International Journal of Industrial Engineering, 16(4), 293-304, 2009.

PACEMAKER, BOTTLENECK AND ORDER DECOUPLING POINT IN LEAN PRODUCTION SYSTEMS

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The purpose of this article as follows: The first is to clarify the theories underlying the definition of three concepts- Pacemaker, Bottleneck and Order Decoupling Point– in the field of production systems design, planning and control; the second is to demonstrate the existing interrelations between the three concepts; and third, to set out guidelines that will make identifying and defining these concepts easier, when attempting to design or redesign a system using a lean production approach. It is hoped that this paper will fill a gap in the literature by relating these three concepts from different points of view, as well as offer practical guidelines to academics or professionals involved in the design, or redesign, of a production system

Keeping this in mind, the findings portrayed in this publication have been organized into the following sections. First the article describes the literature review process that led to acceptable theoretical descriptions for each of the three concepts. Then, from a conceptual point of view and depending on production strategy – Made-To-Order (MTO) or Made-To-Stock (MTS) –a set of considerations, in different practical situations are made establishing the relationships between each of the concepts. At the same time this document provides some procedural guidelines to help identify the three concepts. Then a practical case of production system redesign is proposed, in which aspects and methods described in this article are used. Finally, conclusions are drawn at the end.

Keywords: Pacemaker Process, Bottleneck Process, Order Decoupling Point, Lean Production, Production System Design, Planning And Control.

(Received: 19 December 2008; Accepted in revised form: 9 July 2009)

1. INTRODUCTION

In today's demanding marketplace, manufacturing firms need to redefine and redesign their production systems in order to maintain competitiveness (Dangayach and Deshmukh, 2001; European Commission, 2004; Modarress et al., 2005; Segerstedt, 1999; Singh et al., 2006 Yusuf and Adeleye, 2002). The professionals in charge of conducting such projects should be properly prepared and trained in order to get the maximum benefit from the process of situation analysis and future production system design (Hunt et al., 2004). Lean production is one of the approaches that could help firms to attain this goal. This management philosophy is founded on the minimization of all resources used in company activities. It identifies and eliminates every activity that does not add value for the customer from the design of production and supply chain management related processes (Marchwinski and Shook, 2003; Rother and Shook, 1998; Womack and Jones, 1996).

One of the most prominent decisions in the definition of a manufacturing system is the identification and the definition of the key points or processes. The performance of the manufacturing system will be conditioned by the choice of production strategy, Made-To-Order (MTO) or Made-To-Stock (MTS), which in turn will be determined by the definition of the Order Decoupling Point (ODP), that is to say, the starting point from which products will be elaborated in a MTO way (Gutierrez and Crispin, 2005). With regard to this concept, and depending on which approach is the priority, it is possible to improve the planning and performance of the production system. Redesigning the production system on the basis of pure lean production precepts will require establishing only one point, called the Pacemaker (PM) process, to which scheduling will adhere. On the other hand, according to criteria based on the Theory of Constraints (TOC) (Goldratt and Cox, 1992) one of the most important points to consider is the Bottleneck (BN) or the point that defines the limitation of the production system.

These three concepts, ODP, PM and BN are determined by different approaches and a significant gap in the literature concerning the relationships between them has been detected. Indeed, based on the author's review and experience in implementing lean techniques in factory environments, a lack of adequate fit between the different approaches was found, because each one highlights its own particular concept. Nevertheless, in our work, practitioners want to find ways to combine the concepts in order to find the best way to solve their specific problem.

Nave (2002) attempts a comparison but it is neither focused on production planning nor on how to apply and combine the concepts in the same production system. In Production Strategy, the bedrock of production system performance, the ODP is found; in the Theory of Constraints, the production planning is based on the BN concept, while in lean production, the focus is on PM. Here lies the originality of this contribution, because instead of separate variations of the same problem, these concepts are integrated into one solution. This gap has also been mentioned by Serrano et al. (2006) in a case study in which six manufacturing companies tried to redesign their production system according to lean production precepts; however, none of the teams responsible for the redesign had clear criteria with which to establish the concepts.

2. PURPOSE

The three objectives of this article are to define the three concepts mentioned above, Order Decoupling Point (ODP), Pacemaker (PM) and Bottleneck (BN), as well as analyze the interrelationships between them and to provide practical guidelines for their implementation.

The structure of the article reflects these objectives. Firstly, there is a synthesis of the literature review to give a clear and agreed definition about each one of the three concepts; secondly, the relationships among the three concepts are defined on a theoretical level using two teaching examples: one related to a "pure" MTS environment and the other to a "non-pure" MTS environment where part of the process is working on an MTO basis. Thirdly, in order to meet the third objective, the stages to follow when identifying and establishing the three key concepts are presented. Finally, a real industrial application where the guidelines have been successfully applied is described.

In short, the aim is to go a step beyond existing theory in a way that is useful for both practitioners and academics.

3. LITERATURE REVIEW

Based on a review of the academic literature, the definitions of ODP, the PM process and BN are shown below:

3.1 Order Decoupling Point (ODP)

The ODP is a key concept in redesigning a production system, although this term is also known as interface, decision point, order penetration point or customer ODP by other authors, it is in agreement that it is the point at which the system crosses the boundary between MTS – Made-To-Stock – and MTO – Made-To-Order (Hines and Rich, 1997; Hopp and Spearman, 2000; Shingo, 1989). From this point forward, the product will be tied to a specific order and the period of time from order launch to ODP until customer delivery is known as the order lead time or delivery time (Hopp and Spearman, 2000; Olhager, 2003). Even though this definition means that the orders of the different customers will be entered as they arrive, it must be pointed out that the orders can be re-scheduled or added to before the ODP is reached (Christopher and Towill, 2000). Furthermore, it must be emphasized that this research analyzes the ODP and its relationship to the PM and the BN only at the production operations level, although there also exists literature within the field of supply chain logistics (Hines and Rich, 1997; Hoekstra and Romme, 1992).

Establishing the ODP is a strategic decision that involves finding the equilibrium between the level of service the company wishes to provide to the market and the manufacturing efficiency and inventory investment that the company can afford (Mather, 1999; Van Hoek, 2001). What needs to be identified, specifically, are market, product and production factors that affect the ODP positioning, due to demand volume and volatility as well as the relationship between delivery and production lead times. Likewise, it must be taken into account that the company or supply chain may establish different ODPs for each product family and that the location of each one may also change in time depending on the strategy to be followed (Olhager, 2003). Finally, it is important to point out that these authors, including Hopp et al. (2002), highlight the existing confusion in the literature about ODP when identifying the productive process for MTO with Push systems and the MTS with Pull systems.

3.2 Pacemaker process (PM)

As mentioned in the introduction, according to lean production philosophy, the PM process should be the only scheduling point in the production system. In fact, it is the process that dictates the production rhythm for the rest of the system, with such a pace being based on supermarket pull systems further upstream from this point, as well as First In First Out (FIFO) systems further downstream (Marchwinski and Shook, 2003; Rother and Shook, 1998; Steve, 2006). It is important to note that a system such as this, based on a single scheduling point, demands high production flexibility.

There is no precise formula for the selection of this point. With catalogue products, serial production and differentiation at the end of the production process, that is T or AT structures that could work in an Assembly To Order (ATO) way (Hines and Rich, 1997), locating the PM at the end of the manufacturing system, indeed, near the customer at the end of the value stream, often in a final assembly cell, is good practice (Rother and Shook, 1998). If the PM is situated on a final assembly cell or line, this rhythm is relatively easy to track because the line should produce finished products at the rate of the *takt time* (defined here as the customer demand rate used to synchronise production to sales). Although this time is easy to follow in downstream processes, in upstream production cells and shared processes, the takt time can be harder to gauge (Marchwinski and Shook, 2003; Smalley, 2004).

On the other hand, in MTO manufacturing systems that work with long takt times (for example companies that construct special equipment) it is recommended that the PM should be located in the first process, right next to the ODP; so the schedule is triggered in portions of work at fixed intervals proportional to the takt time. It must also be considered that this schedule ought to be based on the maximum BN capacity (Rother, 2004).

Different criteria, may tie the position of the PM to the cost associated with maintaining stock throughout the production system. This argument will be used in the example in the following section which shows the relationships as well as the rationale for choosing the PM in MTS environments.

3.3 Bottleneck (BN)

According to Cox and Spencer (1998), and also Chen and Lee (1998), every manufacturing system has its own BN, which is defined as the most loaded resource or work centre of the production system; such BN limits the overall system's production throughput (Rother and Fox, 1986).

In cases where the production system has been designed from first principles, there is the chance to determine the BN, which is usually the most expensive resource (Koppel, 2000).

According to the Theory of Constraints (TOC), the BN is the process that should set the production rhythm. This philosophy advocates the idea of DBR (Drum - Buffer - Rope) to ensure the maximum throughput from the manufacturing system. The drum is the master schedule that sets the beat based on the bottleneck output. The buffer refers to the inventory created in front of the bottleneck station to ensure its uninterrupted operation, and the rope is a pace-setter mechanism that releases orders to match the capacity of the bottleneck. (Hyer and Wemmerlöv, 2001)

The TOC approach is aimed more at functional (job shop) production environments with a focus on system limitations (Cox and Spencer, 1998). Lean production however, does not pay too much attention to BNs in the system, as it seeks the balance of all processes in relation to the takt time, and focuses on the elimination of waste and improving flow (Hines and Rich, 1997).

Experience, however, has shown that despite attempting to introduce lean flows, many systems continue to have an imbalance between different production centers, which makes it worth considering the integration of TOC concepts with lean criteria (Serrano et al., 2006). In any event where lean flows are to be introduced in environments with an obvious BN, the BN and PM process do not have to coincide, as will be shown later. Here, suffice to say that in the cases where the PM matches the BN, the scheduling of this point could be the aforementioned Drum of the system, whenever such a program is defined to exploit the constraint capacities. Yet, if this program is designed so that the correct synchronized mix and volume levelling responds to the takt time imposed by the market; this point should not be considered as the system's Drum.

Nevertheless, despite the references presented above, there is still a significant gap in the literature to show the relationship between these three points. This led the authors to present their own perspective on how these key concepts connect.

4. FINDINGS BASED ON RELATIONSHIPS

Using an example based on a simple production system with three linear manufacturing processes, the relationship between the ODP, PM and the BN is analyzed and explored. Two cases are described: a pure MTS system and an intermediate MTS system.

Companies that work with a pure MTO system (for example, builders of special equipment) have the ODP located further upstream in the production system process. However, companies with a pure MTS system (for example, serial manufacturers of mass consumption goods, such as food, electronics, and home appliances) have their ODP located further downstream.

Establishing this point also sheds light on the chosen manufacturing strategy in terms of MTS and MTO operations. Therefore, upstream from the ODP the objective of the production system should be productivity, whereas downstream it should look for flexibility and a quick response to the client. Based on this strategy differential, some authors consider that upstream the approach must be based on lean production, whereas downstream the prevailing paradigm should be agile production (Christopher and Towill, 2000; Naylor et al., 1999). However, leading authors also state that lean production includes the ability to be flexible enough for constant adjustments to the market (Womack and Jones, 1996).

It should also be pointed out that, in those cases where management wants to adopt different market policies for different kinds of product in the same production system, different ODP and PM points can be selected, although this has not been considered here in order to keep the examples as simple as possible.

4.1 Pure MTS system

In Figures 1, 2 and 3 below, it should be understood – given that we are dealing with a pure MTS system – that the ODP is located in the finished product warehouse. Furthermore, it has been decided that the BN or physical constraint is located in the second process (initialled BN in the figures), although it could be located in another position depending on the system type.

In this example, the varying impact that the location of the PM can have on each of the three processes is shown. As discussed above, one of the most important criteria will be the amount of stock needed to support the system, the stock being necessary to maintain production independence between two processes. The amount of stock is represented in the figures by the size of the supermarket icon. It is logical that the average amount of stock located in supermarkets is greater than the amount of stock to be found in FIFO lanes because a supermarket must have the entire product mix. However, it can also be seen in the figures that such stock quantities contrast with the warehouse restocking system response time for the finished product.

Three possible outcomes have been presented. In the first (see Figure 1), the PM coincides with the process nearest to the ODP. As shown, the amount of stock in the finished products' warehouse is slightly less than in Figures 2 or 3. This is due to the fact that the response time from the PM to the finished product warehouse is almost zero. The decision to position the ODP here, however, requires a pull system to the supermarkets upstream. These supermarkets will need to be provided with all the mix needed for the pull. Figure 1 would therefore be more appropriate for AT or T structures (Hines and Rich, 1997), where real product differentiation only happens in the last process. It could be argued that for such cases, a more adequate strategic decision would be to locate the ODP downstream. On the other hand, it should be considered that the program to launch the PM must take into account the maximum work load that the BN can tackle, which would mean checking the supply commands for the finished product warehouse with the BN limitation before specifying the PM.

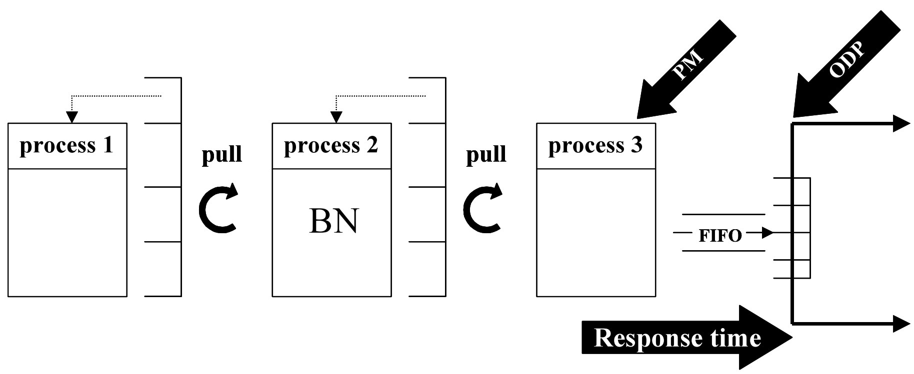

Figure 1. PM located in the last process.

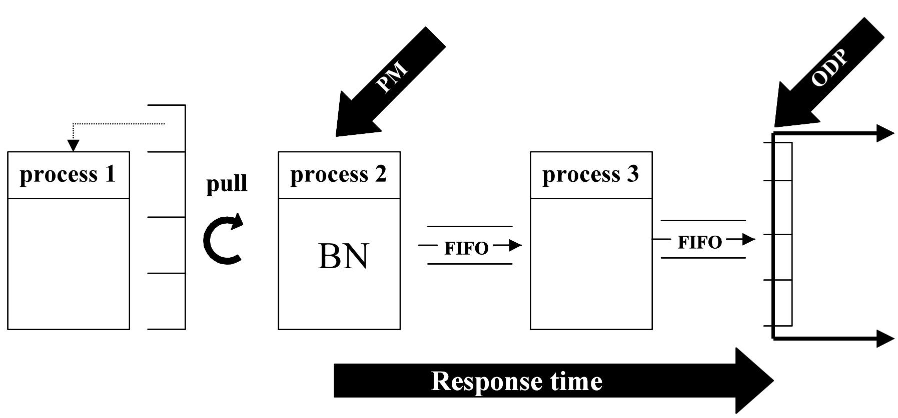

Figure 2. PM located on the BN process

In Figure 2, the PM has been placed in the next process upstream, the second one, which coincides with the BN. In this example, the need for finished product stock increases, because the response time from the PM to this point also goes up. However, as mentioned previously, the stock in process decreases because the supermarkets are replaced by FIFO lines. As with the first placement, two advantages result: first, the complexity of managing the production is minimized, because it is easier to work on products which arrive in a FIFO sequence than managing Kanban signals from downstream processes. Second, the PM coincides with the BN, meaning there is an accurate monitoring of the production limits. It should therefore be simpler to translate the commands for supplying the finished product warehouse to the PM schedule, taking into account that the same process limits the system's productive capacity.

Finally, Figure 3 shows the case in which the PM is located in the first process. Here less stock in process is needed, but there is a bigger need for finished product due to the increase in the response time. The internal management of the plant is simpler because of the FIFO lines. The disadvantage is the difficulty in translating the supply commands to upstream processes in certain types of production systems, such as AT or T. It is also difficult to get a sense of the takt time, in cases where these are manufacturing processes with big batches. Furthermore, this schedule must also take into account the BN production limitation, which may disrupt the scheduling process.

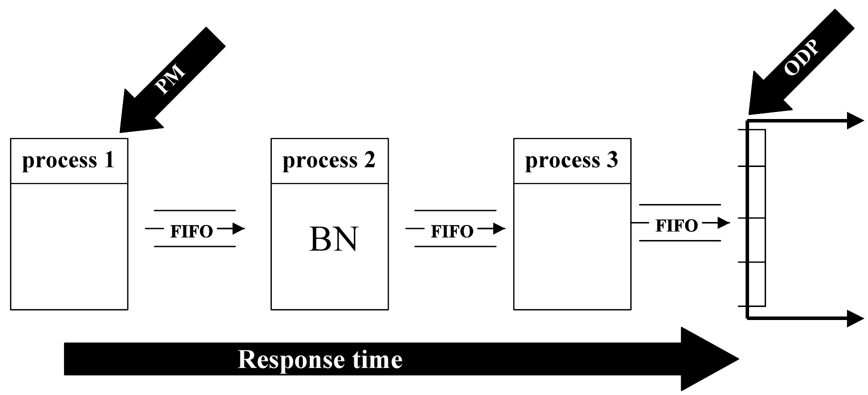

Figure 3. PM located on the first process.

In conclusion, the further upstream the PM is located, the less requirement for stock in process and the greater the requirement for finished product. Production self regulation for the remaining processes is also simpler, although the internalization of the takt time is probably harder to achieve. Another key factor is that it is easier to transmit the limitation of the BN to the PM schedule. Therefore, the choice of PM in this pure MTS case will be based according to two factors:

1. The simplicity of production mix and volume levelling for each process, as it is easy to translate the commands for supplying the finished product warehouse according to two criteria:
   - Typology of the production system, V, A, AT, T.
   - Location of the BN.
2. The calculation of the total amount of stock required for material in process and finished product. The decision in this case will be taken in favour of the minimum level of stock required to meet the level of market service that will be defined by the inventory level.

4.2 Intermediate MTS system, closer to MTO

As mentioned above, locating the ODP further upstream, with part of the process based on customer orders, is a strategic decision related to market, production and product typology. In Figure 4, the ODP has been located between the first and the second process; therefore the client must expect longer delivery times than in the previous examples (Figures 1, 2 and 3) – for which the term response time was used – but with the benefit of a reduction or elimination of stock of the finished product.

If a complete lean system is required, only a single system point needs to be scheduled. It seems logical, therefore, to place the PM right next to the ODP. Thereby a single program is launched – based on customer orders – at the second process. Upstream from the second process, production is triggered by supermarket pull systems; downstream, it is driven by FIFO lanes until shipment to the customer.

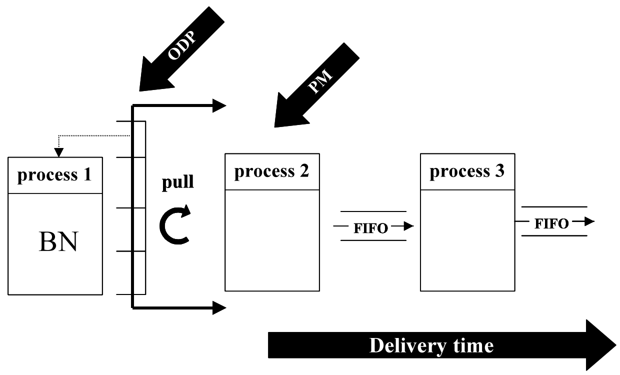

Figure 4. If the ODP is located between the first and the second process, the PM must be located on the second.

As shown, the BN is located in the second process, so the PM scheduling must be adjusted to the limitation imposed by the BN itself.

As for the relationship between the BN and the ODP, Olhager (2003) states that, from a perspective in which the BN must be saturated, it would be good practice to locate the ODP downstream from the BN. However, if the objective of the BN is to manufacture products with signed orders, it would be better to locate the ODP upstream from the BN. The need to add and arrange customer orders in sequence so the constraint will be correctly exploited must also be emphasized; in this case it is probable that the PM schedule would not match completely the sequence of received orders.

Table 1. A summary of the relationships between BN, PM and ODP.

Elements	**Relationship**	
	Pure MTS system	**Intermediate MTS system nearer to MTO**
PM-BN	It is good practice to locate the PM in the BN as it would then control production rhythm. Otherwise, the PM has to take into account the BN limitations.	The PM is already prearranged. If it coincides with the BN, management is easier.
PM-ODP	The PM does not depend on the ODP.	The PM depends on the ODP.
BN-ODP	These are usually independent of each other, although in some cases the ODP is viewed as dependant on the BN (Hopp and Spearman, 2000).	

Table 2. Practical guidelines for specifying the location of BN, PM and ODP.

STEP 1: ODP - The ODP should be located as a function of the market strategy as defined by company management. This is the strategic decision based on Enterprise strategy. The fixed location of the BN can also affect such a decision.	
STEP 2: BN - The BN should be defined by the restrictions of the production system. However, in some design cases, the location of this point can be prearranged depending on the amount of investment. Once the constraint is identified it must be remembered that a lost minute in the constraint is a lost minute for the whole system or company, so an appropriate scheduling system is essential.	
STEP 3: PM - If the system is designed according to lean principles, the PM shall be the single point at which the production program is downloaded. It is time to assume the pure MTS strategy or not.	
3.1	In an MTS environment, the PM decision should be based on criteria such as the ease of adequate mix levelling for the process (not forgetting where the BN is) and the optimum level of stock to be kept in the system for a given level of service.
3.2	In a non-pure MTS system where the ODP is located upstream, it is necessary to launch the program at the following process, so the PM will be predetermined. Then, the scheduling process will also take into account the BN capacity, no matter where it is located.

The BN could also be located anywhere in the two remaining processes as it would not affect the position of the PM. Once the decision has been made to place the ODP between the first and second process, and in order to be more like an MTO strategy, the PM scheduling process needs to take into account the mix and volume that the BN can tackle, because in this case it would no longer be located in the PM.

Table 1 summarizes the relationships among the three elements, ODP, BN and PM, and Table 2 gives some practical guidelines for defining and locating them.

5. INDUSTRY APPLICATIONS

This section presents a case where an industrial production system was redesigned according to lean production precepts, in which the above guidelines for choosing the location ODP, PM and BN were applied.

AKL is an SME in the furniture sector, situated in the Basque Country in northern Spain, with about 100 employees. In particular, it manufactures furniture kits, i.e. unassembled furniture sold in flat packs, for major distribution companies.

The product line within this project specifically involves shelving, a product with two side pieces and a variable number of shelves. The products differ from one another when it comes to particular aspects such as the width of the shelves and sidepieces, the number of shelves, the length of the sidepieces and the finish and surface colours. In all, AKL's catalogue includes four hundred and ninety-two different types of shelves. The demand at the time was for 160,000 units per year with an upward trend both in sales and the number of variations.

The production system consists of two parts separated by a Minimum Stock Level of unfinished product. In the first subsystem, supplied with wooden planks, milling operations are performed to make each shelf and side piece. In the second subsystem, surface finishing and painting operations are carried out. With unfinished stock between the subsystems, there is a better capacity for greater product differentiation and this also guarantees the response time of the second subsystem, which operates, in turn, with a minimum stock of finished product. Such a pure MTS system is necessary given the delivery deadline demands made by the distribution companies. In any case, the production system redesign project described in this section corresponds exclusively to the first subsystem, starting with planks as raw material and ending with the unfinished product.

5.1 Analysis of the initial situation

The first stage of the improvement project was to study the initial situation. AKL's production system was not able to adapt to the increasingly demanding market trends because of its background and the characteristics of the sector (Hunter, 2006).

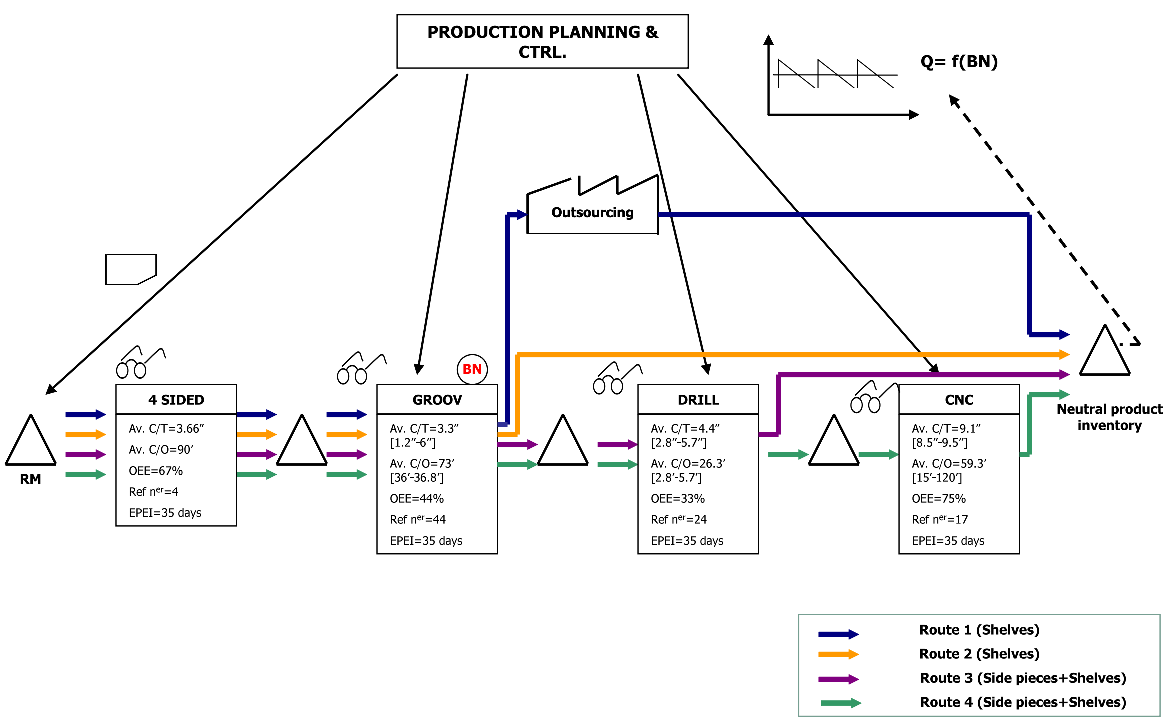

Figure 5. Initial map of subsystem 1 from raw material to unfinished product.

Figure 5 shows the main features of the flow of materials and information at a door-to door level in the selected subsystem. It must be mentioned that this figure is a simplified map of the enormous data capture and processing work carried out to make an initial diagnosis. The main points are highlighted below.

Annual demand for shelves amounted to 160,000 units. This demand was divided and multiplied into different types of shelves and side pieces, set apart in subfamilies depending on the physical route they follow from raw material to unfinished product. This first demand, which triggers production, comes from the demand for resupply at the unfinished products warehouse.

The different subfamilies of shelves and side pieces share the same production processes. At the same time, there are a remarkable number of different production routes depending on the type of component involved. If the data from the process are analyzed, the adjusted time cycles, the efficiency of the machinery and the volumes of product passing through each process, there is quite clearly a BN in the grooving machine. On the other hand, the efficiency and reliability of most of the production processes is rather low. Together with the number of different routes and references, this makes stock accumulate significantly.

As previously mentioned, it is an order point system from the unfinished product warehouse that triggers production upstream. This replenishment method is by no means systemized; it is based on the production manager who checks the state of the warehouse approximately twice a week to see what replenishment is needed and, subsequently, on the basis of the state of stock, programs each work center for each day, always taking into account the minimum number of manufacturing lots the BN can operate with. It is a completely manual process without any computer support; everything is based on the professionalism and experience of the production manager.

The most important indication of the state of the production system is the period of development from raw material to unfinished product. This is forty-one days on average for a work content of about five minutes for each shelf. The main reason this period is so long is, as mentioned before, the low reliability of the production process, the size of the manufacturing lots and the number of routes and references operating in each work center.

An improvement in the production system should definitely have a bearing on reducing this development period and the need for so much stock.

5.2 Future Situation Design

After an in-depth analysis and following lean production guidelines, the future map outlined in Figure 6 was drawn up.

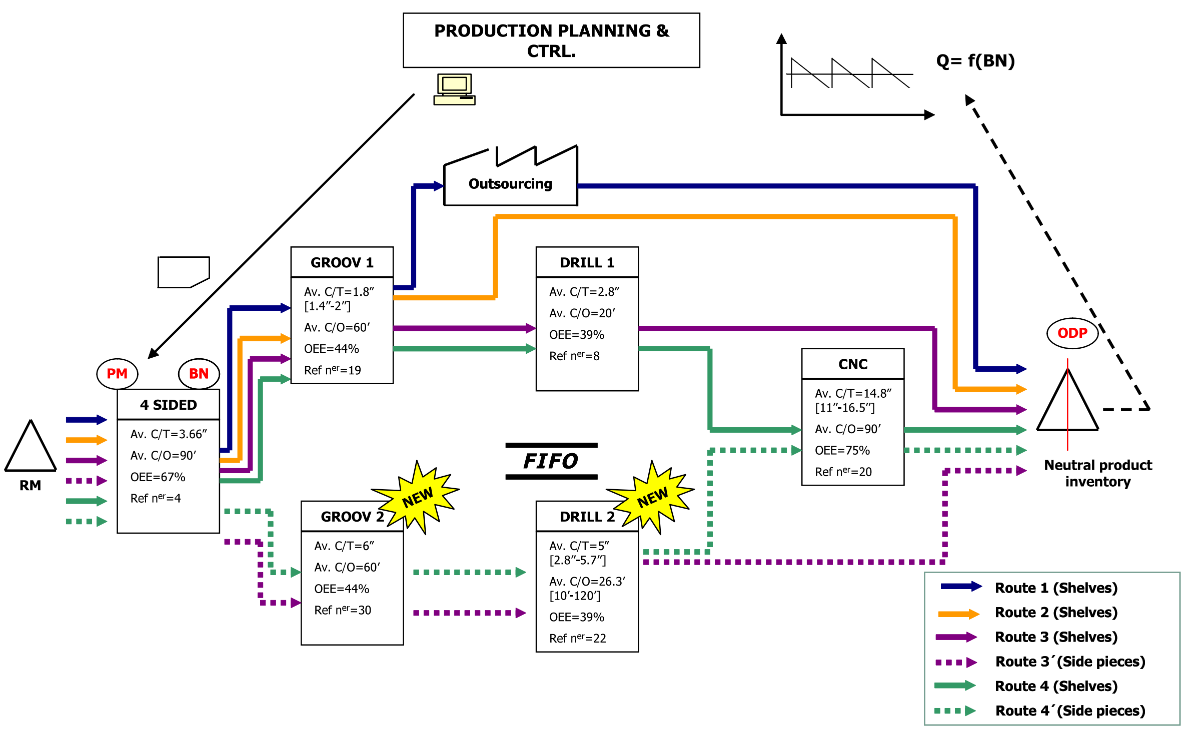

Figure 6. Future map of subsystem 1 from raw material to unfinished product.

The main improvements are two-fold: First, the purchase of new machinery needed to replace the old equipment and relieve bottlenecks; and second, a reorganization of material flows and routes, taking into account the duplication of certain production processes. After the first process, the component in question will continue on its way downstream via the FIFO lines, depending on which component, shelf or side piece it is. On each product line, the production operators will direct the components for each product subfamily towards the appropriate center depending on the labelling on each package.

The purchase of a new drilling machine and a new grooving machine allows one line of machines to be assigned to shelf manufacturing and the other to the manufacture of side pieces. In fact, a load capacity analysis shows that the assignment of each product type (shelf or side piece) to each of the lines is justified, thereby simplifying routes. Given the problem of inefficient production processes, buffers, in the form of FIFO lines, were introduced, but always with a maximum limited quantity (if this maximum amount is exceeded, the previous process must stop). These FIFO lines should tend to become less important as they improve the efficiency of each production center.

The new BN will be located in the so-called “four-sided” machine. This is a logical decision, given that this is the machine which provides the greatest added value and needs the greatest investment.

Thus, with this new map of the system, a new model of production planning and programming is needed. It is precisely at this point where the guidelines defined in this article for identifying the ODP, BN and PM of a new system are applied (see Table 2).

In the first place, the definition of the ODP will depend on the business strategy. It was clear that the ODP should be located in the unfinished product warehouse, at the end of the subsystem, as it was before redesign, because it is the point from which the finishing and painting operations introduce considerable product differentiation. Placing the ODP here guarantees the second subsystem’s response time with a minimum level of stock, so that it operates, in turn, with the minimum finished product stock.

Secondly, the PM needs to be identified. In this case, it was placed at the new BN, i.e., the “four-sided” machine. There were two reasons for doing this. It adjusts the PM to the BN rhythm so that both the programming of minimum lots and the manufacturing sequence are direct and simple. Thus there is minimum level of stock to guarantee that the PM is located in the first process and therefore avoid working with supermarkets that contain all the possible ranges of processed products.

The production *mix* is launched to the PM will be based on the minimum lot to be processed by the same center (BN). Hence, the authors also decided to implement a computerized system for replenishing the unfinished product warehouse per order point.

5.3 Results obtained

Two aspects of the results of this project are highlighted First, the performance of the redesigned production system and second, the results of using the procedural guidelines defined in this article in the section describing the design process of the future system.

Two years after starting the project in 2006, the redesign of the production system has led to a substantial reduction in lead time (from forty-one to thirty days), a simplification in production management and a significant reduction in unfinished product stock (25%). Furthermore, the definition of dedicated centers and FIFO lines has set in motion a dynamic of continuous improvement, resulting in increased efficiency in each work center. Indeed, although certain lean production precepts could help further, the organization has made an important qualitative leap, both in results obtained and in its culture of continuous improvement.

As for the guidelines for the process of defining the target situation, the management team has evaluated very positively the use of these simple procedural guidelines, which have served to clarify the theoretical concepts of PM, BN and ODP that had caused a certain amount of confusion among the management team in charge of the new design. The guidelines have also served to accelerate the process of identifying the three points, and also to generate confidence in the decision-making process.

6. CONCLUSIONS

In the area of Operations Management, much of the proposed theory does not easily transfer into practice. On the one hand, many of the theoretical concepts presented by the various schools of thought cannot be implemented without making a number of adaptations to fit the real world. On the other hand, many theories which are not afforded much significance in the research domain actually present real value in practice.

The objective of this article has been to analyze the existing theories relating to key points in the planning and programming of the production function and the real problems that present themselves at the point of system definition and design as a whole. System definition and design deeply affects the performance of management and, by extension, the production function.

In conclusion, the starting point of the article was the identification of the existing gaps in the theory linking three concepts. As a matter of fact, the ODP, developed primarily by the supply chain management community, is not in general use in operational decisions at the dock to dock level, although it is a relevant concept. Besides, the lean thinking defines only the PM as the key scheduling point at the dock to dock level, the same community, when looking for balancing the production flow do not consider relevant enough the BN concept. However, the authors strongly believe that in many real cases there is an internal limitation that should also be considered in the production planning process.

This article has explained the theory and interrelation among the three key points mentioned, ODP, BN and PM, as well as provide decision guidelines when designing or redesigning production systems with a lean approach. In addition, it has provided a description of how these guidelines have been applied in a real industrial case. Given the present state of research and practice and the problems noted here, it is believed this to be a deeper analysis. The perceived gap has been addressed in the scientific literature and, while much work remains, it is hoped to have provided a platform for future research and practical implementation.

There is no doubt that practical implementation in different manufacturing frameworks should be one of the bases for developing and enriching these theories, as these practical aspects form the bedrock of these approaches. The authors believe the idea that real world experience or case studies must be the key input for validating, enriching and standardizing the theory. Moreover, computer aided modelling and simulation of manufacturing system performance is another interesting way to achieve the objective of creating a standard overall theory as long as these projects and exercises are contrasted and compared in the practical field as much as possible. This kind of programs allow the chance to design numerous manufacturing systems of many different types and test them based on different scheduling rules, in the framework determined by the three concepts. In addition, making simulations in each scenario should achieve very useful satisfactory solutions in real environments, regarding scheduling key points. The risk and investments are minimal due to the fact they are based on virtual engineering although they will not be optimal.

With regard to the specific directions of future research, the main aim must be based on developing a corpus of theory that would integrate the contributions mentioned in this article. Standardized definitions may be necessary, as well as a framework for each scheduling concept. Furthermore, the interrelation among these concepts should also be clearly defined when designing, or redesigning, different manufacturing systems, whatever approach used. It may also be interesting to extend the theory to the whole supply chain as natural evolution. The authors, however, say that this should only be tested once these ideas are correctly implemented at the dock-to-dock level.

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