The missing link between manufacturing strategy and production planning

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This paper presents a strategic master production scheduling (SMPS) model which makes a structured connection between the pertinent part of the manufacturing and execution of the production plan. In creating this missing link, the model incorporates principles of the theory of constraints, linear programming, utility theory and the analytical hierarchy process. A formulation of the SMPS model is presented and illustrated by an explanation of how it can work in a real situation. The SMPS model is appropriate for 'make to order' and 'make to stock' production environments. Special versions are presented for each environment. A special technique for resource availability planning is presented using the de novo programming method.

1. Introduction

Manufacturing priority determination is a key problem in the ongoing planning process. Imagine a situation of several customer orders for different customers in the backlog. Assuming the manufacturing priority decision is made by the planning manager, let us review the conflicts involved in the decision process. A master production schedule (MPS) is made, usually in an intuitive way so that due dates of most or all customer orders are met, depending upon production capacity. The company may use a general policy like 'first in first served' in determining production priorities, but the policy never contains a direct link to the manufacturing strategy. Pressures for changes in the MPS then begin to come in from all over.

One regional sales manager has a very large potential sale but for that he has to supply a few products for demonstration in consignment immediately. The finance manager has taken out large loans and she needs to maximize shipment value for cash flow, so she asks to change priorities according to customer order revenue.

Corporate headquarters have noticed that profits have decreased in the branch and have notified the general manager. The general manager has instructed all his subordinates to prefer profitable customer orders in manufacturing and shipments.

The service manager is complaining that service manufacturing orders are not being given the priority they deserve. He says that customers A, B, and C are furious because of bad service and they are threatening to take their business elsewhere.

The manufacturing manager has a certain production line set up. He asks to manufacture orders 4 and 5 instead of orders 2 and 3 because he already has the setup for 4 and 5 and does not want to change it. He also claims that he cannot manufacture all the MPS of the present month and somebody has to decide what should be postponed to next month.

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No doubt the planning manager is faced with a very confusing situation. In real life it is even more complicated. Each function has a different point of view and wants the priorities to be different. Where can the planning manager get help? Usually nowhere. Corporate policy, in the few companies where it is explicitly defined, does not fit the ongoing planning process. Go to the boss? He usually has his own preference and shaded spots. Search in the computer systems? It can be done, but only in a DSS manner and a 'what if' mode of work. The priorities have to be inserted manually by the user.

Somebody has to make decisions and decisions are made. Either the planning manager is influenced by one of his colleagues or boss or uses his own best judgement. Sometimes the decision is made by the manufacturing manager, the plant manager or even the finished goods warehouse supervisor. There is nothing structured about this way of decision making. No one has a view of the whole picture and no one knows what is best for the company during the ongoing process of determining priorities. The decisions are never optimal. They may be good on the basis of past experience but they are never derived directly from the company's manufacturing strategy.

The strategic master production scheduling model (SMPS) that this paper presents provides the company with a structured way of determining manufacturing priorities. The model's hierarchical structure provides co-operation of all relevant functions in the manufacturing priorities determination process in a dynamic manner. The model assigns a specific priority for each customer order and product according to all possible considerations. Because it is derived directly from the updated manufacturing strategy, it assures an optimal manufacturing sequence. The ability to perform production scheduling according to strategic criteria in a structured manner is new and unique to the SMPS model this paper presents.

The next section briefly reviews the relevant literature. An SMPS model is then formulated and demonstrated using an example.

2. Previous research

2.1. *The importance of manufacturing strategy*

The manufacturing function in an organization can be either a major obstacle or a competitive weapon in the effort to achieve the organizational goal (Hayes and Schmenner 1978). Managing manufacturing according to the manufacturing strategy guidelines, provides the ability to turn it into a competitive weapon.

Western industry is facing rough competition from the east and is struggling for survival. Skinner (1986) reports the frustration arising from extremely high investments in productivity resulting in only minor improvements. Fox (1988) analyses western industry's loss of leadership and determines that even if an improvement takes place, the gap will remain because the competing industries from the far east have a head start. Hass (1987) defined the strategic way of thinking as 'How can we use this to beat the competition?' in contrast to the conventional 'How can we do it better than before?'. Haas showed how the manufacturing function can be used as a strategic lever. The manufacturing function has to participate in the manufacturing strategy definition process rather than being a passive performer, according to Maruchek and McClelland (1986) and Skinner (1986). Leavy (1988) states that a stronger interaction has to be established between business strategy and production and inventory planning, by linking industry analysis to production planning through demand management and resource planning. Wheelwright and Hayes (1985) maintain that integrated planning and control of manufacturing is one of the components of the manufacturing strategy definition.

2.2. *Linking manufacturing with corporate marketing decisions*

In the effort to achieve the corporate goals, connection between the ongoing production planning process and marketing strategy is of prime importance. Hill (1985) defines the following steps for action to make this connection:

(1) Define corporate strategy.
(2) Determine marketing strategies to meet these objectives.
(3) Assess how different products win orders against competitors.
(4) Establish the most appropriate mode to manufacture these sets of products—process choice.
(5) Provide the manufacturing infrastructure required to support production.

The step most relevant to the SMPS model is step 3. Possible criteria for order winning are:

(1) Price—in a low cost strategy.
(2) Quality—attractive for marketing and saves service expenses because of better reliability.
(3) Lead time—deliver faster than the competitors.
(4) Delivery reliability—supply on promised delivery date.
(5) Technological leverage—development of products superior in technology.
(6) Rapid transformation from the R&D phase to the production phase—market share achievement, especially in a high-tech environment.
(7) Wide range of products and options—provides the ability to meet the customer's specific requirements.
(8) Service—crucial for customer–supplier relationship and continuation of orders.

(Hill 1985, Schonberger 1986, Skinner 1988).

The modern conception of manufacturing management does not necessarily regard the above criteria as conflicting with one another. On the contrary, experience shows that lead time, cost and quality can be improved simultaneously (Deming 1986).

In addition to product criteria, marketing strategy includes customer order considerations, as follows:

(1) Client's importance: in differentiation or focus strategy there is a need to address a specific market segment. Thus, orders may have a different strategic priority according to the customer (Powers *et al.* 1988).
(2) Throughput—manufacturing of products that make an immediate contribution to the corporate shipments. Throughput may have two aspects: profit and revenue. A company may choose one of the two aspects at any time as a strategy (Funk 1989, Goldratt and Cox 1984).

Hill (1985) presents a weighing method for order-winning criteria, whereby order-winning criteria are assigned with weights to products over different periods of times. Migliorelli and Swan (1988) present a problem of disconnection between a company's tactical planning and the manufacturing planning system. The solution they present uses a master production schedule planning (MPSP) system which includes inputs from marketing, finance and production planning in the master production scheduling process. King and Benton (1987) stress the importance of co-operation between the marketing and manufacturing functions in determining the MPS. According to Ashton (1985) the MPS is the key function in corporate strategy implementation. Bertrand and Wijngaard (1986) exhibit the MPSP as a tool for solving the conflict between market demand and manufacturing ability. The MPS can serve as the basis for co-ordination between functions. MPSP position as the mediator between external demands and internal capability and it's significant influence on manufacturing scheduling, enables its use as a tool for making the connection between strategy and manufacturing scheduling.

2.3. *Theory of constraints*

Goldratt (1988) defines the main entities of the theory of constraints (TOC) as follows:

Constraint: anything that limits a system from achieving higher performance versus its goal.

The steps of the process are:

(1) Identify the system constraint(s).
(2) Define how to exploit the system constraint(s).
(3) Subordinate everything else to the above decision.
(4) Elevate the system constraint(s).
(5) If, in previous steps, the constraint(s) have been broken, go back to step 1, but do not let inertia become the system constraint.

System constraints may belong to one of the following types:

(1) Internal constraint—when manufacturing capability is smaller than market demand.
(2) External constraint—when market demand is smaller than manufacturing capability.
(3) Policy constraint—when policy limits output beyond manufacturing capability and market demand.

The SMPS model handles internal and external constraints.

The objective of the TOC system is maximization of profit (Fox 1988, Goldratt and Cox 1984). Ronen and Starr 1990 prove consistency between TOC scheduling and linear programming (LP). Internal constraints are available manufacturing resources and external constraints are market demand for each product.

3. SMPS model formulation

3.1. *The model's assumptions*

The SMPS model is designed for operation in a manufacturing organization, where an independent demand exists in the form of customer orders. The production environment is MTO—make to order. In this environment a manufacturing order is opened for each customer order logged in the organizational backlog.

The SMPS model assumes that all customer orders have an immediate demand for production in the near planning period. A production plan is submitted for every planning period, containing all the manufacturing orders that can be executed within the limits of the resources capacity. The products that have customer demands are called MPS products. A planning period may vary from one organization to another. Usually it is a month or 2 weeks and in some places it may even be days. Within the planning period the MPS is frozen.

The SMPS model resources are in the appropriate degree of segregation for rough-cut capacity planning at the MPS level. A resource may be a plant or a department according to the organizational level by which the MPSP is performed.

The model assumes linear loading of resources. Based on this assumption LP is used. Non-lot production is assumed; therefore production for specific customer order can be executed separately in different planning periods.

3.2. *Environment of the model*

The SMPS model receives inputs from management, marketing and manufacturing in the MPS process. Figure 1 presents the SMPS model's operational phases and its connections with the environment.

Model inputs:

(1) Management—strategic criteria for customer orders and product scheduling preference.
(2) Marketing—specific scheduling preference of products and customer orders for each strategic criterion.
(3) Manufacturing—specific scheduling preference of products for some strategic criteria. Maintenance of product routes and resource constraints.

Model outputs:

(1) Manufacturing planning—work orders vector of MPS products for a planning period.
(2) Management, marketing, manufacturing—priorities for maximum strategic contribution.

3.3. *Operational phases of the SMPS model*

The SMPS model is divided into three major operational phases. The partition is determined according to the method used to perform each phase. The operational phases of the SMPS model are described next. The formal formulation of the phases is described in appendix 1.

Phase 1: Manufacturing order utility determination

Step 1. Determining the relative priority of strategic criteria.

This step is performed periodically (quarterly) by top management. Management defines the relevant organizational criteria for determining the relative priorities of customer orders and products. After defining criteria, management determines relative priority using the AHP—the analytical hierarchy process (Saaty 1980). Relative importance is then assigned to the product priorities, in comparison to the customer order priorities.

Step 2. Determining manufacturing order utility through the weighing process.

This step is performed before every planning period by marketing, manufacturing and other functions according to the organization's specific structure. MPS manufacturing order in an MTO environment incorporates two major strategic components: customer order and product. Thus, the manufacturing order utility determination

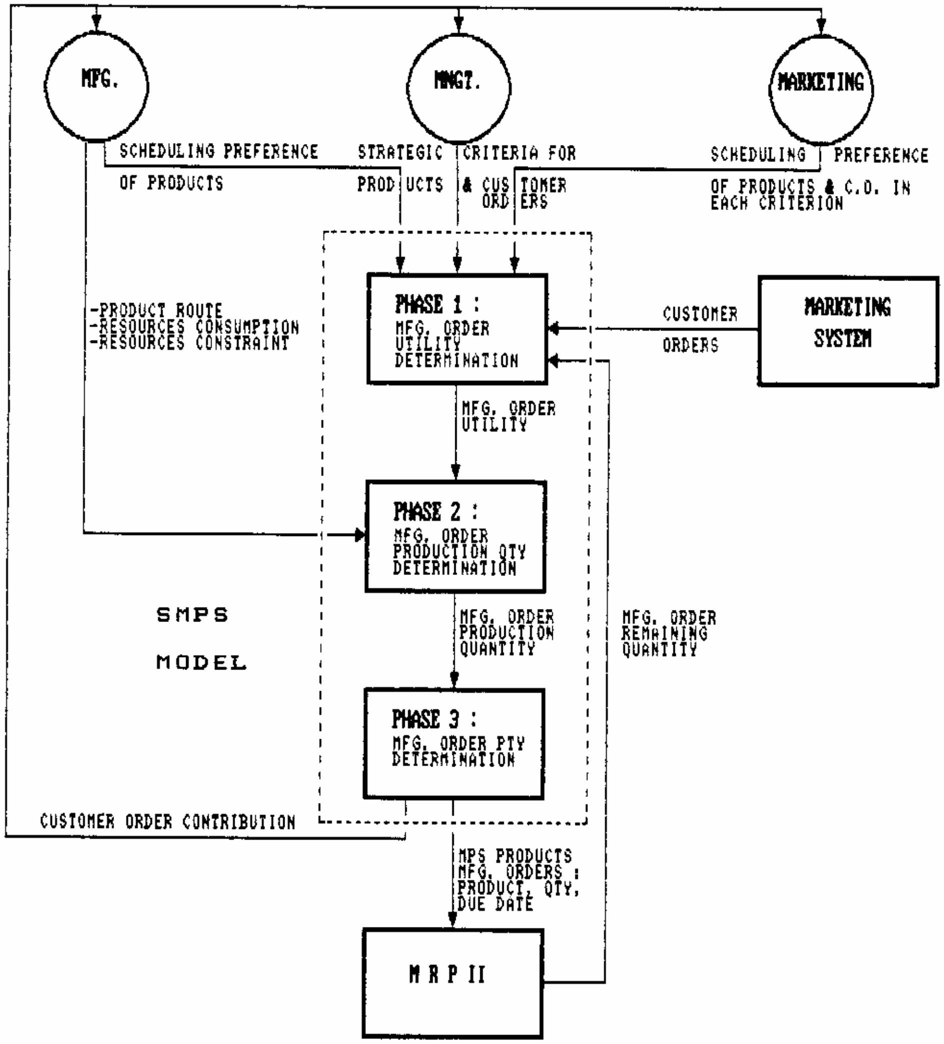

Figure 1. Environment of the SMPS model.

process combines a customer order weighing process and product weighing process. The weighing process is performed according to the AHP method. For every strategic product criterion, products receive their relative priority for scheduling. For every strategic customer order criterion, backlog customer orders receive their relative priority for scheduling. A calculation is then performed for determining the manufacturing order cumulative utility.

Phase 2: Determination of manufacturing order production quantity

Phase 2 is performed before every planning period immediately after step 2 of phase 1, by the organizational MPSP function. Phase 2 receives from phase 1 a list of manufacturing orders with their attached utilities. This vector is used as an objective function of maximum utility in a SIMPLEX execution performed in phase 2. SIMPLEX constraints consist of manufacturing constraints (internal) and marketing constraints (external).

Manufacturing constraints are the organizational resources. Each manufacturing order produces one product. The cumulative resource consumption of all manufacturing order products, must be less than or equal to the resource capacity. Marketing constraints are customer orders. In an MTO environment, the manufacturing order cannot be greater than the demand it supplies. SIMPLEX execution results determine each manufacturing order production quantity. It also provides the dual values of manufacturing and marketing constraints.

In this phase production quantity based on utility, demand and capacity is determined. Phase 3 determines the priority by which the manufacturing orders will be produced within the planning period.

Phase 3: Determination of manufacturing priority

Phase 3 is performed before every planning period, immediately after phase 2 by the organizational MPSP function. If a manufacturing constraint dual value greater than zero exists, then manufacturing resource is the system constraint. The manufacturing order priority is then determined by its contribution in descending order. Contribution of manufacturing order is its utility divided by its manufacturing constraint resource consumption. If the dual values of all manufacturing constraints are equal to zero, the system constraint is marketing. In this situation, the priority of manufacturing orders is their utility in descending order.

4. An illustration of the SMPS model's use in a real situation

4.1. *Determination of the strategic criteria*

The following illustration presents how the SMPS model can be used in an imaginary company—MID-TECH. This company performs all phases of operations including R&D, production, marketing and after-sales service. Its customers set great store by speedy and reliable delivery. MID-TECH uses the SMPS model as a normative way to define strategic guidelines for scheduling preferences.

Every quarter, management reviews the strategic priority criteria and defines the business objectives for the next quarter. In accordance with these objectives, scheduling priority criteria and their relative importance are established, taking into account customer order preferences and product preferences. Based on these criteria, all customer orders are scheduled.

At a certain meeting, the following criteria were chosen as relevant to customer order preference for the next quarter:

Delivery reliability—performing delivery exactly on promised due date.

Service—preference for customer order demanding service or spare parts. The service criterion allows weighing of future incomes, represented by present service, against immediate incomes represented by ordinary customer orders.

Client importance—preference for customers by marketing considerations. This criterion allows marketing to assign a higher priority to a certain market segment to promote sales.

Customer order value—preference for customers orders according to their revenue.

Customer order profit—preference for customer orders according to the profit they generate. The profit criterion allows operation of the SMPS model on a maximum profit objective as an individual case of maximum utility.

Customer order lateness—preference for past due customer orders. This criterion enables use of the SMPS model on a dynamic basis. Past due customer orders receive higher priority on this criterion, have their summarized utility raised, and therefore improve their chances of being entered into the near planning period MPS.

The following criteria were chosen as relevant for product preference:

Delivery speed—production scheduling preference is given to products that win orders by fast delivery.

R&D to production transformation—preference for new products that have to be delivered quickly to an exhibition, benchmark or first customer orders.

Service—preference for spare parts production as opposed to ordinary products.

Excess inventory—preference for products for which there are large inventories of raw material or sub-assemblies that need to be reduced.

Product profit—preference for profitable products. This goes along with the customer order profit preference criterion in a maximum profit operation.

The next step performed by MID-TECH's management was to determine the relative strategic importance of each criterion.

It is important to note that strategic criteria and their relative importance have to be accepted by all the members of the management team. A joint decision ensures that management is totally committed to the strategic priorities given as guidelines to operations for the next quarter.

Table 1 presents MID-TECH's criteria priority value obtained by an AHP weighing operation. All AHP tables have a CR value $<0{\cdot}1$.

MID-TECH's product priorities were deemed to be equally important to the customer order priorities. Thus each is assigned a relative importance of 0·5.

Table 1 shows that delivery reliability and customer order lateness are the most important customer order priority criteria, and delivery speed is the most important product priority criterion. Here MID-TECH's management specifically emphasizes delivery speed and reliability, as the main scheduling considerations for the next quarter.

4.2. *Determination of the first planning period MPS*

4.2.1. MPS planning inputs

We now focus on how the SMPS model can be used as an MPS planning procedure. MID-TECH performs MPS planning at the end of every week, prior to the weekly

Criteria type	Criterion description	Relative priority of criterion
Customer order	Delivery reliability	0·299999
	Service	0·099999
	Client importance	0·099999
	Customer order value	0·099999
	Customer order profit	0·099999
	Customer order lateness	0·300000
Product	Delivery speed	0·601736
	R&D to production trans.	0·050651
	Service	0·148480
	Excess inventory	0·050651
	Product profit	0·148480

Table 1. Relative priority of the strategic preference criteria.

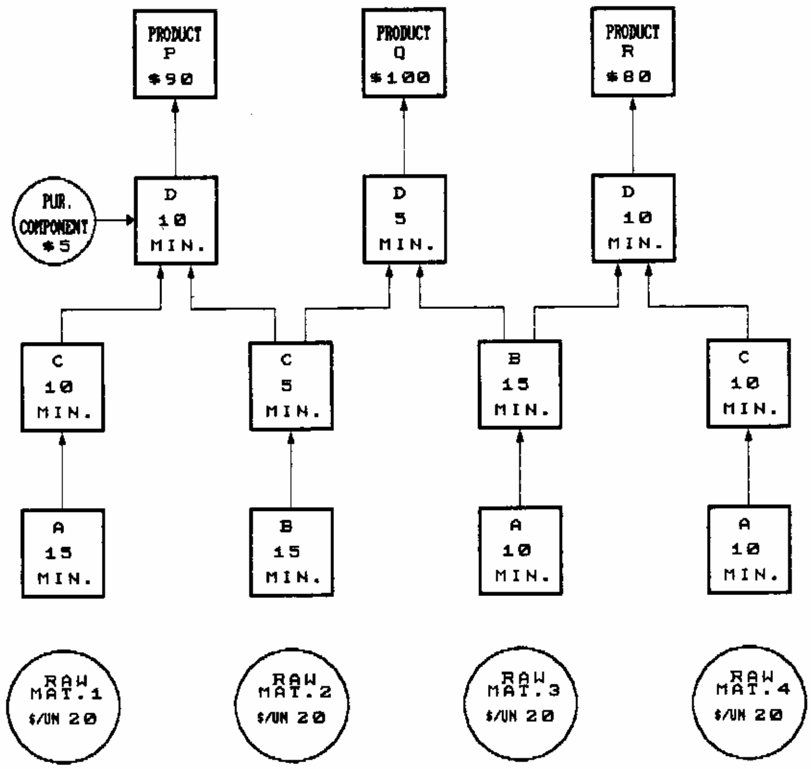

Figure 2. Production flow of the products.

Customer order number	Required product	Required quantity
1001	P	20
1002	P	80
1003	Q	20
1004	Q	30
1005	R	50

Table 2. First planning period backlog.

MRP run. The MPS is also used as a final assembly schedule (FAS) in department D which is the integration department.

MID-TECH manufactures three products, P, Q, and R, in departments A, B, C and D. The production process presented here is an extension of the example presented by Fox (1988).

Figure 2 presents production routes with lead times required for production of one unit of each product. Product profit is calculated as selling price minus the cost of purchasing raw materials. The planning period is 1 week and total operational cost is $6000.

Customer order	Customer order priority
1001	0·065084
1002	0·486742
1003	0·065084
1004	0·318004
1005	0·065084

Table 3. Customer order preference by value.

Product	Product priority
P	0·058242
Q	0·666337
R	0·275419

Table 4. Product preference by delivery speed.

The units of the resource constraint are summarized working minutes in a week. The company operates one working shift; thus each MID-TECH manufacturing resource has 2700 working minutes available for planning in a week.

Customer order demands logged for the first planning period are presented in Table 2.

4.2.2. *Master production schedule planning procedure*

Phase 1: Determination of manufacturing order utilities

Each of the five customer orders in the backlog is weighed against the others on every customer order priority criterion. The weighing process is performed by the relevant departments. As an example, Table 3 presents the customer orders scheduling priority by the 'customer order value' criterion. MID-TECH assigned the finance department to weigh customer orders by value.

Table 3 shows a preference for scheduling CO. 1002 first for production, because it has the highest value and the best payment terms.

The same procedure is performed for products that have a customer demand, that is products P, Q and R. Each of the three products is weighed against the others, according to every product priority criterion, by the relevant department. A priority value is then assigned to each product for every criterion.

Table 4 presents an example of the product scheduling priority in the 'delivery speed' criterion. This criterion weighing is performed by marketing.

Table 4 shows that marketing gives high priority to customers who demand product Q. This priority is given because of marketing expectation that fast delivery will win more orders, especially for product Q.

Each customer order and product priority on every criterion is now summarized according to the criterion's relative priority. Summarized values are then calculated to give a manufacturing order utility value. Manufacturing order utility value represents strategic scheduling preference. Table 5 presents the summarized priorities and manufacturing order utilities for MID-TECH's first planning period.

Manufacturing orders	Quantity	Item	Item's relative priority	Customer order	Customer order's relative priority	Manufacturing order utility
MFG1001	20	P	0·051805	1001	0·133184	0·184989
MFG1002	80	P	0·051805	1002	0·102211	0·154016
MFG1003	20	Q	0·336131	1003	0·077738	0·413869
MFG1004	30	Q	0·336131	1004	0·061287	0·397419
MFG1005	50	R	0·112062	1005	0·125578	0·237641

Table 5. Summarized priorities and utilities.

The summarized utilities exhibit a relative scheduling preference value for each MPS manufacturing order opened to supply a customer order (MTO). These utility values are the result of a joint weighing procedure, performed by several departments in the company and its management. The utilities in descending order can give a scheduling sequence if production can manufacture all customer demands. Phase 2 analyses MID-TECH's situation.

Phase 2: Determination of manufacturing quantities

This phase determines production quantities for each manufacturing order based on phase 1 utilities, the products production flow (Fig. 2) and the current backlog. Phase 2 is performed by the planning department. A utility vector, obtained from phase 1, is now used in a SIMPLEX execution as an objective function of maximum utility. The manufacturing constraints consist of the lead time in minutes each product consumes for each manufacturing resource. The summarized consumption must be less than or equal to the resource's maximum capacity. The maximum capacity of MID-TECH's resources is 2700 min per week. Marketing constraints are the quantities demanded by the customer orders.

SIMPLEX results show that the manufacturing orders MFG1001, MFG1003, MFG1004, MFG1005 are planned for production of quantities that supply the customers' demand. Only MFG1002 is planned for production of 10 of the 80 items P ordered. It is obvious that MID-TECH has a production constraint. Phase 3 identifies the constraint and suggests an adequate scheduling sequence.

Phase 3: Determination of manufacturing order priority

The SIMPLEX results exhibited a positive dual value for manufacturing constraint resource B. An addition of resource B would result in a positive addition to the total utility value. Manufacturing order priority is determined in this situation according to the contribution in descending order as shown in Table 6. Note that MFG1002, which is planned for partial production, indeed received the lowest priority.

The manufacturing order due date is determined by the planning department according to its priority within the planning period. The model assumes that the manufacturing order's start date cannot be past due at this stage (as a result of lead time calculated backwards from due date). Scheduling manufacturing orders according to their strategic priority within the planning period assures that maximum possible utility will be obtained within that time, even if an unexpected delay occurs.

At this point of the procedure, the MPS is transferred as an essential input to the MRP run, which can be executed immediately.

The priorities of the manufacturing orders are issued by the planning department to MID-TECH's management and marketing department. They represent the strategic

Manufacturing order	MFG1001	MFG1002	MFG1003	MFG1004	MFG1005
Production quantity	20	10	20	30	50
Unit utility	0·184989	0·154016	0·413869	0·397419	0·237641
Resource B consumption	15	15	30	30	15
Contribution	0·012332	0·010267	0·013795	0·013247	0·015842
Mfg. order priority	4	5	2	3	1

Table 6. Determination of manufacturing order priority.

priorities of customers and products, and are the best guideline for investment of money and time that decision-makers can obtain.

4.3. *Determination of the second planning period MPS*

Second planning period scheduling is performed at the end of the first week. MID-TECH's MPS for the first week has been accomplished in full. New customer orders have been received for the second planning period. In order to control for the SMPS model's behaviour over time, the new customer orders are taken to be identical to the first planning period customer orders. Therefore:

$$MFG1006 \equiv MFG1001$$

$$MFG1007 \equiv MFG1003$$

$$MFG1008 \equiv MFG1004$$

$$MFG1009 \equiv MFG1005$$

All relative preferences in the second planning period are identical to the preferences in the first planning period except for those of the criterion 'customer order lateness'. On this criterion, a higher priority, in comparison with the first planning period, is assigned to customer order 1002 because of the lateness of its delivery. This affects the summarized priority of customer order 1002, as shown in Table 7.

The utility of the manufacturing orders is also affected, but to a lesser degree because the summarized product priority factor does not change. Table 8 presents the second planning period SIMPLEX results. The objective function contains the manufacturing order utility vector, in which MFG1002 has a higher utility value than in the first planning period.

First planning period priorities		Second planning period priorities	
Customer order	Total priority	Customer order	Total priority
1001	0·266368	1006	0·263697
1002	0·204422	1002	0·296864
1003	0·155476	1007	0·159436
1004	0·122575	1008	0·148070
1005	0·251157	1009	0·131931

Table 7. Summarized customer order priorities in the first and second periods.

Manufacturing order	MFG1006	MFG1002	MFG1007	MFG1008	MFG1009
Production quantity	10	70	20	30	0
Unit utility	0·183654	0·200237	0·415849	0·410166	0·178028
Resource B consumption	15	15	30	30	15
Contribution	0·012243	0·013349	0·013861	0·013672	0·011868
Mfg. order priority	4	3	1	2	5

Table 8. Second planning period master production schedule.

Table 8 shows that the higher utility of MFG1002 caused it to enter the second planning period MPS. MFG1009 (MFG1005), which was scheduled for production in the first planning period is now being delayed. Ten units of product P are also delayed in MFG1006 (MFG1001). Note that delayed manufacturing orders are not necessarily produced in the next planning period. Production depends upon their new relative scheduling priority. MFG1002 received priority = 3 in the second planning period, instead of priority = 5 in the first planning period, at the expense of MFG1006 and MFG1009, which received a lower priority than before.

4.4. *Marketing constraint*

A marketing system constraint exists when manufacturing can produce all of the company's backlog in one planning period. Relating to the MID-TECH company example, the number of available working units per manufacturing constraint now changes. Resources A and B are now working one and a half shifts every day. Therefore the new resources constraint is: $1{\cdot}5 \times 2700 = 4050$ working minutes per week. A new LP model with these changes and first planning period data was constructed. SIMPLEX results and scheduling priorities are presented in Table 9.

Table 9 shows that the backlog can be produced in one planning period. All manufacturing resources' dual values are zero because none of them is the system constraint. The marketing constraints' dual values equal the manufacturing order utilities found in the SMPS model, phase 1. Scheduling sequence is determined according to manufacturing order utility in descending order. The importance of scheduling according to strategic priorities within the planning period is that it assures that manufacturing and deliveries are performed according to descending strategic value. It also assures that if a production stop happens, the delayed manufacturing orders will always have a lower strategic utility than the produced manufacturing orders.

5. Comparison to TOC

The SMPS model performs the first two steps of the theory of constraints.

Step 1. Identify the system constraint(s).

This is performed by the SMPS model, phase 2. The system constraint is identified by the dual value. If a manufacturing constraint has a positive dual value then the system constraint is manufacturing. Otherwise, the system constraint is marketing.

Step 2. Define how to exploit the system constraint(s).

System exploitation is performed by the DRUM. The DRUM in an MRPII environment is the manufacturing orders. Since the MPS vector is the input by which

Manufacturing order	MFG1001	MFG1002	MFG1003	MFG1004	MFG1005
Production quantity	20	80	20	30	50
Unit utility	0·184989	0·154016	0·413869	0·397419	0·237641
Mfg. order priority	4	5	1	2	3

Table 9. Marketing constraint master production schedule.

Manufacturing order	MFG1001	MFG1002	MFG1003	MFG1004	MFG1005
Production quantity	20	80	0	15	50
Unit profit	45	45	60	60	40
Resource B consumption	15	15	30	30	15
Contribution	3	3	2	2	2·67
Mfg. order priority	1	1	3	3	2

Table 10. TOC model master production schedule.

Manufacturing order	MFG1001	MFG1002	MFG1003	MFG1004	MFG1005
Production quantity	20	80	0	15	50
Unit utility	0·249351	0·249351	0·318008	0·318008	0·22621
Resource B consumption	15	15	30	30	15
Contribution	0·016623	0·016623	0·0106	0·0106	0·015081
Mfg. order priority	1	1	3	3	2

Table 11. SMPS profit model master production schedule.

the MRP schedules components and sub-assemblies, it dictates the pace of the system. Therefore, MPS manufacturing orders that are SMPS model phase 3 output are the system DRUM.

Step 3 of the TOC is performed within the MRPII system. Step 4 relates to the constraint release. The resources availability planning demonstrated in section 6.1 below, presents a DSS for planning the most profitable manufacturing resources capacity.

Exploitation of the system constraint in TOC step 2 is performed to achieve a goal of maximum profit. The SMPS model assumes a goal of maximum utility, where profit is one of the components. An individual case of maximum utility may be maximum profit. Therefore, the SMPS model presents an extension of the TOC by using a goal of maximum utility rather than maximum profit.

An example was developed to test the above argument. The purpose of the test was to see what output would be received in a similar situation from the TOC model and the SMPS model. The TOC model was defined with an objective function of maximum profit based on MID-TECH's first week data. SIMPLEX results and manufacturing priority determination are presented in Table 10. The unit of measure of contribution is \$/min. The resource B dual value is 2 \$/min; all other manufacturing resources' dual values are zero.

The next step was to construct the SMPS model for the same situation. Since profit is the only important factor, it was defined as superior to the other criteria during the weighing process. Customer orders and products received relative priority according to their profit alone. The result was a utility function consisting of profit as the only strategic criterion. Table 11 presents SMPS model SIMPLEX results and priority determination. The unit of measure of contribution is utility units/min.

As shown in Table 11 the test example results are identical. The SMPS model can operate with a maximum profit objective function as a corporate strategy. The SMPS model's utility function contains a variety of business considerations in addition to profit; therefore its scope is wider than that of the TOC model.

6. Additional options

6.1. *Resource availability planning*

The discussion in the previous sections assumed that manufacturing resources constraints are fixed. Using *de novo* programming (Zeleny 1982), resources can be considered as variables. The manufacturing variable cost cannot exceed an operational budget. Required resource units planning can be used by the SMPS model for two applications:

(1) Planning optimal required resource units and manufacturing quantities.
(2) Planning the above for overtime hours in an existing manufacturing setup.

Optimal inclusive manufacturing and resource planning

The following example is based on MID-TECH's first planning period data with maximum profit (in \$) as the objective function. Table 12 presents production quantities and required resources, determined on the basis of a working minute cost of \$0·555 and an operational budget of \$6000.

The results in Table 12 exhibit profitability of manufacturing the whole backlog. Total profit of \$3527·7 is the highest possible. The above technique may be used only when there is enough time to implement the desired manufacturing capacity set up.

Optimal overtime manufacturing and resource planning

When a planning period is close and there is not enough time for inclusive resources and manufacturing planning, the organization can still plan extra work either as overtime or as sub-contractor work. If the hourly rate for overtime is 150% of the regular cost, then the overtime cost per minute is \$0·8333. Table 13 presents an example with an overtime budget of \$2000.

Table 13 shows that manufacturing the whole backlog is still profitable, though total production profit is smaller than in the previous example. If overtime cost surpasses the constraint dual value then overtime work is not profitable. If, for example, overtime/subcontractor cost is \$3/min., while the dual value of system constraint resource B is \$2/min., then optimal production quantities equal the basic situation without additional work (see Table 10).

6.2. *Make to stock (MTS) SMPS model*

In defining the model we assumed an MTO manufacturing environment, but the SMPS model can be suitable for an MTS manufacturing environment as well. In an MTS environment, production is performed according to a forecast of market demand for products. As a result, customer orders cannot be weighed. Thus, in the SMPS model, only products may be weighed using product preference criteria. In this case the MPS contains products planned for production. The utility function contains only the product's strategic summarized priority.

Manufacturing order	MFG 1001	MFG 1002	MFG 1003	MFG 1004	MFG 1005	Resources min. rate							
						OTA	OTB	OTC	OTD				
Order Profit	45	45	60	60	40	−0·55	−0·55	−0·55	−0·55				
Production routes and constraints										Total usage	Resource consumed	Resource remaining	Dual value
Resource A	15	15	10	10	20	−1				0	⩽0	0	0·555
Resource B	15	15	30	30	15		−1			0	⩽0	0	0·555
Resource C	15	15	5	5	10			−1		0	⩽0	0	0·555
Resource D	15	15	5	5	10				−1	0	⩽0	0	0·555
Order 1001	1									20	⩽20	0	14·444
Order 1002		1								80	⩽80	0	14·444
Order 1003										20	⩽20	0	32·222
Order 1004			1							30	⩽30	0	32·222
Order 1005					1					50	⩽50	0	9·444
Work min.						0·555	0·555	0·555	0·555	5972	⩽6000	27·7	0
Prod.→ Quantity & work	20	80	20	30	50	3000	3750	2250	1750	Total profit 3527·7			

Table 12. Resources capacity and manufacturing planning.

Manufacturing order	MFG 1001	MFG 1002	MFG 1003	MFG 1004	MFG 1005	Resources overtime rate OTA	OTB	OTC	OTD	Fixed cost			
Order profit	45	45	60	60	40	−0·83	−0·83	−0·83	−0·83	−6000			
Production routes and constraints										Total usage	Resource consumed	Resource remaining	Dual value
Resource A	15	15	10	10	20	−1				2700	⩽2700	0	0·833
Resource B	15	15	30	30	15		−1			2700	⩽2700	0	0·833
Resource C	15	15	5	5	10			−1		2250	⩽2700	450	0
Resource D	15	15	5	5	10				−1	1750	⩽2700	950	0
Order 1001	1									20	⩽20	0	20
Order 1002		1								80	⩽80	0	20
Order 1003			1							20	⩽20	0	26·667
Order 1004				1						30	⩽30	0	26·667
Order 1005					1					50	⩽50	0	10·833
Work min.						0·833	0·833	0·833	0·833	1125	⩽2000	875	0
Prod. → Qty & work	20	80	20	30	50	300	1050	0	0	Total profit 2375			

Table 13. Overtime planning for 150% rate.

Product	P	Q	R
Product utility	0·10361	0·672263	0·224125
Production qty	30	50	50
Res. B consumption	15	30	15
Contribution	0·006907	0·022408	0·014941
Mfg. priority	3	1	2

Table 14. SMPS model MTS master production schedule.

Phase 2 uses product utilities as an objective function. Marketing constraints are determined as summarized forecasted product demand. Manufacturing constraints are identical to those of the MTO model but the variables are now products instead of manufacturing orders.

MTS model example data is taken from the MID-TECH example. Table 14 presents the use of summarized product utilities as a maximum utility objective function in a SIMPLEX execution.

As shown in Table 14, contribution is calculated for each product, using the product's utility and manufacturing constraint processing time. The MPS can now be transferred to MRPII or JIT systems.

In JIT the MPS is also the final assembly schedule (Bose and Rao 1988). Implementation of the SMPS model in its MTS version, provides the ability to plan a JIT schedule according to strategic priorities. Product contribution is delivered as feedback to management and marketing.

7. Conclusions

The SMPS model presented in this paper provides the ability to link manufacturing strategy qualitative criteria in a structured and practical way with the ongoing production planning process. The link is performed through the MPSP function, which is an integrated module in MRPII and JIT systems. The model incorporates an applicable combination of manufacturing strategy and the theory of constraints through the use of a utility function.

An extension of the TOC is presented, applying a goal of maximum utility rather than maximum profit. The paper shows that maximum profit is an individual case of maximum utility.

An additional extension of the TOC is presented by answering, in a structured manner, a situation of marketing system constraint.

The SMPS model has a significant application potential. Using an existing module (MPSP) allows users to apply TOC and manufacturing strategy through the model in MRPII and JIT planning environments. The SMPS model may be used as an integrated MPSP system or a DSS. It may be applied as a whole or in parts, if a user wishes to combine it with existing systems.

By using the customer order lateness criterion the SMPS model becomes dynamic through time. It may be applied in MTO and MTS manufacturing environments. In an MTS manufacturing environment, the strategic weighing process is performed on products.

By using the SMPS model as an MPSP system, an organization may achieve structured participation of management, marketing and manufacturing in the production plan determination process. A partition between strategic and tactical decision levels is defined by the use of different steps at different frequencies.

Contribution feedback guides management and marketing to invest in a way that will maximize strategic utility.

The SMPS model successfully integrates the AHP technique and linear programming. It presents an integration of strategic criteria from the literature. The resource availability planning method using *de novo* programming is demonstrated. It may be applied within the SMPS model as a DSS for manufacturing constraints determination.

Further research is required in situations beyond the scope of this study. Additional manufacturing environments such as 'assemble to order' should be analysed. A manufacturing by lots situation, where the planner cannot split lots, should be investigated.

The SMPS model provides a solution to strategic scheduling at the MPS level. Further research should be done to extend strategic scheduling to the sub-assemblies and components levels.

The SMPS model presents a scheduling technique according to strategic priorities. This technique may be applied in additional areas and systems. It may be used whenever there exists a system with demands, limited resources and different business priority criteria. It may be applied in a service environment as well as manufacturing. It may be applied in systems such as project management or time management.

This paper investigates only one aspect of manufacturing strategy. Further research may find ways to perform a structured connection between additional manufacturing strategy aspects and the manufacturing management function.

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Appendix 1. Formulation of the SMPS model's operational phases

Phase 1: Manufacturing order utility determination

Definitions

A_i $i=1,\ldots,m$	Strategic criteria affecting customer orders manufacturing scheduling priority.
B_j $j=1,\ldots,n$	open customer orders in the organizational backlog
C_k $k=1,\ldots,p$	strategic criteria affecting MPS products manufacturing scheduling priority
D_l $l=1,\ldots,q$	MPS products: products on which at least one open customer order demand exists
E_j $j=1,\ldots,n$	MPS manufacturing order
$F(A_i)$	relative priority of criterion A_i
$G(B_j, A_i)$	relative priority of customer order B_j on criterion A_i
$H(C_k)$	relative priority of criterion C_k
$I(D_l, C_k)$	relative priority of product D_l on criterion C_k
J_j $j=1,\ldots,n$	summarized relative priorities of customer order B_j
K_l $l=1,\ldots,q$	summarized relative priorities of MPS product D_l
$L(B)$	relative priority of customer order weighing as compared to the MPS product weighing; $0 \leqslant L(B) \leqslant 1$
$L(D)$	relative priority of MPS product weighing as compared to the customer order weighing; $0 \leqslant L(D) \leqslant 1$; $L(B)+L(D)=1$
$U(E_j)$	manufacturing order E_j summarized utility

Operational steps

Steps 1–5 are performed periodically (quarterly) by management.

Step 1. Determination of the relevant organizational strategic criteria A.

Step 2. Determination of the relative priority $F(A_i)$ of each criterion A_i in comparison to the other criteria. Relative priority determination method is AHP. AHP is used in all of the following steps that perform weighing.

Step 3. Determination of the relevant organizational strategic criteria C.

Step 4. Determination of the relative priority, $H(C_k)$ of each criterion C_k in comparison to the other criteria.

Step 5. Determination of $L(B)$ and $L(D)$.

Steps 6–13 are performed before every planning period by marketing, manufacturing and other departments.

Step 6. Updating corporate backlog and identifying open customer orders B_j.

Step 7. Updating MPS manufacturing orders E_j with the remaining quantity for production.

Step 8. Updating D_l: products on which at least one open customer order demand exists.

Step 9. Determination of the relative priority of customer order B_j on criterion A_i. Repetition of the above for all customer orders and computation of $G(B_j, A_i)$ for each.
Repetition of the above for all criteria A.

Step 10. Calculation of J_j according to the following:

$$J_j = \sum_{i=1}^{m} G(B_j, A_i) \times F(A_i)$$

Repetition of the above for all customer orders B.

Step 11. Determination of the relative priority of MPS product D_l on criterion C_k. Repetition of the above for all MPS products and computation of $I(D_l, C_k)$ for each.
Repetition of the above for all criteria C.

Step 12. Calculation of K_l according to the following:

$$K_l = \sum_{k=1}^{p} I(D_l, C_k) \times H(C_k)$$

Repetition of the above for all MPS products D.

Step 13. Calculation of $U(E_j)$—manufacturing order E_j summarized utility according to the following:

$$U(E_j) = J_j \times L(B) + K_l \times L(D)$$

Repetition of the above for all manufacturing orders E.
Note: K_l refers to the product on which the manufacturing order is open.

Phase 2: Determination of manufacturing quantity

Definitions

- $TQ\ (E_j)$ maximum quantity allowed for production in manufacturing order E_j as determined by the remaining customer order demand
- $Q\ (E_j)$ calculated planned production quantity in manufacturing order E_j at the near planning period
- $R_m\ m = 1, \ldots, r$ manufacturing resource
- TR_m maximum available resource units for planning at resource R_m
- DR_m computed dual value of resource R_m
- $DTQ\ (E_j)$ computed dual value of customer order constraint
- $Q\ (R_m, E_j)$ resource R_m units used for production of a single product in manufacturing order E_j.

Operational steps

The following steps are performed before each planning period by the MPSP function.

Step 14. Assigning routes to manufacturing orders according to the manufactured products D.

Step 15. Determination of TR_m.

Step 16. Determination of $Q(R_m, E_j)$ for every resource R_m according to the lead times.

Step 17. Assigning the above data in LP format:

$$\text{Max} \sum_{j=1}^{n} U(E_j) \times E_j$$

s.t.

$$\sum_{j=1}^{n} Q(R_m, E_j) \times E_j \leqslant TR_m \tag{A1}$$

For each resource R_m $\quad m = 1, \ldots, r$

$$E_j \leqslant TQ(E_j) \tag{A2}$$

For each manufacturing order E_j $\quad j = 1, \ldots, n$

Executing SIMPLEX.

Step 18. Assigning $Q(E_j)$ to each manufacturing order.

Step 19. Calculating DR_m and $DTQ(E_j)$—dual values for manufacturing and marketing constraints.

Phase 3: Manufacturing priority determination
Definitions

- R^* system manufacturing constraint
- $W(E_j)$ manufacturing order E_j contribution
- $PTY(E_j)$ manufacturing order E_j production priority
- $DD\ (E_j)$ manufacturing order due date

Operational steps

The steps of phase 3 are performed immediately after completion of phase 2 by the MPSP function.

Step 20. If there exists a $DR_m > 0$ then system constraint is manufacturing. The resource that has $DR_m > 0$ is determined as R^*—system manufacturing constraint.

If this case occurs, continue to the next step. Otherwise, go to step 25.

Step 21. Calculating the contribution $W(E_j)$ of each manufacturing order E_j.

$$\text{W}(\text{E}_j) = U(E_j)/Q(R^*, E_j).$$

Step 22. Determination of $PTY(E_j)$. $PTY(E_j)$ is defined by $W(E_j)$ in descending order. E_j with the highest value of $W(E_j)$ will receive $PTY = 1$ and so on.

Step 23. Determination of $DD(E_j)$. Manufacturing order due date expresses its priority within the planning period. The higher $PTY(E_j)$ is, the sooner $DD(E_j)$ will be.

Step 24. Forward feedback containing priorities, planned manufacturing quantities and due dates to management and marketing.

Step 25. Determination of $PTY(E_j)$. In this case manufacturing priority is determined by $DTQ(E_j)$ in descending order. The E_j with the highest dual value receives $PTY = 1$ and so on. For continuation, go to step 23.

Note: in a situation of marketing constraint $DTQ(E_j)$ equals $U(E_j)$—manufacturing order summarized utility. As a result of this, manufacturing priorities are determined by phase 1 of the SMPS model alone.