Study of buffer placement impacts on Demand Driven MRP performance

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Abstract: Trying to answer industrial challenges regarding production planning and control, Ptak and Smith propose a new method called Demand Driven MRP. Their basis is to cope with variability instead of facing it. Amongst the different key points of the method, buffer location choice is not clearly defined. We aim to investigate its impact on the industrial performance. This study will rely on a design of experiments led with a discrete event simulator. It includes an in vitro case study with 7 different buffers placements and three types of variability (customer, supplier and process) with 3 levels each. The results show that the choice concerning buffer placement can affect the performance up to 15 point of OTD and 100% of Working capital. They also demonstrate that there is no buffer placement that would allow dealing with all types of variability and levels. Buffer placements policy has to be adapted to variability context to reach a high level of performance.

Keywords: Industrial production system, Discrete event system, buffers, decoupling points, performances

1. INTRODUCTION

Industrial production planning and control becomes harder and harder to manage as the economic environment is more and more tumultuous. The acronym VUCA for Volatile, Uncertain, Complex and Ambiguous is often used to define this new context like the new geopolitical conditions after the cold war. It also signs that traditional tools and strategies can be less effective than before because of those deep changes. This is what Ptak and Smith (2011) consider when they make the analogy into the industrial world. They emphasize that traditional tools, such as MRP2 created in the mid 70's by Orlicky (1975), cannot be effective into the new competitive world while variability is too high. They think that variability causes disruptions into the planning systems and can lead to counterproductive decisions such as safety stock, safety lead times for example (Ptak and Smith, 2017). Those protections can worsen the situation because they disturb the real demand signal that leads to complicate planning decision process.

This is why Ptak and Smith created their new theory called Demand Driven MRP (DDMRP) to answer those new constraints. They wanted to simplify production and planning control. Amongst other tools, they namely use stock buffers allowing decoupling points within the bill of materials. Decoupling points are supposed to dampen variability effects. If some heuristics are given to decide buffer locations, they are not really detailed in the method and Miclo (2016) showed that it can vary from one expert to another facing the same case. The present study aims to evaluate buffer location impact on the system performances by using a design of experiment led with a discrete event software.

We will first explain the key points of DDMRP and buffers location challenges, then the research process with design of experiments and the study case, then the results and finally conclusion and perspectives.

2. DDMRP AN ORIGINAL APPROACH

Ptak and Smith want to simplify the planning and production control, so they have been developing their concept since 10 years. We will first explain the theory, then its reported results, and then the buffer location challenge.

2.1 Demand Driven Adaptive Enterprise basics

Ptak and Smith' theory is still evolving and DDMRP is now considered as the first step of a whole system called Demand Driven Adaptive Enterprise (DDAE) (Ptak and Smith, 2018). Its first step, DDMRP, uses inventory buffers strategically placed and managed through a new method. Then Demand Driven Operating Model integrates the use of capacity and time buffers in addition to control points. Next, the authors recommend using a Demand Driven Sales and Operations Planning (DDS&Op) as a *tactical reconciliation* step and finally an Adaptive S&Op as a strategic layer. All details can be found in the dedicated literature (Ptak and Smith, 2011, 2016, 2017, 2018).

The present study only focuses on DDMRP as most firms experienced this first step. Bayard et al. (2020) showed that out of 60 industrial cases studied between November 2018 and November 2019 only 3 companies were above DDMRP i.e. inventory buffers. Experts' and users interviews, done during this period, also highlighted expectations concerning DDMRP set up especially upon buffer locations choice.

2.2 DDMRP tools

DDMRP cannot be sum up as only the use of strategically placed buffers. It includes different others innovations and tools.

First, buffers sizing is totally renewed. Instead of having only a whole buffer it is now divided into 3 coloured zones: the red one is the safety, the yellow one the average consumption during the average lead time and the green zone that represents the art of the ordering system.

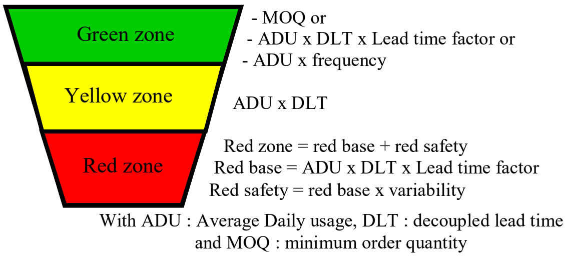

Fig. 1. Buffer zone calculations and purposes"(Ptak and Smith, 2017)

Those zones are exploited to determine whether or not the planner has to refill the buffer. The DDMRP system will calculate the Net Flow Equation (NFE) and positions it into the buffer zones. The NFE is determined by the following formula

NFE = On-hand + on-order- qualified actual order demand
With:

- on-hand: stock physically available,

- **the on-order**: total quantity that has been ordered but not received

-**qualified actual order demand**: sales orders past due + sales orders due today + qualified spikes. Qualified spikes are "cumulative daily demand within a qualifying time window that threatens the integrity of the buffer" (Ptak and Smith, 2018b). This last point is subject to adaptation.

An order is triggered only if the NFE is situated into the yellow or the red zone. The order quantity, to supply or to make, is determined by the difference between the NFE and the top of the green zone, the maximum quantity in the buffer. Once the order is launched, DDMRP also determines its relative priority by indicating a ratio between the NFE and the top the zone. All orders are displayed with this same indicator allowing quick decision making concerning production planning and control.

The innovation is to consider only real orders in the NFE calculation, the parameters are dynamically adjusted and the priority indicators simplify decision making in the planning process.

2.3 DDMRP results

Interesting results have been shown both on the academic and on the industrial worlds.

Table 1 below shows the good results with industrial sector risen by the study of Hudelmaier et al (2019) concerning 3 main Key Performance Indicators (KPI) and published on the official website of Demand Driven Institute.

Table 1 : DDMRP results in Industrial Manufacturing (Hudelmaier et al., 2019)

	Median	Best In Class
Service Level increase	+17pts	+45pts
Lead Time Reduction	-60%	-85%
Inventory Reduction	-26%	-54%

Those industrial results were partially confirmed by the benchmark led by Bayard et al (2020).

2.4 Decoupling points and buffers

One central concept of DDMRP is the decoupling point created while buffering an item.

Decoupling points is defined by the APICS as "the locations in the product structure or distribution network where inventory is placed to create independence among processes or entities".

Decoupling point is not a new idea and its history can be traced back to the concept of order penetration point (OPP) defined by Sharman (1984). Different other authors work on this concept and especially on its optimal positioning (Hoekstra et al., 1992; Olhager, 2003). Yet in those studies, the decoupling point was considered as the point where the production flow shifted from pushed to pull thanks to the customer order arrival. The choice of its location relies on the customer tolerance lead-time.

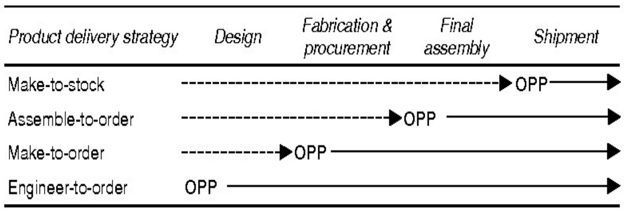

Fig. 2. The customer decoupling point (Olhager, 2003)

DDMRP is a method relying on a multiple decoupling points system. From the first definition of a unique OPP, the concept of decoupling points has evolved into multiple decoupling points. This notion was first evocated by Swaminathan and Tayur (1998) and was adopted in supply chains context since beginning of 2000's. The target is to create the independence into the process or supply chains. If the unique decoupling point positioning rely on the customer tolerance lead-time, multiple decoupling points location become more challenging.

Therefore, before discussing the buffer locations methods, it is interesting to evaluate its influence on performance facing variability. To achieve this goal, we will develop a research methodology.

3. RESEARCH METHOLOGY

3.1 Research framework

Our research framework is widely customizable and so adaptable to most industrial cases. Indeed, it has been developed to support different design of experiments concerning production planning and execution. It is able to represent different industrial contexts without remodelling it even with major changes such as number of references and their parameters, bill of materials, resources, suppliers, planning methods and their parameters (MRP2 or DDMRP), process flow structure (job shop, flowshop)… All changes are made in the input date not on the model structure itself.

Our model is based upon different elements: (1) a data table, (2) a demand table, (3) a design of experiments parameters table, (4) a planning process simulator, (5) a discrete event software, and (6) a results' spreadsheet. They are all interconnected to allow an automatic run of the design of experiments. It can be represented in the figure 4.

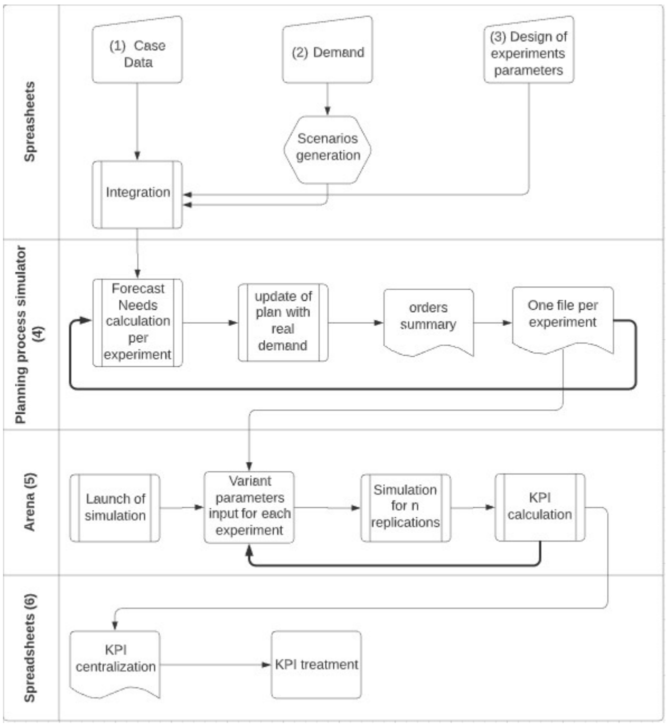

Fig. 4. Research framework

The data table includes in a defined format all information needed to run the simulation. This includes item data, resources data, schedules, times, bill of materials… It can be compared to a company items database.

The design of experiments table includes the parameters that can be updated during the experiment. Information is then transferred into the planning process simulator which will generate production and supply orders for each reference considering their own parameters and the conditions of the experiment and for the length of the simulation. A spreadsheet is generated for each experiment.

The discrete event simulator based on Arena automatically launches the whole design of experiments. It plays the different experiments reading the files. Arena is only the player, no decision is taken in this stage except delaying orders in case of shortage. It calculates a set of pre-determined KPI and exports them to the results spreadsheet. After centralization, results can be treated as needed for each design of experiments. The model was validated by following classical steps recommended by Sargent (2010).

3.2 Performance measurement

To evaluate the global performance of the planning process, 2 types of performances are evaluated through 2 KPIs:

- Customer performance through the On Time Delivery (OTD) in percentage (1). It has to be maximized.
- The financial performance: with the total Working Capital (WC) (2). It has to be minimized.

4. DESIGN OF EXPERIMENT

To be able to evaluate impact of buffer location on production and planning system performance, we developed a design experiments led on an in vitro case. We will first present the case, then the design of experiments and finally the results.

4.1 The case study

The case we chose is the item FPB of the ABC Company developed in Ptak and Smith (Ptak and Smith, 2019). This item is simple, parameters are known and buffer location is discussed by the authors. Figure 4 represents the bill of materials of item FPB.

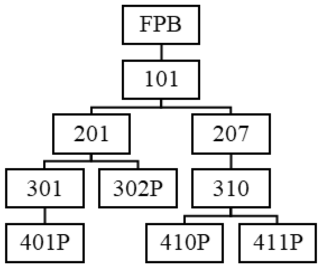

Fig. 3. Bill of material of item FPB

The example originally offers 3 final products but our goal is to get a clear understanding of buffer placement effect without considering multiple cases of usage of an item. This why only one final product is considered. We choose FPB amongst the others because its average usage is 100 pieces per week. This figure allows a quick analysis of results highlighting links between demand changes and items behaviour. To simplify the analysis, we also choose to set all bill of material links at 1 unit opposite to some coefficients 3 used in the original case. We want to avoid some leveraging phenomenon due to multiple links in the BOM.

Other parameters such as lead times and unit costs come from the authors. As the original example is limited to planning operations, we had to create manufacturing data respecting industrial reality and fitting given lead times. We calculated process lead times allowing an 80% loading rate based on the average weekly consumption and planning lead times. This calculation highlighted the need for multiple resources for all manufactured items except FPB. We assume to use a dedicated set of resources and a single step per manufactured item to avoid prioritization issues. Therefore, the industrial organization can be assimilated to a job shop. We also consider the added value of the production process. We use a cost of 70€ per working hour which is an average given for traditional mechanical industry in France. Main parameters are summed up in table 2.

Table 2 Main Items Data

Item	Lead Time (weeks)	Unit Cost	Unit operation time (hours)	Nb of Resource
FPB	1	500	0,3	1
101	3	500	0,9	2
207	3	290	0,9	3
310	2	290	0,6	3
411P	30	200		
410P	30	90		
201	5	210	1,6	5
301	4	110	1,2	4
401P	10	110		
302P	12	100		

4.2 The design of experiments

Based on this in vitro case, the design of experiments was conducted to evaluate the impact of buffer location upon global performances in different variability contexts as shown in figure 5.

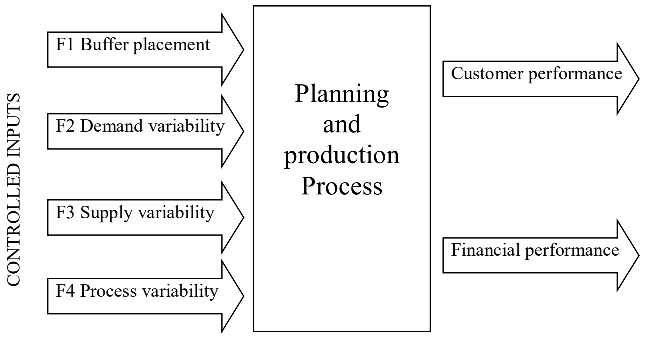

Fig. 5. Design of experiments scheme

The buffer placement factor (F1) embeds 7 values : based on 3 main policies and all their combinations: final product (F), made items (M) in this case items 201 and 207 to synchronize the flow after the buffers- and purchased items (P). Table 3 sums up the buffer positions for each value of F1 value.

Table 3 Buffer position for each F1 value

Factor 1 Value	1	2	3	4	5	6	7
Buffer placement policy	F	M	P	FM	FP	MP	FMP
FPB	B			B	B		B
101							
207		B		B		B	B
310							
411P			B		B	B	B
410P			B		B	B	B
201		B		B		B	B
301							
401P			B		B	B	B
302P			B		B	B	B

Buffer sizing is made as recommended by Ptak and Smith and we assume to choose the maximum calculation result for the green zone as recommended. Upon this assumption, the validation step of the model showed that the size of the generated orders does not fit with the industrial organization. Namely, for an average demand of 100 FPB per week, we have less but larger orders. This led to seize a resource for a much longer lead-time than expected and generated multiple shortages. In real industrial world, planners would take decisions to adjust the production organization. Therefore, we decided to create transfer orders allowing to dispatch job orders between available resources of the set dedicated to the item. This phenomenon highlighted the need for an additional task of scheduling while the green zone sizing generates orders much larger than the average demand.

Variability is considered through 3 angles: demand side, supply side and process side. For all of them we define 3 levels from low (1) to high (3) of variability defined by uniform low to apply to the average demand for the demand, to the lead time for the supplier variability and to the process time for the process. We apply the following laws to the different levels of variability level 1, UNIF(0.95,1.05), level 2 UNIF (0.85,1.15) and level3 UNIF(0.5,1.5). A global variability level is calculated by aggregating the 3 levels of the 3 variability factors therefore this global variability indicator can vary from 3 to 9. Due to the combination of factors and levels, the design of experiments embeds 189 experiments. For each of them, 50 replications of 78 weeks were run.

4.3 Results

Our goal is to evaluate if buffer placement can affect global performance under different variability types and levels. Confidence intervals are globally good. For the OTD, 67% of them are equal or under 5% with a maximum at 15% concerning low results. Even with the upper bound, there is no overlapping of intervals in the same set of parameters. For the Working Capital, only 16% of them are over 5% with a maximum of 14%. Consequently, we can use average to analyse results.

We will first study the average results of each buffer placement choice over the whole design of experiments. We will consider in this synthesis the KPI OTD in percentage and the working capital(WC) basis 100 the overall average WC represented by the green point . As shown in the figure 6, there is no ideal solution.

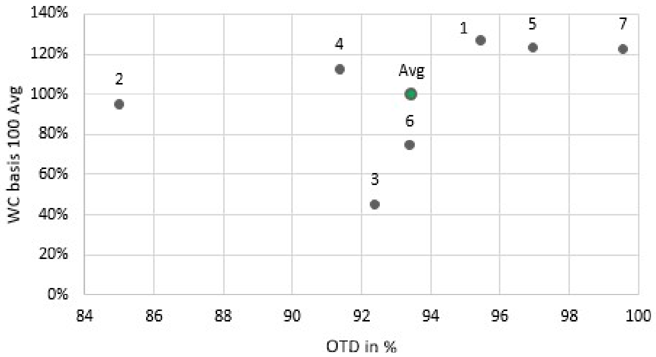

Fig. 6. OTD vs WC synthesis

We can see that the **most effective regarding OTD is the buffer placement 7 (policy FMP) that involves the 3 types of buffers. The average OTD reaches 99.5% with a confidence interval under 5% at its maximum level. However, this good performance is reached with an average WC 20% over the average performance**. Two other buffer placement choices presenting the same profile (high OTD – high WC) are the 1 (F) and the 5 (FP). They both involve a buffer on the final product explaining a high working capital. The less performant choice is the number 2 with buffer only on the sub-assembly level. The OTD is poor with a WC next to the average. Therefore, this option would be to be unsuitable in the industrial world. The choices numbers 3 (P), 4 (FM) and 6 (MP) are closed regarding the OTD, next to 92%. But number 3 and 6 (with no buffer on the final product) seem to be better as they present a lower WC than solution 4 which includes buffer on FPB. They can be good trade-off for companies who do not target 100% OTD.

Those results are the ones given on average whatever the level of variability. If we consider the level of global variability, results can be refined. As shown in table 4, the global variability indicator consists of the sum of the level (1 for low, 2 for medium or 3 for high) of the 3 types of variability (customer, supplier and process).

Table 4 Global performance through level of variability

F1	Policy	KPI	Global Variability Index						
			3	**4**	**5**	**6**	**7**	**8**	**9**
1	**F**	OTD	95,4	95,8	95,7	95,6	95,4	94,9	94,4
		WC	126	126	126	127	127	127	128
2	**M**	OTD	75,1	83,4	85,0	86,8	85,8	85,0	81,8
		WC	98	96	96	95	95	95	95
3	**P**	OTD	98,2	98,7	96,5	92,7	89,4	84,9	81,1
		WC	49	47	46	45	44	43	44
4	**FM**	OTD	74,4	82,9	87,1	92,6	95,7	99,7	99,6
		WC	115	114	113	112	112	112	112
5	**FP**	OTD	98,7	99,2	97,9	97,7	96,1	94,5	89,7
		WC	108	105	114	120	132	141	161
6	**MP**	OTD	100	100	97,4	93,9	90	85,4	83,8
		WC	81	78	76	74	73	72	72
7	**FMP**	OTD	98,1	99,3	99,5	99,7	99,7	99,7	99,7
		WC	191	157	140	118	106	89	89
		OTD	**91,4**	**94,2**	**94,2**	**94,1**	**93,2**	**92,0**	**90,0**
		WC	**110**	**103**	**102**	**99**	**98**	**97**	**100**

In the case of low global variability (Index 3 or 4), the best option is probably the choice 6 (MP) with an OTD at 100 and an improvement of the WC next to 20% compared to average. Buffering at all levels such as in choice 7 (buffer at all levels) leads to a large increase of the working capital without reaching a perfect OTD. Buffering only the final product seems to be unsuitable in this case with a large increase of the WC with a lower OTD. At the opposite with the high variability index (7 to 9), the choice 7 offers the best trade-off with the best OTD and WC under the average. In the medium situation (5 and 6), the choice is harder as no option combines very high OTD and low working capital.

In our case with DDMRP, in a context of **low variability**, it is not necessary to buffer too many items. It also shows that **buffering the final product is not the good answer**. Nevertheless, it seems that **the higher the variability is, the better the choice 7 (FMP) is. Multiplying buffers allows to diminish buffers size, therefore the WC and improves the OTD**. Choice 3 (P) offers the best WC but never the best OTD. It appears as not a very recommendable solution.

The first results were given for a global variability index. We can also analyse results per type of variability considering the two other variability types as low.

Concerning customer variability, it appears that the best solution varies with the increasing variability. With low variability, the best solution is buffer placement 6 (MP) with a 100% OTD and a WC -19 points. For level 2 and 3 of the variability, concerning the OTD (100%) is the choice 7 with buffers at all levels and a WC -11points. Nevertheless, this solution is not suitable with a low variability because it leads to a +91% increase of the WC. Surprisingly, we notice that **buffering only the final product is never the best solution with a lower OTD and a higher WC**.

If we consider **supplier variability**, the **best choice regarding the OTD is also policy number 6 (MP) with buffers on purchased items and sub-assemblies**. This allows a 100% OTD and a 19% of the WC **whatever the degree of variability.** The worst solution is the number 4 with buffer on the final product and on sub-assemblies (OTD

74.4 and WC +15pts). Buffering only on final product is much more effective concerning the OTD (95.4 %) with a higher increase of the working capital (+26 points). Finally, **buffering only purchased items (3) can be a good alternative with a 98.3 OTD and a working capital divided by 2**.

Regarding **process variability**, the situation is not clear as there **no dominating solution**. If the variability is **low**, then policy **6 (MP) is the best solution** with a decrease of the working capital (- 19points) but results are deteriorated for a high level of variability (95.9 OTD). For the **higher level** of variability, this is **no real ideal solution**. Buffers on all levels (solution 7) gives a good OTD (99.3%) but doubles the working capital. It can be suitable for a company that can afford it. Otherwise, a good trade-off is to buffer the final product and the purchased items (5).

It appears that there is **no ideal buffer placement that would allow combining good OTD and low working capital in all variability types and levels.**

5. CONCLUSION AND PERSPECTIVES

DDMRP is a relatively new method generating interest of the industrial world. The first academic results and industrials testimonies globally confirm announced results. However, research and experts also showed a need for deeper investigation especially on parameters fine tuning.

Buffer placement is one of the elements that is not really documented. If the rules exist, it is not easy to choose and experts do not always agree on the same case. The purpose of this research was to evaluate if buffer placement has an impact or not on DDMRP performances. We use a design of experiments based on Arena and multiple variability contexts.

Results show that there is not an absolute best solution. Amongst overall results, **buffer placement at all levels (Final product sub assembly and purchased items) seems to reach the best average OTD with 99.5% but with a greatly high working capital.** However, detailed results per level of global variability demonstrated that this solution is not the best one in case of low variability context. In the same vein, if we focus on a single type of variability, results are more balanced and different **trade-off can be considered**. Nevertheless, in our case, **buffering only the final product or only the sub-assemblies seems be ineffective in all tested variability types and levels**. With our assumptions, choosing the wrong buffer placement can lead to a loss of performance of almost 15 points regarding OTD and 100% regarding the WC.

Therefore, we can conclude that buffer placement seems to have an impact on global performance. Those results have to be confirmed through other design of experiments embedding various bills of materials, more or less complex. We also consider that the long lead times used in this case can impact results. Further studies with different lead times could be led to extend them. We also highlighted that, in our case, the orders size generated by DDMRP requires an additional stage of collocating work orders in the short term scheduling. This observation has to be investigated to validate if it can be extended to all DDMRP situations.

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