Advanced Production Plan System of Military Manufacturing Enterprises Based on Linear Programming Model

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Abstract. The problem encountered by military manufacturing enterprises in the preparation of production plans is mainly attributable to the failure to optimize supply and demand resources in the supply chain. The article innovatively employs the advanced planning system based on linear programming model to solve the problem. The problem is first of all described mathematically; then its linear programming model is constructed, and the latter’s APS system designed; at last, the model is solved and checked. Upon the verification, the model is proven helpful for enterprises to work out production plans quickly and efficiently, and carry out what-if analysis. While winning the time advantage for military manufacturing enterprises in the market competition, it also enhances their operating management efficiency.

1. Introduction

With the advent of industrial 4.0 in the recent years, the preparation of corporate production plans in the framework of supply chain is no longer the behavior of individual nodes but the behavior of combining both upstream and downstream resources. Its contents involve all factors such as information sharing, resource allocation, production plan arrangement, internal and external cooperation and coordination, etc. MRP/MRP II system[1] developed in the middle period of the last century presents a relatively perfect solution to the arrangement of internal production plans of enterprises, but it does not completely applies to the preparation of production plans in the environment of supply chain. Presently, a great number of enterprises spare no effort to promote ERP system, which incorporates some of supply chain management ideas but are still subject to restrictions of functions of MRP model[2, 3]. APS (Advanced Planning System) emerging in the past several years is gaining the popularity among all enterprises, and has become one of the most active plan modes in the supply chain management[4]. Being synchronous, timely, and comprehensive, and adopting some advanced management plan technologies and effective algorithms, APS makes up for some defects of the previous production planning methods, and meets the needs of corporate production planning and scheduling.

The military industry is one of the traditional backbone industries with the most complete categories, and the problem encountered in the preparation of corporate production plans is mainly attributable to the failure to optimize supply and demand resources in the supply chain, thus restraining the enhancement of corporate operating efficiency. Therefore, it is extremely urgent to construct a production scheduling system that is intended to optimize the configuration of upstream and downstream supply resources in the military industry[5]. Apart from the change of traditional management modes in the military industry, it is also required to employ modern corporate supply
chain information technology and resource optimization technology[6]. The system is designed to comprehensively integrate and optimize all resources in the supply chain, such as supply resource, client resource, internal resource, etc. The paper is innovative in: applying the advanced planning system based on linear planning model to the preparation of corporate production plans and bringing forth the corresponding model.

2. Advanced Planning System (APS)

APS is an advanced planning and scheduling tool based on supply chain management constraint theory, and involves a good many mathematical models, optimization algorithms, and simulation technologies. In the process of planning and scheduling, APS employs complicated algorithm rules for planning and calculation based on internal and external resource and capacity constraints of military manufacturing enterprises[7]. APS software is usually composed of 5 major modules: demand planning, production planning and scheduling, distribution planning, transportation planning and supply chain analysis. Production planning is the key link of APS supply chain planning matrix (Figure 1), and its rationality determines whether the supply chain planning is scientific, systematic and effective.

3. Mathematical description of production plans of military manufacturing enterprises

It is supposed that a military supporting factory manufactures \( I \) product (model), and the products’ client (upstream and downstream) demand and selling price in a given period of time are \( m_{it} \) and \( p_{it} \) respectively. The quantity of raw material \( J \) required for the production of unit \( I \) product is \( b_{ij} \) (unit consumption). The maximum supply of raw material \( J \) in a given period of time is \( s_{jt} \). Try to consider how to arrange production plan, sales plan and inventory plan in a given period of time so as to maximize the enterprise’s profit. Parameter description: \( t \) : time period, \( t \in T \), in which \( T \) is the aggregation of all plan periods; \( i \) : product, \( i \in I \), in which \( I \) is the aggregation of final products; \( j \) : material, \( j \in J \), in which \( J \) is the aggregation of raw materials.

4. Construction of military model based on linear planning

According to the description of the problem and the construction analysis of mathematical model of supply chain above, decision variables of the model selected are the planned production quantity,
planned inventory, and planned distribution quantity of product \( i \) in period \( t \); the goal of the model is the maximization of profit\[8, 9\]. Mathematical expressions of target functions are related to sales income, production cost, and inventory cost; constraints of the model include product balance constraint, client demand constraint, material supply constraint and capacity limitation constraint\[10\]. An optimization model for advanced production plans of supply chain is constructed according to the selected decision variables, model targets, and model constraints.

\[
\begin{align*}
\text{Max} & \quad Z = \sum_i \sum_t \{ p_{it} z_{it} - c_i x_{it} - s_i y_{it} \} \\
\text{S.T.} & \quad \sum_i 1/r_i \cdot x_{it} \leq a_t \quad \forall t \quad \cdots \text{Capacity constraint} \\
& \quad x_{i0} + q_i - z_{i0} - y_{i0} = 0 \quad \forall i \quad \cdots \text{Initial equilibrium constraint} \\
& \quad z_{it} \leq m_{it} \quad \forall i, t \quad \cdots \text{Customer demand constraint} \\
& \quad \sum_i x_{it} b_{ij} \leq s_{jt} \quad \forall j, t \quad \cdots \text{Raw material supply constraints}
\end{align*}
\]

The model’s input parameters are described as follows: \( r_i \) is the quantity of products \( i \) produced in unit time; \( q_i \) is the initial inventory of product \( i \); \( a_t \) is the available working hours in the period \( t \); \( m_{it} \) is the client demand of product \( i \) in the period \( t \); \( c_i \) is the production cost of product \( i \); \( s_i \) is the inventory cost of product \( i \); \( p_{it} \) is the selling price of product \( i \) in the period \( t \); \( s_{jt} \) is the maximum supply quantity of material \( j \) in the period \( t \); and \( b_{ij} \) is the quantity of material \( j \) needed for the production of unit product \( i \). The model’s decision variables are described as follows: \( x_{it} \) is the planned production quantity of product \( i \) in the period \( t \); \( y_{it} \) is the planned inventory of product \( i \) in the period \( t \); and \( z_{it} \) is the planned sales quantity of product \( i \) in the period \( t \).

5. Design of APS based on linear planning model

(1) Logic structure design of APS is shown as Figure 2;
(2) Function structure of APS;

The functional structure of APS is constructed with production plan model of supply chain as the core. APS needs to call material supply data, raw material supply data of upstream and downstream demands and customer demand data through Web Service, which can be used as input parameters of production planning optimization model. Other relevant input parameters such as product information price, production cost and inventory cost can be obtained internally through military manufacturing enterprises. The production plan model of supply chain is constructed and solved through the calling of CPLEX optimization engine so as to obtain production plan, inventory plan and sales plan\[11\]. Based on input and output parameters, APS of supply chain is functionally divided into customer maintenance, supplier maintenance, BOM maintenance, available man-hour maintenance, product parameter maintenance, production planning maintenance, sales planning maintenance, inventory planning maintenance, material information maintenance and procurement planning maintenance.

(3) Database structure of APS

APS involves varied and complicated data and data structures, and the paper employs ERwin tool for logical design of database. The concrete data logic model constructed is shown as Figure 3. The entities included are shown as Table 1. Each entity has its own properties, and there are the corresponding connections among entities\[12\].
6. Solution to APS based on linear planning model

The system adopts Concert Technology framework. IloNumVar, IloRange and IloObjective are the classes that correspond with decision variables, constraint conditions and target functions of linear planning model. IloCplex.Algorithm.Auto is adopted to make ILOG CPLEX select suitable algorithms to solve linear planning problems. The eight statuses obtained are: wrong, unknown, feasible, bounded, optimal, infeasible, unbounded, infeasible, or unbounded.

Application steps of CPLEX for JAVA are:
Step 1: input and output parameters[13] are shown as Table 2;
Step 2: as for target functions and constraint conditions, the needed parameters are shown as Table 3;
Step 3: proper optimization methods are selected to solve the constructed model according to the actual situation. Algorithm selection, solution status and maximum value of target function are adequately considered. Functions used in the paper include: cplex.setParam(), cplex.solve(), cplex.getStatus() and cplex.getObjValue().

7. Example verification of linear planning model

It is known from system model and production plan model of supply chain that: constructing production plan model requires considering material supply information of suppliers, demand information of upstream and downstream clients, internal production capacity, manufacturing price, manufacturing cost, and productivity[14, 15], and such parameters can be vested in the constructed production plan model (See Equation 1) so as to obtain the practical example. The following example is related to the preparation of production plans of a military manufacturing enterprise in four production periods. It is assumed that the enterprise uses two kinds of materials to produce three kinds of products. Based on input parameters of the given model and system model of military manufacturing supply chain, input parameters mainly involve Table 4 BOM Table, Table 5 Product...
Input Parameter Table, Table 6, Product Price Table, Table 7 Product Demand Table and Table 8 Raw Material Supply Table.

Input parameters of Table 4 and Table 8 are brought into the production plan model of supply chain to construct the practical example. Through example calculation, the following results can be obtained: production plan table (Table 9), inventory plan table (Table 10) and sales plan table (Table 11) of the military manufacturing enterprise in a period.

In the example above, the maximum profit obtained through the model is 57,465.3. In the production plan results produced by the model, Products II and III are produced in the first period. It is known from the output of product profit analysis table (Table 12) and production plan table: in the first period, unit profit of Product III is the highest, with the production being 705, and the demand of Product III in the period is 600, thus meeting the requirement of unit profit maximization; in the second and third periods, unit profits of Product III are the highest as well. In addition, conditions such as working hours available and inventory cost meet market demand as well.

In the fourth period, since Product II brings about the highest unit profit, and its production reaches 420, it meets working hour constraint, material supply constraint and market demand constraint. According to the inventory plan obtained from the production plan model of supply chain, the inventory of Product I with high inventory cost and low profit is the lowest.

It is deduced from the model calculation above that the production plan model of supply chain can, after the consideration of capacity constraint, product balance constraint and supply and demand constraint, quickly work out production, inventory and sales plans and offer “if-else” analysis according to raw material supply and demand of suppliers and clients, and also internal BOM parameters and product input parameters of military manufacturing enterprises.

**Table 1.** Entity of the system data logical model.

| material supplier | product | Available time interval |
|-------------------|---------|-------------------------|
| SCM_Providers     | SCM_Products | SCM_TimeZone |
| materiel          | product    | plan input parameters  |
| SCM_Materiels     | BOMSCM_ProductBOMs | SCM_PlanIn |
| Product demand    | Material supply | Planned output |
| SCM_MketProduct   | SCM_MaterielSupply | SCM_PlanOut |

**Table 2.** Input and output parameters.

| double[t] _avail | double[p] _rate | double[p] _inv | double[p] _prodCost |
|------------------|-----------------|----------------|---------------------|
| Available hours in the T cycle | Product P productivity | Initial Inventory of Product P | Production cost per unit product P |
| double[p] _invCost | double[t][p] | double[t][p] | double[p][m] _raw |
| Inventory cost per unit product P | Price of unit P product in T cycle | Product P Customer Demand in T Cycle | Number of M raw materials per unit product P |
| double[m][t] _supply | IloNumVar][] | Make | IloNumVar][] | Inv |
| Supply of Raw Material m in T Period | Total sales revenue | Inventory Planning quantity | Sales Planning Volume |

**Table 3.** Objective function and constraint parameters.

| IloLinearNumExpr | oLinearNumExpr | IloLinearNumExpr |
|------------------|----------------|------------------|
| TotalRevenue     | TotalProdCost  | TotalInvCost     |
| Total sales revenue | Total cost of production | Total inventory cost |
Table 4. BOM table.

| Raw material dosage | A material quantity | B material quantity |
|---------------------|---------------------|---------------------|
| Type of I product   | 5                   | 10                  |
| Type of II product  | 4                   | 8                   |
| Type of III product | 4                   | 7                   |

Table 5. Product Input Parameter Table.

| Product name       | Production costs | Inventory cost | Productivity |
|--------------------|------------------|----------------|--------------|
| Type of I product  | 10               | 2.5            | 400          |
| Type of II product | 11               | 3              | 460          |
| Type of III product| 12               | 1              | 500          |

Table 6. Product price list.

| Time interval | 1 | 2 | 3 | 4 |
|---------------|---|---|---|---|
| Type of I product | 25 | 26 | 27 | 27 |
| Type of II product | 30 | 35 | 37 | 39 |
| Type of III product | 30 | 35 | 37 | 23 |

Table 7. Product Requirement Table.

| Time interval | 1 | 2 | 3 | 4 |
|---------------|---|---|---|---|
| Type of I product | 850 | 420 | 530 | 650 |
| Type of II product | 630 | 250 | 350 | 420 |
| Type of III product | 600 | 450 | 390 | 650 |

Table 8. Material supplier supply list.

| Time interval | 1 | 2 | 3 | 4 |
|---------------|---|---|---|---|
| A material    | 5230 | 2350 | 4530 | 1420 |
| B material    | 7230 | 4320 | 5230 | 5000 |

Table 9. Production plan.

| Time interval | 1 | 2 | 3 | 4 |
|---------------|---|---|---|---|
| Type of I product | 0 | 0 | 0 | 0 |
| Type of II product | 287 | 0 | 533 | 237 |
| Type of III product | 705 | 586 | 138 | 0 |

Table 10. Inventory plan.

| Time interval | 1 | 2 | 3 | 4 |
|---------------|---|---|---|---|
| Type of I product | 0 | 0 | 0 | 0 |
| Type of II product | 250 | 0 | 183 | 0 |
| Type of III product | 115 | 252 | 0 | 0 |
8. Conclusion

The model brought forth in the paper helps prepare production plans in the integrated environment of upstream and downstream according to material supply constraint, client demand constraint, production capacity constraint, and product balance constraint, thus truly realizing the optimized allocation of upstream and downstream resources. More importantly, it can help enterprises quickly and efficiently draw up production plans and carry out what-if analysis, thus winning time advantage for enterprises in market competition and greatly increasing their operating management efficiency.

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Table 11. Sales plan.

| time interval | 1  | 2 | 3 | 4 |
|---------------|----|---|---|---|
| product       |    |   |   |   |
| Type of I product | 10 | 0 | 0 | 0 |
| Type of II product | 47 | 250 | 350 | 420 |
| Type of III product | 600 | 450 | 390 | 0 |

Table 12. Product Profit Analysis Statement.

| time interval | 1  | 2 | 3 | 4 |
|---------------|----|---|---|---|
| product       |    |   |   |   |
| Type of I product | 12.5 | 13.5 | 14.5 | 14.5 |
| Type of II product | 16 | 21 | 23 | 25 |
| Type of III product | 17 | 22 | 24 | 10 |
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