Production Process and Inventory Management for Machine Tool Companies: Analysis and Development of Optimisation Models

A.A.G. Bruzzone, P.M. Lonardo, E. Rossi
Dipartimento di Ingegneria della Produzione, Termoenergetica e Modelli Matematici (DIPTEM),
via Opera Pia 15, 16145 Genova, Italy

Abstract
An approach to assess competing firms efficiency connected to the production process is proposed. The method is based on the analysis of the balance sheet and income statement to obtain financial ratios that permit to measure inventory and production process performances. The application of this analysis to an Italian milling machines producer suggested new improvement actions to overcome the outlined inefficiencies. Two scheduling and planning approaches based on a management hybrid system and on lot-sizing rules and freezing techniques have been considered. The possible improvement has been evaluated by using a total penalty earliness and tardiness function.

Keywords:
Production scheduling and planning, Inventory control, Machine tool

1 INTRODUCTION

Global market requires nowadays a careful analysis of the production strategies: fundamental decisions such as outsourcing internal production activities can determine the success or the failure of a company. Market competition among machine tool manufacturers is very hard and management and technology improvements eventually provide advantages not only to the producer but also to the end users. Usually improvements start from a careful analysis of the state of art of the technology and competitors products.

In this study an approach to assess the competitors efficiency related to the production process of machine tools is proposed. The method starts from the analysis of financial data, specifically balance sheet and income statement that are publicly available. The financial figures measure the efficiency of the production process and consequently permit to compare manufacturers, point out possible inefficiencies and classify the performances of their organizations.

This preliminary analysis guides the assessment of the manufacturing process and inventory management policies, suggesting new improvement actions.

Figure 1: Milling machine made by MECOF (model DYN).

The presented methodology was used to assess the performance of an Italian machine tool producer: EMCO MECOF (formerly MECOF S.p.A.).

The company, which complies with ISO9000 quality standard, produces large milling machines sold mainly to the automotive industries; the milling centres are designed to machine dies for the production of car bodies (Fig. 1). In consequence of the confidential nature of the discussed information, the reported results refer to a study carried out in the year 2001.

Two models to overcome the critical conditions detected during the financial analysis are discussed. One suggests the adoption of a management hybrid system which integrates Just In Time (JIT) and Material Requirement Planning (MRP) or Manufacturing Resource Planning (MRP II) [1, 2, 3, 4, 5]. Another model considers lot-sizing rules and freezing techniques in Material Production Schedule (MPS) and MRP systems [6, 7].

2 FINANCIAL ANALYSIS

Balance sheet and income statement are the main source of data together with patents applications which are publicly available. International accounting standards (IASs) establish the guidelines that must be observed for balance compilation to make it an accurate and valid snapshot of the considered company.

Although balance sheet analysis is useful to check the reliability of companies, point out economic trend and compare competitors, several objections have been opposed. They mainly concern the homogeneity of the balance sheets due to subjectivity in the use of accounting principles, lack of harmonization between national laws, use of different currencies, terminology and reference periods.

Nevertheless profitability and activity ratios are likely the only parameters that allow a comparison between competing companies. The main indices considered in this study are shown in Table 1. Tables 2, 3 and 4 show respectively the values of the Inventory Turnover, Average Collection Period and Account Payable period for the years from 1997 to 1999 of five milling machines producers including MECOF S.p.A. The selected companies were the main competing firms of MECOF.

Profitability ratios	
Return On Equity (ROE)	Net profit after taxes (= net income) / stockholders' equity
Return On Investment (ROI)	Net profit after taxes / total assets
Return On Sales (ROS)	Income before taxes / net sales
Return on Capital Employed (ROCE)	Pre-tax operating profit / Capital employed
Activity ratios	
Inventory Turnover (IT)	Cost of goods sold/Average inventory value
Accounts Receivable Turnover (ART)	Net sales / Average Account Receivables for the Period
Average Collection Period (ACP)	Average Accounts Receivable / (Net sales / Number of days in the period)
Accounts Payable Period (APP)	Accounts payable / (purchases on credit/ period of accounting statements)

Table 1: Definition of analysis ratios.

Company	Inventory Turnover (IT)		
	1997	1998	1999
MECOF	2.23	2.61	2.81
MCM	3.12	2.96	2.91
FPT	4.62	3.82	3.15
PARPAS	4.16	5.2	4.51
FOREST LINE	3.55	5.22	10.35
DROOP & REIN	3.63	3.77	5.16

Table 2: Inventory Turnover.

Company	Average Collection Period		
	1997	1998	1999
MECOF	67	60	68
MCM	125	104	77
FPT	124	109	93
PARPAS	188	172	180
FOREST LINE	180	163	179
DROOP & REIN	42	65	55

Table 3: Average Collection Period (days).

Company	Accounts Payable Period		
	1997	1998	1999
MECOF	106	89	100
MCM	133	131	120
FPT	160	128	129
PARPAS	162	137	145
FOREST LINE	131	130	130
DROOP & REIN	25	34	33

Table 4: Accounts Payable Period (days).

Inventory Turnover (IT) is the number of times the entire inventory is sold in the year; it considers the cost of goods sold instead of the market value and gives consequently a more realistic ratio. It directly influences ROCE and, indirectly, ROI since ROI = ROS x ROCE. Actually ROCE indicates the efficiency of decisions on the utilization of production capacity and manufacturing structure.

IT ratio depicts the company's own trends and compares it to the industry's averages: high IT indicates a good inventory and production process management. IT ratio however ignores the cost of each element of inventory, as it moves through the manufacturing process. Indeed the total cost of a product TC_{pc} depends on the costs of materials C_m and processing steps C_1, on the Manufacturing Lead Time MLT and on the holding cost rate h, according to the following simplified equation:

$$TC_{pc} = C_m + C_1 + \int_0^{MLT} \left[C_m + \frac{C_1 \cdot t}{MLT} \right] \cdot h \cdot dt$$

IT ratio has a positive trend for MECOF, FOREST LINE' and DROOP&REIN while FPT exhibits a negative trend. MCM and PARPAS have almost constant values in the observed years. IT ratios are between 2 and 5.2 with the exception of FOREST LINE' that reaches 10.35. Actually FOREST LINES' IT is higher than the other ones; the French firm could have implemented in 1999 an inventory management system to minimize its stock.

Considering the Average Collection Period and the Account Payable Period it can be observed that these indices measure the efficiency of the commercial department, respectively the ability to collect credits from the customers and to obtain a long span of time to pay purchases from suppliers.

The analysis of the figures indicates that MECOF and DROOP & REIN have good collecting capabilities with periods of about two months, while PARPAS and FOREST LINE show an average period of six months. Considering the payment of suppliers DROOP & REIN has lowest index with 33 days; the others pay the suppliers in periods ranging from 100 days, for MECOF, to 145 days, for PARPAS.

These data indicate that although MECOF has an efficient commercial policy that permits to collect promptly credit from customers and delay payment to suppliers, it has the lowest IT ratio. A greater competitiveness could be achieved by a more efficient inventory management.

3 PRODUCTION PROCESS

In year 2000, the period considered by this study, MECOF catalog included nine typologies of machine tools with working volume up to 14000 x 1250 x 2000 mm^3. The factories of the company employed nearly 500 people that produced machine tools for 58 M€. Since its foundation in 1946 to the end of 2001 MECOF had produced 1852 milling machines sold to 1096 customers. Typically the total number of parts included in each milling machine is about 2000; nearly 50 parts yield the 80% of the machine cost while 800 components take the 15% of the cost.

The production was actually controlled by an MRP system. The production of a machine was launched by a specific customer's order or by an internal order. In the latter case the machine tool is customized only after it is sold to the customer. Table 5 and 6 show respectively the number of milling centers (N) produced to fulfill a specific customer order or an internal order. For each type of machine, Table 5 reports also the observed mean MLT, the mean delivery delay and the ratio between delay and MLT.

Model	N	Mean delay	delay / lead time	Mean lead time
		Months	%	Months
CR 15/SPEED	4	1,7	18,7 %	9,1
CS 50	3	0,9	14,8 %	6,1
CS 500	15	0,5	7,5 %	6,7
DYN. 2000/L	1	1,0	6,5 %	15,4
DYN. 3000/L	4	1,1	8,9 %	12,4
M 3	3	1,9	15,4 %	12,3
M 5.3	1	5,2	24,6 %	21,1
MILLER M1	1	0,6	5,2 %	11,6
Total	32	1,1	11,7 %	9,1

Table 5: Production, MLT, delivery delay for customer orders.

Model	N	Mean lead time
		Months
CR 15/SPEED	8	0,9
CS 50	6	0
CS 500	15	0,5
DYN. 3000/L	2	1,3
M 3	4	0,7
PERFORMA	1	-1,0
Total	36	9,1

Table 6: Production, delivery delay for internal orders.

Table 6 shows only the mean delivery delay for the typology of machine tools whose production was launched by an internal order.

In the year 2000 the Plant Capacity (PC) was 68, the Work In Process (WIP) reached 25 milling centers and the Time In Process (TIP) ratio was approximately 1.

4 PLANNING AND SCHEDULING MODEL

The results of the financial analysis concerning inventory indicated the necessity to improve the manufacturing organization. Specifically two approaches reported in literature were considered. One proposes the integration of MRP and JIT to achieve a hybrid system; the other concerns lot-sizing rules and freezing techniques.

MRP systems give inventory information in order to establish the right order quantities at the right time. JIT systems demand the right execution of the tasks and the on time delivery of the products. MRP/JIT integration is based on the peculiarities of each system: MRP is very effective in long range planning, scheduling, materials planning and coordination; JIT production systems give advantages in the shop floor scheduling and control. Consequently MRP assumes the role of an integration planning tool where the production control is carried out by JIT.

In this way it is possible to face the ‘‘schedule instability’’ arising from continual adjustments to the Master Production Schedule (MPS) that cause major changes in the detailed MRP schedules. Uncertainty is furthermore responsible of high inventory costs since the order quantities are essentially based on the forecast demand.

Improvement strategies based on freezing techniques have been reported in [8]. Four MPS parameters can be frozen: the planning horizon for which the production is scheduled in each re-planning cycle; the freezing proportion that establishes the fraction of the planning horizon in which schedules cannot be changed; re-planning periodicity that sets successive re-planning and the freezing methods that determines how the schedules are frozen.

In MECOF efficiency improvement could be achieved with the definition of a new Bill of Materials (BOM) structure that considers the needs of three company functions: design, purchasing and production. The new structure classifies products into seven classes in order to reduce information redundancy:

- family: similar products developed cooperatively by the design, purchasing, marketing and production;
- basic: products designed to facilitate production, forecasting and planning;
- function: similar products to improve production, forecasting and planning;
- module: products characterized by efficient engineering and forecasting;
- model: the end product;
- kit: parts with specific functions;
- manufacturing assembly: sub-assembly: used for production.

A new planning and scheduling framework characterized by a multi-stage approach has been proposed: concisely sales forecasting governs inventory, annual production volume and capacity requirement plans. The orders for components and production facilities are set accordingly to their delivery time in order to avoid any delay. The schedule horizon for the machine tool final assembly programs three weeks providing daily plans for each production line. The plans of the first two weeks are frozen i.e. cannot be changed.

5 MODEL EVALUATION

An effective integration of MRP and JIT can be achieved implementing an earliness-tardiness production scheduling and programming (ETPSP) system [9, 10].

Earliness is the difference between the delivery date and the due-date of the considered product; tardiness consider only the positive values of this difference otherwise it assume the nil value. The model assumes N types of products manufactured to satisfy market requirements in a time horizon $[1,T]$. The final products are obtained through M assembly or processing steps.

The model requires information on the quantity $d_i(k)$ of product i required in period k; the available capacity $c_j(k)$ of process j in period k; the unit capacity w_{ij} required by product i for process j, and the initial inventory I_i of product i.

Optimization consists in minimizing the total penalty P due to earliness and tardiness by a suitable choice of the lot size s_i of product i considering the planning production quantity of product i in period k, $p_i(k)$.

The optimization is performed by solving the following programming problem P:

$$\min_P = \sum_{i=1}^{N}\sum_{k=1}^{T}\left\{\alpha_i\left[I_i+\sum_{t=1}^{k}p_i(t)-\sum_{t=1}^{k}d_i(t)\right]^+ + \beta_i\left[\sum_{t=1}^{k}d_i(t)-\sum_{t=1}^{k}p_i(t)-I_i\right]^+\right\}$$

which is subject to the following constraints:

$$\sum_{i=1}^{N} w_{ij} \cdot p_i(k) \le c_j(k),\ \ j = 1,2,\cdots,M; k = 1,2,\cdots T$$

$0 \le p_i(k) \in S_i$, $(i = 1,2,\cdots,N; k = 1,2,\cdots T)$ with

$S_i = \{r \cdot s_i, r = 0,1,2\cdots\}$ and

α_i and β_i : $(i = 1,2,\cdots,N)$ are respectively the unit time earliness and tardiness penalty of product i ,

$(x)^+ = \max\{0, x\}$

Since the objective function is not linear, the problem cannot be solved by common techniques such as simplex methods; a method to find near-optimal solutions based on genetic algorithm was proposed in [11]. A Goal Programming (GP) approach was recently reported in [12].

In this study the ETPSP model was not used for the optimization of lots sizes; actually the objective function was employed to measure the efficiency of the proposed production and inventory management approach.

The analysis assumed a time horizon T = 1 year, N = 6 classes of milling machines i.e., CR 15/SPEED, CS 50, CS 500, DYN 3000/L, M3, and the remaining class including: DYN 2000/L, M 5.3, MILLER M1, PERFORMA. During the year 2000 the quantities d_i of each type of machines produced by MECOF were respectively 12, 9, 30, 6, 7, 4; the planned quantities p_i were 16, 9, 33, 7, 7, 4 and the lot sizes s_i were 5, 1, 4, 2, 1, 1.

There are four production stages (M) necessary to manufacture a machine tool, i.e. mechanical sub-assembly, final mechanical assembly, no mechanical parts assembly and final assembly. The production capacity c_j = 68 was assumed equal for all the production stages since every machine undergoes the same manufacturing processes. The unit capacity requirement of product i for process j, w_{ij} is given by the ratio between the production capacity c_j and the produce quantities d_i.

Since no data on the inventories level I_i was available they were considered empty. Analogously as the number of machines delivered earlier or after the due-date was unknown, unit time earliness and tardiness penalties were assumed equal ($\alpha_i = \beta_i$). Their numerical values were set identical to the mean delays for the make-to-order and the make-to-stock production.

These assumptions permitted to compute the penalty for the actual production obtaining P_0 = 7,9.

Penalty computation was carried out by a simulation program considering the production and inventory controlled with the proposed approach. The obtained results are shown in Table 7.

The total penalty obtained in this case is P_{new} = 2,45.

The reduction of this figure suggests a remarkable improvement. A reduction of MLT and delays was also observed (Table 8).

Machine tools typology		s_i	$\alpha_i = \beta_i$
1	CR 15/SPEED	4	0,65
2	CS 50	1	0,23
3	CS 500	3	0,25
4	DYN 3000/L	1	0,60
5	M3	1	0,65
6	Other milling machines	1	1,45

Table 7: Lot sizes and penalties (proposed model).

Model	Mean delay	Mean MLT
	months	months
CR 15/SPEED	0,85	8,3
CS 50	0,45	5,7
CS 500	0,25	6,5
DYN. 3000/L	0,55	11,9
M 3	0,95	11,4
Others milling machines	1,32	14,9
Total	0,53	8,5

Table 8: Delay and MLT for the proposed model.

6 CONCLUSION

After identifying the inefficiencies of a milling machines producer through the analysis of financial ratios, this study investigated the possibility of improving production planning and programming policies. The results obtained by evaluating the tardiness-earliness penalty function demonstrate the potential of a new approach based on MRP/JIT integration, lot sizing and freezing rules.

7 REFERENCES

[1] Huq, Z., Huq, F., 1994, Embedding JIT in MRP: the Case of Job Shops. Journal of Manufacturing Systems, 13/3:153-164.

[2] Ding, F.Y., Yuen, M.N., 1991, A Modified MRP for a Production System with the Coexistence of MRP and Kanbans. Journal of Operations Management, 10/2:267-277.

[3] Lee Y.Q., Shin H.J., 1996, CIM implementation through JIT and MRP integration, Computers ind. Engng, 31/3-4:609-612.

[4] Benton, W.C., Shin, H., 1998, Manufacturing Planning and Control: the Evolution of MRP and JIT Integration, European Journal of Operational Research, 110:411-440.

[5] Ho, J.C., Chang, Y.L., 2001, An Integrated MRP and JIT Framework, Computers & Industrial Engineering, 41:173-186.

[6] Zhao, X., Lam, K., 1997, Lot-sizing Rules and Freezing the Master Production Schedule in Material Requirements Planning Systems, Int. J. Production Economics, 53:281-305.

[7] Xie, J., Zhao, X., 2003, Freezing the Master Production Schedule Under Single Resource Constraint and Demand Uncertainty, Int. J. Production Economics, 83:65-84.

[8] Wang, D.-W., 1995, Earliness/tardiness production planning approaches for manufacturing systems, Computers and Industrial Engineering 28/3:425–436.

[9] Sridharan, S.V., Berry, W.L., 1990, Freezing the Master Production Schedule Under Demand Uncertainty, Deci. Sci., 21:97-120.

[10] Li, Y., Wang, D.-W., Ip, W.-H., 1998, Earliness/tardiness production scheduling and planning, and solutions, Production Planning and Control 9 (3), 275–285.

[11] Ip, W.-H., Li, Y., Man, K.-F., Tang, K.-S., 2000. Multi-product planning and scheduling using genetic algorithm approach, Computers and Industrial Engineering 38, 283–296.

[12] Li, L., Fonseca, D.J., Chen, D.S., 2006, Earliness–tardiness production planning for just-in-time manufacturing: A unifying approach by goal programming, European Journal of Operational Research, 175:508–515.