed order, including the requirement for materials and purchases, scheduling of workshops.

3. Planning tools
All companies with limited financial resources have to meeting increasingly high customer demands. Enterprises are in particular danger of suffering the consequences of implementing an inappropriate production planning systems. Planning material requirements, demand management, capacity planning and the scheduling are typical function of such systems. The use of such systems leads to minimize shop floor throughput times and lead times, reducing work [16]. Most planning systems are designed for MTS production needs. Typical functions of such systems include material requirements planning, demand management, capacity planning, and scheduling. When implemented effectively, such systems enable to reduce work in progress, lead time, inventory storage costs and improve delivery compliance.

Enterprise Resource Planning (ERP) systems are widely used. These systems for managing production, human resources and finance, focused on optimizing enterprise resources. Supply chain management, inventory accounting, customer relationship management, and personnel management
are features of such systems [17]. With effective implementation of the ERP system, businesses will be provided with business benefits. The core of ERP system was based on MRP/MPS/CRP methods. These systems have become the de facto standard for business management, where automation is possible. Software products of this class are widely available on the market, and suppliers claim that their products are widely applicable and customized to meet the needs of any production. But MTO companies, as well as companies that have high quality requirements, have quite complex requirements in decision support. It remains unclear whether ERP systems can meet their requirements. It is important to note that ERP systems also have shortcomings in the planning area, cause consecrate on business process management and transactional activities.

Advanced Planning and Scheduling (APS) systems appeared due to limitations in classic ERP systems. In general, APS have better performance and more complete functionality than the ERP-system in the field of production planning, because this is their main goal [18]. Using data obtained from an ERP or MES system, APS is a software product that allows optimally loading production capacities taking into account existing restrictions. It is defined as the concept and methodology of the decision-making process of calendar and operational planning, which allows synchronizing individual departments and workshops within the enterprise to achieve automatic optimization. In reality, the successful use of APS systems in the manufacturing sector with a large number of batch and components is limited [19]. Most commercial APS systems have a complex structure that is quite difficult to modify to meet the needs of a particular enterprise. In addition, the algorithms used to make decisions in these systems require a huge amount of data for correct operation, often excessive. The main challenge of APS is the decomposition of tasks into sub-tasks and selection effective sub-task solution algorithm.

4. Proposed planning & scheduling system framework
The purpose of APS systems is considered in the context of scheduling theory. The problems, that this theory solves, include ordering, distribution, and reconciliation. Most often in planning systems, the task of ordering is implemented, and the distribution of work by job and the duration of these works are considered to be set [20]. The system distributes the order queue to jobs most efficiently. In distribution tasks, orders are distributed to jobs based on the condition that different operations can be performed on the same job. Reconciliation tasks are essentially network planning tasks [21]. In real small-batch MTO production situations, it is not possible to get one of these tasks in its pure form. Using implemented solutions to these problems in automated planning systems does not lead to the desired result [22]. The decomposition of tasks into sub-tasks leads to the best-planned decisions.

We develop a new model of manufacturing planning system that allows taking into attention the possibility of rapid (dynamic) adjustments through automated assessment of key performance indicators and making appropriate decisions. The model is aimed at optimizing the operation of production in a constantly changing production plan, which allows increasing its management efficiency in accordance with the specified criteria of optimality. The first step is to describe the model of the planning system functionally; based on the typical functions of APS systems (Figure 2).

The purpose of developing system is the efficient use of production resources in time. Planning system is designed to adjust the order progress and production plans in case of unexpected deviations orders portfolio. The capacity estimation subsystem performs optimal load of production capacities, minimizes the production cycle and reduces production losses. The main source data is orders from customers and data on equipment loading and the priority of the order is calculated based on the completion date and the date of its receipt. Based on the priority of orders in portfolio, this subsystem generates orders list for manufacturing and evaluates the timing of their execution. Then the generated orders are planned for manufacturing by using different approaches, such as minimizing the work in progress or minimizing the production time. The hardest part is evaluating job performance and Overall Equipment Efficiency (OEE) [23]. The uneven processing of orders and uncertainties in the condition of the equipment make a static performance estimate inaccurate and untimely. The state of the equipment and OEE should be evaluated in real time, coordinated with the mathematical model.
performance evaluation for orders portfolio. In addition suitable models are provided for different situations and degrees of workshop loading.

![Diagram of Planning System](image)

**Figure 2.** Framework of planning & scheduling system.

The purpose of the scheduling subsystem is scheduling of workshops. This subsystem gets date from the capacity estimation subsystem and solves two main tasks, such as determines the order execution sequence and the assignment of jobs. It is important to coordinate production in real time, using different criteria to form production tasks in the optimal sequence. The execution control subsystem monitors production activities in real time. It displays the progress of execution of production plans, controls errors and violations in production. This system is needed primarily to reduce work in progress and synchronize the scheduling subsystem.

5. Conclusion

Facing with global trend of Industry 4.0, many enterprises proposed its industry policy of customer-oriented production. MTO with ETO jointly is the strategy that produces customized products but not repeated on regular basis. There are many companies around the world that are using MTO strategies and require the application of planning and scheduling system, as well as MTS companies. Due to the difficulty for MTO production to implement standard solution an advanced planning and scheduling systems, in this paper, we considered MTO production scheduling problem. The real case analysis shows that existing planning tools is applicable in real MTS production, but not for MTO.

The paper discusses the current definitions of planning and scheduling systems based on literature sources. We contribute by providing an assessment of the applicability of planning tools to the MTO sector. There is a significant gap between the requirements of MTO companies and the functionality of common planning tools. We propose the framework to coordinate decisions and operations across production stages. Direction for the extension of this research could be to optimize production plans and schedules as well as to ensure that they are executed and real-time controlled according to the dynamic changes and operational constraints. Future research can also explore the methodology for generating alternative versions of plans and schedules.

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