

Study on Production Planning and Control Strategies for Small-Batch, Multi-Product Manufacturing

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Abstract

With the rapid development of the world economy, people's living standards are also improving, people's demand for products is becoming more and more diversified, because of the change of market demand, manufacturing enterprises must also change to the direction of product diversification, privatization and differentiation, but the transformation of multi-variety and small batch production methods has brought great challenges to manufacturing enterprises. Due to the small batch size and many varieties, there are deficiencies in quality control, cost size, on-time delivery, etc., so enterprises must improve the manufacturing problems existing in the multi-variety and small batch mode under the premise of meeting market demand to improve the competitive advantage of enterprises in market competition. After fully analyzing the characteristics of multi-variety and low-volume production, various modes of production planning and control, production planning and control process, this paper puts forward three suggestions based on the actual problems of factory A: before compiling the production plan, the production capacity should be measured, and the bottlenecks that restrict production should be optimized and improved; When preparing the production plan, there should be a certain margin to adapt to the changes in the market; When arranging the production plan, the production plan for the near future should be carefully arranged, the process is accurate to each process, and the time is accurate to the hour; Each station should fill in the daily production completion, and the production management personnel should timely collect statistics and deal with abnormal processes and data.

Keywords

Multi-variety Small Batch; Production Planning; Process Control; Theory of Constraints.

1. Introduction

1.1. Source and Background of the Paper

In the early 20th century, product demand far exceeded production efficiency, so sellers held the dominant position in the commodity market. Mass production was widely used in manufacturing, with companies lowering costs through large-scale production. However, with the rapid development of modern manufacturing and the diversification of market demands, along with technological advancement and increasingly personalized consumer needs, companies face a growing variety of products and constantly changing market requirements. In this context, the traditional single, large-scale production model can no longer meet market needs, giving rise to small-batch, multi-product production models. However, such small-batch, multi-product production has notable characteristics: many product types, small production batches, and complex production routes. This makes production planning and control more complicated and challenging. To effectively tackle these issues, companies need to seek more

flexible and efficient production planning and control strategies to optimize resource allocation, improve production efficiency, reduce costs, and meet market demands while maintaining a competitive edge. At the same time, the continuous development of information technology provides new tools and methods for research on production planning and control strategies. By incorporating advanced IT like big data, cloud computing, and AI, companies can more accurately forecast market demands, optimize production plans, and monitor production processes, achieving intelligent and automated production management. Thus, changes in market demand, shifts in production models, and ongoing IT development suggest that small-batch, multi-product production will replace large-scale production as the mainstream method for modern enterprises^[1-2].

1.2. Purpose and Significance of the Research

The main purpose of studying production planning and control strategies for small-batch, multi-product manufacturing is to meet the growing personalized demands of the market and adapt to the rapidly changing market environment. By optimizing production planning and control strategies, companies can better understand market demand, improve production efficiency and product quality, reduce costs, and ultimately boost market competitiveness^[2].

In terms of significance, research on production planning and control strategies for small-batch, multi-product manufacturing has the following importance:

- (1) Improve production efficiency: Through reasonable production planning and control strategies, companies can use production resources more efficiently, reduce waste during the production process, and increase production efficiency.
- (2) Reduce production costs: Optimizing production plans and control strategies helps companies minimize inventory backlog and lower inventory costs, while avoiding resource waste caused by overproduction or underproduction, thus reducing overall production costs.
- (3) Enhance product quality: By implementing strict production plans and control strategies, companies can ensure that every production stage meets quality standards, thereby improving product quality and customer satisfaction.
- (4) Strengthen market competitiveness: The small-batch, multi-product production approach allows companies to respond more quickly to changes in market demand, launch new products, or improve existing products, enhancing market competitiveness. With the continuous changes in the market environment and the growing personalized demands, this research area will continue to play an important role in promoting sustainable development for enterprises.

2. Planning and Control Process for Multi-Variety, Small-Batch Production

2.1. Demand Forecasting

Demand forecasting is a crucial business process. It primarily relies on market research data to conduct an in-depth study of the future market demand changes for the products of a proposed project. The objective is to grasp the inherent patterns of demand and make accurate estimations and judgments about its development trends. In this way, enterprises can ensure that the products produced after launch meet market demand and possess strong competitiveness.

Demand forecasting is not only concerned with existing demand but also with exploring potential demand. Through market research, user feedback, and industry insights, businesses can identify and satisfy needs that consumers have not yet realized. At the same time, demand forecasting also needs to pay attention to social and technological trends, as these factors can have a profound impact on market demand^[3-5].

2.2. Formulation of the Master Production Schedule

The Master Production Schedule (MPS) determines the production quantity and timeline of various finished products based on the aggregate plan. It is a crucial component in manufacturing, as it dictates what the enterprise should produce, how much to produce, and when to produce over a certain period.^[2] The main objective of the Master Production Schedule is to ensure that the enterprise can deliver products on time, meet market demand, and at the same time achieve optimal use of resources and cost efficiency^[6,12].

MPS has three constraints:

- (1) Production total consistency: The total production determined by the MPS must be consistent with the total production determined by the overall plan (or aggregate plan).
- (2) Resource constraints: When determining product batch sizes and production times, resource constraints must be considered. There are many types of resource constraints related to production volume, such as equipment capacity, personnel capacity, inventory capacity (size of storage space), total working capital, etc. The MPS cannot include items that exceed available materials and possible capacities^[7].
- (3) Production batch and cost considerations: While determining production batches by unit planning periods in the master production schedule, the switching costs and inventory costs of operations must be considered to ensure the economic efficiency of production activities^[5].

Steps for formulating MPS:

- (1) Calculate the existing inventory

Existing inventory refers to the available inventory remaining after the weekly demand has been met. Its calculation formula is:

$$I_t = I_{t-1} + P_t - \max\{D_t, MO_t\} \quad (1)$$

I_t ----- existing inventory at the end of week t

I_{t-1} ----- existing inventory at the end of week $t-1$

P_t ----- production quantity in the master production schedule for week t

D_t ----- forecasted demand for week t

MO_t ----- customer orders scheduled for delivery in week t

- (2) Determine production quantities and production times for the master production schedule. (including demand forecast, order quantities, existing inventory, and MPS quantities)

- (3) Calculate Available-to-Promise Inventory (ATP)

2.3. Production Job Scheduling

Production Job Scheduling (PJS) is a core aspect of enterprise production management. It involves transforming production orders into specific production tasks and reasonably allocating production resources to ensure that the enterprise can achieve refined management of the production job schedule^[7], improve production efficiency, reduce operational costs, and simultaneously ensure product quality and timely delivery, thereby maintaining a competitive advantage in a highly competitive market.

The steps for preparing a production job schedule are as follows:

- (1) Determine the lead time quota and batch quota for each production stage: Lead time includes input lead time and output lead time. For a certain workshop, input lead time = workshop output lead time + workshop production cycle; the calculation of output lead time needs to consider whether the batches of two consecutive workshops are equal. If the batches are equal, the output lead time of a certain workshop = subsequent workshop input lead time + safety period; if the batches are unequal, the output lead time of a certain workshop =

subsequent workshop input lead time + safety period + current workshop production interval - subsequent workshop production interval^[8].

(2) Calculate the cumulative numbers of production output and input that each workshop should achieve by the end of the planned period:

$$N_o = N_{oe} - N_d * T_o \quad (2)$$

$$N_{in} = N_{oe} - N_d * T_{in} \quad (3)$$

N_o ----- cumulative output number of the current workshop

N_{oe} ----- cumulative output number of the final workshop, i.e., the assembly workshop

N_{in} ----- cumulative input number of the current workshop

T_o ----- output lead time of the current workshop

T_{in} ----- input lead time of the current workshop

N_d ----- daily average output of the final workshop

(3) Calculate the production output and input quantities for each workshop during the planned period:

$$\Delta N_o = N_o - N_{o1} \quad (4)$$

$$\Delta N_{in} = N_{in} - N_{in1} \quad (5)$$

ΔN_o ----- production output of the current workshop during the planned period

N_{o1} ----- initial cumulative output number of the current workshop

ΔN_{in} ----- input quantity of the current workshop during the planned period

N_{in1} ----- initial cumulative input number of the current workshop

Adjust the calculated production output and input quantities so that the workshop's output or input quantity equals the economic batch size or a multiple thereof.

2.4. Production Process Control

Production Process Control (PPC) is a systematic set of methods and techniques aimed at ensuring the stability and reliability of production processes through precise monitoring, analysis, and adjustment of production activities. Its core objective is to maximize production efficiency and ensure consistency in product quality, while reducing production costs and risks. PPC achieves comprehensive control over the production process through real-time data collection, statistical process control, process capability analysis, fault prevention, quality control, and continuous improvement^[5,8,13].

Production Process Control Steps:

(1) Establish Standards: This is the initial step of the control process, primarily aimed at specifying the desired equilibrium state required by the control system.

(2) Measure Effectiveness: After establishing standards, it is necessary to supervise and inspect actual production activities according to these standards. This includes comparing the actual process with the planned schedule and comparing the actual results achieved with the planned objectives.

(3) Correct Deviations: When discrepancies are found between the actual results and the plans or standards, deviations occur. At this point, the key to the control process is to take appropriate measures to correct these deviations.

(4) Confirm Results: Monitor the adjustment process, verify the implemented results, and make further adjustments if necessary.

3. Case Study of Production Planning and Control Strategies at Factory A

3.1. Basic Situation of Factory A

Factory A is a domestic factory specializing in the production of automobile components. Its main products include mufflers, exhaust pipes, and downspout assemblies. There are numerous different models for each product; for instance, there are over a thousand types of exhaust pipes, and the demand for each model varies over time-some have high demand reaching tens of thousands of units, while others have very low demand, requiring only one unit. Therefore, Factory A adopts the classic small-batch, multi-variety production method. Currently, the main issue facing Factory A is how to fulfill customer demands on time at the lowest possible cost^[9,11].

3.2. Problems and Solutions in the Production Planning of Factory A

In the past, Factory A used a production method that combined short-term production operation plans with long-term production operation plans for batch production of products. The long-term production operation plan could not accurately predict product demand, while the short-term production plan was frequently arranged unreasonably. This led to an inability to meet customer demand when orders were high and to wasted production capacity when orders were low. There were also issues in process control. After the production plan was formulated, planners and actual production personnel could not communicate quickly, the production process was not controlled in real time, resulting in some delays, and the production planning system could not rapidly respond to changes in order information. These problems led to a longer production cycle, and the factory's current average first-pass yield is 98.7%.

This article will integrate the characteristics of MRP II, JIT, and the Theory of Constraints to develop the production plan and process control for the factory's exhaust pipes. Before production, the factory's production capacity must be measured to identify bottleneck processes in the production workflow, address these bottlenecks, and optimize the factory's production capacity. Push production is prone to significant waste and cannot quickly adapt to market changes. The factory's production capacity struggles to meet the requirements of pull production. Additionally, although the factory produces many types of exhaust pipes, their sales volumes sometimes vary significantly. Therefore, when arranging production plans, product demand for the current year should first be forecasted based on sales records from previous years.

3.3. Overview of Exhaust Pipe Production at Factory A

(1) Production Data

Determine production capacity and identify bottleneck processes in the production workflow, and explore possible ways to eliminate these bottlenecks^[10]. The production preparation time and processing time for the exhaust pipe in each process are shown in Table 1.

Average Processing Time=42.015+40+73.428+60+47.46+90+64.392+60+149.365+30+67.775+102.986=827.403

As shown in the table, the processing time for assembly welding is generally long, which can be reduced by replacing machines or training workers. The total processing time for the exhaust pipe of model Q7 is the longest because the Q7 product is the largest in size. Therefore, in the Q7 processing operation, it is possible to choose a different processing method from other products to effectively reduce processing time. Below, solutions will be sought for the identified bottleneck processes.

Table 1. Exhaust Pipe Production and Setup Time Schedule (Unit: Seconds)

Work station Name Model	Material Cutting		Curved		Cutting Allowance		Spot Welding		Assembly Welding		Inspect ion	Apply oil and paint
	Process ing Time	Prepara tion Time	Process ing Time	Preparati on Time	Process ing Time	Preparati on Time	Process ing Time	Preparati on Time	Process ing Time	Preparati on Time	Inspect ion Time	Processi ng Time
KINZ	75.64	40	64.12	60	45.73	90	42.12	60	263.14	30	98.54	96.42
L7-y4	27.56	40	62.66	60	32.16	90	75.32	60	97.52	30	60.12	78.65
D114	30.12	40	122.15	60	35.12	90	75.69	60	121.13	30	60.12	75.21
Q7	68.47	40	61.43	60	107.56	90	45.32	60	176.26	30	85.54	185.21
DO07	25.34	40	65.21	60	34.21	90	52.81	60	113.14	30	52.33	92.32
K8-B5	25	40	65	60	30	90	95	60	125	30	50	90
Average Processing Time	42.015	40	73.428	60	47.46	90	64.392	60	149.365	30	67.775	102.968

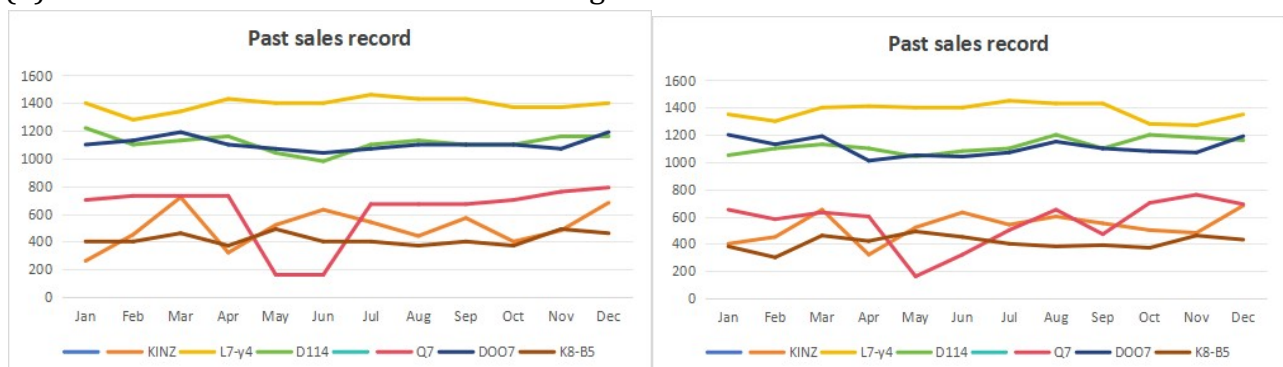
The factory has replaced the machines used for assembly welding, which has reduced processing time. Although model Q7 has the longest processing time, the machines and processing methods for the same operation in the factory are the same. Purchasing separate processing machines or changing processing methods specifically for Q7 would be too costly^[11-12]. Moreover, Q7's sales volume is only a small portion of the total, so the Q7 processing process will remain unchanged. The production preparation time and processing time for each procedure after the improvement of the bottleneck process are shown in Table 2:

Table 2. Production and Preparation Time Table for the Improved Exhaust Pipe (Unit: Seconds)

Work station Name Model	Material Cutting		Curved		Cutting Allowance		Spot Welding		Assembly Welding		Inspect ion	Apply oil and paint
	Process ing Time	Prepara tion Time	Process ing Time	Preparati on Time	Process ing Time	Preparati on Time	Process ing Time	Preparati on Time	Process ing Time	Preparati on Time	Inspect ion Time	Processi ng Time
KINZ	75.64	40	64.12	60	45.73	90	42.12	60	199.82	30	98.54	96.42
L7-y4	27.56	40	62.66	60	32.16	90	75.32	60	76.53	30	60.12	78.65
D114	30.12	40	122.15	60	35.12	90	75.69	60	100.86	30	60.12	75.21
Q7	68.47	40	61.43	60	107.56	90	45.32	60	152.91	30	85.54	185.21
DO07	25.34	40	65.21	60	34.21	90	52.81	60	95.34	30	52.33	92.32
K8-B5	25	40	65	60	30	90	95	60	99	30	50	90

3.4. Preparation of Annual Production Plan for Factory A

(1) Historical sales records are shown in Figure 1:

**Figure 1.** Sales Record Chart

From the chart, it can be seen that the sales records of these product models from the factory have been steadily increasing by small numbers over the past two years. Based on the historical sales records of Factory A, the demand for next year's products can be forecasted, and the annual production plan can be prepared accordingly^[13].

Table 3. Annual Production Plan

Product Category	January	February	March	April	May	June	July	August	September	October	November	December	Total
KINZ	450	510	510	510	510	510	510	510	510	510	510	510	6060
L7-y4	1400	1400	1370	1400	1400	1400	1400	1400	1400	1400	1370	1400	16740
D114	1160	1130	1100	1100	1100	1100	1130	1130	1100	1130	1130	1100	13410
Q7	730	730	730	730	700	700	700	700	700	700	730	700	8550
D007	1130	1130	1130	1100	1100	1100	1070	1100	1100	1100	1100	1130	13290
K8-B5	430	430	400	430	430	400	400	400	430	430	430	430	5040

Because enterprises engaged in small-batch production of multiple varieties operate based on orders, production is organized according to customer requirements after receiving an order and is therefore random. Consequently, the annual production plan serves only as a predictive reference indicator, intended merely for the advance planning of monthly raw material allocation. The specific monthly production plan must still be appropriately revised and adjusted according to customer orders.

3.5. Preparing the Order Scheduling Table

Production management personnel prepare the order scheduling table based on customer orders and delivery schedules. Since the batch sizes for each product are equal, the production lead time equals the input lead time plus a safety period, so the manufacturing schedule is calculated as the delivery date minus the safety period^[14]. The safety period for factory product production is 1 day. The order scheduling table is shown in Table 4:

Table 4. Partial Order Schedule of Factory A

Production batch	Model	Quantity	Manufacturing Schedule	Production Cycle (minutes)
10	KINZ	50	March 20~21	13
10	L7-y4	10	March 22	15
10	D114	40	March 23	15
10	Q7	20	March 24	16
10	D007	30	March 25	12
10	K8-B5	10	March 27	14

3.6. Preparation of Team Schedule Plan

After the production team receives the production operation plan, they prepare a schedule plan, and then, based on the standard time for each specific process, prepare an operation plan for each workstation. Once the operation plan is completed, it is issued to each workstation in the form of a production notice.

The team prepares the work schedule for each workstation based on the standard time for specific processes. Once the work schedule is prepared, it is issued to each workstation in the form of a production notice. Each workstation, at the end of daily operations, records the actual completion status for production control purposes. Production management personnel analyze the data reported into the system daily to control the production process, checking whether

each step arrives and departs on time. In case of any abnormalities, immediate action is taken. At the same time, the reasons for the abnormalities are analyzed to prevent the recurrence of the same issues.

3.7. Improvement Results

Previously, the average processing time at Factory A was 827.403 seconds. After implementing the new production scheduling method and process control, the production cycle for exhaust pipes at Factory A has been significantly improved, with the average processing time reduced to 583.319 seconds. The optimized product production cycle time has been shortened by 29.5%. It is necessary to maintain this progress and apply the successful experience to more products to achieve more efficient production. Since the implementation of the improvement measures, the current average pass-through rate has reached 99.35%, surpassing last years pass-through rate of 98.7%.

4. Conclusion

Small-batch production of multiple varieties indeed has its unique advantages and challenges. On the advantage side, this production mode can meet the diversified demands of the market, flexibly adjust product types and quantities, and quickly respond to market changes. At the same time, because the production batches are small, it can reduce the risk of inventory backlog and lower capital occupation. However, the challenges should not be overlooked. Small-batch production of multiple varieties usually means that production lines need to be adjusted frequently, equipment utilization may be low, and production efficiency is affected. In addition, due to the variety of products, quality management becomes correspondingly more difficult, requiring stricter quality control and traceability systems.

Through the new production planning and scheduling methods, the number of work-in-progress items has been reduced, inventory levels decreased, and the production process has become clear and smooth. This not only enhances the competitiveness of the enterprise but also brings economic benefits to the company.

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