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Simulation of Lean Principles Impact in a Multi-Product Supply Chain

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***Abstract*—**The market competition is moving from the single firm to the whole supply chain because of increasing competition and growing need for operational efficiencies and customer orientation. Supply chain management allows companies to look beyond their organizational boundaries to develop and leverage resources and capabilities of their supply chain partners. This creates competitive advantages in the marketplace and because of this SCM has acquired strategic importance.

Lean Approach is a management strategy that focuses on reducing every type of waste present in an organization. This approach is becoming more and more popular among supply chain managers.

The supply chain application of lean approach is not frequent. In particular, it is not well studied which are the impacts of lean approach principles in a supply chain context. In literature there are only few studies aimed at understanding the qualitative impact of the lean approach in supply chains. Therefore, the goal of this research work is to study the impacts of lean principles implementation along a supply chain. To achieve this, a simulation model of a three-echelon multi-product supply chain has been built.

Kanban system (and several priority policies) and setup time reduction degrees are implemented in the lean-configured supply chain to apply pull and lot-sizing decrease principles respectively. To evaluate the benefits of lean approach, lean supply chain is compared with an EOQ-configured supply chain. The simulation results show that Kanban system and setup-time reduction improve inventory stock level. They also show that logistics efforts are affected to lean implementation degree. The paper concludes describing performances of lean supply chain in different contexts.

***Keywords*—**Inventory policy, Kanban, lean supply chain, simulation study, supply chain management, planning.

I. Introduction

COMPETITION increases and puts pressure on the performances of the supply chain's players: the main emphasis is generally given to cost reduction by optimizing production, inventory and transportation processes. In this environment the supply chain planning is one of the major tasks.

Lean Management is becoming more and more popular among supply chain managers. The main feature of lean approach is to reduce every type of waste present in the production flow whether it means material waste, time waste or activity waste. It is largely demonstrated that lean approach implementation leads to cost reductions, higher quality level and shorter delivery time in a company. In what direction and how much Lean approach impacts on the whole supply chain is not well defined.

This research work studies the supply chain through a simulation model of a multi-product and three-echelon supply chain.

This study deals with the analysis of supply chain's performance comparing two different supply chain planning policies: EOQ policy and Lean policy. To increase the knowledge about the impact of lean approach to the supply chain several Lean rules are studied.

II. Literature Review

The lean approach is not new; it was born in Japan after Second World War, developed by lean mentor Taichi Ohno in the Toyota production system.

Lean approach became famous during the 1990s when researchers as Womack and Jones studied the superiority of Japanese automotive firms compared to American automakers and explained the reasons of this superiority in the book "The machine that changed the world" [1].

There isn't a clear and precise definition of lean approach: It is recognized as a philosophy of manufacturing products without any kind of waste.

Ohno classified seven different types of waste: over production, waiting, transportation, unnecessary inventory, inappropriate processing, defects and unnecessary motions [2]. The other important concept of lean philosophy is the creation of a smooth, fast and flexible flow of material and information [3], [4].

The purpose of lean approach is to improve overall levels of productivity and product quality, waste reduction, integration and interaction across functional departments, and improved work force autonomy [5].

The traditional research field of lean approach is the manufacturing firm operations [6]. However, in the last years the application of lean principles in not traditional ambits is increasing. One of these ambits is the supply chain context.

The term Lean supply chain refers to the extension of lean principles throughout the supply chain, both downstream and upstream [7].

The concept of applying lean principles along a supply chain (lean supply chain management) is not recent in the academic world: the first appearance of the Lean supply chain concepts was done by Womack and Jones [8] when they introduced Lean Enterprise that is the extension beyond of firm boundaries of lean principles. Time after time lean enterprise translated in lean supply chain. Liker and Wu [9], Lamming [10] investigated the extension and application of

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Lean principles to the entire value stream for a product and highlighted the several uses of practices between companies working in Lean environment and companies not working in lean environment.

Liker and Wu [9] studied lean practices between Japanese automakers and their supplier: level production schedules, a disciplined system of delivery, handle mixed-load transportation, small-lot deliveries, encourage suppliers to deliver only what assembly plant needs, help supplier to develop their capabilities.

Lean approach management enables significant improvement in supply chain and addresses all its goals: to be efficient, responsive, and cost effective [11]. The author further states that decreasing the inventory is not the ultimate objective for lean approach; the ultimate goal is to increase customer service performance, eliminate waste and solve problems throughout the supply chain. Inventory reduction happens as the desired consequence of implementing this concept.

III. Experimental Design

The simulation model represents a three echelons supply chain composed by 4 suppliers, one manufacturer and one retailer. Suppliers and manufacturer stages are composed by the input warehouse which stores the pieces received from upstream, the production plant that processes the pieces and the output warehouse which stores the worked pieces. It is assumed an infinite stock in the suppliers' input warehouse according to many papers that study supply chain through simulation [12]-[14]. Retailer stage is represented by just one distributor, it doesn't process items and it is composed only by a warehouse.

There are 24 different products from 4 different product families in the supply chain. One product family consists of 6 different products.

Each of the suppliers is responsible to produce one product family for the supply chain. However, the suppliers are not fully dedicated to this supply chain; they produce other products for other supply chains as well. The manufacturer works all the 24 products and its operations are fully dedicated to this supply chain.

Suppliers and manufacturer stages have finite production capacity. The production systems are composed of a queue for the items to work and a single machine where the items are processed. The production lines have various set-up times depending on the product type. The set-up times for the products within the same product family are naturally shorter than set-up times for the products from different product family. The processing times vary on the different stage of the supply chain.

Finally, the retailer receives every day the demands from final customers and she has to satisfy the demand in Make-To-Stock logic.

The final customer demands faced by the retailer are random numbers generated with the following equation:

$$Dt=k+\rho*Dt-1+\varepsilon$$

where Dt = the demand in period t; k = a non-negative constant; ρ = the correlation parameter which is set to 0.7 in this research; ε = the normally distributed variability factor with mean 0 and variance $\sigma 2$.

The same formula is used by Chen in [15], Lee in [16] and Portioli Staudacher and Bush in [17].

For the aim of this study downtimes caused by system failure, delay or lack of information and other causes are neglected; the production processes in both Primary and Secondary Manufacturers have no downtime.

The products are transferred between different stages of the supply chain by trucks with limited capacity. In order to minimize the transportation cost, the trucks will not deliver the products to downstream stage unless a minimum quantity of products to be delivered is reached. However, the system also considers a maximum amount of waiting time; products will be transported in spite of not reaching the minimum quantity if they have been waiting in the queue for 1 day or more. The lead-time to transport an item to the next stage of the supply chain is deterministic and equal to two days between supplier and manufacturer and equal to one day between manufacturer and retailer.

In the supply chain all members use the same planning policy. This research work studies the impact difference of setup time reduction in supply chain governed by different planning policies. The different planning policies studied in this paper are described below.

A. EOQ Policy

The EOQ configuration is that all the components of the SC follow (r,Q) policy.

Every warehouse is exposed to a continue check: when the inventory-position go down a certain level (reorder point), it is created an order to the previous warehouse.

If it's an internal order, the production of a batch will start, if it's an inter-stages order, the shipping.

The inventory position is calculated as:

Inventory position = inventory level + ordered items but non arrived – backlog orders

B. Lean Policy

Referring to the lean principles explained by Womack and Jones, the principles that are more related to the supply chain context are the "pull strategy" and the "flow".

A kanban system implementation along the chain develops the pull supply chain planning strategy: the production starts only if there is a consumption of material in the downstream stage of the chain.

The second cited principle to create the flow aims at a production levelled as much as possible. The setup time and the batch-size reduction represent this principle in the simulation model.

There are different variants of the lean policy and they depend on the Kanban board rule set in the production stages.

IV. Kanban Board Rules

In this simulation model, there is only one product in each container, meaning that one kanban represents one product. In order to have an optimum utilisation of the resources, there are two triggers to launch the check in the Kanban Board. The first trigger is every time the resource finishes with a batch and results idle. The second trigger is to perform a check of the kanban board every time a kanban arrives to the Kanban Board.

The Kanban board rules determine which the next product the plant has to process is. Two simple priority rules are compared. One considers setup times and selects the product that implies the shortest setup time (SETUP). The other rule considers the inventory level and the product with the smallest coverage is selected (COVER). During the selection of the next product the Kanban board rule considers only product types that have the number of kanban attached on the Kanban board greater than a minimum batch size. Additionally, different minimum batch size levels necessary to stat the production are compared. From the combination of priority rules (shortest setup and smallest coverage) and minimum batch size levels (low and high) are derived four different Kanban board rules.

V. Main Performance Measures

A. Service Level

The service level of the SC is measured by the mean of the service levels at the single warehouses. The service level of the single warehouse is calculated by the number of days of stockout over the simulation period.

The warehouse is in stockout whether it hasn't handled all the orders at the end of the day. This research work tested the supply chain performance of different service levels. In this research work are compared the performance of supply chains that reach a service level equal to 96%. This service level target is set us an adequate target for the contemporary market context.

B. Inventory Level

The inventory level is the sum of all the average stocks along the chain measured during the simulation run period.

C. Logistics Performance

The measure of the logistic effort is the newness of this simulation study. It is rare that simulation study about the supply chain consider logistic performance along the supply chain. The logistic performance bases on the amount of trips done during the simulation run, there are two kinds of trips: FTL (full truck load) when the truck travels full, LTL (less than truck load) when the truck travels without having saturated its capacity.

TABLE I
Kanban Board Rules

Name	Priority rule	Minimum batch size
COVER-1	Smallest coverage	High
SETUP-1	Shortest setup	High
COVER-0	Smallest coverage	Low
SETUP-0	Shortest setup	Low

VI. Plan of Experiment

The experiment consists to collect data from 5 independent replications for each supply chain policies and for each setup time reduction in order to evaluate the statistical confidence of the results. It means that 5 different demand profiles were created and all the possible supply chain configurations responded on the same 5 demand profiles.

All demand profiles follow a truncate normal distribution with mean equals to 384 pieces per day. These values coincide with 80% of the production capacity for both stages.

For all the 5 different supply chain configurations (EOQ, 4 Leans) they were simulated several setup time reductions: no setup time reduction, 20%, 40% and 60% setup time reduction.

The service level target (96%) was reached in an empirical way for each replication by changing the level of safety stock for each item.

Each run has a length of 2050 days and includes a warm-up period of 50 days.

VII. Results

A. EOQ Configuration

It is clear that the setup time reduction led to a decrease of the mean inventory level, an increase of the number of batches and it decrease of the utilization rate of the production capacity. This means that setup time reduction gives some benefits to the supply chain.

Opposite considerations whether the logistic point of view is taken: the setup time reduction led to a greater number of trucks trips to move the same amount of pieces. The use of LTL transport increased.

B. LEAN Cover-1

The data collected shows that the setup time reduction leads to a significant inventory level reduction. Comparing the same supply chain configuration (SCC) with no setup time reduction and SCC with the maximum setup time reduction (60%) inventory level saving is 45%. The utilization rate of the plants remains constant and it seems not affected by setup time reduction. On the contrary, the number of batches increases whether the setup time is reduced.

On average the product type selection takes place among five different products: at the moment of the next production batch launch there are 5 types whose necessity of replenishment overtakes the minimum batch size level.

The setup time reduction leads to transportation effort increase: the maximum setup time reduction coincides with the maximum transportation effort increase (13%).

C. Lean Setup-1

The results for this SCC follow the same trend of the results of FIFO-1 SCC but the intensity of the setup time reduction impacts are smaller. The setup time reduction means reduction on the mean inventory level but the maximum saving comparing this SCC with no setup time reduction is 26,5%. The setup time reduction increases the average number of considered product types during the batch selection phase, from 5 types to more than 6. 9,5% is the maximum truck trips increase that coincides with the 60% setup time reduction.

D. Lean Cover-0

The inventory levels of COVER-0 SCC are generally very low if they are compared with the other SCC. In this context the setup time reduction doesn't lead to big savings: the maximum setup time reduction leads "only" 25% of inventory saving if it is compared with the same SCC with no setup-time reduction. The utilization rate decreased whether the setup time decrease. Increasing setup time reduction, the number of product types good for the production launch selection increased from 6 to nearly 11. The number of trips is generally very high and the difference related to the setup time reduction is not so big: the maximum variation is 5,6%.

E. Lean Setup-0

Also for this SCC the setup time reduction leads to inventory savings: 17% of inventory saving coincides with 60% of setup time reduction. The utilization rate decreases whether setup time decreases similarly to COVER-0 SCC. The number of trips necessary increases whether a setup time reduction is applied.

VIII. Analysis

Data shows clearly that lean supply chain leads to lower inventory level than EOQ Supply chain. The Kanban system creates the pull structure that directly links the customer with the supplier and allows limiting stocks along the chain. From collected data it is possible to state:

- Lean approach adoption leads to inventory saving.
- The setup time reduction is more effective if it is applied in lean environment.

In this paper four dispatching rules were proposed: four simple Kanban board rules (or dispatching rules) and the FIFO-0 resulted dominant about the inventory saving.

The selection based on "smallest inventory coverage" rule leads to lower inventory than "shortest setup" rule. The SCCs with a low minimum batch size have lower inventory level, higher utilization rate and greater transportation effort than the corresponding SCCs with a high minimum batch size.

The Lean supply chain appears more efficient than the EOQ supply chain: the logistic efforts increase is compensated by the reduction of the inventory carrying cost.

The field of application of the Kanban system is affected by the weight of the logistic cost on the single piece.

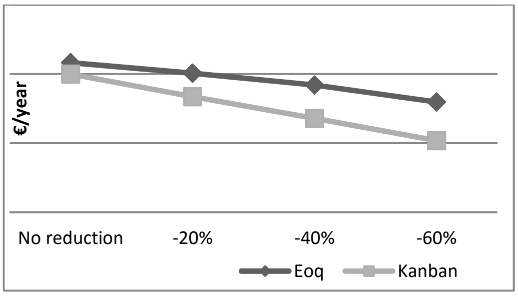

Fig. 1 Comparison EOQ SCC and LEAN SCC

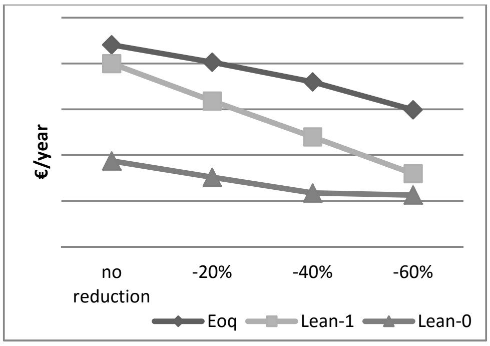

Fig. 2 Impact production and order batch size reduction

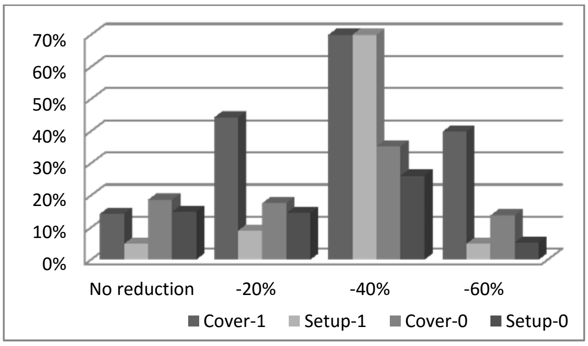

Fig. 3 Maximum admissible impact of logistic cost on the single product value

Using collected data performances of different supply chain configurations have been estimated in several contexts. The result is that there is a threshold for difference of weight between inventory carrying cost and logistic cost. The Fig. 3 shows the maximum admissible logistic weight on product value in order to have lean supply chain more efficient than EOQ supply chain: if there is no setup time reduction the maximum logistic impact is around 10% of the value of the single piece; the setup time reduction seems to increase the benefit in lean supply chain until 40% setup time reduction, after this value the benefits of the lean supply chain decrease. This can be explained by the fact that the logistic effort increase and the inventory level decrease are not linear and the logistic effort increase is not more sustainable by the inventory carrying cost decrease.

IX. Conclusion

Through this research work, a complete supply chain simulation model has been built. This simulation model is useful for further researches because it allows to replicate different supply chain planning policies and differently from the most part of the simulation models present in literature that study a single-product and two echelon supply chain, it simulates a multi-product and three echelon supply chain. The results showed in this paper state that the lean supply chain configuration leads to a more competitive supply chain in the market so this work could be an initial support to implement lean approach in firms' operations system.

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