

CASE STUDY

Developing manufacturing resource planning (MRP II) systems in the medical garment industry - a case study

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This article developed a Manufacturing Resource Planning (MRP)II for a company specializing in the medical garment industry. The resources of the company had not been planned and controlled effectively, leading to high production costs and low on-time delivery, affecting the competitive edge of the company. The research effectively planned all the company's resources to reduce production costs, increase the on-time delivery rate, and finally improve the competitive edge of the company. The paper integrated all MRP II functional modules of the companies, including Demand Management (DM), Production Planning (PP), Master Production Schedule (MPS), and Material Requirement Planning (MRP). The paper applied the available to promise (ATP) model to help process customer orders effectively and applied operations research models in PP to minimize production costs.

Keywords: manufacturing resource planning (MRP)II, demand management, forecast consumption, production planning, master production schedule (MPS), available to promise (ATP), material requirement planning (MRP)

Introduction

Since the beginning of 2020, the Covid-19 epidemic has had a major impact on most industries. However, demand was increasing for the medical garment industry, opening up great opportunities for businesses in this industry. Instead of being able to take advantage of the opportunity to increase customers, MZ company (a company in medical garment industry in Vietnam) (MZC), lost a significant number of orders.

The 5-Why method was applied to find the initial causes of the lost-order problem. The initial causes were high production costs and low service levels. The company faced cost problems. An increased cost in resources leads to an increased cost in production that affects their market share. Manufacturing resources needed to be used effectively to cut costs.

The company's current service level, ability to meet orders on time, was quite low. The average order delay rate in

the first 10 months of 2020 is about 64.8%. A fishbone diagram combined with the brainstorming method was used to analyze the main causes of late orders, as shown in [Figure 1](#).

Using the failure mode and effects analysis (FMEA) method to identify and prioritize the causes of late orders in the production of the company. The result with risk priority number (RPN) percentage P(%) and RPN cumulative percentage CP(%) was shown in [Table 1](#).

The Pareto chart for the main causes of late orders was shown in [Figure 2](#).

The six main causes of late delivery with an RPN cumulative percentage of more than 80% were inappropriate production plans, improper production schedules, unspecific forecasting models, incorrect material requirement planning (MRP), wrong order promising, and inconsistent bills of materials. The six causes with corresponding solutions were shown in [Table 2](#).

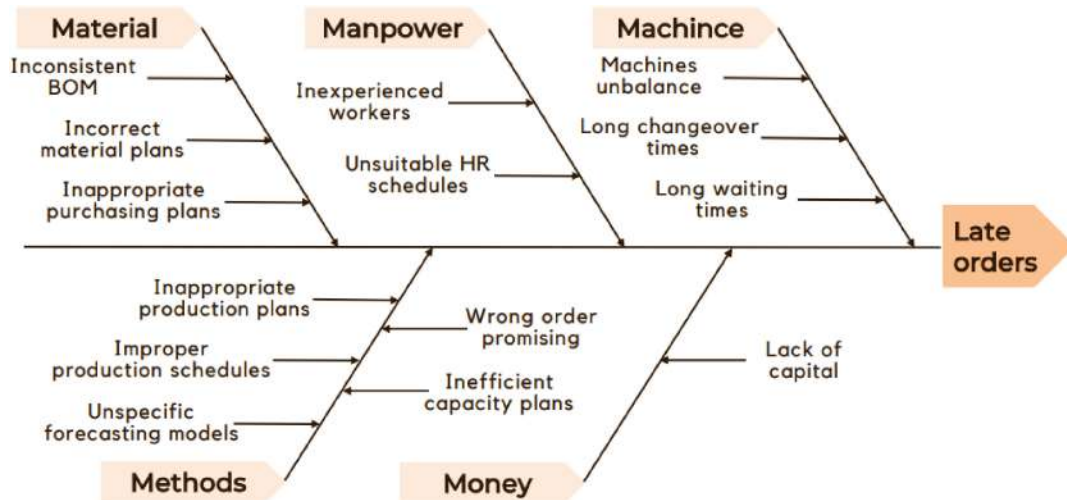


FIGURE 1 | Fishbone diagram for the possible causes of late orders.

TABLE 1 | Analyzing and prioritizing possible causes.

No.	Causes	Codes	Severity (SEV)	occurrence (OCC)	detection (DET)	RPN	P	CP
1	Inappropriate production plan	A	8	8	7	448	22.63	22.63
2	Improper production schedule	B	8	7	6	336	16.97	39.60
3	Unspecific forecasting models	C	7	7	6	294	14.85	54.44
4	Incorrect material plans	D	8	6	5	240	12.12	66.57
5	Wrong order promising	E	8	5	4	160	8.08	74.65
6	Inconsistent Bill of Materials (BOM)	F	6	5	4	120	6.06	80.71
7	Inefficient capacity plans	G	8	3	4	96	4.85	85.56
8	Inappropriate purchasing plans	H	6	4	3	72	3.64	89.19
9	Inexperienced workers	J	5	2	6	60	3.03	92.22
10	Long waiting time	J	5	4	3	60	3.03	95.25
11	Lack of capital	K	7	3	2	42	2.12	97.37
12	Machines unbalance	L	3	4	2	24	1.21	98.59
13	Unsuitable HR schedule	M	4	2	2	16	0.81	99.39
14	Long changeover time	N	3	2	2	12	0.61	100.00

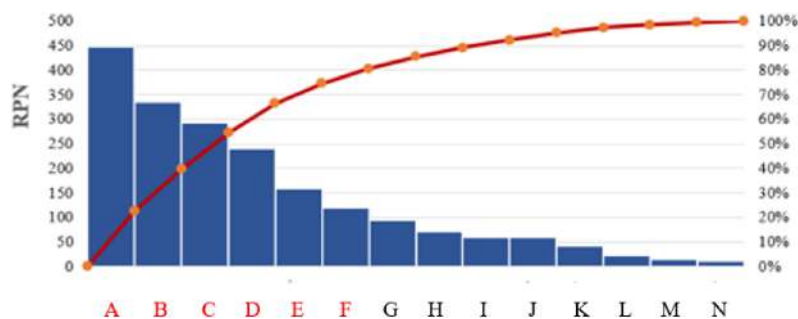


FIGURE 2 | The Pareto chart for the causes of late orders.

The solutions led to a manufacturing resource planning (MRP)II, which consists of four functional modules as shown in Table 2. The MRPII system was designed to reduce late orders and then increase the customer service level. The system also reduced

resource costs, thereby helping to solve the problem of lost orders for the company. The MRPII system was constructed for the SS product family of the company, including six models: SS1, SS2, SS3, SS4, SS5, and SS6.

TABLE 2 | Causes analysis and solutions.

No.	Causes	Solutions	Functional modules
1	Inappropriate production plan	Establish an optimal production plan to meet customer needs	Production Planning (PP)
2	Improper production schedule	Establish, adjust, and control the production schedule efficiently to meet the production plan.	Master Production Schedule (MPS)
3	Unspecific forecasting models	Establish forecasting models that matched the historical data	Demand Management (DM)
4	Incorrect material plans	Establish a material requirement plan to meet the MPS	Material Requirement Planning (MRP)
5	Wrong order promising	Develop Available to promise model in MPS	MPS
6	Inconsistent BOM	Control BOM in MRP	MRP

Literature review

According to (1), the MRPII is a system for effective planning of all resources of a manufacturing company. It is made up of a variety of interlinked functions such as Demand Management (DM), Production Planning (PP), Master Production Schedule (MPS), MRP, Capacity Requirement Planning (CRP), and Vendor Requirement Planning (VRP). The MRPII is an approach to managerial planning, execution, and control of productive activity. It integrates, in a feedback manner, the forecasting of demand, PP, scheduling and control, and purchase planning and control.

Amad-Uddin et al. designed a bespoke MRPII system for an small and medium enterprise (SME) company with the critical modules DM, MPS, MRP, and CRP (2). Phong et al. developed an MRPII system in the electric generator manufacturing industry with modules of DM, PP, MPS, and MRP (3).

Purna Chandra Padhan used Seasonal Autoregressive Integrated Moving Average (SARIMA), a time series forecasting model, in forecasting cement productions. The forecasting performance of various competing models was evaluated through forecast accuracy criteria mean absolute percentage error (MAPE) (4). Emiro Antonio Campo et al. proposed and implemented an aggregated PP model to provide optimal strategies in the medium term for a textile company. Linear programming was used to minimize total costs associated with labor and inventory levels. The model took into account characteristics associated with fabric contraction, wastes in the process, the efficiency of new employees, and training requirements (5).

Jia-Nian Zheng and Chen-Fu Chien developed a system for excelling enterprise resources for light-emitting diode (LED) manufacturing that optimizes chip procurement and PP by linear programming (6). P.J. Weeda constructed a stochastic model for the reduction of the initial forecast in the master schedule of an MRP system during the progress of time by the acceptance of customer orders (7).

Raqeyah Jawad Najy found out that an overstated MPS caused raw materials and work in process (WIP) inventories to increase and led to missed due dates. He used rough cut capacity planning (RCCP) to validate the MPS with respect to available capacity (AC) (8). Juin-Han Chen and Chin-Tai Chen proposed a two-phase order promising process

in which available to promise (ATP) was first reserved in phase I to meet the most important demand. Customer orders were promised in Phase II according to the time-phase manufacturing resource supply calendar and restricted via the ATP in Phase I (9).

Teeradej Wuttipornpun et al. developed a practical finite capacity MRP system based on the needs of an automotive-part manufacturing company in Thailand. The proposed system offered a good trade-off between conflicting performance measures and resulted in the best weighted average performance measure when compared with conventional forward and forward-backward finite capacity scheduling systems (10).

Research methodology

The research methodology for developing the MRPII system includes the following steps.

- Step 1: Develop DM module
- Step 2: Develop PP module
- Step 3: Develop MPS module
- Step 4: Develop MRP module

Develop demand management (DM) module

This module has to achieve the objective of accurately forecasting customer demand. The DM module has two inputs: the long-term demand, or historical demand, and short-term demand, or customer order. Historical demand data in the product family will be used to make a demand plan for the PP module by suitable forecasting models. Forecasting models are also used to forecast product mix percentages for each product in the product family. Customer orders will go through the DM module to the MPS.

Forecasting is done according to the following steps:

1. Determine forecast parameters
2. Collect data
3. Eliminate outliers in the data
4. Select appropriate forecasting models

5. Forecast according to the best model.

Forecast parameters include forecast objects and forecast times. The forecast object can be a product family or individual product. The forecast time is 1 year with a cycle of 1 month. Past data is collected to forecast the forecast object. The data is processed, and outliers are eliminated to ensure the reliability of forecast data. Data patterns are analyzed to select appropriate forecast models. The best forecast model is selected according to forecast errors.

Develop production plan (PP) module

The PP module receives the demand plan from the DM module and constructs the production plan of the product family to minimize the cost of using the resources and constraints on resource capacity (1). Production plans are constructed by using operations research models in (11).

The PP steps are as follows.

1. Identify resource alternatives.
2. Construct the model
3. Collect data, estimate model parameters
4. Determine the production plan.

Resource alternatives used to meet demand in the case include regular-hours production, overtime production, inventory, and back-order. The model is constructed by defining model indexes and parameters, thereby determining the objective and constraints.

The index and parameters used in this case are defined as shown in **Table 3**.

The decision variables used in this case are defined in **Table 4**.

TABLE 3 | The model index and parameters.

The index and parameters	Meaning
t	Time period (t = 1÷12)
D(t)	Demand in time period t
r	Regular hour production cost per unit
RC(t)	Regular hour production capacity
o	Overtime production cost per unit
OC(t)	Overtime production capacity
h	Inventory cost per unit per period
MI	Maximum inventory
II, EI	Initial and ending inventory
b	Backorder cost per unit per period
MB	Maximum backorder percentage
IB, EB	Initial and ending backorder

TABLE 4 | The model variables.

Variables	Meaning
X(t)	Number of products produced in a regular hour in period t
Y(t)	Number of products produced in overtime in period t
I(t)	Number of products in inventory in time period t
B(t)	Number of products in back order in time period t

To minimize the total resource cost, the objective function is defined as follows.

Min C

$$C = \sum_{t=1}^T (rX(t) + oY(t) + hI(t) + bB(t))$$

The constraints are constructed as follows with t = 1÷12.

1. Demand constraint: $X(t) + Y(t) + I(t-1) - I(t) + B(t) - B(t-1) = D(t)$
2. Regular hour production capacity constraint: $X(t) \leq RC(t)$
3. Overtime production capacity constraint: $Y(t) \leq OC(t)$
4. Inventory constraint: $0 \leq I(t) \leq MI$
5. Backorder constraint: $0 \leq B(t) \leq MB * D(t)$
6. Inventory & Back-order relation: $I(t) * B(t) = 0$
7. Initial & ending inventory: $I(1) = II, I(12) = EI$
8. Initial & ending backorder: $B(1) = IB, B(12) = EB$
9. Non-negativity restrictions: $X(t), Y(t), I(t), B(t) \geq 0$

After the model is built, data is collected to estimate model parameters. The model is solved to determine production plans for the product family.

Develop master production schedule (MPS) module

The MPS module makes a production schedule for each product to meet the production plan of the product family (1) in three steps.

1. Step 1: Design the MPS
2. Step 2: Make the MPS
3. Step 3: Control the MPS

Design the MPS

Designing MPS determines scheduling objects, scheduling time, and scheduling parameters. The scheduling objects are products within the product family. Scheduling time is monthly with daily cycles. The scheduling parameters include the number of production days per month (DPM), consumption periods for adjusting MPS in step 2, and time fences for controlling MPS in step 3, as in **Table 5**.

TABLE 5 | The MPS parameters.

Parameters	Meaning
DPM (d)	Number of production days per month
BCP (d)	Number of backward consumption periods
FCP (d)	Number of forward consumption periods
DTF (d)	Demand time fences
PTF (d)	Planning time fences

Make the MPS

Making MPS includes the following steps.

1. Draft an initial production schedule from forecast demand.
2. Adjust the production schedule according to actual customer orders.
3. Make the production schedule feasible.

Draft an initial production schedule from the forecast demand. The MPS receives a demand forecast (DF) for each product from the PP module. The DF for each product is derived from the production plan for the product family and the product mix percentage of each product, forecasted by the DM module. The monthly forecasted demand for each product will be divided equally among each day to create an initial production schedule.

Adjust production schedule according to actual customer orders. The MPS also receives actual orders from the DM module. The forecast consumption model (1) will be used to revise the production schedule as customer orders consume the forecast from the production plan. When there are orders that exceed forecast demand, the excess quantity will consume the unconsumed forecast (UF) quantities in the previous cycles (backward consumption) and the following cycles (forward consumption). After consumption is completed, the revised production schedule (RPS) will be defined according to the customer order (CO) and the UF, as follows.

$$RPS = CO + UF$$

Make the production schedule feasible. Making the production schedule feasible includes the following steps.

1. Determine the critical station and its profiles.
2. Determine the rated capacity (RC) of the station.
3. Determine the RC of the station.
4. Check the feasibility of the production schedule.
5. Adjust when the schedule is not feasible.

The critical station is often the bottleneck station in the production process with the lowest cycle time (CT). The

station profiles include parameters of the stations as shown in the following **Table 6**.

The rated capacity (RC) of the stations is determined as follows.

$$AC = NoM * DPP * SPD * (RHPS + OHPS - TOM) * E * U$$

For the sake of simplicity, with the assumption that the CTs are the same for every product produced in the station, the required capacity is defined according to total demand (TD) per date, and the station CT, as follows.

$$RC = TD * CT$$

The production schedule is considered feasible when RC is lower than AC at every scheduling period. If RC exceeds AC at some scheduling periods, loads in these periods will be reallocated to other periods to make the schedule feasible.

Control the MPS

The production schedule must also be controlled by using models of projected available balance (PAB), and ATP, to keep the MPS stable under demand fluctuations (1).

Projected available balance (PAB). Projected available balance (PAB) is used to evaluate the performance of the production schedule and whether scheduled production balances with future demand. With t as the time index of the MPS, the PAB is defined according to the time fences (DTF) and PTF, the beginning on-hand (BOH), the MPS, the CO, and the forecast (F) as follows:

1. $1 \leq t \leq DTF$: $PAB(t) = PAB(t - 1) + MPS(t) - CO(t)$, $PAB(0) = OHB$.
2. $DTF < t \leq PTF$: $PAB(t) = PAB(t - 1) + MPS(t) - \text{Max}[CO(t), F(t)]$.

Available to promise (ATP). Available to promise (ATP) is used to promise the customer orders at specific periods in the

TABLE 6 | Critical station profile.

Parameters	Meaning
NoM	Number of machine in station
DPP	Number of days per planning period
SPD	Number of shift per day
RHPS (h/s)	Number of regular hours per shift
OHPS (h/s)	Number of overtime hours per shift
DOM	Dates of maintenance
TOM (h)	Time of maintenance
U (%)	Station utilization
E (%)	Station efficiency
CT (sec)	Station cycle time

future. At first, discrete ATP without looking ahead DATP-WOL is defined according to the BOH, the MPS, and the CO before the next MPS. For periods that $MPS = 0$:

$$DATP - WOL = 0.$$

For periods that $MPS \neq 0$:

1. $t = 1$: $DATP - WOL = OHB + MPS - \Sigma CO$
2. $t > 1$: $DATP - WOL = MPS - \Sigma CO$

Then discrete ATP with look-ahead DATP-WL is defined according to discrete available to promises - without look-ahead (DATP-WOL). In periods that DATP-WOL is less than 0, the ATP will be set to 0, and the over-promised amount will be compensated by taking the ATP of the nearest previous periods that have positive ATP. Finally, the ATP is defined by cumulating the discrete ATP with a look ahead.

Develop material requirement plan (MRP) module

The MRP module determines the requirement of materials based on the structure of the products and the inventory status of each material to meet the MPS (1). The steps for planning material requirements are as follows:

1. Determine the production schedule.
2. Determine the product structure.
3. Determine the inventory status of materials.
4. Determine the MRP.

The production schedule is identified from the MPS module. Product structure is often presented through a Bill of Materials (BOM). The inventory status of materials is determined by the inventory status record (ISR), which includes parameters as shown in [Table 7](#).

Material requirements are planned through variables as shown in [Table 8](#).

Material requirements are planned over time through the following steps (1).

1. Determine the gross requirement (GR).

TABLE 7 | Inventory Status Record (ISR) parameters.

Parameters	Meaning
LC	Level code
Q	Lot size
LT	Lead time
OH	On hand
SR	Scheduled received
SS	Safety stock
AL	Allocated

TABLE 8 | MRP variables.

Variables	Meaning
GR	Gross Requirement
SR	Scheduled Receipt
POH	Projected On Hand
PAB	Projected Available Balance
NR	Net Requirement
PORc	Planned Order Receipt
PORl	Planned Order Release

2. Determine the net requirement (NR).
3. Determine the planned order receipt (PORc).
4. Determine the projected on-hand (POH).
5. Determine the planned order release (PORl).

The GR is determined by the production schedule for the final product and by the PORl of the corresponding parents of the material. The NR, PORc, the POH, and the PORl are determined as follows.

$$NR(t) = \text{Max} [GR(t) - SR(t) - POH(t-1); 0]$$

$$PORc(t) = \{NR(t), NR(t) < Q; Q, NR(t) \geq Q\}$$

$$POH(t) = SR(t) + PORc(t) + POH(t-1) - GR(t)$$

$$PORl(t) = PORc(t - LT)$$

The research methodology will be applied to the case in the following sections.

Demand management (DM)

The DM module used for demand forecasting was included.

1. DF for product family SS.
2. DF for individual products in the product family.

Demand forecast for product family

To forecast the demand for the product family of SS in the next 12 months of the next year, 2021, SS demand for the last 3 years, 2018, 2019, and 2020, was collected as shown in [Table 9](#).

Processing the data showed that the data set has no outliers. After analyzing both the trend and seasonal behavior of the data set, the proposed models were auto-regressive integrated moving average (ARIMA), Decomposition, and Winter. Minitab software was used to forecast the three methods. Mean absolute deviation (MAD) and tracking

TABLE 9 | Demand of SS for the last 3 years.

Months	1	2	3	4	5	6	7	8	9	10	11	12
2018	2,100	880	550	720	390	1,980	780	1,340	805	1,370	1,305	1,340
2019	2,140	1,220	1,640	2,190	2,420	3,255	3,280	3,550	3,510	3,448	2,250	2,455
2020	2,160	1,320	1,395	1,105	1,410	2,124	1,205	1,460	1,805	1,490	1,310	1,355

TABLE 10 | Forecast errors of the proposed models.

	ARIMA	Decomposition	Winters
MAD	456	591	329
TS	-1.1145	0	0.9018

TABLE 13 | Forecast errors of the proposed models.

	NM	MA	ES
MAD	0.137687	0.0916	0.1031
TS	0.005692	0.00597	-0.00309

signal (TS) were used as the forecast errors to choose the most suitable model. The forecast errors of the proposed models were shown in **Table 10**.

The Winters method was selected. The forecast result was shown in **Table 11**.

Demand forecast of each product

To determine the DF of each of the six products SS1, ... SS6, the demand percentages (DP) of all products were collected in the previous year. The DP of SS1 was forecasted, and the remaining products were done similarly. The DP of SS1 in the last 2 years is shown in **Table 12**.

Since the data were collected random and not trending, forecasting methods of Naive Method (NM), Moving Average (MA), and Exponential Smoothing (ES) were proposed. The forecast errors of the proposed models were shown in **Table 13**.

The method of MA was selected. The forecast result was shown in **Table 14**.

The demand for each product in 1/2021, $D(1)$, is forecasted by the corresponding $DP(1)$ and $PP(1)$ as shown in **Table 15**.

$$D(1) = DP(1) * PP(1) = DP(1) * 1,966$$

TABLE 11 | Demand D of SS for the next year, 2021.

Month	1	2	3	4	5	6	7	8	9	10	11	12
D	1,966	966	1,014	1,151	1,212	2,251	1,546	1,901	1,818	1,873	1,385	1,473

TABLE 12 | Demand percentage (DP) of SS1 in 2019, 2020.

Month	1	2	3	4	5	6	7	8	9	10	11	12
2019	0.004	0.221	0.227	0.006	0.005	0.008	0.007	0.006	0.005	0.082	0.083	0.112
2020	0.231	0.247	0.479	0.068	0.084	0.163	0.314	0.103	0.143	0.201	0.191	0.221

Production planning (PP)

The PP model, as in section “Develop production plan module PP,” was constructed as follows.

Min C

$$C = \sum_{t=1}^T (rX(t) + oY(t) + hI(t) + bB(t))$$

St.

$$X(t) + Y(t) + I(t-1) - I(t) + B(t) - B(t-1) = D(t)$$

$$X(t) \leq RC(t)$$

$$Y(t) \leq OC(t)$$

$$0 \leq I(t) \leq MI = 2,000$$

$$0 \leq B(t) \leq 5\% D(t)$$

$$I(t) * B(t) = 0$$

TABLE 14 | The DP for each product in 1/2021.

Model	SS1	SA2	SS3	SA4	SA5	SS6	SUM
DP(1)	0.201481	0.108389	0.084141	0.055543	0.066297	0.484149	1

TABLE 15 | The demand D(1) for each product in 1/2021.

Model	SS1	SA2	SS3	SA14	SA5	SS6	SUM
DP(1)	0.201481	0.108389	0.084141	0.055543	0.066297	0.484149	1
D(1)	396	213	165	109	130	953	1,966

TABLE 16 | Production capacity in 2021.

t	1	2	3	4	5	6	7	8	9	10	11	12
RC(t)	1,846	1,182	1,994	1,772	1,846	1,920	1,994	1,920	1,772	1,920	1,920	1,994
OC(t)	692	443	748	665	692	720	748	720	665	720	720	748

TABLE 17 | Production costs, inventory, and backorder parameters.

Parameters	Value
r(VND/u)	131,011
o(VND/u)	145,384
h(VND/u*m)	22,320
b(VND/u*m)	248,000
MI(u)	2,000
II(u)	0
EI(u)	0
LI(u)	0
MB	0.05
IB(u)	0
LB(u)	0

$$I(1) = II, I(12) = EI$$

$$B(1) = IB, B(12) = EB$$

$$X(t), Y(t), I(t), B(t) \geq 0$$

The monthly demand of the SS product family $D(t)$, $t = 1-12$, was forecasted according to [Table 11](#). Data were collected, and model parameters were estimated. Regular and overtime production capacity in units of products per month in the next year are estimated as shown in [Table 16](#).

Parameters of costs, inventory, and backorder were estimated as shown in [Table 17](#).

Applying the Open-Solver add-in in Excel, the production plan in units of products for the next year, 2021, was found in [Table 18](#).

With the above production plan of product family SS, the total cost of resources was minimal as follows.

$$C = 2, 438, 420, 206 \text{ VND}$$

Master production schedule (MPS)

Design the MPS

The production schedule for all models of the product family was made daily for a month. The SS1 would be selected to make its production schedule, and the production schedules of other products were made similarly. The month chosen to be scheduled is January 2021. The MPS parameters were defined in [Table 19](#).

January has 31 days, of which 25 are production days, as in [Table 20](#).

The 25 production days of January are shown in [Table 21](#).

Make the MPS

Draft the initial production schedule

The DF of SS1 in January was 396, as shown in [Table 15](#). This DF was equally distributed for the production days of the month to make the initial production schedule, as in [Table 22](#).

Revise the production schedule according to actual customer orders

Along with the initial MPS, or the DF, were the CO, as shown in line CO in [Table 23](#). The forecast consumption model

TABLE 18 | Production plan in 2021.

Month	1	2	3	4	5	6	7	8	9	10	11	12
X	1,846	966	1,014	1,151	1,212	1,920	1,546	1,901	1,772	1,873	1,385	1,473
Y	120	0	0	0	0	331	0	0	46	0	0	0
I	0	0	0	0	0	0	0	0	0	0	0	0
B	0	0	0	0	0	0	0	0	0	0	0	0

TABLE 19 | The MPS parameters.

Parameters	Values
DPM (d)	25
BCP (d)	6
FCP (d)	6
DTF (d)	5
PTF (d)	12

TABLE 21 | The 25 production days in January.

Day	2	4	5	6	7	8	9	11	12	13	14	15	
Day	16	18	19	20	21	22	23	25	26	27	28	29	30

was used to consume DF by CO to make the revised MPS. The model applied backward forecast consumption first, then forward forecast consumption later, and the number of days for the consumption was 6 days, as in **Table 19**. The result with the consumed forecast (CF), the UF, and the revised MPS was shown in **Table 23**.

The revised MPS for model SS1 daily in January 2021 was shown in **Table 24**.

Similarly, the revised MPSs for the remaining models were made as shown in **Table 25**, with the TD of all models per day.

Make the MPS feasible

The MPS was checked for feasibility by applying the resource profiles method in (1). The SS production process consists of nine stations: M0, M1, ..., and M8. According to station CT, the critical station in the process was M5. The parameters of the M5 station were all estimated and shown in the station profiles shown in **Table 26**.

The AC of M5 in minutes per day was calculated as follows.

TABLE 22 | The initial production schedule of SS1.

Day	2	4	5	6	7	8	9	11	12	13	14	15	
DF	15	15	16	16	16	16	16	15	16	16	16	16	
Date	16	18	19	20	21	22	23	25	26	27	28	29	30
DF	16	15	16	16	16	16	16	16	16	16	16	16	

TABLE 23 | The MPS of SS1 after consumption.

Day	2	4	5	6	7	8	9	11	12	13	14	15
DF	15	15	16	16	16	16	16	15	16	16	16	16
CO	10	15	10	12	20	12	20	14	12	20	10	10
CF	0	0	0	4	4	4	4	0	4	4	0	0
UF	5	0	6	0	0	0	0	1	0	0	6	6
MPS	15	15	16	12	20	12	20	15	12	20	16	16

Day	16	18	19	20	21	22	23	25	26	27	28	29	30
DF	16	15	16	16	16	16	16	16	16	16	16	16	16
CO	12	12	11	17	10	15	12	20	10	13	10	8	10
CF	0	0	1	1	0	0	4	4	0	0	0	0	0
UF	4	3	4	0	6	1	0	0	6	3	6	8	6
MPS	16	15	15	17	16	16	12	20	16	16	16	16	16

$$AC = \text{NoM} * \text{DPP} * \text{SPD} * (\text{RHPS} + \text{OHPS}) * E * U * 60$$

$$AC = 1 * 1 * 2 * (8 + 3) * 0.946 * 0.998 * 60 \approx 622.8 \text{ (m)}$$

The AC of M5 in the three dates of maintenance was calculated as follows.

$$AC = \text{NoM} * \text{DPP} * \text{SPD} * (\text{RHPS} + \text{OHPS} - \text{TOM}) * E * U * 60$$

TABLE 20 | 31 days in January.

Day	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

Day	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun
	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31

TABLE 24 | The revised MPS of SS1 in January 2021.

Day	2	4	5	6	7	8	9	11	12	13	14	15	
SS1	15	15	16	12	20	12	20	15	12	20	16	16	
Day	16	18	19	20	21	22	23	25	26	27	28	29	30
SS1	16	15	15	17	16	16	12	20	16	16	16	16	16

TABLE 25 | The revised MPS of all models in the SS family in January 2021.

Day	2	4	5	6	7	8	9	11	12	13	14	15	
SS1	15	15	16	12	20	12	20	15	12	20	16	16	
SS2	10	6	6	12	9	7	10	8	9	9	9	8	
SS3	7	5	6	8	6	5	9	2	3	15	7	7	
SS4	7	2	3	8	2	2	12	4	5	3	2	3	
SS5	7	3	3	8	2	5	9	2	3	15	2	4	
SS6	30	15	35	73	38	38	24	15	34	80	38	38	
TD	76	46	69	121	77	69	84	46	66	142	74	76	
Day	16	18	19	20	21	22	23	25	26	27	28	29	30
SS1	16	15	15	17	16	16	12	20	16	16	16	16	16
SS2	8	8	9	9	9	8	8	8	9	4	14	7	8
SS3	6	6	7	7	7	6	6	6	7	7	7	7	6
SS4	4	3	11	5	2	2	4	10	4	5	5	4	4
SS5	5	5	3	7	6	5	5	5	5	6	5	5	5
SS6	20	35	35	23	36	90	27	20	30	64	36	38	38
TD	59	72	80	68	76	127	62	69	71	102	83	78	77

$$AC = 1 * 1 * 2 * (8 + 3 - 2) * 0.946 * 0.998 * 60 \approx 509.6 \text{ (m)}$$

TABLE 26 | M5 station profile.

Station	NoM	DPP	SPD	RHPS (h)	OHPS (h)	DOM	TOM (h)	U (%)	E (5)	ST	CT
M5	1	1	2	8	3	3*	2	94.6	99.8	4	6.5

(*) The 3 days of maintenance were 2nd, 16th, and 30th.

TABLE 27 | M5 load report in January 2021.

Day	2	4	5	6	7	8	9	11	12	13	14	15	
AC	509.6	622.8	622.8	622.8	622.8	622.8	622.8	622.8	622.8	622.8	622.8	622.8	
TD	76	46	69	121	77	69	84	46	66	142	74	76	
RC	494	299	448.5	786.5	500.5	448.5	546	299	429	923	481	494	
OL	-15.6	-323.8	-174.3	163.7	-122.3	-174.3	-76.8	-323.8	-193.8	300.2	-141.8	-128.8	
Day	16	18	19	20	21	22	23	25	26	27	28	29	30
AC	509.6	622.8	622.8	622.8	622.8	622.8	622.8	622.8	622.8	622.8	622.8	622.8	509.6
TD	59	72	80	68	76	127	62	69	71	102	83	78	77
RC	383.5	468	520	442	494	825.5	403	448.5	461.5	663	539.5	507	500.5
OL	-126.1	-154.8	-102.8	-180.8	-128.8	202.7	-219.8	-174.3	-161.3	40.2	-83.3	-115.8	-9.1

The AC of M5 in January was shown in the AC lines of the load report in **Table 27**. For the sake of simplicity, with the assumption that the CTs are the same for every product, the RC in minutes per date was defined according to TD per date and the CT of M5, as follows:

$$RC = TDPD * CT = 6.5 * TD$$

The required capacity (RC) in January to meet the TD in **Table 25** was shown in the RC lines in **Table 27**. The station load report of the M5 with AC, RC, and overload (OL) was shown in **Table 27**, where the OL was defined as follows.

$$OL = RC - AC.$$

The M5 station was overloaded on days 6, 13, 22, and 27 and under load on the other days, as shown in **Figure 3**.

The load on the OL days would be reallocated on the days of underload to make the MPS feasible. The MPS after load reallocation was shown in **Table 28**.

The M5 load report after load reallocation was shown in **Table 29** and **Figure 4**. The OLs of all planning periods were now all negative; the MPS was now feasible.

Control the MPS

To control the MPS, PAB, and ATP were calculated from the MPS, DF, and CO; the initial OH of 2; the demand time fence (DTF) of 5 days; and the planning time fence (PTF) of 12 days. The PAB and ATP for model SS1 were calculated and shown in **Table 30**. The MPS of other models could be controlled similarly.

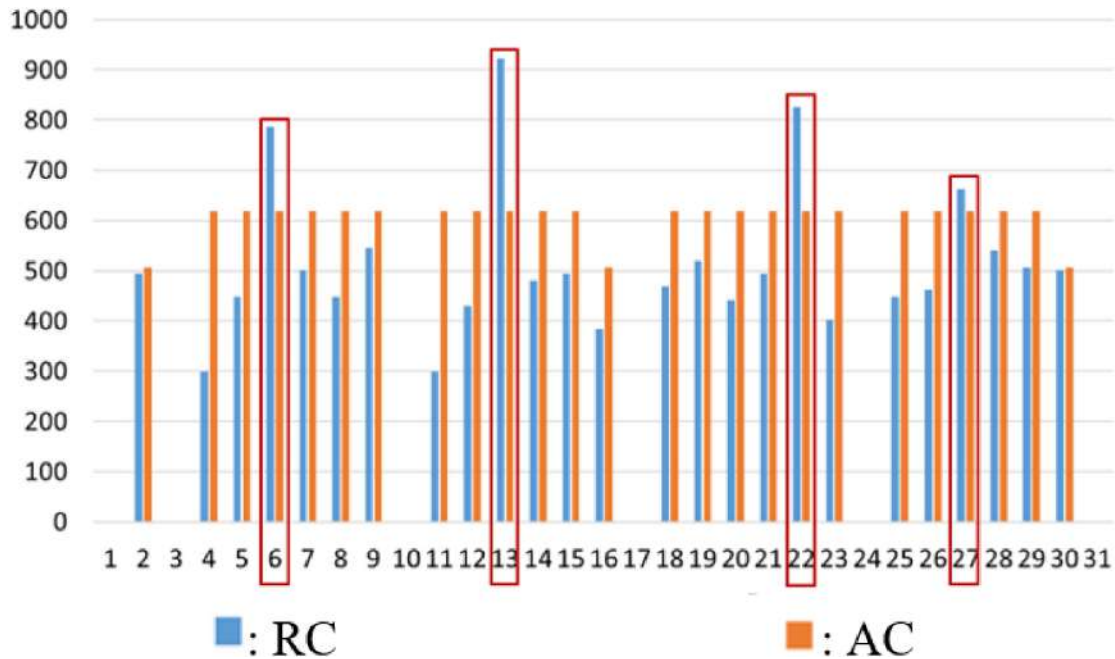


FIGURE 3 | The load diagram of M5.

Material requirement planning (MRP)

Material requirement planning (MRP) determines the materials plan based on the BOM of the products, and the ISR of each material to meet the MPS (1). SS1 was selected as the representative to do the MRP; other products were done similarly.

The MPS of SS1 was shown in Table 28. The BOM of SS1 was shown in Table 31. The materials with units of pieces

(P), or rolls (R), included two types of purchasing (P), and manufacturing (M).

The ISR of manufacturing materials was shown in Table 32.

The ISRs of purchasing materials were shown in Table 33.

From the BOM and ISR, use the MRP add-ins in Excel to plan the material requirements that meet the MPS. The plan for manufacturing materials was shown in Table 34.

The plan for purchasing materials was shown in Table 35.

The plan of manufacturing materials would be the input for CRP. The plan of purchasing materials would be the input for VRP. CRP and VRP were beyond the scope of this study.

TABLE 28 | The revised MPS in January after load reallocation.

Day	2	4	5	6	7	8	9	11	12	13	14	15
SS1	15	27	16	0	20	12	20	35	12	0	32	16
SS2	10	17	6	0	9	16	10	8	10	0	9	8
SS3	7	5	6	6	6	20	9	2	5	0	12	7
SS4	7	2	3	8	2	2	12	6	5	1	2	3
SS5	7	3	3	8	2	5	9	2	3	15	2	4
SS6	30	15	35	73	38	38	24	16	34	79	38	38
TD	76	69	69	95	77	93	84	69	69	95	95	76

Day	16	18	19	20	21	22	23	25	26	27	28	29	30
SS1	16	15	15	17	16	0	12	20	16	16	16	16	16
SS2	16	8	9	9	9	0	12	8	9	0	14	8	8
SS3	6	6	7	8	7	0	8	6	7	5	7	7	6
SS4	5	3	11	5	2	1	4	10	4	5	5	4	4
SS5	6	5	3	7	6	4	6	5	5	5	5	5	5
SS6	20	35	35	23	36	90	27	20	30	64	36	38	38
TD	69	72	80	69	76	95	69	69	71	95	83	78	77

Conclusion

The article evaluated the current state of the resource planning system of the company and developed an MRPII system for the company under study with functional modules including DM, PP, MPS, and MRP.

Initially, forecasting models in the DM module were used to forecast the demand of the product family. The PP module developed a production plan that met the demand for the product family and the resource constraints. The MPS module developed production schedules for each product in the product family that matched the production plan. Finally, the MRP module developed material plans that met the production schedules.

The research integrated these functions to reduce production costs and improve customer service levels, then reduce late orders. The article has the following advantages.

TABLE 29 | The M5 load report after load reallocation.

Day	2	4	5	6	7	8	9	11	12	13	14	15	
AC	509.6	622.8	622.8	622.8	622.8	622.8	622.8	622.8	622.8	622.8	622.8	622.8	
TD	76	69	69	95	77	93	84	69	69	95	95	76	
RC	494	448.5	448.5	617.5	500.5	604.5	546	448.5	448.5	617.5	617.5	494	
OL	-15.6	-174.3	-174.3	-5.3	-122.3	-18.3	-76.8	-174.3	-174.3	-5.3	-5.3	-128.8	
Day	16	18	19	20	21	22	23	25	26	27	28	29	30
AC	509.6	622.8	622.8	622.8	622.8	622.8	622.8	622.8	622.8	622.8	622.8	622.8	509.6
TD	69	72	80	69	76	95	69	69	71	95	83	78	77
RC	448.5	468	520	448.5	494	617.5	448.5	448.5	461.5	617.5	539.5	507	500.5
OL	-61.1	-154.8	-102.8	-174.3	-128.8	-5.3	-174.3	-174.3	-161.3	-5.3	-83.3	-115.8	-9.1

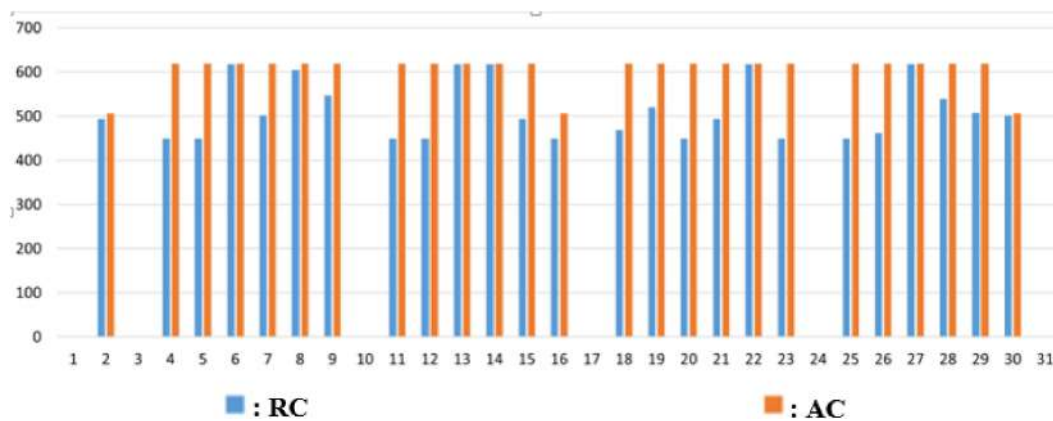


FIGURE 4 | The load diagram of M5 after load reallocation.

TABLE 30 | The PAB & available to promise (ATP) for model SS1.

Day	2	4	5	6	7	8	9	11	12	13	14	15
DF	15	15	16	16	16	16	16	15	16	16	16	16
MPS	15	27	16	0	20	12	20	35	12	0	32	16
CO	10	15	10	12	20	12	20	14	12	20	10	10
PAB	0	5	17	23	7	7	3	3	23	19	-1	15
ATP	0	5	17	23	11	11	11	11	32	32	12	34
Day	16	18	19	20	21	23	25	26	27	28	29	30
DF	16	15	16	16	16	16	16	16	16	16	16	16
MPS	16	15	15	17	16	0	12	20	16	16	16	16
CO	12	12	11	17	10	15	12	20	10	13	10	8
PAB	15	15	14	14	14	-6	-6	-6	-6	-6	-6	-6
ATP	44	47	51	51	57	42	42	42	48	51	57	65

1. Applied forecasting techniques to accurately forecast customer demand.
2. Applied operations research to minimize the cost of using resources when developing a production plan.
3. Used the forecast consumption method to adjust the production schedule.
4. Checked the feasibility and controlled the MPS through PAB and ATP.
5. Used the ATP model to promise orders efficiently to increase service level.
6. Established MRP that met the MPS.

TABLE 31 | BOM of SS1.

Level codes						Materials	Quantity	Units	Types
0	1	2	3	4	5				
0						SS1	1	P	M
	1					BB	1	R	P
		1				HA	1	R	P
			1			SS	1	P	M
				2		V2	1	P	M
					2	DD	1	P	M
						SBR	1	R	P
						DG3	1	P	M
						DB	1	P	M
						TL	1	R	P
						V1	1	P	M
						DG5	2	P	M
						VM	1	P	M
						VH3	1	R	P
						VL	1	R	P
						VH5	2	R	P
						VC	1	P	M

TABLE 32 | The ISR of manufacturing materials.

Materials	LC	Q	LT (d)	OH	SR	SS	AL
SS1	0	1	0	0	0	0	0
SS	1	1	0	0	0	0	0
V2	2	1	0	0	0	0	0
V1	3	1	0	0	0	0	0
VM	4	1	0	0	0	0	0
DD	2	5	0	0	0	0	0
DG3	3	5	0	0	0	0	0
DB	3	5	0	0	0	0	0
DG5	4	5	0	0	0	0	0
VC	5	20	0	0	0	0	0

TABLE 33 | The ISR of purchasing materials.

Materials	LC	Q	LT (d)	OH	SR	SS	AL
BR	2	1	7	50	0	0	0
VH3	2	1	7	50	0	0	0
TL	2	1	7	100	0	0	0
VL	2	1	7	50	0	0	0
VH5	2	1	7	25	125	0	0
BB	1	1	7	0	0	0	0
HA	1	1	7	0	0	0	0

TABLE 34 | The plan order release for manufacturing materials.

Day	2	4	5	6	7	8	9	11	12	13	14	15	
SS1	76	69	69	95	77	93	84	69	69	95	95	76	
SS	76	69	69	95	77	93	84	69	69	95	95	76	
V2	76	69	69	95	77	93	84	69	69	95	95	76	
V1	76	69	69	95	77	93	84	69	69	95	95	76	
VM	76	69	69	95	77	93	84	69	69	95	95	76	
DD	60	65	70	95	80	90	85	70	70	95	95	75	
DG3	30	65	70	95	80	90	85	70	70	95	95	75	
DB	30	65	70	95	80	90	85	70	70	95	95	75	
DG5	5	135	140	190	155	185	170	135	140	190	190	150	
VC	80	80	60	100	80	80	100	60	80	80	100	80	
Day	16	18	19	20	21	22	23	25	26	27	28	29	30
SS1	69	72	80	69	76	95	69	69	71	95	83	78	77
SS	69	72	80	69	76	95	69	69	71	95	83	78	77
V2	69	72	80	69	76	95	69	69	71	95	83	78	77
V1	69	72	80	69	76	95	69	69	71	95	83	78	77
VM	69	72	80	69	76	95	69	69	71	95	83	78	77
DD	70	70	80	70	75	95	70	70	70	95	80	80	75
DG3	70	70	80	70	75	95	70	70	70	95	80	80	75
DB	70	70	80	70	75	95	70	70	70	95	80	80	75
DG5	140	145	160	135	155	190	135	140	140	190	165	160	150
VC	60	80	80	60	80	100	60	80	60	100	80	80	80

TABLE 35 | The plan order release for purchasing materials.

Day	2	4	5	6	7	8	9	11	12	13	14	15	
BR	84	69	69	95	95	76	69	72	80	69	76	95	
VH3	84	69	69	95	95	76	69	72	80	69	76	95	
TL	84	69	69	95	95	76	69	72	80	69	76	95	
VL	84	69	69	95	95	76	69	72	80	69	76	95	
VH5	69	72	80	69	76	95	69	144	160	138	152	190	
BB	84	69	69	95	95	76	69	72	80	69	76	95	
HA	84	69	69	95	95	76	69	72	80	69	76	95	
Day	16	18	19	20	21	22	23	25	26	27	28	29	30
BR	69	69	71	95	83	78	77	0	0	0	0	0	0
VH3	69	69	71	95	83	78	77	0	0	0	0	0	0
TL	69	69	71	95	83	78	77	0	0	0	0	0	0
VL	69	69	71	95	83	78	77	0	0	0	0	0	0
VH5	138	138	142	190	166	156	154	0	0	0	0	0	0
BB	69	69	71	95	83	78	77	0	0	0	0	0	0
HA	69	69	71	95	83	78	77	0	0	0	0	0	0

However, the research still had some disadvantages. It was only studied and implemented on a product family and just stopped at the planning level. Operations research did not apply to capacity planning. The parameters of

the MPS module were chosen by experience. Furthermore, it had not been performed in a practical environment to evaluate the effectiveness of the system. The system would be complete with CRP and VRP. These restrictions lead to further research to improve the system and move towards the ERP system.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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