Production Flow Between Workstations Using the Kanban and DBR Methods – Comparative Study

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Abstract. Enterprises are constantly looking for methods and tools that will make them more efficient and competitive. The choice of good practice should be consistent with the individual goal of the enterprise. There is no one golden mean, as the dynamics and predictability of enterprises differ. It is very important to be consistent with the changes introduced, to keeping priorities and to be motivated to maintain them. The aim of the study is to present a comparison of two methods of organizing the production flow between workplaces, considering the management concepts under which methods were developed. This comparison includes the Kanban method (from Lean Manufacturing) used in the analyzed enterprise against using the Drum-Buffer-Rope method (from Theory of Constraints) instead of Kanban. The study presents, among other things, the similarities and differences between the methods in this comparative study. In addition, the scientific article contains proposals for further simulation studies of the application of the DBR versus Kanban method.

Keywords: Lean Manufacturing · Theory of Constraints · Kanban · Drum-Buffer-Rope · Case study

1 Introduction

Lean Manufacturing is one of the common, most frequently used method of production management in an enterprise. According to the definition, a Lean company builds its process management in such a way that the customer ordering a specific product only pays for its production, and not for the functioning of the enterprise [1]. Lean creates a work culture within the organization that makes all partners of the organization interested in striving for continuous improvement. Aimed at the elimination of waste, understood as: overproduction, waiting, inappropriate methods of production, unnecessary transport, unnecessary stocks, shortages, unused human potential. The main evil in system productions is waste [2]. The liquidation of losses increases the added value of activities carried out within the organization. Theory of Constraints (TOC) formulated in the 1970s by Eliyahu Goldratt, according to which an organization is as good as its weakest link. The most important concept of TOC is system constraints. Constraints can be physical in the form of resources, described as "bottle-necks", defined as a set of rules,

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measures, or premises of the value of the basis on which the policy of the enterprise is developed. The bottleneck determines the theoretical production capacity, or the highest quality maximum production delivered to the market [3]. The bottleneck determines a system's output [4]. The idea behind TOC is concept that there is always one constraint, that hinders the throughput of any process. Depending on the flow, complexity of the production, that may be more than one resource limiting system performance (however, their number is always very small). Increasing the efficiency of the system will be possible when the weakest link is identified.

The aim of the article is to compare two methods of organizing the production flow between workplaces, the Kanban method, and the Drum-Buffer-Rope (DBR) method, considering the management concept under which these methods were developed. The most important, but not the only research question is the assessment of the effects when the Kanban system is replaced by the DBR method in a selected manufacturing enterprise.

The study contains introduces and presents theoretical issues related to Kanban and DBR methods. In addition, it contains information about the research tools used. The article uses a case study in an enterprise, and the purpose of the analysis was to identify bottlenecks in the process and to compare the application of the Kanban and DBR methods. Which was presented in the following chapters of this study, along with the similarities and differences between the analyzed methods, and conclusions.

2 Kanban Method

The Lean method uses several dozen complementary tools and techniques that simplify the production process, positively affecting the effectiveness of the entire enterprise [5]. One of the methods is Kanban, which belongs to pull systems, that is based on production to order not to the warehouse.

Figure 1 shows the overall material flow diagram for Kanban method.

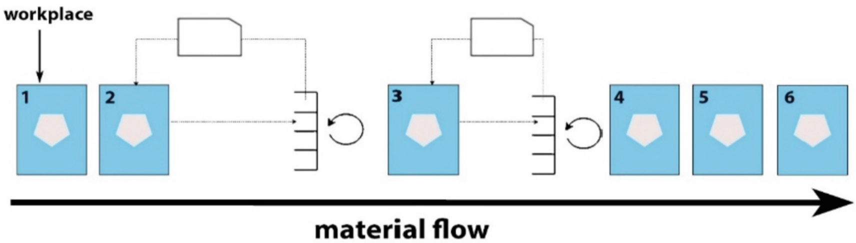

Fig. 1. General material flow diagram – Kanban. Source: own study.

Kanban consists in synchronizing the need to replace or supplement the materials necessary for production. It allows to integrate the material flow with the workplace for all workstations, reducing the amount of work-in-progress by using visual signals. In other words, it is about placing a work order or request for the delivery of a specific resource (raw, material, component, product, information) in a specific place, time, and quantity. Information can be sent in many ways. The simplest case is a signal that the product needs to be supplemented by the process, for example arrival of an empty container at a previous processing workstation. Another case is a card placed next to the goods during the production process, used to track current resources. Kanban can be used for a production order – it will allow to determine whether the production is ahead or late with the implementation of the schedule.

3 Drum-Buffer-Rope Method

Theory of Constraints focuses on the elimination or appropriate management of the constraints that occur in the flow. Goldratt proposes to remove or manage bottle-necks by using Drum-Buffer-Rope (DBR) methodology [6]. It presents its use to synchronize the use of resources and material flow in production operations [7].

Figure 2 shows the overall material flow diagram in DBR method.

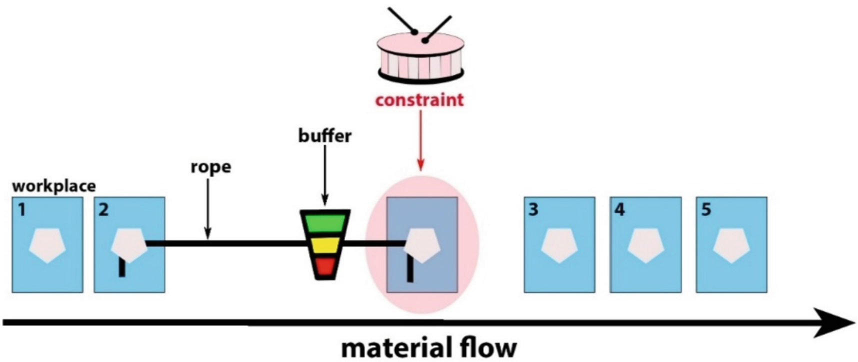

Fig. 2. General material flow diagram – DBR. Source: own study.

Each acronym in the BDR name has a special meaning:

(D) – The drum accentuates the pace at which the constraint works. Goldratt describes the bandwidth constraint as line drum beat. The drum is a constraint, a bottle-neck, a limitation. The rhythm of the drum indicates the maximum delivery rate because is the slowest.

(B) – The buffer determines the inventory at system or process checkpoints to protect against unforeseen changes. Prevents constraint inactivity caused by a lack of material to be processed. Ensures that the short interruption and fluctuations is no constraints do not contribute to the constraint. Traditional DBR has two buffers – one for the constraint and one for the shipment. The one against constraints is to protect the constraint, the shipping buffer protects the delivery date [8]. The dimensioning of the inventory buffers depends on customers' demand for a given product as soon as they are used up and how quickly they can be replenished [9]. The necessity to use buffers depends on how smooth the flow is (the more changes there are in the flow, the larger buffers should be used).

(R) – The rope provides communication between checkpoints to ensure system synchronization. This is the signal generated by the constraint, indicating that a portion of the inventory has been used up, releasing an inventory of the same size as the process. The role of the rope is to maintain capacity without creating excessive inventories [8]. The length of the rope, therefore, the amount of inventory in the system is determined by the protection against the constraint provided by the buffer. As the stocks of production in progress under the constraint are negligible, the rope works to maintain minimum and constant stock levels in the system [10].

4 Research Method

The research tools that were used: observation, interview, and comparative case study. A case study is a research methodology based on a detailed study of a single person, group, or event, especially to present, investigate the reasons underlying its principles. Presented as case-based science [11]. A case study was used in the analyzed enterprise. The purpose of the analysis was to identify bottlenecks in the process and to compare the application of the Kanban and DBR method. The packaging production process was analyzed. The processes occurring in the stream are planning, printing production, finishing processes, quality control, shipment to the customer. Three production workstations were analyzed successively in the process flow. The flow is the use of successive tasks associated with the production of a product without holding, scrapping, or moving backwards [12].

The first workplace is "punching", consisting in cutting sheets along the designed shape with a toll consisting of appropriately profiled blades. Next "stamping" workstation, carried out in semi-automatic presses, is used to finish the product. The last position is "packing". Depending on the customer's requirements, various methods and standards are used for packing and transporting a given product. The batches of the product are placed on pallets, which are transported to the storage bay, where they wait for the further production process. The problem noticed during the observation was the stock in progress, accumulating at the "stamping" workstation. The position had the highest average utilization, moreover 99% of the production was based on this resource. Therefore, the second workplace was indicated as a constraint of the process.

5 Case Study - Kanban

The production process is shown in Fig. 3 using the Kanban method in the analyzed enterprise.

In the Kanban method, the concept of Tact Time (T/T) appears, which determines the time in which the material moves through the entire production system. To match the customer's order, the production sequence must be in Tact Time. If the production time is shorter than the Tact Time, then the resources of the enterprise are not fully used, resulting in wasted waiting and an increase in the cost of production. The number of seconds per unit of product is the most common measure of the Tact Time [13]. In the analyzed case of the production process, the Tact Time is 0,4 s (seconds per piece). The product batch from the first workstation is made in a Tack Time equal to 0,25 s. The next workplace performs production with a Tact Time of 0,9 s. The second workstation performs the work the slowest, therefore it is defined as a bottleneck in the flow. So, the batch from the first workstation is transferred to the storage bay for the inventory

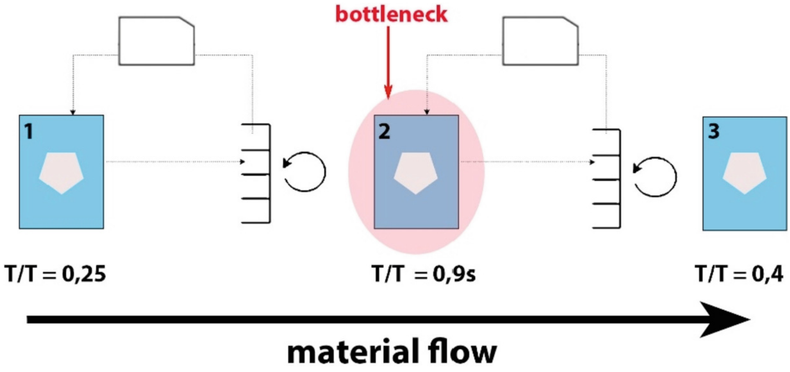

Fig. 3. Diagram of material flow in the analyzed production process - Kanban. Source: own study.

warehouse, which is called a supermarket in the Kanban method. The supermarket signals the quantity of each part needed from the upper supermarket - sending him Kanban in motion. Receiving a Kanban in motion causes the reloader to withdraw the required number of parts from the supermarket and then transfer these parts to the customer's resources. Creating a supermarket before the bottleneck requires creating a plan for the supermarket and filling inventories according to this plan (in this case the maximum available storage area). Marking a production order in green means, that the prepared materials and tools needed to perform the given order are complete. Marking an order in red indicates, that now there are not enough resources to complete the order. Thanks to this solution, operators notice the queue of prepared orders. If one order is incomplete, the operators in second workstation will execute the next order in the queue, minimizing the possibility of operator error. The completed production order is transferred to the next workstation in the flow, for which the tact time is 0,4 s. It can be noticed that the work on the third position is performed faster than on the previous position, therefore it is waiting for the next batch of the product. That's why, to minimize the wastage arising, position three works in two shifts. The product batches from the second workplace are placed in the supermarket in front of the third workplace during the downtime.

6 Application DBR Method Instead of Kanban Method

The applications of the DBR method instead of the functioning Kanban method in the analyzed production process are presented in Fig. 4.

According to the idea of the Theory of Constraints, all resources should be focused on the identified constraint [7]. In the analyzed case, the constraint is the "stamping" workplace. All workstations work at the constraint rate (D), the tact time is 0,9 s. To prevent unlimited inventory build-up ahead of the slowest workplace, so material should be "released" at a constraint rate. The rope (R) acts as a final for inventory release in the process, ensuring process throughput. Each time the constraint ends a unit of work-in-progress (WIP), the rope beeps (for example in the form of a message in the integrated management program) to release the raw material unit to the buffer at the level of workstation one. Before constraint, buffer (B) was placed. If the first workstation is

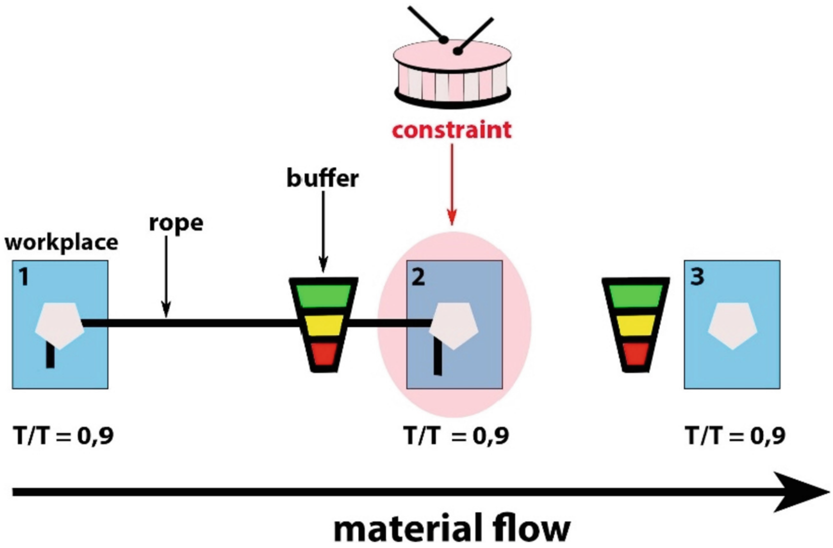

Fig. 4. Diagram of material flow in the analyzed production process after applying DBR. Source: own study.

in a failure state, the (WIP) units are placed in the buffer [14]. An important step is to determine the size of the buffer that should be adjusted to the constraint. The buffer may be presented as the time that work-in-progress should be delivered before being used first. Referring to the case study, the buffer may be 1 h, therefore approximately 4,000 batch pieces should be delivered to the constraint site every hour. Such action ensures the stability of the stock operation. The greater the variety of the process, the greater the buffers must be. The stock buffer can be divided into 3 areas, it is marked by visual criteria: top green level, yellow and red. The first green means that the stock is sufficient, and no action is required. If the buffer status is yellow, it means that the order should be shipped. In case the buffer level reaches the red level, it means that replenishment plans must be executed immediately. In the analyzed case, the safe stock may cover the range of 4000–2001 items, the alarming level 2000-501 items, and the critical level 500-0 items of packaging. By monitoring the three levels shown, for each order over a period, it will be possible to determine whether the buffers are approximately real in relation to the consumption rhythm [9]. Planning of the production schedule is based on the productivity data of key workstations and working time in buffers. There is no need to collect detailed information from all workstations, because in the theory of limitations in the production process, the operating status in buffers before bottlenecks is controlled. Information on what to produce, in what order and quantity is determined by the schedule on the drum (D).

7 Discussion

Both Lean and TOC focus on continuous improvement and control of material flow in the production hall. Their use allows you to significantly simplify operations, increase the implementation time, and the profitability of the enterprise. Correctly implemented DBR with TOC results in resource synchronization and effective use of materials in relation to the identified system limitations. Both methods are aimed at more efficient use of resources and improvement of operational efficiency [15]. Each of the methods does it in a different way [16].

Table 1 shows a comparison between Kanban and Drum-Buffer-Rope.

Table 1. Comparison between Kanban and DBR method.

Area	Comparison methods	
	Kanban	Drum-Buffer-Rope
Idea	Increasing profit by enhancing the added value of the product from the customer's point of view	Increase your profit by increasing your throughput
Organization of the flow	Continuous	Compliance with constraint
Stimulation	The customer sets the pace	Constraint sets the pace
Production enviroment	Repeatable production	Serial and unit production
Flow type	Pull	Pull
The sequence of operations	FIFO	FIFO
Methods implementation steps	5 Lean principles	POOGI
Inventory	Elimination of all possible	Handling enough quantity to maximize the flow of constraint
Component	Supermarket, Kanban	Buffer, rope
Result	Lower production costs and prevention of waste	Increased production capacity

Source: own study.

Kanban method and DBR strongly focus on the customer, as a result companies achieve favorable, efficient process management. When comparing Kanban with DBR, the following similarities can be noticed:

1. Both cases are pull systems (as opposed to the "push" method where long series are created, based on previous sales forecasts). In a trailed system, successive processes define the production needs in the previous processes. They only "take out" the goods they need, in the time and in the quantity, they need [17]. They synchronize the productive "activity" of the process with each other on the higher and lower streams [13].
2. The sequence of operations in both methods is based on FIFO ("First-In, First-Out"), which is a method in which goods from the warehouse are issued in the order in which they were entered into this warehouse. FIFO helps to manage the

assortment in the warehouse in an orderly and efficient manner. Avoidance of expiry of the materials and wastage of making complicated calculations of the valuation of individual assortments over time [18].

3. The best way to shorten batch transit times is to eliminate stockpiling - nothing stops work, production starts to “sound” as it should. The Kanban method prevents overproduction and excessive movement of materials between processes. It provides actual production orders to processes according to the principle of replenishment, by synchronizing the time of movement of materials and the amount of delivered materials. It supervises the production by means of visualization, which shows whether the production is delayed or ahead of the schedule. Correctly used Kanban will prevent you from overloading multitasking. Similarly, DBR minimizes the excessive flow of materials because it adjusts their quantities to the pace of work of the constraint, considers the problem of waste of resources [19].
4. DBR in Theory of Constraints is like the Kanban from the supermarket before the bottleneck. Every portion is taken from the buffer/supermarket, the information is sent via the rope/Kanban to the beginning of the rope/Kanban loop to replenish the materials [20].

The following information can be distinguished among the differences:

1. The stages of implementing changes in Kanban are based on the concept of Lean management. In DBR, the stages of implementing changes focus on 5 steps of POOGI (Process of On-Going Improvement): identifying the constraint, exploiting the constraint, subordinating everything to the constraint, increasing the power of the constraint, returning to the beginning.
2. Unlike DBR, Kanban offers guidance on what to produce next - waiting in the Kanban queue. This possibility minimizes the risk of error.
3. In Kanban, if one workstation stops working for longer than the buffer allows, the whole process is forced to wait until the suspended workstation is restored. In the case of DBR, the risk of production stoppage exists when the constraint is unable to process resources due to failures, shortages. In DBR, it is not possible to make up for losses in the event of losing any production on the drum [7]. Therefore, all possible measures must be taken in DBR to keep the drum running continuously and efficiently. Increasing the productivity of the drum will lead to an overall increase in process efficiency [21].
4. The Kanban method to be effective, requires a stable production environment and uniformity of production [22]. It is most effective in a production environment with regular and constant demand, where products have a simple and flat bill of materials, short lead times and low order volumes [23]. DBR can be used in a production environment based on both serial production and unit production [24].
5. The use of DBR makes sense to standardize the process as it will indicate where to improve to have the greatest impact on performance and throughput. It prevents system overload as it minimizes work-in-progress. Keeping your WIP to a minimum means optimizing your flow and lead times. It leads to systematic and sustained process improvement that Kanban is not capable of [25].

6. The criterion for applying Kanban is the occurrence of a signal, usually visual, limiting WIP. In Kanban, the point of commitment is important, symmetrical between the business and the enterprise providing specific services. The criterion for applying DBR is the presence of a constraint in the process.

DBR technique - was developed to meet the basic assumptions of the Theory of Constraints, aimed at streamlining production processes to increase throughput and reduce inventory and operating costs [26]. Kanban visualizes the workflow, defines work-in-progress limits and the measurement of lead times. It enables a proactive approach that solves the problems of downtime and bottlenecks when a signal occurs, not after a noncompliance. Kanban is a universal solution [27].

The main factor that causes the Theory of Constraints not to be widely applied is the need to change the financial paradigm. It requires enterprises to „give up" what they know, that is the classical thinking process. Enterprises want to make the most profit in the shortest possible time, not necessarily slowing down the machines. It is a classic approach to production management, which is focused on working with 100% use of production capacity. The Kanban method is widely and willingly used by enterprises. Of course, the Kanban mantra is to start the next steps when the work in progress is completed. However, improper use, not controlling Kanban, involves a hidden, excessive amount of work-in-progress. Determining the size of the buffer in an environment with high uncertainty in the supply chain is very important, however, in many companies in practice it is determined by trial and error. Using the right approach to determining the size of the buffer, the level of WIP units in the supply chain would remain adequate, with minimum inventory cost and maximum response to customer demand [28].

To increase the throughput of the production process, enterprises invest in the development of a position which is a constraint or use cooperation consisting in delegating part of the production to the bottleneck. Using outsourcing services is beneficial because it allows you to achieve a certain level of sales while maintaining low production costs, however, it also involves the risk of patent leakage or the company's dependence on an outsourcing company [29].

Nowadays, most companies decide to introduce agile management methods, for example Agile rather than TOC, for some projects the cost of introducing the critical chain is too high. Enterprises consider the implementation of TOC as economically unprofitable, as they require a change in the company's organizational culture, training of employees and fighting their old habits, or purchasing software [30]. Adjusting people's work to the constraint is often the most difficult stage. During the adaptation phase, resistance from workers who are used to their work based on performance indicators is encountered [31]. This approach may result in excess inventory and a shift in priorities in various positions that will not coincide with the company's goals and the use of DBR. The development of robotization and production automation may lead to changes in the culture of enterprises employing good and open managers who will be willing to implement DBR. Synchronization of the speed of the feeders and robots to be reduced may be easier to implement and maintain (for example in economic terms).

8 Conclusions

A one-piece flow is ideal to detect any waste in your production processes. Production without stocks, except in exceptional circumstances, is practically impossible, and the appropriate methods of the suction system allow you to determine their correct level [13]. The continual improvement process in the Theory of Constraints is a consequence of concentrating all efforts on the purpose of the system. It must not be possible to lead to a situation where inertia (concentration on a resource which, from the point of view of the entire system, is no longer a constraint) becomes an obstacle, a constraint of the system [7]. The elimination of one constraint of the system does not exclude the appearance of another. Each process is variable; therefore, it should be constantly analyzed and the elements (drum position, rope size, buffer size) should be constantly adjusted [20].

The mere establishment of a permanent bottleneck will lead to problems. The greatest similarity between the DBR technique and Kanban is the minimization of overproduction and excessive movement of materials between processes. Kanban can fulfill DBR roles. An example is the occurrence of work-in-progress limits, in which the production adjusts to the work pace of the process, new production orders are not "released" until the open tasks are completed. In comparison, this is the same DBR application case where the environment adjusts to the constraint. Both methods provide the actual production orders to the processes according to the principle of replenishment, by synchronizing the time of movement of materials and the amount of delivered materials. They supervise the production by means of visualization, for example in buffers, which shows whether the production is delayed or ahead of the schedule. Correctly used Kanban will prevent you from overloading multitasking, adjusts their quantity to the pace of work of the constraint, considers the problem of waste of resources [19]. It is possible to combine these methods, for example in production environments that execute several orders simultaneously [32]. Supporting them by computer will positively affect the streamlining of the flow, eliminate multitasking reducing the efficiency of the entire enterprise [33].

Subsequent studies of the Kanban and DBR comparisons may include a broader analysis beyond simple serial flow lines with more than 3 stations. It is also possible to compare a computer simulation of the application of the DBR method in a selected company process, in which Kanban is currently used.

If a satisfactory simulation is obtained, the tests can be applied to the actual implementation of DBR. Simulation studies may be carried out on more than one enterprise to confirm the research problem. Interviews with production managers, Lean specialists on the application of the Kanban method and DBR by companies from various industries will allow to obtain key practical knowledge that will allow for a more accurate reflection of the actual process in a simulation study.

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