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An empirical study of Demand-Driven MRP

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Abstract. The Demand-Driven MRP (DDMRP) is a method for managing flows in manufacturing and distribution flows that is supposed to manage uncertainties better than traditional Manufacturing Resources Planning (MRP) using some of the principles of pull approaches. In this paper, a case-study is investigated in order to objectively and quantitatively compare these two systems. A Discrete-Event Simulation (DES) approach is used to evaluate the impacts on system behaviors regarding both management methods. Results show insights on the interests of DDMRP.

Keywords: Production control, JIT Manufacturing, DDMRP.

1 Introduction

Satisfying customers and making margins are companies' main purpose. In order to achieve these goals, they must find a compromise between various objectives; on time delivering, reducing lead-times and thus Work In Progress (WIP), reducing costs of goods sales. To manage physical or economical flows lots of methods are known. Manufacturing Resource Planning (MRPII) is the most widespread [1]. Pull flow policies (production depends on the real consumption, the real demand) are also famous.
Another recent and promising method is Demand-Driven Material Requirements Planning (DDMRP) [4]. "DDMRP is a multi-echelon demand and supply planning and execution methodology. " Its main originalities are in the strategic DDMRP buffer positioning, dimensioning and execution replenishment policies so that the different sources of variability (from supply, operational, demand and management) can be managed. Therefore, DDMRP is said to combine best practices of MRPII [1], Lean [5], Theory Of Constraints (TOC) [6], Distribution Resource Planning [7], 6 sigma [8] and with some innovations. There is no scientific comparison to objectively demonstrate the differences between managing flow with DDMRP or MRPII and other pulling methods such as Kanban [2] or ConWIP [3]. This paper focuses on the comparison of DDMRP with the classical MRPII, analysing scenarios on a famous academic case study. A literature review is used to identify DDMRP contributions that are discussed on the case study.

2 LITERATURE REVIEW

2.1 *Manufacturing Resource Planning (MRPII) versus* flow management policies

Manufacturing Resource Planning (MRPII) is the most widespread planning method in the world. It requires demand forecasts and plans all the manufacturing activities: it is a push flow method. MRPII is "a method for the effective planning of all resources of a manufacturing company. Ideally it addresses operational planning in units, financial planning in dollars, and has a simulation capability to answer what-if questions. It is made up of a variety of processes, each linked together: business planning, production planning (sales and operations planning), master production scheduling, Material Requirements Planning (MRP) [9], capacity requirements planning, and the execution support systems for capacity and material. […] Manufacturing Resource Planning is a direct outgrowth and extension of closed-loop MRP". The general market behavior has evolved in the last 30 years generating more instabilities of the demand, of the supplies and of internal processes. These variabilities result in creating

more difficulties to establish accurate forecasts, generating nervousness in Material Requirement Planning behavior what is a bullwhip effect source [11].
Pull methods aim at directly manage production from the real demand in order to reduce variability created by planning and decrease WIP in the process only with "what is needed". Kanban [2] is a just-in-time manufacturing process in which operators are informed of buffers consumption (usually throughout Kanban cards) and replenish their buffers according to inventory priorities and real time machines availability [12].
ConWIP is another pull flow management method developed in the Theory of Constraints [3]. This method constrains the level of WIP in a process [13].
Both push flow method (MRPII) or pull flow methods (such as Kanban and ConWIP) have their advantages, their lacks and hypothesis need to be set up.

2.2 Demand-Driven Materials Requirements Planning (DDMRP)

Demand-Driven Material Requirement Planning (DDMRP) is a "multi-echelon materials and inventory planning and execution solution." [4, 14]. It is implemented in 5 steps.
The first step deals with "Strategic Inventory Positioning". It evaluates from a financial point of view if there are benefits, to position or not a buffer on an article of a Bill Of Materials. Succeeding in positioning DDMRP buffers will help a lot to correctly implement the method. Then, the DDMRP principle is to pull replenishments between strategic buffers; but to deduce and push plan orders for unbuffered articles. Buffers are supposed to control the dispersion of variability (supply, operational, demand and management) in the manufacturing system.
As soon as the buffers are positioned it is possible to define the "buffer profiles and levels". A buffer is replenished according to its "Available Stock Equation" (ASE) that is the inventory position menus qualified spikes. Qualified spikes refer to huge demand orders whose production have to be anticipated of some production lead-time and thus made on demand. This available stock equation (ASE) is compared to 3 buffer alert levels: top of red (the safety stock), top of yellow (the mean in-process replenishment quantity) and top of green (the replenishment size). These zones will visually help to decide on buffer replenishments: anytime the ASE enters the yellow zone a replenishment order is put to reach the top of green level. In execution context, stock buffer is also decomposed in three zones (red, yellow and green), but different, so that orders can be prioritized and scheduled according to the alert.

In DDMRP, the design of buffer levels (for planning and execution) is made dynamically according to formulas (1). Average Daily Usage (ADU) is the result of a demand forecasting. Actively Synchronized Replenished Lead Time (ASRLT) is an original concept of DDMRP. It is the longest unprotected sequence (considering a sum of lead times) in the bill of material of a buffered article. As buffers are supposed to control variability, unprotected sequences are considered between buffered articles. As for MRPII, the choice of the lead time value remains a critical point of DDMRP.
Plan Adjustment Factors (PAF) are percentages used to raise or lower the ADU. They enable to model and smooth big seasonal variabilities, promotions, and can be considered as the result of a Rough Cut Capacity Planning. Variability factor is used to protect from uncertainty: it is a part of the red zone and represents the safety stock. Lead-time factor is different for long lead-time or short lead-time products: when the ASRLT is long the lead-time factor is small (in order to often produce long-lead time products with a small order quantity).

$$
\begin{aligned}
&\text{Green Zone} = \text{Max}(\text{Yellow Zone} . \text{Lead Time Factor}; \text{Lot Size})\\
&\text{Yellow Zone} = \text{ADU} . \text{ASRLT} . \text{PAF}\\
&\text{Red Zone} = \text{Yellow Zone} . \text{Lead Time Factor} . (1+\text{Variability Factor}) \qquad (1)\\
&\text{Top Of Red} = \text{Red Zone} ;\\
&\text{Top Of Yellow} = \text{Top Of Red} + \text{Yellow Zone}\\
&\text{Top Of Green} = \text{Top Of Yellow} + \text{Green Zone}.
\end{aligned}
$$

Finally, when DDMRP zones are defined, planners and operators can visually decide on quantity to replenish (plan view) and orders to prioritize (in execution view).

3 AN EMPIRICAL STUDY

3.1 Case Study

The dynamic adaptation properties of DDMRP are promising. Nevertheless, we still lack of some empirical or theoretical studies in order to validate them. In order to address this issue, we use Discrete-Event Simulation (DES) as a tool enabling to get predictive results, evaluate impact of parameter changes. Lanner Witness® is the DES software used here. In order to compare differences from each flow management policy, the management part (simulator) was separated from the operational part (emulator). The DES operational model (emulator part) will therefore be the same for various flow management policies evaluation. The simulator sends orders to the emulator.

Table 1: Products sold with respective BOM.

R1	Oil_pan_red	Gear_yellow	B_crown_white
R2	Oil_pan_red	Gear_yellow	B_crown_green
R3	Oil_pan_red	Gear_yellow	B_crown_red
R4	Oil_pan_red	Gear_white	B_crown_white
R5	Oil_pan_blue	Gear_white	B_crown_green
R6	Oil_pan_blue	Gear_white	B_crown_red
Spare parts	/	/	A_crown_white

Table 2: Machine input parameters

Machines	Oil pan machining	Gear machining	Crown machining phase A	Crown machining phase B	Assem-bling
Cycle Time (hr)	1	1	1	1	1
Lot size	100	100	200	200	100
Setting-up time (hr)	3	3	2	4	1
MTBF (hr)	NegExp(17.80)	NegExp(11.6)	NegExp(9.70)	NegExp(15.19)	NegExp(21.25)
MTTR (hr)	Triangle(1.1,2.2,4.4)	Triangle(0.86,1.73,3.46	Triangle(0.48,0.96,1.92)	Triangle(0.4,0.8,1.6)	Triangle(0.8,1.6,3.2)

Table 3: Article input parameters.

Parts	R1	R2	R3	R4	R5	R6	A crown white	Yellow gear
Initial state	500	100	100	600	200	100	1000	700
Forecasts	700	75	550	900	400	350	1100	
Variations	100	75	150	150	200	150	400	
Production costs (€)	100	100	100	100	100	100	9	25
Selling price (€)	150	150	150	150	150	150	30	

Table 4: sequencing for one week

Oil Pan Making		Gear making		Crown A Make		Crown B make		Assembly	
Part	Qty	Part	Qty	Part	Qty	Part	Qty	Part	Qty
blue	600	white	1100	red	600	red	800	R3	600
red	2500	yellow	1500	green	800	green	800	R2	100
blue	400	white	900	red	600	white	1800	R5	400
				white	3200	red	400	R4	1000
								R1	700
								R6	500

Table 5: The 6 weeks stable demand orders

Week	Period	R1	R2	R3	R4	R5	R6	A crown white
1	1	200		100	200			
	2	100		200	300			500
	3				100	200	100	500
	4	200	100	100	200	100		
	5	200		100	200	100	200	400
2	6	100		200	400			
	7	200		200	400	100		
	8				100	200	200	400
	9	100		200		100	100	
	10	200		100	200	100	200	400
3	11	100	100	200	300			600
	12	200	100	100	400			
	13				100	200	200	400
	14	100		200		100		
	15	200			200	100	100	400
4	16	200		100	200			
	17	100		200	300			500
	18				100	200	100	500
	19	200	100	100	200	100		
	20	200		100	200	100	200	400
5	21	100		200	400			
	22	200		200	400	100		
	23				100	200	200	400
	24	100		200		100	100	
	25	200		100	200	100	200	400
6	26	100	100	200	300			600
	27	200	100	100	400			
	28				100	200	200	400
	29	100		200		100		
	30	200			200	100	100	400

Table 6: Seasonal PAF factors

PAF /month	R1	R2	R3	R4	R5	R6	A White
1	100%	100%	100%	100%	100%	100%	100%
2	110%	80%	75%	120%	80%	90%	80%
3	120%	60%	50%	140%	80%	110%	60%
4	90%	100%	100%	100%	70%	130%	120%
5	100%	140%	125%	80%	120%	80%	160%
6	90%	120%	150%	60%	150%	90%	80%
7	100%	100%	100%	100%	100%	100%	100%
8	110%	80%	75%	120%	80%	90%	80%
9	120%	60%	50%	140%	80%	110%	60%
10	90%	100%	100%	100%	70%	130%	120%
11	100%	140%	125%	80%	120%	80%	160%
12	90%	120%	150%	60%	150%	90%	80%

The case study comes from the “Centre International de la Pédagogie d’Entreprise“ (CIPE) Kanban serious game [16]. This case study has been used to teach numerous professional and students the differences between MRP and Kanban. The case study deals with a company that produces reducers composed of three parts: one oil pan, one gear and one crown. Each of these components needs one machining step except for crowns which need two (A crown and then B crown). An oil pan can be red or blue, a gear white or yellow and a crown white, green or red. 6 different reducers and one spare part (A crown white) are sold (table 1). Products are made to stock. Demand occurs every morning.

The 5 machines (table 2) have a cycle time of 1 hour each. The production lot size is 100 parts in 1 hour except for both crowns making steps with 200 parts per hour. Mean-Time Between Failure (MTBF) is modeled with a negative exponential distribution law and Mean-Time To Repair with a triangle distribution law. There are also fixed set-up times per machine for each change of article. Depending on failures and demand, the bottleneck can move from Assembly, to Oil Pan or Gear machines.
For the 16 references (6 reducers, 2 oil pans, 2 gears and 6 crowns), an initial state (initial on-hand inventory), forecasts and variations of these forecasts (for a week) must be managed. Production costs enable to evaluate the working capital in the simulation model [17]. Selling prices are also given and enable to evaluate the gross sales. This input data is given in table 3 for 8 of the 16 parts (only the yellow gear is not sold).
Table 3 gives forecast data for one week with a hypothesis of a stable demand trend over the weeks. 6 weeks of demand orders are given (table 4). Undelivered articles are delivered as soon as possible.

In the case study, the system has enough capacity (in theory) but has a consequent general load. The goal is first to deliver customers on time and then to minimise the WIP amount (and therefore the Working Capital [WC]). With MRPII, a choice must be made to define an amount of reducers to produce (Sales and Operations Planning). At the Master Production Scheduling level the production is divided into the 6 reducers by keeping a total amount of 3,000 reducers. Then the Material Requirement Planning can compute for each reference the production orders. A final step is realised each week to get the sequencing. Table 5 shows the final sequencing for one week (it will be repeated all along the simulations, but the orders quantity depend on the MRP computation).
As regards DDMRP, with all the input data the “Strategic inventory positioning“ can be done. All the components have to be buffered except some of the ACrown (Green and red). For each product, ASRLT is computed considering the number of cycles, of setups it is possible to do in a week, but also, so that the weekly load remains under the weekly capacity. The variability factors will be adjusted considering various sources of uncertainty.
From an execution point of view, when there are two orders to sequence, the priority is given to the reference with the lowest percentage of its stock compared to the Red plus Green buffer zone (mean stock). Therefore, the production sequence can dynamically change in DDMRP.

3.4 Experiment Plan

Comparing DDMRP when MRPII, the bibliography (§2.3) enables to formulate the following hypothesis:
(H1) DDMRP have better performances when considering external or seasonal variabilities,
(H2) DDMRP counteracts, more than MRP, the variabilities within the management of buffers,
(H3) DDMRP reduces risks on spike demand using an anticipation mechanism in the ASE calculation,
(H4) DDMRP maintains the buffers in less risky zones.
In order to test these hypotheses, two scenarios have been implemented as defined in Table 7.
For each scenario the simulation protocol is the following:

- Each simulation repeats 8 cycles of 6 weeks of demand. The simulation horizon is thus of 48 weeks. Each scenario is replicated 5 times.
- The first 4 cycles (24 weeks) were necessary as warm up in order to stabilize the system. So, only the last 24 weeks are considered for the assessment of any scenario.
- The management policy (MRP or DDMRP) is adjusted so that the system has at least 99,3% of on-time delivery (OTD) and minimise the working capital (WC = cost of {WIP + stocks}). This assessment of WC using a DES is based on a methodology proposed in [17].

- In order to assess hypothesis H2 to H4, The stability of inventories and the nervousness of the supplies are analysed.

This protocol aims at approximating the behaviour of a decision maker that tries to reach a desired operating point: low working capital but high on-time delivery rate. This operating point induces that the bottleneck is saturated. So, the system is very sensible to small changes of parameters that can make the system under-capacited and diverge in term of backorders.

Sc#	Scenario	Parameters	Sc#	Scenario	Parameters
Sc0	Basic	Stable weekly demand			
Sc1	Sc0 with Seasonal + Spike Demand	Each product has a seasonal demand profile (PAF) but so that total load per month is stable. Spike = 8*forecasted demand	Sc2	Sc1 + demand visibility	Demand is known 1 week before (assembly Lead time)

Table 7: Simulation scenarios

3.4 Experiment Results

Table 9 exposes the assessment of the simulation for each scenario considering both MRP and DDMRP management policies. Two performance indicators are measured: On time delivery (OTD) and Working Capital (WC). WC is presented in % of the WC for the reference scenario (WC for Sc0 with the MRP policy is base 100).

It can be seen that the objective OTD can be satisfied in nearly all the situations (except Sc1 for DDMRP). But, DDMRP requires less Working Capital what means less WIP and stocks: in general 10% less. Moreover, analysing at the policy adjustment, DDMRP appears to be impressively stable when facing variabilities: the same adjustment satisfies all the scenarios while safety stocks need to be adapted for MRPII: this validates hypothesis H1.
Compared to Sc1, Sc2 considers that demand can be known 1 week before. The impact for MRPII, is that the MRP calculus can be done considering real demand for the first week and forecasts for the rest of the planning horizon. The consequence is that products are assembled on order and safety stocks are reduced.
In DDMRP, the consequence is that spike demand orders are considered in the computation of the "Available Stock Equation" (ASE) 1 week before their real demand and thus generate replenishment orders anticipated of 1 week (the assembly lead time). Consequently, only the spike demand orders are assembled on demand. In Sc1, we could not take advantage of this process for reducing some of the DDMRP parameters. Therefore the only effect was a small increase of final inventories.
Now, it can be noticed that in Sc1, DDMRP does not succeed in satisfying the objective OTD. Analysing at this specific simulation, it appears that some of the spike demand orders happen at moments of high seasonal demand. In such cases, one demand order can exceed the TopOfGreen Level (see equation (1)) what means that the shop cannot have enough final inventory to serve the demand. This does not happen for DDMRP in Sc2, because the spike demand is anticipated. Consequently, hypothesis H3 can be validated: the spike anticipation is useful for huge demand orders that cannot be replenished with a pull mechanism. Such orders require to be made on demand or, at least, forecasted.

	MRPII			**DDMRP**		
Sc#	**OTD%**	**WC %**	**Policy adjustments**	**OTD%**	**WC %**	**Policy adjustments**
Sc1	99.8	139	Safety Stock = 3500	98.8	117	LT Factor Green= 80%. variability Factor = 50% , Lot Size = 200
Sc2	99.3	137	Safety Stock = 2900	99.3	119	LT Factor Green = 80%, Variability factor = 50%

Table 8: Simulation scenarios assessment: On Time Delivery (OTD) and Working Capital (WC)

	MRPII					DDMRP					Real
Sc#	**R**	**Gear**	**Oil Pan**	**B crown**	**A crown**	**R**	**Gear**	**Oil Pan**	**B crown**	**A crown**	**Demand**
Sc1	35.4%	43.9%	33.4%	36.6%	35.4%	53.4%	37.2%	26.8%	52.2%	40.2%	45.0%
Sc2	34.4%	39.8%	29.1%	42.2%	43.5%	59.2%	42.3%	32.6%	58.5%	52.3%	45.0%

Table 9: standard deviations of the replenishment size for each part expressed in percent of the seasonal forecast

In order to answer to hypothesis H2, it is necessary to compare the variabilities of the replenishment for each part but without considering the seasonal variability. For each part, we therefore expressed the weekly replenishment orders in percent of what is required for answering seasonal requirements (table 2). Table 10 gives for each part the standard deviation of these 'percentaged' replenishment orders. The higher the standard deviation the higher is the variability around the forecast. In can be seen that MRPII and DDMRP both induce variabilities that are less or equivalent to that of the demand: there is no bullwhip effect in both cases. Nevertheless, variabilities are higher in DDMRP (20% more in table 10). H2 cannot thus be validated
The stock level of reducers (finished products) and components were read twice a day during a simulation. Figure 2 plots the distribution probability of the stock level for MRPII and DDMRP in scenario Sc2. Similar plots were obtained in other scenarios. It can be seen that for MRPII the distribution is quite flat: the probability is high to have over stocks at some moments and lack of stocks at other moments. Nevertheless, the distribution is not bimodal as suggested by [4]. On the contrary in DDMRP, the plot is much more centered: the stock more rarely enters the dangerous extreme zones. Consequently hypothesis H4 can be validated.

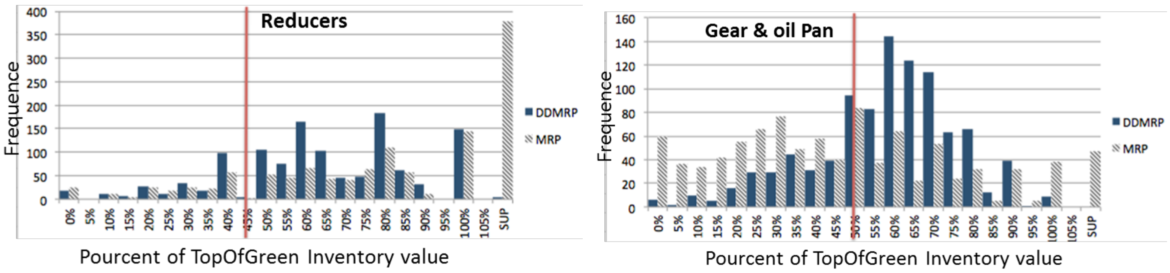

Fig. 1: Frequency of some stock level for Sc2

3 CONCLUSION

This paper developed a comparative study of Demand Driven MRP to the classical MRPII on a use case using Discrete Event Simulation. Several sources of external variabilities have been combined: spike demand and seasonality of demand. Nevertheless, DDMRP appears to dominate MRPII in all the scenarios as it enables to reach the same level of On Time Deliveries with less working capital (10% less in general). If DDMRP does not generate some bullwhip effect, it appears to generate more variability of the replenishment orders that MRP.
Such results show that DDMRP develops properties that are recognized to pull flow management policies. But they were obtained while demand was not stable at all. Indeed, DDMRP continuously adapts the buffer level to the demand trend changes but appeared to be sensible to huge unforecasted demand. Nevertheless, a spike management process is proposed in DDMRP that proves to be efficient if huge demand can be anticipated. Therefore, DDMRP appears to be pull oriented for normal demand and push oriented for spikes.
Two kinds of perspective appear as evidence. The first consists in testing DDMRP in other environment in particular some industrial complex situation with a huge product variety and important variabilities. The second consists in comparing DDMRP to pull flow management policies such as some adaptations of Kanban and ConWIP systems and potentially mix DDMRP with them.

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