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ARTICLE



Supply chain planning: a quantitative comparison between Lean and Info-Sharing models

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ABSTRACT

Both practitioners and scientists recognise importance of supply chain planning (SCP) for improving supply chain (SC) effectiveness and efficiency. Although many SCP policies have been developed in past decades, the debate on the best SCP model is still an open issue. This article compares Lean and Info-Sharing approaches as SCP models, with the aim of allowing a better understanding of pros and cons of each of them and to identify under which condition Info-Sharing is better, and when, on the contrary, Lean is better. To complete this objective, a broad simulation study has been carried out. The results show that Lean Supply Chain Planning model leads to huge inventory saving but, on the other hand, it requires greater transportation efforts than information-sharing-based SCP model. These opposite outcomes do not clarify which models is more efficient but, a set of indexes has been developed in order to solve the gap created by these discordant indications. Managers can use the proposed indexes to position their supply chain in the proposed multi-dimensional space, and see whether info-sharing or Lean is the best for them. A few examples of the use of the set of indexes and the results of the research are presented at the end of the article.

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KEYWORDS

Lean supply chain; supply chain planning; production control; inventory management; lean logistics; simulation

1. Introduction

In recent years, competition has moved from single firms to supply chains and the management of inter-organisational relations has acquired strategic importance (McCarter & Northcraft, 2007). There are many opportunities to improve performances in supply chains, as for example, reducing excess of inventories, backlogs, supply and transportation extra-costing (Lee, Padmanabhan, & Whang, 1997). Poor performances are mainly linked to the fact that players of supply chains have different goals, different ways to work, different thinking and, above all, each player aims at optimising its own performances (Barnes & Liao, 2012; González-Benito, Lannelongue, & Alfaro-Tanco, 2013; Lambert & Cooper, 2000). Such local pursue of improvement does not lead to an improvement of the overall system.

An important branch of research on SC performance improvement focuses on supply chain planning (SCP) (Ketchen & Hult, 2007; Kim, 2000). SCP is the way companies align

operations activities among different players of the supply chain (Holmström, Jonsson, & Holmström, 2016). SCP concerns inventory management and production control rules, and all decisions necessary for moving physical products and information along the SC (Wu, Yale, Xu, Chu, & Zhang, 2017). Several SCP models have been developed in order to improve performances in a supply chain (Yang, Pan, & Ballot, 2017), but the identification of the best approach is still an open issue (Holmström et al., 2016). In particular, many models have been built but few quantitative studies and less-structured comparisons between models are present in the literature (Smirnov & Gerchak, 2016). Therefore, there is not a clear understanding which conditions affect the relative performance of the different models, and when a model is better than another one.

This research work uses simulation to quantitatively analyse the performances of two different SCP models, one based on Info-sharing and the other one based on Lean approach.

The purpose of this research is to increase the knowledge of inner features of the two models and to identify the conditions where a SCP model is better than the other one, giving to practitioners and managers a complete framework which supports them on evaluating the characteristics of their SC and the SCP model that would give them the best performances.

Section 2 briefly provides a theoretical background of the two SCP models analysed, VIS-P and LEAN-P. Then, Section 3 describes the simulation experimental design to compare the two SCP models. Section 4 presents simulation results and Section 5 sets up the evaluation framework necessary for understanding which SCP models is better; finally, Section 6 concludes the article including managerial implications and future research directions.

2. Research background

2.1. Information-sharing-based SCP model (VIS-P)

During the recent years, the vast majority of SCP models considered Information Sharing the key element for improving SC performances (Yildiz, Duhadway, Narasimhan, & Narayanan, 2016). SC players communicate production plans, purchasing orders, customer orders and inventory levels to their SC partners in order to facilitate them in defining the timing of production orders and purchasing orders (Pan, Nigrelli, Ballot, Sarraj, & Yang, 2015). In such SCP models, players share private data about their inventories/orders/forecast with other SC players which often do not belong to the same holding firm (Dejonckheere, Disney, Lambrecht, & Towill, 2004). SC players have ‘visibility’ on activities of their supplier and/or customers and this allows to have the real-time monitoring of SC system, to anticipate final customer behaviour and to prevent criticalities that could happen in any point of the chain (Bartlett, Julien, & Baines, 2007; Caridi, Crippa, Perego, Sianesi, & Tumino, 2010; Francis, 2008). With SC planning model based on Info-sharing (VIS-P), firms improve their performances in terms of inventory reduction or of SC logistic costs reduction (Fisher, Cachon, & Fisher, 2000; Francis, 2008; Göksu, Kocamaz, & Uyaroğlu, 2015). So, as seminal papers in this research field showed, supply chain performance is improved by means of sharing data among SC members (Chen, Drezner, Ryan, & Simchi-Levi, 2000; Datta & Christopher, 2011; Lee, So, & Tang, 2000; Li, Ghadge, & Tiwari, 2016). But, in the last decades, VIS-P has been studied in depth, and here we present some main aspects analysed in SCP research stream (de Kok et al., 2018).

2.1.1. Type of shared information

In literature, it is possible to find VIS-P implementation with different types of shared information. The most part of research works studied impact of sharing information about inventory level: Kwak and Gavirneni (2011) showed the positive effect on SC efficiency of sharing inventory level and final demand data between retailer and supplier under different order policies (Kwak & Gavirneni, 2011). Bottani and Montanari (2010), studied the impact of inventory information sharing in several SC configurations and found that every SC with information sharing incurs in lower total costs than SC without info-sharing (Bottani & Montanari, 2010). Kumar et al. studied how a global manufacturer with many subsidiaries could improve SC performances by sharing information within whole supply chain network. The authors showed that, considering properly uncertain lead times and given order fill rates, an improvement of 3% in inventory level has been reached (Kumar, Yang, & Strike, 2015). Other authors analysed the impact of sharing information about demand forecast and trend (e.g. Angulo, Nachtmann, & Waller, 2004; Warren Liao & Chang, 2010; Zhu, Mukhopadhyay, & Yue, 2011) and they found that this decreases SC inventory carrying costs.

2.1.2. Information-sharing frequency

A different perspective in studying VIS-P was used in Datta and Christopher (2011). Authors studied the impact of information transmission frequency. They analysed SC performance change as information sharing frequency is increased. They defined SC members transmit data monthly, weekly, daily, instantaneously, and the authors found that increasing frequency of information transmission leads to total SC cost reduction (Datta & Christopher, 2011). In another research work, Grewal, Enns, and Rogers (2015) studied a SC which exploits information-sharing model and analysed the impact frequency of adjustment of data transmission and policy rule, such as order size and timing, to optimise replenishment system decision (Grewal et al., 2015).

2.1.3. Information reliability

With another interesting perspective other authors studied the impact of the reliability of shared information and demonstrated how information sharing has a negative impact on performance if the reliability degree of such information is low (Raghunathan, 2001; Zhao, Xie, & Leung, 2002).

VIS-P concept is to increase info sharing in order to better foresee and predict demand behaviour, optimising the production plan and hence minimising SC production/logistic costs (Costantino, Di Gravio, Shaban, & Tronci, 2015; Dominguez, Cannella, & Framinan, 2014).

2.2. Lean management-based SCP model (LEAN-P)

A total different approach is proposed by Lean management: while VIS-P approach aims at improving the capacity of the system to anticipate future demand behaviour, Lean approach aims at improving capacity of system of reacting to demand behaviour (Tortorella, Miorando, & Marodin, 2017).

Lean management is famous for its hunt against wastes and, nowadays, it is becoming more and more popular among different management positions such as SC managers (Jasti & Kodali, 2014, 2015). The core thrust of lean in SCP is to reduce wastes in order to create a

streamlined and highly efficient system that produces at customer demand pace (Shah & Ward, 2003). Differently from single firm planning, Lean in SCP needs to consider that the different links of the SC may be far off each other and have different ownerships (Tortorella, Miorando, & Tlapa, 2017). Lamming (1996) and Liker and Wu (2000) compared operations practices used along supply chains by lean Japanese automakers and not-lean automakers (Lamming, 1996; Liker & Wu, 2000). The practices of Lean Japanese automakers are: levelling production schedules, a disciplined system of delivery, handling mixed-load transportation, small-lot deliveries, encouraging suppliers to deliver only what assembly plant needs, helping supplier to develop their capabilities. Other authors analysed the impact on SC performances of adopting Lean principles in SCP: in an interesting work, Swenseth and Olson simulated continuous improvement implementation in SCP and compared it with different SCP models. Results showed that Lean-based SCP model (LEAN-P) leads to better performances than other SCP (Swenseth & Olson, 2016). An analysis of a supplier-manufacturer relationship in a LSC environment using simulation tool was presented by Frazzon, Tortorella, Dávalos, Holtz, and Coelho (2017). Authors compared two different supermarket configurations for the integration of information and material flows, aiming to understand scientific implications and the applicability of such kind practice to realistic cases (Frazzon et al., 2017). A similar simulation work carried out by Rossini and Portioli Staudacher, analysed in-depth the impact of implementing Pull and Flow principles in SCP and compared it with other SCP models in a multi-product SC (Rossini & Staudacher, 2016).

Despite the research done over the last years, quantitative works on SCP models are still scarce (Jonsson & Myrelid, 2016) and very few papers carry out a through comparison of different SCP models (Holmström et al., 2016; Prakash & Chin, 2014). Moreover, SC production planning and control literature, excepting some cases (Acar & Atadeniz, 2015), misses considering transportation performances (Olhager, 2013). In many cases, this is not a mistake, because the SCP models analysed are different on the timing of transportation but they do not differ in the structure transportation are done and so transportation costs result as not differential between SCP models (Georgiadis & Athanasiou, 2013; Ogier, Chan, Chung, Cung, & Boissière, 2015). However, when SCP are much different, transportation could have significant impact, as in the case of two 'distant' SCP models as LEAN-P and VIS-P.

Thus, there is not a clear understanding of the full potential of Lean SCP model in improving SC performances (Swenseth & Olson, 2016; G. L.Tortorella et al., 2017) and, in general, there is not a clear understanding on which SCP model works better in which conditions. There is no agreement on what is the best SCP model for improving SC performances.

Therefore, this research aims at comparing systematically LEAN-P model with VIS-P model, observing storage performances and enlarging the study even to transportation performances in order to understand which is the set of conditions where LEAN-P performs better and the one where VIS-P performs better.

In order to achieve these research objectives a simulation study has been carried out and a framework has been provided.

3. Experimental design

To reproduce the dynamic behaviour of the supply chain and the decision models explained in the next paragraphs, we construct discrete event simulation (DES) models

in Rockwell Arena 14.0 (Kumar et al., 2015). DES is suitable for modelling and simulating the systems with non-linear relationships and supports managers to evaluate difficult decision in huge and complex systems such supply chains (Ramanathan, 2014; Terzi & Cavalieri, 2004). The model used in the simulation study is kept as simple as possible to avoid any noise that might cloud the sight on causes and effects.

3.1. The supply chain model

We chose a three-echelon supply chain rather than the much commonly studied two-echelon one, because three-echelon SC allows to understand the combined upstream and downstream effect of an action and because three echelons is closer to realistic SC of nowadays (Bottani & Montanari, 2010; Costantino et al., 2015; Xiang & Rossetti, 2014). For most of other characteristics, as single stage structure, production capacity constrain, transportation lead-time and lot-sizing, we have adopted common assumptions in inventory control literature (e.g. Gavirneni, 2002; Gavirneni, Kapuscinski, & Tayur, 1999; Kwak & Gavirneni, 2011). As showed by Figure 1, both supplier and manufacturer stages are composed by an input warehouse, a single-resource production phase and an output warehouse. Because of the intention to provide useful insights to practitioners, production resources have a limited capacity (Datta & Christopher, 2011; Tako & Robinson, 2012; Xiang & Rossetti, 2014).

An infinite stock in the supplier's input warehouse is assumed and production systems are not affected by failures. Retailer stage is composed just by a warehouse. Every day, final customers demand finished product to the retailer that has to satisfy it by delivering from stock (Make-To-Stock logic). If retailer does not satisfy demand before the end of the day, stock-out is recorded and the order goes in back-log.

3.2. SC planning models (experimental variables)

3.2.1. Economic order quantity: EOQ-P

In this model all SC players order the fixed amount of Q whenever their inventory level reaches or falls below r , (Q,r) policy (Chen, 1998; Gavirneni, 2002; Kwak & Gavirneni, 2011). When inventory-position at a warehouse decreases below a certain threshold (reorder point), an order is placed to upstream. If it is an output warehouse, the order is a production order and goes to the production resource queueing for the production of a batch. In all the other cases, the order is a shipping order from the warehouse upstream. Order-size and reorder point could be different for each warehouse, but they are fixed during the single replication. Inventory position is calculated as:

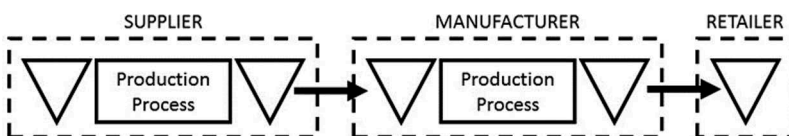


Figure 1. SC structure.

$$\text{Inventory position} = \text{inventory level} + \text{ordered items but none arrived} \\ - \text{backlog orders}$$

In this research work as EOQ-P, we replicated the model (Q,r) presented by Gavirneni (Gavirneni, 2002; Kwak & Gavirneni, 2011).

3.2.2. *Info-sharing: VIS-P*

Sharing information along the supply chain allows to take better decisions. With VIS-P every stage has visibility over inventory position of downstream stage and can take advantage of that (Chen, 1998; Gavirneni, 2002; Gavirneni et al., 1999; Kwak & Gavirneni, 2011; Zhu, Gavirneni, & Kapuscinski, 2009). With this SCP model, once the upstream stage receives an order, it continuously checks downstream stage inventory position and postpone the order until downstream stage inventory position goes below a threshold. By means of this information, a stage is able to optimise production order or purchasing order timing and so to reduce inventory levels. In this research work as VIS-P, we replicated the best performing model with information sharing presented by Gavirneni (Gavirneni, 2002; Kwak & Gavirneni, 2011).

3.2.3. *LEAN-P*

Referring to five lean principles proposed by Womack and Jones (Womack & Jones, 1996), for this research work it has been decided to focus on 'pull' and 'flow'. 'Pull' principle is applied through adopting a Kanban system implementation in all SC stages. 'Flow' principle aims at a flow as smooth as possible, without any kind of interruption. 'Flow' principle is implemented through batch-size and setup time reduction. Lean-100% is LEAN-P model with just pull principle implemented, for implementing flow principle improvements we tested a reduction to 60% of setup time with a connected reduction to 60% in batch size (Lean-60%) and a reduction to 20% (Lean-20%).

3.3. *Experimental parameters*

Supplier and manufacturer stages have finite production capacity (Chen & Gavirneni, 2013; Kwak & Gavirneni, 2011; Prakash & Chin, 2014). Moreover, supplier is not fully dedicated to this SC so every day a variable amount of capacity is available for this SC (65% on average). Processing times and demand rates have been defined so that manufacturer and supplier have a saturation of 80% and the batch size equal to 150 items (Kwak & Gavirneni, 2011). An infinite number of trucks are available to transport finished and semi-finished products (de Kok et al., 2018). Each single truck has a limited transport capacity (equal to 450), and lead-time to transport an item to the next stage is constant: full truck load (FTL) trips leave the stage at the end of the day and shipped items are available to the next stage 2 days later, at the beginning of the day. Less than full truck load (LTL) trips are possible, however the minimum truck capacity saturation is 50%. If the saturation does not satisfy this threshold, the shipment is postponed to the following day: if it is possible, there is a consolidation with next day shipments, thus increasing truck saturation. In case there are no shipments to consolidate, the truck leaves anyway, disregarding its saturation level.

Like in most SC simulation works, daily demand follows a normal distribution with a mean of 384 demanded items per day (de Kok et al., 2018). Many papers demonstrated the relevance of demand variability in SC planning policy performance (Kwak & Gavirneni, 2011; Viswanathan, Widiarta, & Piplani, 2007). Therefore, three different level of demand variability have been studied (coefficient of variability equal to 0.4, 0.6, 0.8) (Datta & Christopher, 2011; de Kok et al., 2018; Kwak & Gavirneni, 2011). The single run-length is 2050 days or 410 weeks and includes a warm-up period of 50 days, which statistics are discharged (Law & Kelton, 1991).

3.4. Main performance measures

3.4.1. Inventory level

Inventory level is the sum of all stocks along the supply chain and it is the performance target considered in all SCP papers (Chen & Gavirneni, 2013; Datta & Christopher, 2011; Frazzon et al., 2017).

3.4.2. Transportation performance

Transportation performance is based on the total number of trips necessary to move items along the chain. In this research work, we count separately LTL and FTL trips. This an innovative element in the literature of SC planning, that is scarce in considering transportation performances in general. We decided to introduce this feature because the different use of LTL or FTL could give a relevant impact on the final cost.

3.4.3. Service level

The service level of the SC is measured considering the mean of service levels considering all warehouses (but supplier input warehouse). The single warehouse service level is measured by the percentile number of days without stock-out over the total number of days in the simulation period.

3.5. Plan of the experiments

The simulation plan is a full factorial that derives from the combination of the experimental parameters such demand coefficient of variability (cv) (3) and the values of experimental variables (5). One of the aims of the authors is to analyse the impact of SCP at several service levels. Service level is an output of the simulation and it is affected by the reorder point value of each stage while EOQ-P or VIS-P are adopted, and by the number of Kanbans at each stage while LEAN-P is adopted. Thousands of combinations of reorder points and number of kanbans have been tested in order to get several values of SC service level (15 SC service levels between 92% and 99%), empirically changing value of reorder point (or the number of Kanban) of a stage to reach a stable service level along the chain. Initially, a very high reorder point had been set to assure a service level of 100%. Then, run by run, single values of reorder point (or number of kanbans) have been reduced little by little to decrease service level values. The simulation model adjusts automatically, run by run, values of such parameter in order to get SC service level that is close to service level target with a tolerance of $0/+0.1\%$. This leads to analyse 225 scenarios. To have a good confidence on the results, at least 10 replications per scenarios have been collected. Table 1 summarises the plan of experiments of this study.

Table 1. Plan of experiment.

Experimental parameters	Saturation	80%		
	Demand cv	3 levels [0.4;0.6;0.8]		
	Service level	15 levels [From 92% to 99%]		
Experimental variables	SC policy	EOQ	VIS	LEAN
	Setup time and batch size	1 level [100%]	1 level [100%]	3 levels [100%;60%;20%]

4. Results

This section describes and discusses the results of the simulation study.

4.1. Inventory level

An overview of inventory levels for different SC planning policies at different service levels is presented in Figure 2.

VIS-P shows inventory levels lower than EOQ-P for each service level tested: on average VIS-P saves 15% of inventory; the greatest inventory saving is in low service level contexts (23% of inventory saving) and the minimum saving (6,5%) is in high service level context. As service level increases, VIS-P savings decreases. VIS-P inventory reduction over EOQ-P in 99% service level context is similar to the reduction presented by Gavirneni (Gavirneni, 2002), where VIS-P performance has been studied in a 100% service level context.

Lean-100% leads to greater inventory savings than VIS-P: on average Lean-100% needs 33% less inventory than EOQ-P at same service level. Lean-100% savings are between 29% and 38%: the lowest saving is at low service level and high savings are reached in medium-high service levels context.

It is worth noting that not only Lean-100% requires less inventory than VIS-P but, as service level requirements increase, the advantage of LEAN-P over EOQ increases, while the one of VIS-P decreases.

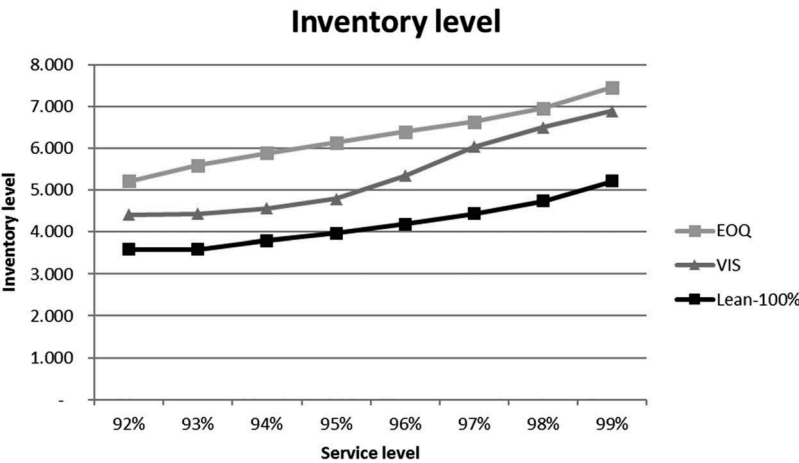


Figure 2. Inventory level of SCP models.

The LEAN-P inventory level curve depicted in [Figure 1](#) is the effect of pull system (Kanban) implementation along the SC (Lean-100%). [Figure 3](#) shows the impact of flow (setup time and batch-size reductions) on SC inventory level.

Simulation results show that setup and batch-size reduction lead to much lower inventory levels. An initial 40% batch-size reduction (Lean-60%) leads to an average of 34% inventory saving compared with Lean-100% inventory level, a further batch-size reduction (Lean-20%) adds an average of another 14% inventory saving. Reducing the batch size from 100% to 20%, the total stock decrease is 48%. The setup time and batch-size reduction always lead to inventory savings, but reductions effects are not linear with setup time reduction. Moreover, the greater setup and batch reduction the smaller the need of additional inventories to improve service level. Considering the comparison between EOQ-P and LEAN-Ps, the LEAN-P that uses the batch size equal to EOQ-P size (Lean-100%) has minimum inventory saving equals to 29% and the maximum equals to 38%, the LEAN-P with the greatest setup time and batch-size reduction (Lean-20%) achieves inventory savings between 56% and 68%.

Simulation results clearly show that both VIS-P and LEAN-P lead to inventory level improvements. But, LEAN-P achieves better results.

To deepen the value of this statement, we analysed impact of LEAN-P in different demand variability conditions. Regardless demand variability level tested LEAN-P always leads to inventory savings vs VIS-P and this saving increases while demand variability increases as showed in [Figure 4](#).

In low variability context, LEAN-P inventory saving vs VIS-P is lower than 22.0%, while in the high variability context it increases to 23%. This saving grown could appear little looking only at the relative percentage, but absolute values of LEAN-P inventory savings vs VIS-P (columns in [Figure 4](#)) increased of 40% while demand variability increased from $cv = 0.4$ to cv equal to 0.8. In few words, when final demand variability increases there is a general increases of the inventory level along the SC regardless the SCP model adopted.

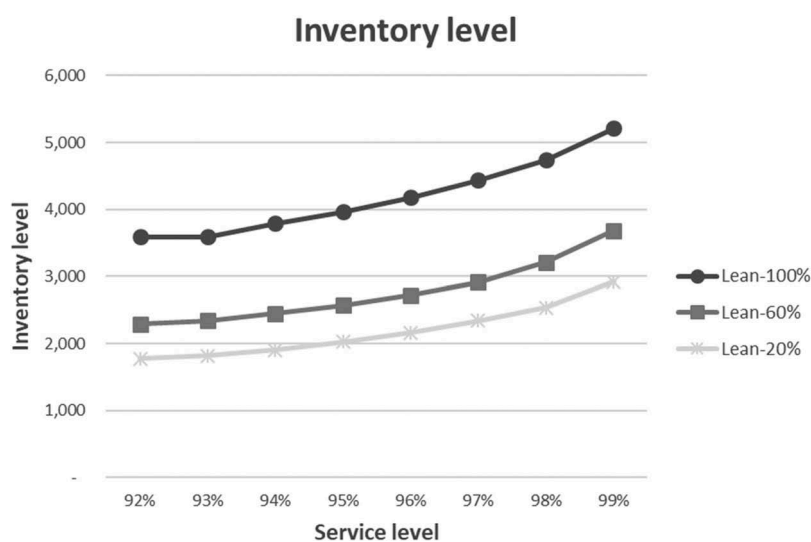


Figure 3. Inventory level for different level of LEAN-P.

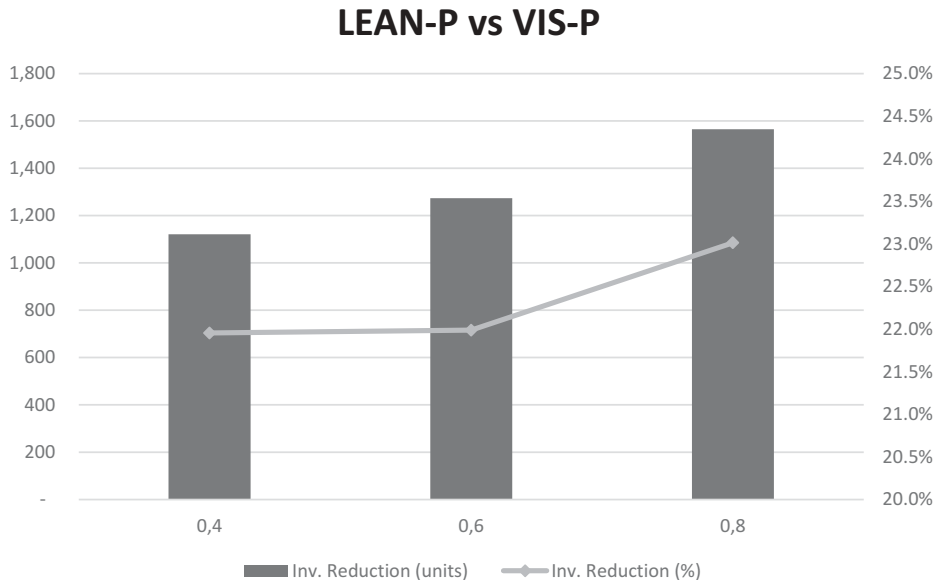


Figure 4. Inventory level savings of LEAN-P vs VIS-P.

However, inventory level grows less with LEAN-P than with VIS-P. According to this, we can state that LEAN-P appears as more robust on demand variability than VIS-P.

4.2. Transportation performance

Most research works on SCP do not take transportation performances into account and focus on inventories reduction, but in external SC, transportation costs could impact heavily on SC efficiency. An overview of transportation performances for the different SC Planning models analysed is presented in [Figure 5](#).

The overall average trucks saturation of VIS-P and EOQ-P is 92%, the average truck saturation only for LTL trips is 61%. The overall average trucks saturation of LEAN-P is 85%, the average truck saturation considering only LTL trips is 58%. The difference between VIS-P and EOQ-P is not statistically significant (p -value = 0.57). On the contrary, LEAN-P uses on average 7.8% trips more than VIS-P and EOQ-P. LEAN-P leads to a great increase in the number of trips: introducing pull and batch-size reduction LEAN-P increases orders frequency and the result is a larger number of trips.

5. Comparison framework and discussion of results

SCP models manage and control flows of information and items which direct impact on SC logistic cost (Swenseth & Olson, 2016; Tako & Robinson, 2012), therefore aim of managers is to identify the SCP model that guarantees the lowest logistic cost for their SC.

Simulation results show that, when LEAN-P is implemented, inventories level is lower than other SCP models are implemented. On the other hand, when LEAN-P is implemented, the number of supply transportation trips increases.

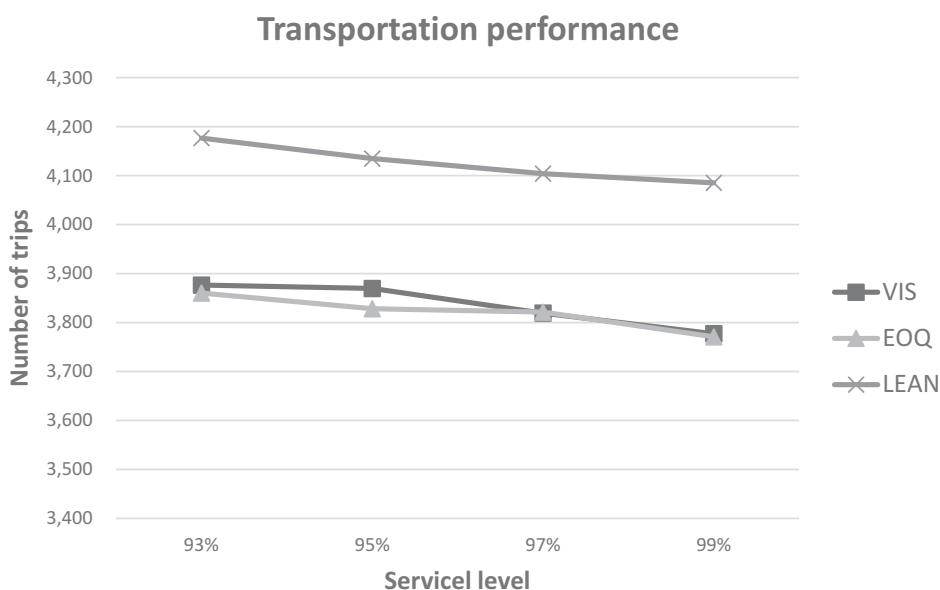


Figure 5. Transportation performances.

Having inventories and transportation contrasting effects, it is not clear which is the SCP model with the lowest overall cost. However, there is not a commonly adopted method to model the transportation costs. Therefore, in this article, we propose a framework that models transportation costs considering the different use of FTL or LTL transports, in order to support managers on positioning their SC in the right area and on choosing the most appropriate SCP model.

SCP model regulates production control and inventory management along the SC, so it affects SC logistic costs connected to inventories and transports.

$$\text{SC logistic cost} = \text{SC inventory carrying costs} + \text{SC transportation costs}$$

The SC inventory carrying cost is computed as:

$$(\text{Average inventory level}) * (\text{UICC})$$

The unit inventory carrying cost (UICC) is the unitary cost rate per year that considers different costs related to product storage: capital cost, obsolescence cost and warehousing cost (Fisher et al., 2000).

However, computation of SC transportation cost is quite complicated, because there are many different cost structures among logistic providers.

In [Figure 6](#), the graph supports managers on understanding which SCP is better for their SC according to the lowest SC logistic cost.

The graph depicts different contexts giving two dimensions: shipment cost, on the horizontal axis, and the UICC, on the vertical axis. The curve represents the boundary/condition where LEAN-P is equivalent to VIS-P assuming that company pays a fixed cost per shipment, regardless the number of items sent. According to these two dimensions, a manager will be able to position their company's SC and to understand

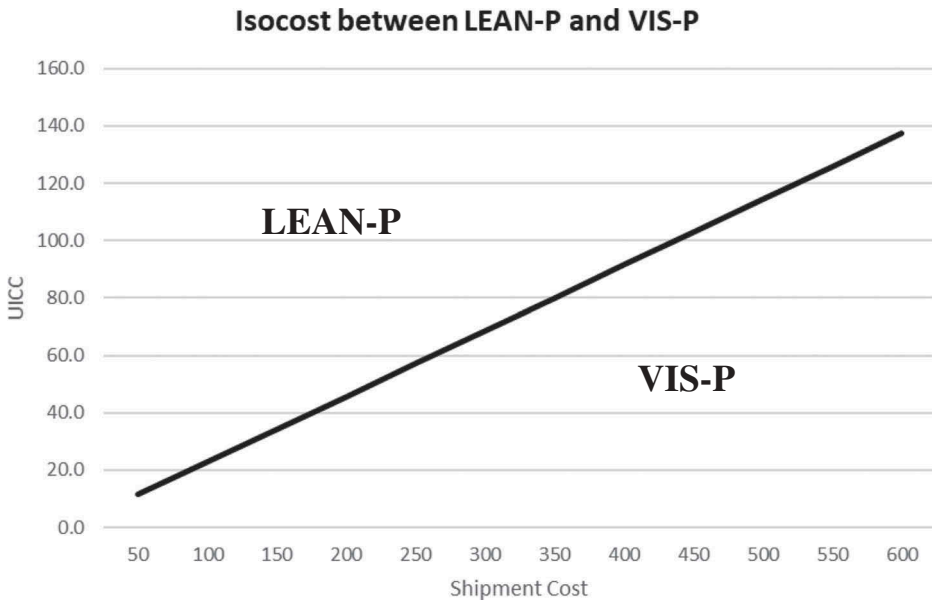


Figure 6. Isocost curve between LEAN-P and VIS-P;

which SCP leads to the lowest SC logistic cost: while the SC is positioned above the curve, LEAN-P is better, while SC positioning stays below the curve, VIS-P is better than LEAN-P.

To further analyse this aspect, we investigated how manager decision could change under a different transportation cost framework where managers pay transportation according to the number of items shipped and so, concept of unit shipment cost (USC) is introduced. USC is the average shipment cost per unit assuming a FTL trip.

$$USC = \frac{\text{single shipment cost}}{\text{truck capacity}}$$

Both coefficients (UICC and USC) are strictly connected to the context, so they are different from SC to SC. A piece moved via FTL costs USC. A piece moved via LTL costs $USC \cdot (1 + \beta)$. β is the average percentage of cost increasing which companies pay for moving an item through a LTL trip instead of a FTL trip. This modelling is close to the groupage rates that logistic providers give to companies. According to this transportation cost structure the SC transportation cost is:

$$FTL_{\text{pieces}} * USC + LTL_{\text{pieces}} * (USC) * (1 + \beta)$$

Adopting this transportation cost structure, a comparison between LEAN-P and VIS-P is presented in [Figure 7](#).

$$\beta = 0\% \quad \beta = 0\% \quad \beta^*$$

Similarly to [Figure 6](#), the graph in [Figure 7](#) depicts different contexts giving two dimensions: the UICC, on the vertical axis, and unit shipment cost, on the horizontal axis, which gives the difference from the graph in [Figure 6](#). The curve

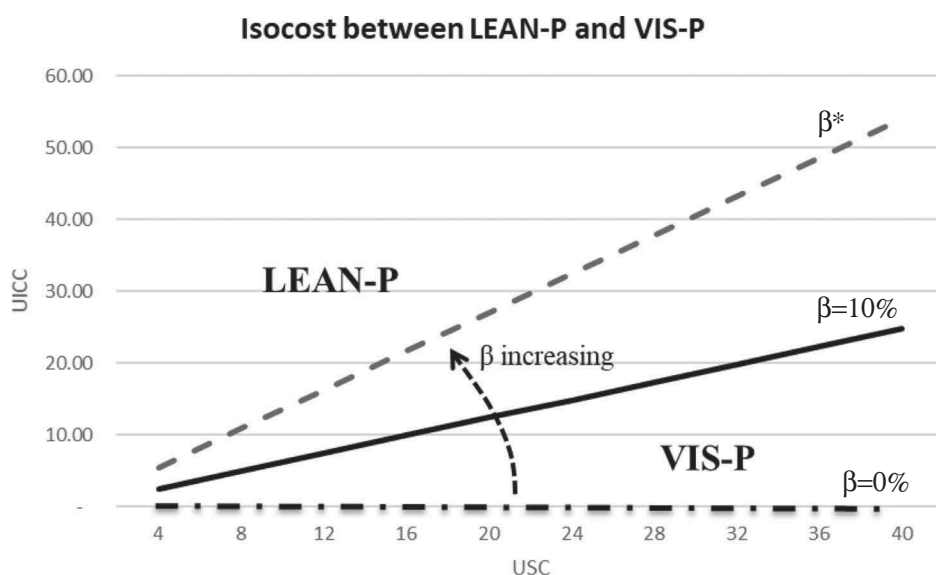


Figure 7. Different Isocost curve with different β values.

represents the boundary/condition where LEAN-P is equivalent to VIS-P assuming that company pays a cost per unit shipped, that is different if the unit is shipped in a FTL trip or in a LTL trip. According to these two dimensions, a manager is able to position its SC and to understand which SCP leads to the lowest SC logistic cost: while the SC is positioned above the curve, LEAN-P is better, while SC positioning stays below the curve, VIS-P is better than LEAN-P. Of course the penalty (β) has an impact on the slope of the isocost curve and boundaries where a SCP model is better: when β is equal to zero there is no cost difference between moving items through an LTL or an FTL trip, so each unit has the same transportation cost thus the overall transportation cost is not differential between LEAN-P and VIS-P and can be disregarded. Under such conditions, LEAN-P results always the best choice for SC managers. Instead, while β increases, the slope of the curve increases and area where LEAN-P is less performant than VIS-P increases. Nevertheless, there is an upper limit on the slope of the isocost: if β is too high, a company has advantage on buying a trip instead of negotiate a price based on the number of units shipped. Hence the upper limit of the isocost curve is the isocost curve that is represented in Figure 7 by β^* and corresponds to the isocost curve represented in Figure 6, where companies pay the trip of the truck the same amount regardless of the number of units loaded.

Previous frameworks show which SCP model is better in different context, but do not show the magnitude of the benefits. In order to do this, a new parameter μ is introduced to describe with a single value the relative weight of the UICC and USC in the cost analysis.

$$\mu = \frac{USC}{UICC}$$

μ represents the proportion between transportation cost and inventory carrying cost for a single item. The μ parameter could refer to a single product, but it could represent a group of products which belongs to the same flow along the supply chain. In this case USC and UICC values, which build up μ parameter, are approximated by the weighted average of USC and UICC values of the different products considered in the flow.

The higher the μ value, the higher the transportation relative impact on SC logistic cost.

Adopting μ parameter, it is possible to estimate the magnitude of the benefits of adopting a SCP model. In fact, a manager could estimate benefits according to μ , which describes the context, and according to β , which describes the transportation cost as showed in Figure 8.

In Figure 8 there is an average SC logistic cost saving implementing LEAN-P over VIS-P. These values do not consider detail as the service level desired and the level of LEAN-P implementation. But, using the above-described model, we can analyse the performance of LEAN-P vs VIS-P. For example, with a service level of 98% and a β of 25%, Figure 9 shows overall SC logistic cost savings of LEAN-P vs VIS-P as a function of μ .

For low values of μ , LEAN-P gives larger benefits. As μ increases, LEAN-P benefits decrease as for the fixed cost per trip case. The sensitivity of Lean to μ increases as setup time and batch size are reduced. According to this, it is not possible to state that batch-size reduction leads always to a better performance.

The cause of this is the transportation costs structure: the batch-size reduction does not change significantly the number of trips necessary to satisfy the demand but changes the proportion between pieces moved by FTL trip and pieces moved by LTL

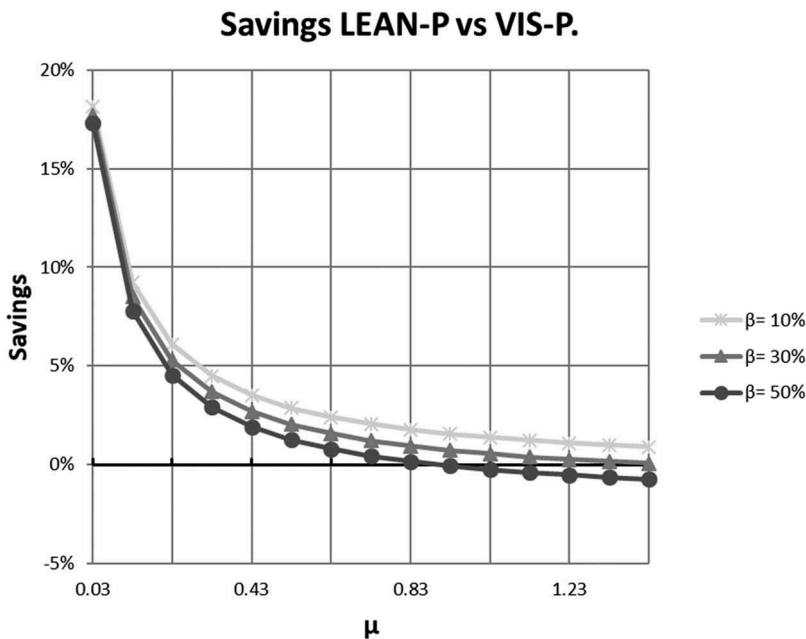


Figure 8. Saving of LEAN-P over VIS-P with different β values.

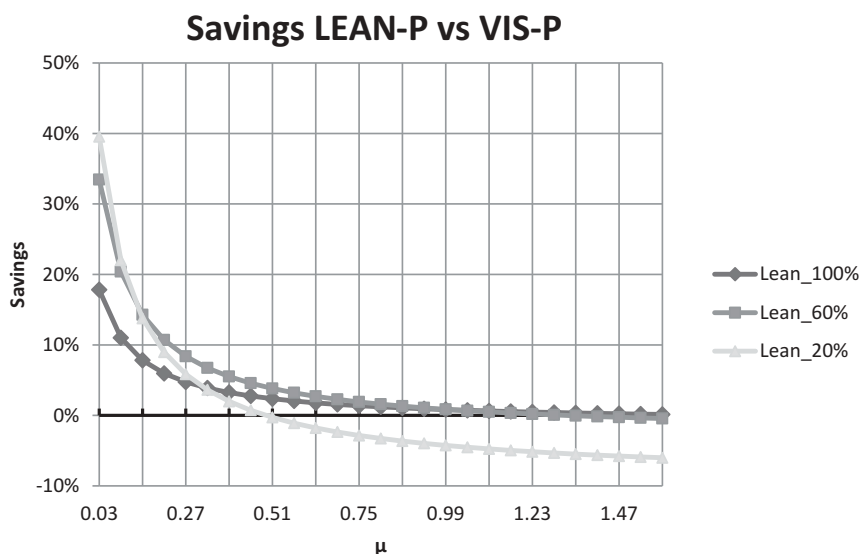


Figure 9. Saving of LEAN-P over VIS-P with different Lean levels.

trips. Lean-100% moves 77% of pieces by FTL transports, Lean-60% 70% and Lean-20% 45%. When transportation cost is proportional to the number of trips the batch-size reduction is not relevant for transportation cost and all LEAN-Ps are comparable. While the type of trip influences the transportation cost, batch-size reduction is relevant because the higher the batch-size reduction the higher the percentage of the pieces moved by LTL trip. The μ isocost value is different for the three LEAN-Ps: the greater the batch-size reduction, the more intense the μ value impact on savings.

6. Conclusion

For many years SCP literature focused on improving performances through increased visibility along the SC and by developing more and more sophisticated algorithm to make use of information available through such visibility. Lean management is a totally different approach which does not require extended visibility, rather a change in perspective and in the direction of the investments done in operations. This research work is giving a first answer on whether Lean approach is better than visibility, under what conditions, and why; thus giving researcher and practitioners a better understanding of the functioning of the two approaches and when one is giving better performances than the other one.

As expected, LEAN-P is the most effective policy in reducing inventory level, but an interesting insight was that the advantage over EOQ-P and VIS-P increases as the desired service level increases. Moreover, LEAN-P advantage over VIS-P increases as demand variability increases. This shows that LEAN-P is better than VIS-P to reduce inventory level when conditions are tougher.

However, LEAN-P leads to an increase in the number of delivery trips, which can yield an increase in the transportation costs.

Most research works on SCP do not take into consideration transportation cost, or they do considering a constant transportation per unit that makes the overall transportation cost the same for all models. In this article, we analysed also transportation cost performances considering three different options for transportation cost, representing three different conditions: (i) a totally constant cost per unit: i.e. a cost per unit shipped that does not depend on how many units are per shipping; (ii) a fix cost per trip: i.e. a cost per shipment that is independent from the number of unit shipped (as long as they do not exceed truck capacity, otherwise more than a truck is used and paid); (iii) a mix of the two, considering different cost per unit if the shipment is a full truck, and a higher cost per unit if the quantity shipped does not completely fills the truck.

When the transportation unit cost does not depends on the quantity shipped, LEAN-P is better than VIS-P under all tested conditions.

When the transportation unit costs depends on the quantity shipped, the advantage of LEAN-P decreases as the unit cost for shipping a quantity less than truck load increases and increases as the UICC increases.

In order to give a practical idea of LEAN-P potential benefit, some numerical examples are presented in Table 2, obtaining UICC and USC values from case studies present in literature which treat SCP but without comparing different SCP models,

i.e., assuming β value equal to 20% and taking values of UICC and USC used in the research work on visibility carried out by Ogier et al. (Ogier et al., 2015), LEAN-P leads to 3% savings on total SC logistic costs compared to VIS-P.

Similarly, Fattahi, Mahootchi, Hussein, Keyvanshokoh, and Alborzi (2015) presented a simulation study on different replenishment policies (Fattahi et al., 2015). According to simulation study description, it is possible to obtain UICC and USC values and estimate that LEAN-P adoption would lead to 14% SC logistic cost savings over VIS-P. In another research work, Swenseth and Olson (2016) simulated a manufacturing SC where LEAN-P is adopted in order to measure the impact of continuous improvement program (Swenseth & Olson, 2016). According to USC and UICC parameters from their study, LEAN-P implementation leads up to 9% SC logistic costs saving. Bozorgi et al. tested the impact of different replenishment policies in the cold SC (Bozorgi, Pazour, & Nazzal, 2014). This case study of Bozorgi et al. is an example where LEAN-P is less profitable than VIS-P: LEAN-P SC logistic cost results 2% greater than VIS-P SC logistic cost.

These examples clearly show that LEAN-P adoption is not always the best option and the results of the research presented in this article can help in better deciding which SCP model to adopt.

Table 2. Numerical examples from literature.

Research work	Industry	Saving of LEAN-P vs VIS-P
Ogier et al. (2015)	Academic study	3%
Fattahi et al. (2015)	Academic study	14%
Swenseth and Olson (2016)	Manufacturing	9%
Bozorgi et al. (2014)	Cold SC	-2%

7. Future implications

This article represents an important step forward in understanding impact of using different SC planning models, and a reference to identify which approach to use depending on the conditions. In order to do that, a structured framework for comparison and evaluation of SCP models under different conditions has been provided, in particular including external transportation costs. However, future research should build on this contribution. First, further improvements in shipment rules may allow LEAN-P to improve its transportation performance. In this simulation study, a simple general shipment rule of a minimum truck saturation has been applied. Further studies could analyse more complex rules that can increase efficiency of transportation, as milk-run or compound deliveries. Second, a simulation study on a multi-product SC could lead to more insights on the potential of lean approach adoption along the SC. Third, this study investigated practices focusing on ‘pull’ and ‘flow’ principles and further improvements can be achieved by considering also other aspects, linked to other principles.

Disclosure statement

No potential conflict of interest was reported by the authors.

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