Lean Supply Chain strategies based on the pull-production system: a simulation-based analysis

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Abstract

Nowadays, supply chains must be able to manage highly challenging market conditions due to increased volatility and uncertainty. The application of Lean practices in the scope of Supply Chain Management (LSCM) can promote the reduction of inventory levels, delivery times, and costs, thus improving customer satisfaction. In this context, this paper aims to identify suitable strategies to implement the pull production system that enable higher operational performance in dyadic supply chains. For this, three replenishment pull system strategies related to a supplier-customer relationship were considered. The proposed strategies were evaluated based on a case study in a company belonging to a metal-mechanic supply chain. The results obtained through computer simulation were analyzed comparing the supply chain performance in relation to lead time and service level (delivery). With the evaluation of the proposed strategies, this paper contributes to the knowledge of the applicability of this practice in the supply chain, and provides support for decision making on the best strategy to promote the success of a lean supply chain.

Keywords
Lean Supply Chain Management, Simulation-based Analysis, Pull-Production, Supplier-Customer Relationship.

1. Introduction
With increasingly globalized markets and increased competition in all sectors, competition is no longer limited to the capabilities of each organization but occurs between supply chains (dos Santos and Alves, 2015, Moyano-Fuentes et al., 2019). Thus, in this scenario, the integration in the supply chain management (SCM) becomes necessary to enable differentiation and sustainability of the business (Rivera et al., 2007). SCM is an approach that connects each component of the manufacturing and supply process from the raw material to the delivery to the final customer (Ariffin et al., 2015).
However, these efforts do not always work due to the poor connection and alignment between company strategies and their supply chain processes, operations, and practices (Mehrjerdi, 2009). To adapt and maintain competitiveness, it is necessary that the SCM allows the elimination of waste, smoothing of material and information flows, and increased efficiency and quality (Basu and Wright, 2010). Such adaptation involves the incorporation of lean practices and principles, which were originally conceived on the shop floor, giving rise to the so-called Lean Supply Chain Management (LSCM). Thus, the implementation of LSCM practices can be applicable and efficient for supply chains that want to streamline their processes by eliminating waste and activities that do not add value to their entire extent (Manzouri and Rahman, 2013).
Strategies adopting lean practices have been widely studied since their implementation allows benefits such as cost reduction, increased operational performance, and better financial performance (Elking et al., 2017). Among LSCM

practices, Kerber and Dreckshage (2011) and Anand and Kodali (2009) highlight the relevance of the implementation of pull production systems for value flow management along the supply chain. This practice drives production according to customer demand, i.e. the sequence of upstream activities and processes will only be performed after signaling the downstream customer's need. Therefore, the pull system refers predominantly to the flow of information from a downstream agent to an upstream supply chain agent, requesting the necessary demand regarding material flow. Additionally, according to the results shown in the study by Takeda-Berger et al. (2021), this practice is one of the most critical for operational improvement, besides being of a technical nature, which enables a greater chance of adherence and application. Thus, the adoption of this practice along the supply chain becomes fundamental to assist in inventory control, reducing overproduction and consequently reducing the costs associated with this waste (Vlachos, 2015, Sharma et al., 2015, Berger et al., 2018c).

Noteworthy are some additional challenges to lean implementation in the supply chain, such as its higher level of complexity, the different organizational cultures and the difficulty for strategic partnerships mutually beneficial with the agents involved in the supply chain (Cudney and Elrod, 2011, Jadhav et al., 2014). In this sense, one of the most used methods in previous studies considering the complexity intrinsic to SCM has been computational modeling and simulation techniques (e.g., Carvalho et al., 2012, Sandhu et al., 2013, Cigolini et al., 2014). The experimentation based on computer simulation offers several advantages, since it is expensive to obtain real observations for some processes. In simulation, the reality is reproduced in a controlled environment, allowing studies that analyze the behavior of the system under different conditions, without risks or significant costs involved (Torga, 2007, Avventuroso et al., 2017). Furthermore, it allows a meaningful analysis to test different strategies and scenarios, providing a comparison of various operational alternatives and enabling better decision making (Smew et al., 2013, Vieira et al., 2017, Leusin et al., 2018). Thus, as the controlled experimentation of the reality of a supply chain is extremely difficult, it becomes advantageous to use simulation to support the analysis of the behavior of this system (Chang and Makatsoris, 2001, Berger et al., 2018a).

Hence, from the presented context, the following research question arises: "*how to adapt the pull production practice to obtain better operational performance in a supply chain?*". To answer this question, this paper aims to identify the best implementation strategy of pull production to improve operational performance in the supply chain, considering simulation-based analysis. More specifically, three strategies related to the replenishment pull system proposed by Dennis (2016) were considered, characterizing a supplier-customer relationship. To evaluate the proposition of these strategies, a case study was conducted in a company belonging to a metal-mechanic supply chain in southern Brazil. The results obtained through the simulation of the different strategies allowed a comparative analysis of the supply chain performance in relation to lead time and service level (delivery). For a better understanding of the research, this paper is structured as follows. In Section 2 the methodology approach is described. Section 3 presents the adaptation of the replenishment pull system strategies. Section 4 shows the results of the simulated strategies. Finally, in Section 5, the final considerations of the research are exposed.

2. Methodology approach

The methodology approach used in this paper was composed for five steps: (i) selection and adaptation of pull system strategies; (ii) adjustment of the pull system strategies according to the investigated supply chain; (iii) computational modeling and simulation of strategies; (iv) data collection; (v) test and comparative analysis of computational results.

In step (i), it was defined which strategies of pull production would be adopted. For that, three strategies were adapted from the papers by Frazzon et al. (2017) and Berger et al. (2018b) which were: (i) pull system with a single supermarket at the supplier; (ii) pull system with a single supermarket at the customer; (iii) pull system with a double supermarket (supermarket at the customer and the supplier). These strategies compose the replenishment pull system proposed by Dennis (2016), and the author comments that this system is the most basic and widely spread among different sector of supply chain.

In step (ii), the pull system strategies were adjustment according to the investigated supply chain. Thus, to better understand the particularities of the relationship between the supplier-company and its customers, on-site visits and semi-structured interviews were conducted with leaders from related areas such as quality, production planning and control (PCP), continuous improvement, engineering, sales and demand management, logistics and procurement.

In step (iii), the strategies were modeled using the Anylogic® Software. Moreover, it was decided to use a Discrete Event Simulation (DES) model, since it allows a simplified representation of a system developed to understand its performance over time and to identify potential improvements. For each of the strategies, it was analyzed the effect of the variability of the value flow on the service level (OTIF delivery, on time in full or on time and quantity), lead time, and finished goods inventory (in the customer and the supplier). Among the uncertainties considered as the input of the model, there are the production time of the batch of the supplier-company, transportation times, and customer consumption times. These variables were chosen because they directly influence the dynamics of the system, i.e. the

production times of the supplier-company batch and the transportation times impact in the time that the customers will have to wait to receive the finished goods in their lines. The computational simulation considered the unit of analysis in days, and the horizon of the simulation was of twelve months. This period was used to execute the simulation because it is possible to analyze the effect of the strategies on the supply chain behavior.
Then, in step (iv), data was collected to be imputed in the simulation. Firstly, for the processing times of the supplier-company, the process map with its respective times was obtained from the PCP area. For the transportation times between the supplier and its customers, records were collected showing the departure times of the trucks in the Distribution Center (DC) and the delivery area, and the arrival times at the customers, hence establishing transportation time data. Regarding the quantity and frequency of the customers' order, the sales and demand management area provided the historical demand data, according to the volume in quantity of items requested during the last twelve months. To fit the demand data, the triangular distribution was considered, which is indicated when having a few data quantity. However, it results in an adequate approximation of the probabilities of occurrence in a given event, starting from a minimum value, a maximum value, and the most likely value (average).
Finally, in step (v), the tests and the comparative analysis of the computational results were carried out. Thus, it was possible to discuss the results obtained and propose the best strategy for the supply chain.

3. Adaptation of the replenishment pull system strategies

The supply chain investigated in this paper operates in the metal-mechanic sector, which is led by a large Brazilian company that has been on the market for more than 55 years. In the context of its supply chain, the company is supplying around twenty thousand clients in more than 20 countries, with a product portfolio of more than fifteen thousand items. The supply chain of this company has a high level of complexity due to a large number of customers and products. Then, it was decided to segment the items according to three family groups (composed of customers) represented by their percentage in the revenue: Industry (30%), Wholesale and Retail (60%), and Civil Construction (10%). For a better comparison of the strategies analyzed, a specific item was chosen that has important representativity considering the revenues by these three family groups.
The three strategies based on the replenishment pull system were adapted to consider the characteristics of the supply chain investigated (Figures 1, 2, and 3). Accordingly, the three family groups were defined as the three main customers that the supplier-company planned to deliver. Thus, the models were constructed using four information flows, three flows being responsible for the storage of customers' orders, and one flow for the management of order deliveries. Moreover, a material flow, which starts at the supplier-company and expands to the three customers interconnected with the transportation time of the trucks, was considered. For more details and descriptions of the strategies, see the paper by Berger et al. (2018b).

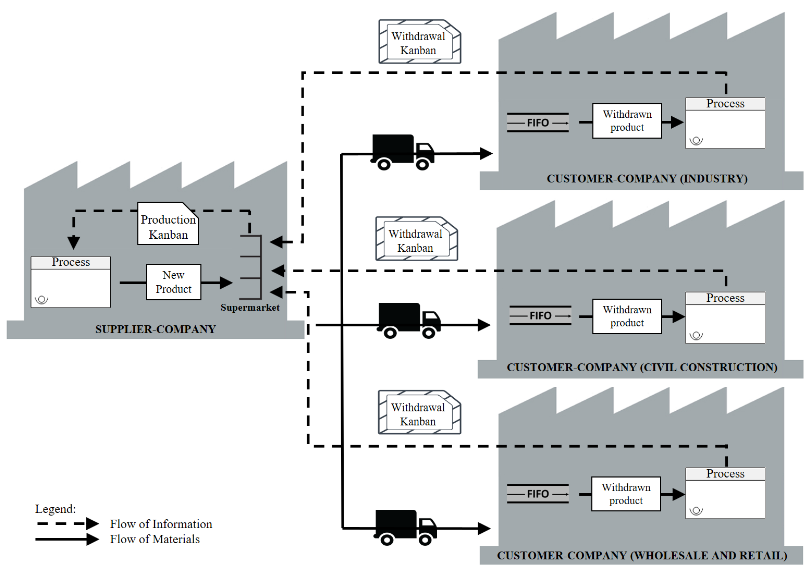

Figure 1. Strategy 1: Replenishment pull system with a single supermarket (at the supplier)

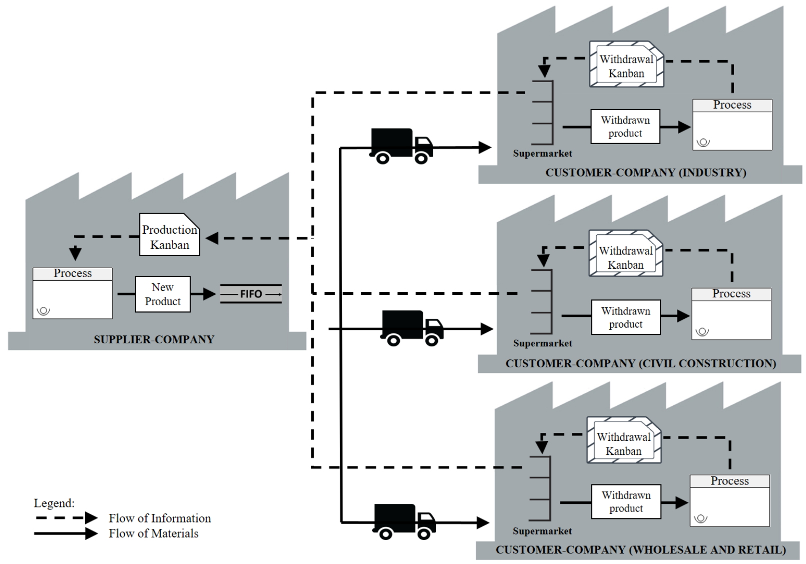

Figure 2. Strategy 2: Replenishment pull system with a single supermarket (at the customer)

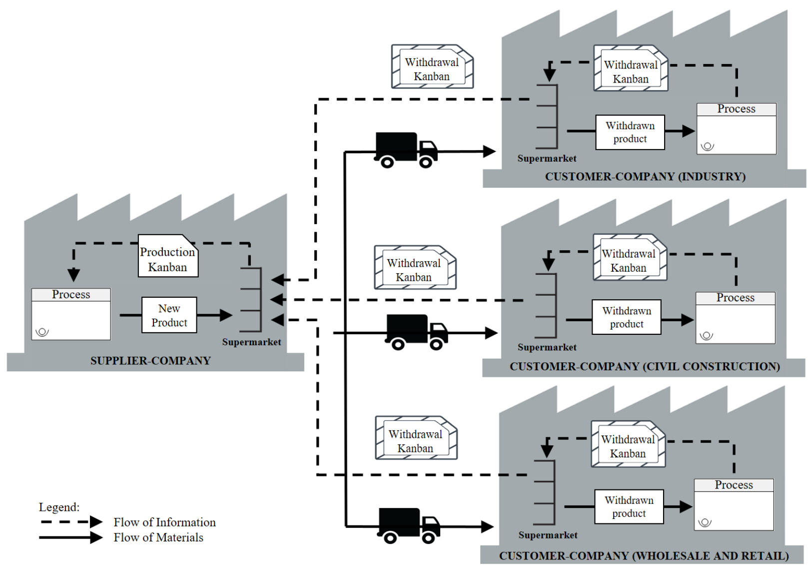

Figure 3. Strategy 3: Replenishment pull system with a double supermarket (at the customer and the supplier)

4. Results

4.2 Numerical simulation parameters

In order to facilitate the computational simulation process, some information was consolidated and simplified as a unit of analysis. For example, each batch of analyzed consumer represents 1.500 units of the selected item. The times can be expressed in days, and then the simulation requires less computational power. Customer orders are processed by the supplier-company every fortnight, and the priority of processing these orders is due to two factors. The first one is about the order of arrival of the requisition, and the second one is the more extended the delivery time, i.e. if the requisitions arrive together, the customer whose service time is more extended is produced first.

The parameters presented in Table 1 were used in the simulation of the three strategies. For the operation of the replenishment pull system, it is necessary the information about the time that each batch takes to be consumed by the customer. Thus, this value was based on the customers' monthly order history, where the consumption time is equal to the inverse of the average quantity. Likewise, based on the maximum and minimum orders, a triangular variation was determined for the time of consumption. A minimum batch quantity was also defined to start production at the supplier according to the information obtained from the supplier-company.

Table 1. Parameters used in the simulation

Parameters for the three strategies	Values		
Customer consumption time 1 (Industry)	min.= 0.0050 month/batch	max.= 0.0521 month/batch	average = 0.0286 month/batch
Customer consumption time 2 (Wholesale and Retail)	min.= 0.0050 month/batch	max.= 0.0327 month/batch	average = 0.0189 month/batch
Customer consumption time 3 (Civil Construction)	min.= 0.0139 month/batch	max.= 0.0417 month/batch	average = 0.0278 month/batch
Transport time to customer 1 (Industry)		14 days	
Transportation time to customer 2 (Wholesale and Retail)		5 days	
Transport time to customer 3 (Civil Construction)		9 days	
Supplier Production Time		0.07 days/batch	
Minimum amount for production at the supplier		200 batches	
Parameters for strategy 1		**Values**	
Initial supermarket at the supplier		318 batches	
Initial line inventory at customer 1 (Industry)		35 batches	
Initial line inventory at customer 2 (Wholesale and Retail)		53 batches	
Initial line inventory at customer 3 (Civil Construction)		36 batches	
Parameters for strategy 2		**Values**	
Initial finished goods inventory at the supplier		124 batches	
Initial supermarket in customer 1 (Industry)		90 batches	
Initial supermarket in customer 2 (Wholesale and Retail)		136 batches	
Initial supermarket in customer 3 (Civil Construction)		92 batches	
Parameters for strategy 3		**Values**	
Initial supermarket at the supplier		318 batches	
Initial supermarket in customer 1 (Industry)		90 batches	
Initial supermarket in customer 2 (Wholesale and Retail)		136 batches	
Initial supermarket in customer 3 (Civil Construction)		92 batches	

For strategy 1, an initial batch value was used in the supplier's supermarket corresponding to the actual value of the item in inventory in the supplier-company, verified in October 2017. In addition, data were collected from the monthly average of orders from each customer family to obtain their respective initial line inventory values.

For strategy 2, the customer order averages were summed to determine the supplier's initial finished goods inventory. As for the values of the initial supermarkets in the customers, the initial supermarket value of strategy 1 was distributed according to the representativeness of each family of customer regarding demand: Industry (28%), Wholesale and Retail (43%), and Civil Construction (29%).

Finally, for strategy 3, it was used the same initial quantity of the supplier's supermarket of strategy 1, as well as the quantities of the initial customers' supermarkets of strategy 2. For both strategies 1 and 2, the same total quantity of batches was maintained, i.e. 442 batches, in order to provide a better comparison between the strategies. However, strategy 3 presents a more significant total quantity of batches in the supply chain, since both the supplier-company and the customers have supermarkets.

4.3 Simulation results and discussion

After defining all the parameters, it is possible to present and discuss the results. However, it is important to note that for the calculation of the lead times, the first two simulated months were not considered in order to remove the initial transitory effect on the model until the supply chain came into equilibrium.

In the first strategy, the delivery service level reached 100% for two customers, "Civil Construction" and "Wholesale and Retail". For the "Industry" customer, this strategy presented a small break at the service level, reaching a percentage of 99.73% (Figure 4).

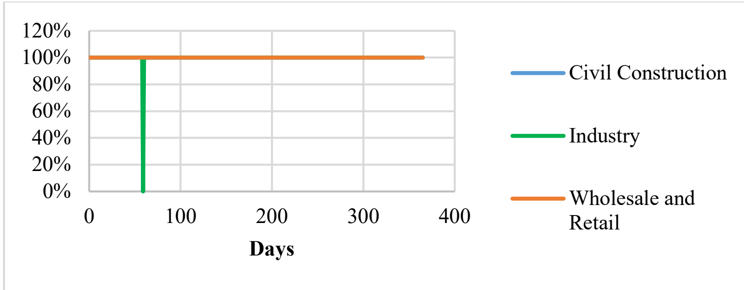

Figure 4. Strategy 1 – Service Level

This result can be confirmed because only the customer's inventory level "Industry" reaches the value of zero on certain days, which can be interpreted as the lack of availability of the item for the customer consumption, causing the rupture in the service level (Figure 5). In addition, it is possible to observe that the initial inventory of all the customers does not demonstrate possibilities of reduction in their values, due to the small margin presented.

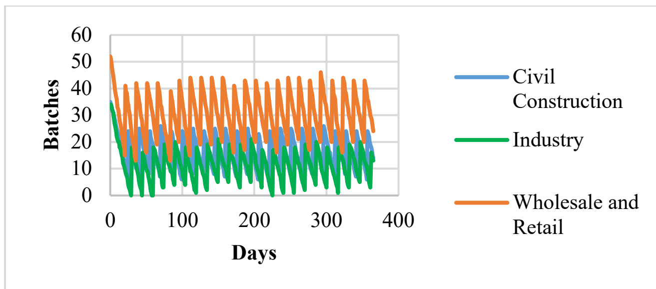

Figure 5. Strategy 1 - Inventory level in customers

Regarding the lead time, the average values obtained were 60.51 days for "Construction", 70.53 days for "Industry" and 60.80 days for "Wholesale and Retail". Lead time is the time that items remain within the supply chain. Thus, the higher the number of items in the supply chain, the higher your lead time will be. The lead time results of strategy 1 were compiled in Table 2.

Table 2. Strategy 1 - Lead time

	Civil Construction	Industry	Wholesale and Retail
Average (days)	60.51	70.53	60.80
Minimum (days)	27.32	29.30	26.16
Maximum (days)	105.06	107.37	103.99

As well as the inventory levels in the customers, the supermarket in the supplier does not present the possibility of reduction since its supermarket reaches a minimum of 6 batches, as can be seen in Figure 6.

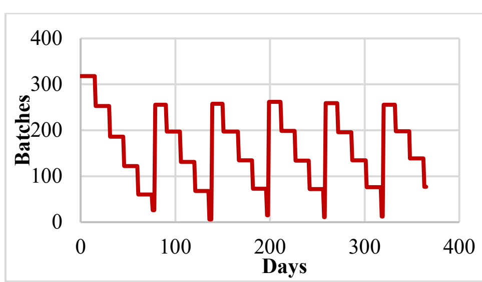

Figure 6. Strategy 1 - Supermarket level in the supplier

In the second strategy, the service level reached 100% for all customers. Compared with the previous strategy, this result is as expected since, in this strategy, the finished goods supermarket is located in each customer, which guarantees to supply the consumption of items for a longer period until the supplier replenish the supermarket of each customer. The initial supermarket of each customer has a margin for reduction without impacting the service level, since, as shown in Figure 7, supermarket levels never lower than 31 batches.

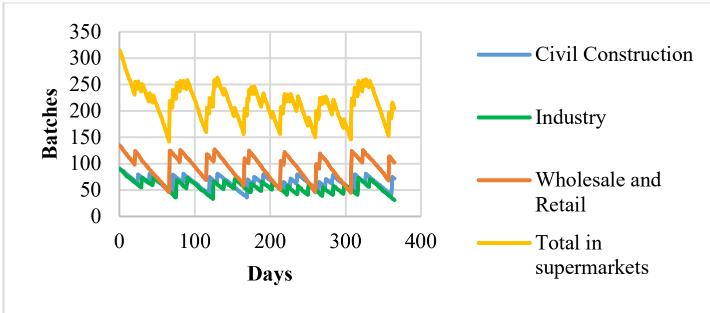

Figure 7. Strategy 2 - Supermarket level in customers

Table 3 presents the compiled results for lead times in strategy 2. The average lead time values obtained were 72.96 days for “Civil Construction”, 74.08 days for “Industry” and 67.51 days for “Wholesale and Retail”.

Table 3. Strategy 2 - Lead time

	Civil Construction	Industry	Wholesale and Retail
Average (days)	72.96	74.08	67.51
Minimum (days)	46.20	45.08	37.20
Maximum (days)	107.68	105.67	107.46

Regarding the initial finished goods inventory at the supplier, this presented adjusted values, since its level reaches the minimum of 8 batches, which entails in a little margin for its decrease, as can be seen in Figure 8.

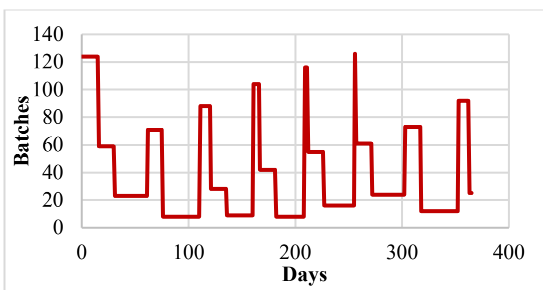

Figure 8. Strategy 2 - Finished goods inventory level at the supplier

Finally, the third strategy also presented a 100% service level for all customers. This result is as expected, since this strategy has a supermarket in both the supplier and the customers, resulting in a higher quantity of items to fulfill the orders. However, this higher quantity of items in supermarkets impacts on the increase of the lead time, becoming strategy 3 with the higher time of products in the supply chain. Table 4 compiles the lead times resulting from this strategy. The average values obtained were 103.37 days for “Civil Construction”, 111.40 days for “Industry” and 103.08 days for “Wholesale and Retail”.

Table 4. Strategy 3 - Lead time

	Civil Construction	Industry	Wholesale and Retail
Average (days)	103.37	111.40	103.08
Minimum (days)	60.15	60.08	60.26
Maximum (days)	153.35	152.60	150.42

About the supermarket in the customers, it can be observed in Figure 9 that there is the possibility of decreasing the number of initial batches. Since the minimum number of batches reached 54 batches for “Industry”, 61 batches for “Civil Construction” and 96 batches for “Wholesale and Retail”.

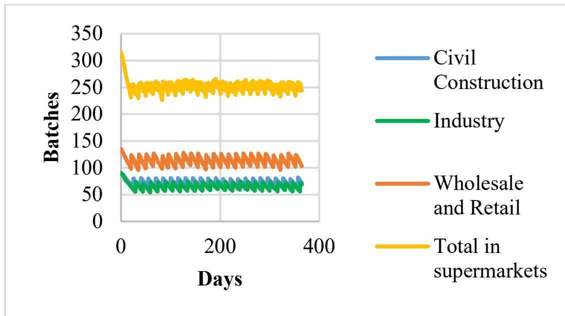

Figure 9. Strategy 3 - Supermarket level in customers

Regarding the supermarket level in the supplier, this does not present a margin to reduce the initial quantity, since it reaches the minimum of 7 batches during the simulation (Figure 10).

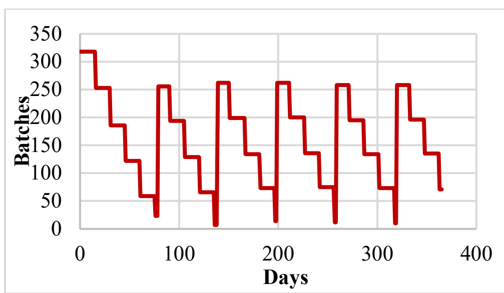

Figure 10. Strategy 3 - Supermarket level in the supplier

Comparing the three strategies, strategy 1 did not provide good results, as it presented a break in the service level for the “Industry” customer. Although this failure affects only 0.27% of the service level, this strategy does not present opportunities to decrease the initial inventory levels of customers and also in the initial supermarket of the supplier, not providing a lean supply chain. Strategy 3 presents a more conservative supply chain, as the supplier and customers have supermarkets to store finished products, providing 100% of the service level. However, this implies a higher cost due to the high quantity of items in the supermarkets in the entire supply chain. Moreover, in this strategy, there is only the possibility of reducing the initial inventory levels of customers. Nevertheless, even if this reduction is implemented, delivery times for this strategy will be higher than strategies 1 and 2, due to the higher quantity of supermarkets in the supply chain.

Thus, strategy 2 has shown to be the best possible choice for the investigated supply chain. In this strategy, service levels for the three customers reached 100% delivery. Although the lead times obtained are higher than in strategy 1, there is a margin for reducing the initial quantities of the product, which will lead to an overall decrease in supermarket levels in the chain and, consequently, to lower lead time values. In order to verify this hypothesis, a new analysis was conducted, where these initial values were systematically reduced until adjusting initial supermarket levels at the customers (Table 5). It is justified to propose values from different supermarkets since such supermarkets are not currently defined. Thus, if this strategy is implemented, the companies involved would be able to determine their initial levels.

Table 5. New supermarket parameters used in Simulation 2

Parameters for Strategy 2	Values
Initial finished goods inventory at the supplier	124 batches
Initial supermarket in customer 1 (Industry)	30 batches
Initial supermarket in customer 2 (Wholesale and Retail)	106 batches
Initial supermarket in customer 3 (Civil Construction)	62 batches

From the new simulation conducted, strategy 2 remained at 100% service level. The supermarket levels of the customers were compiled in Table 6 along with the values from the previous simulation, allowing for a comparison. Thus, it can be observed that there was a 44% reduction in the average of the total items in the entire chain, which leads to a lean supply chain. Figure 11 shows the behavior of the supermarket levels in the customers after the adjustment.

Table 6. Strategy 2 - Comparison of supermarket levels in customers

	Simulation 1			Simulation 2		
	Average (batches)	Minimum (batches)	Maximum (batches)	Average (batches)	Minimum (batches)	Maximum (batches)
Civil Construction	64.70	36	91	33,05	6	51
Industry	56.21	31	89	23,79	2	43
Wholesale and Retail	94.21	45	135	63,04	15	97
Total in the supermarkets	215.12	142	315	119,88	52	173

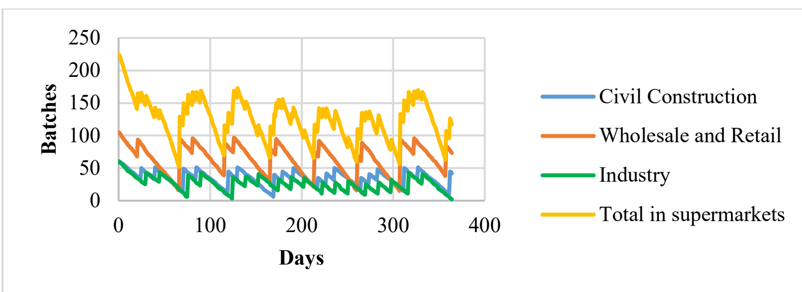

Figure 11. Strategy 2 - Supermarket level in customers (Simulation 2)

Regarding the level of finished goods inventory at the supplier, it remained similar to strategy 2 of the first simulation, since the initial quantity was not altered (Figure 12).

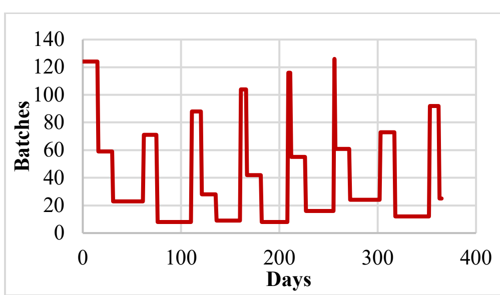

Figure 12. Strategy 2 - Finished goods inventory level in the supplier (Simulation 2)

Finally, about the lead time, there were reductions in the average values of 35%, 34% and 25% respectively for "Civil Construction", "Industry" and "Wholesale and Retail". Table 7 presents the minimum, maximum, and average values for the lead times obtained in Simulation 2 with the values resulting from Simulation 1.

Table 7. Strategy 2 - Comparison of lead times in customers

	Simulation 1			**Simulation 2**		
	Average (days)	**Minimum (days)**	**Maximum (days)**	**Average (days)**	**Minimum (days)**	**Maximum (days)**
Civil Construction	72.96	46.20	107.68	47.73	20.36	81.82
Industry	74.08	45.08	105.67	49.06	20.50	81.42
Wholesale and Retail	67.51	37.20	107.46	50.54	21.17	89.75

Thus, it can be concluded that the strategy with supermarkets in the customers is the most recommended for the investigated supply chain. This strategy satisfied the two indicators proposed to evaluate the impact of the "pull production" practice on the replenishment pull system, reaching 100% of service level and lead time lower than other strategies.

5. Conclusion

This paper proposes to identify the best strategy for the "pull production" practice, enabling greater operational performance in the supply chain supported by a simulation-based analysis. Thus, given the established parameters, the most appropriate strategy for the context of the supply chain in this research is the strategy with supermarkets in the customers. However, it is important to emphasize that, to implement any of the proposed strategies, it is necessary to establish a close relationship among those involved in the chain since partnerships are fundamental for enabling LSCM and achieving success in its implementation.

Two essential contributions can be highlighted from the results of this paper. First, of practical nature, is to establish a direction for managers on the impact that such practice can have on the operational performance of the supply chain. With the results obtained, it is possible to evaluate the proposed strategies and focus on the improvement efforts to allow the implementation of the best strategy. In addition, the proposed strategies can be adapted and replicated in the context of other supply chains, enabling leaders to obtain similar results comparable to those in this paper. Second, of theoretical nature, covers the identification of conceptual strategies related to the replenishment pull system, developing them from its adaptation enabling the modeling and simulation. The strategies generated allow understanding the different aspects of the implementation of the replenishment pull system to mitigate difficulties in its implementation and provide its sustainability in the long term. Therefore, this contribution provides decision support to supply chain managers and increases the body of knowledge in the area.

Some limitations of the presented paper should be highlighted. The application of the proposed strategies occurred in a supply chain of the metal-mechanic sector and its results cannot be generalized to other segments. Moreover, the analysis of the simulations refers to the period in which the data were collected and provided by the supplier-company. Therefore, the strategy identified is a proposal in the current supply chain situation. Thus, as future research, it is suggested the application of the proposed strategy in the supply chain of other segments to generate a comparison with the results obtained here. In addition, research that incorporates cost analysis into the strategies developed may support in choosing the best strategy, since the financial gains linked to the decrease in the quantities of items in the supermarkets would be evident. Finally, new research can introduce the use of other LSCM practices in the modeling and simulation developed, intending to investigate the impact that other practices can have on the operational performance of the supply chain.

Acknowledgment

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