Profiling the Resilience of the Blood Supply Chains: Lean Versus Agile

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Abstract

The Blood Supply Chain (BSC) deals with multi-dimensional complexities, primarily caused by its very perishable nature and the substantial variability at the demand and supply sides. Coherently, BSCs are often expected to be agile; however, blood quality could be better addressed by adopting a lean strategy. Since the resilience of BSC is paramount for the continuity of healthcare service delivery, the present research performs a systematic assessment of the resilience characteristics of BSCs, in routine and emergency scenarios, according to different SC strategies. To this end, a game-based approach, with the aid of discrete-event simulators, is adopted.

Keywords: Supply Chain Strategies, Resilience, Blood Service

Introduction

The blood supply chain (BSC) extends across the phases of the blood donation (supply side) up to the phase of transfusion of blood components and delivery to patients (demand side) (Stanger et al., 2012). The BSC emerges as a relevant area of research in operations management due to its particular characteristics, where the population's health is tightly linked to its efficiency and effectiveness (Jabbarzadeh et al., 2014; Fahimnia et al., 2017). The continuity of blood service therefore becomes fundamental to national healthcare systems, in which the preservation of the population's health relies on the technical capability of the hospitals to provide the blood products with up to date processes, high quality standards and at an uninterrupted service level (Beliën and Forcé, 2012; Katsaliaki et al., 2014).

The scene of blood supply chain involves high levels of operational complexity that is primarily driven by the tight quality and safety regulations for both products and processes. Such complexity is augmented considering the highly perishable nature of blood products and their limited shelf life, so do they have high vulnerability to physical alteration and, as such, need to be carefully handled and stored (Zhou et al., 2011; Duan and Liao, 2014; Sarhangian et al., 2017). The configuration and strategy of BSC is particularly challenging in view of its institutional mission of maintaining high resource-efficiency, coupled with high effectiveness and waste elimination (Fahimnia et al., 2017). There is a growing body of research investigating different supply chain strategies for managing blood services (see e.g., Katsaliaki et al., 2014; Fahimnia et al., 2017). In the supply chain domain, the lean, agile and hybrid *leagile* supply chain strategies are often investigated. On the one hand, the primary focus of lean supply chain concepts, as in Lamming's (1996) study, is cost-efficiency. On the other hand, Lee (2004) emphasises the agility dimension, in which supply chains need to be adaptable and aligned to ensure matching demand with supply under different conditions of demand volatility and variability. Subsequent to the emergence of lean thinking and agile manufacturing concepts, many supply chain researchers (see e.g., Naylor et al., 1999; Aitken et al., 2005) argued that lean and agile are not mutually exclusive concepts, rather they can be complementary. Fugate et al. (2010) argue that organisations who focus simultaneously on efficiency and effectiveness reach superior performance. They demonstrate this idea through the models of Dell Computers and Zara, where it is very difficult to categorise their strategy as purely efficient or effective. They argue that embedding efficiency and effectiveness and differentiation as performance dimensions lead to improve the organisational performance.

By embracing Lee's (2004) concepts on adaptability, resilience emerges as a capability that potentially combines the benefits of both lean and agile strategies to address the management and design of BSC. Supply chain resilience aims at increasing flexibility, creating redundancy (spare capacity and inventory, multiple suppliers and facilities), forming collaborative relationships, and improving agility (Tukamuhabwa et al., 2015). Though resilience is linked to agility while lean concepts often record success in stable environments, however, some synergies are identified in empirical studies in extant literature between lean practices and the operational resilience performance improvement, especially in times of disruption and in high-uncertainty environments (Birkie, 2016).

Considering the outlined multifaceted and potentially conflicting objectives of BSC, some beneficial insights can be drawn from investigating the lean and agile supply chain strategies in managing blood services. The purpose of the present research is to systematically assess the resilience performance of both the agile and lean strategies in two scenarios: routine, and emergency conditions. To this end, the paper poses the following research question; *How do different supply chain strategies shape the resilience performance of BSC?* The paper employs a game-based approach, in which a researcher plays the role of a supply chain planner. As such, the research process created a reality-based game that allowed a quantifiable measurement of the performance variations generated by the two BSC strategies. Our investigation is performed referring to the blood service delivery system of Lombardy region (Italy), that was carefully selected to be the location of this investigation since it manages up to 20% of Italy's entire blood volume (approximately 450.000 units/year).

Theoretical Background

Blood Supply Chain Management

The BSC encompasses production and storage activities, these extend across: donor recruitment and blood collection, laboratory testing of blood donations for standard infection markers, production of standard cellular blood components and special cellular components (e.g., blood stem cells), storage, and pre-transfusion testing and distribution to the ordering wards (Osorio et al., 2015). The clinical activities, of BSC, include patient blood sampling and transfusion. Multiple actors can be involved in the BSC depending on the activities performed. Whilst the clinical activities are primarily performed by the hospital transfusion services or single wards. The production activities are carried out by different actors, according to the blood service model adopted by different national or regional health systems.

In the USA and most European countries, blood banks (or blood establishments) are responsible for the collection, testing, processing, storage and distribution or disposal of blood and blood components (Faber, 2007). The hospital blood banks are responsible for pre-transfusion testing, storage and management of blood stocks, distribution and issue to the ordering wards or disposal. Meanwhile in other countries, among which is Italy, both the production and clinical activities are carried out by hospital transfusion services (Seidl et al., 2007). Referring to both organizational and institutional aspects three different models can be identified; (i) national centrally-managed organizations (by the Red Cross or a local government) with big blood banks, (ii) decentralized organizations, where hematologic centers are localized in hospitals, and (iii) Hybrid organizations.

Blood Supply Chain Resilience

Resilience is a concept discussed in several different domains (Birkie et al., 2014) and can be defined as the *"adaptive capability of the supply chain to prepare for unexpected events, respond to disruptions, and recover from them by maintaining continuity of operations at the desired level of connectedness and control over structure and function"* (Ponomarov and Holcomb, 2009). Resilience is investigated from different perspectives in literature. There are two key forms for its conceptualisation, first by considering the core functions of the disruption profile: sense, build, reconfigure, sustain and re-enhance, or second, by focusing on its constituents and formative elements such as flexibility, velocity, visibility and collaboration (Johnson et al., 2013; Jüttner and Maklan, 2011; Tukamuhabwa et al., 2015).

Noticeably, the research on BSC resilience in extant literature is sparse. Given its peculiar characteristics and strategic importance (Stanger et al., 2012), ensuring the resilience of BSC becomes a key for the quality and sustainability of the delivery of national healthcare services (Williamson and Devine, 2013). Responding to disruptions, generated by unexpected disruptions and multiple threats, augments the complexity of managing the BSC (Jabbarzadeh et al., 2014, Müller et al., 2015, Jittamai et al., 2014). The performance of BSC faces multiple risks as sources of variability, uncertainty and vulnerability to disruption of both the demand and supply sides (i.e. the patients and donors) (Buyx, 2009, Farrugia et al., 2010). As such, developing resilient strategies, combining proactive and reactive countermeasures, becomes a cornerstone in managing the BSC.

Research Design

Methodology

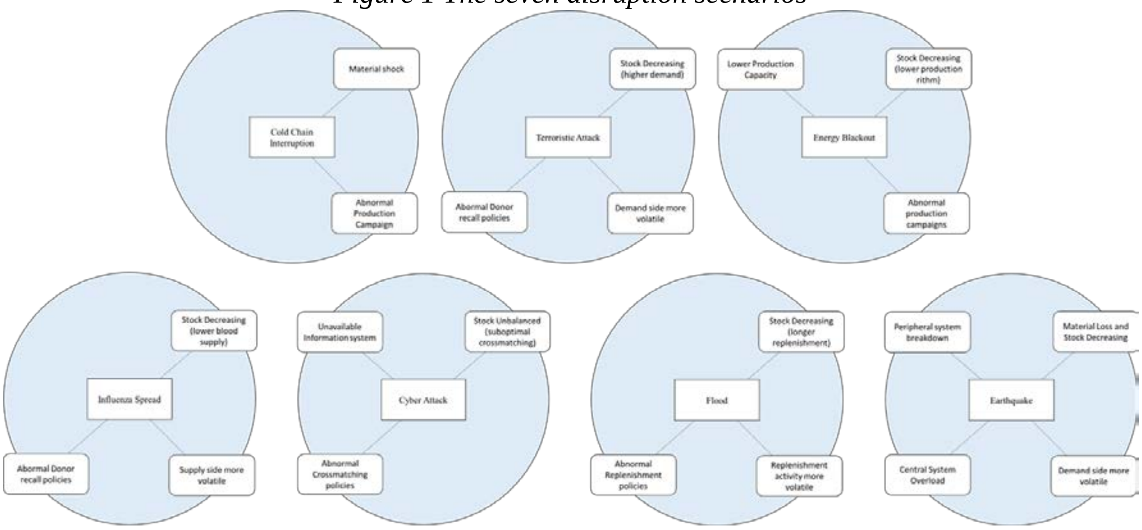
This research follows a game-based approach, in which a researcher plays the role of a supply chain planner. Game-based approach recently has been applied in the context of healthcare and BSC (see e.g., Katsaliaki and Brailsford, 2007; Katsaliaki et al., 2014), and it is usually facilitated by modelling and simulation techniques (Fahimnia et al., 2017). Simulators are often applied as a research tool in the BSC domain, primarily for their explanatory power that helps decision making in real life events. Furthermore, simulators are selected to investigate the research question of this paper, since it was difficult to observe in real life the BSC resilience performance and under wide-range of disruption scenarios.

Development of the simulation models

For the purpose of this research, we developed two discrete-event simulators to investigate the impact of lean and agile supply chain strategies on the BSC resilience performance. The overall research methodology is organised into three steps. The **first step** involves developing a Performance Measurement System (PMS) to support the performance assessment and comparison of the agile and lean strategies. The PMS specification stems from a critical review of existing literature (c.f., Osorio et al., 2015; Beliën and Forcé, 2012). We organised the PMS dashboard in a tetrahedron shape, based on the concepts presented in Norrman and Jansson (2004, p.453), to incorporate the resilience dimension to the three traditional performance areas of Cost, Time, and Quality. As such, a vertical dimension was added for the resilience performance.

We assessed the resilience performance by monitoring three indicators: the Stock-Out Rate Deviation, Time-To-Disruption and Time-To-Recovery. The objective for the Stock-Out Rate indicator is minimisation, whereas the Time-To-Disruption is a resilience indicator since it measures the system capability of postponing the effects of a disruption. The longer the supply chain delays the consequences of the disruption, the longer is the period of time available for better preparation to absorb the consequences of the disruption. The Time-To-Recovery indicates the amount of time required by the supply chain for self-recovery to its original status. It is worth pointing out that in case of disruption, specific contingency plans are built and implemented in the supply chain for a quicker recovery. The Time-To-Recovery is measured considering the independent recovery time of the entire supply chain, without any external intervention.

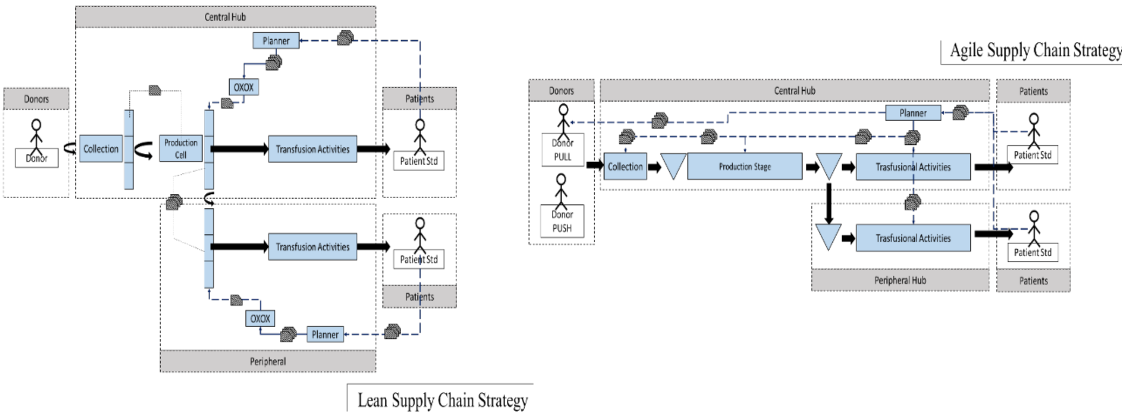
Figure 1 The seven disruption scenarios



The **second step** dealt with the design of the scenarios of routine and emergency conditions. In order to properly identify the emergency scenarios a risk analysis process was used (Jittamai and Boonyanusith, 2014), in which we identified eight simulation scenarios: first is the routine (standard) operational conditions. The remaining seven scenarios cover emergency conditions based on different risk sources that incorporate two dimensions of disruption intensity; shock and pressures. As follows; (A) cold chain interruption, (B) terrorist attack, (C) energy blackout, (D) Influenza spread within the donors' population, (E) cyber-attack, (F) Flood, and (G) Earthquake. They were meant to cover all the most relevant risk categories, allowing a complete and systematic assessment of the system's vulnerability and resilience, as depicted in Fig. 1. Disruptions are to be considered pressure events if they generate a long-lasting effect on the supply chain.

The **third step** focuses on the development of the discrete-event simulators for the lean and agile supply chain configurations, as depicted in figure 2. It also dealt with the calibration and validation of the two simulators. The Agile Simulator was implemented into a custom spreadsheet in MsExcel. The Lean Simulator was implemented in MatLab. The simulators were run under the routine and the 7 emergency conditions following a systematic gaming procedure, as reported in the following sections.

Figure 2 Schematic representation of the two simulation models



Game Structure and scope

The three main supply chain phases covered by the game are Collection, Production activities and Transfusion. The assumptions of the game excluded the communication with patients and donors, practices for donor management, facility and maintenance management, since they are considered exogenous to the SC planning process and independent from the specific strategy (agile vs lean) implemented in the BSC.

The Simulation Implementation logic and Researcher/Player Role

The agile and the lean supply chain strategies have different approaches toward the market and the supply side (Lee, 2002). The lean strategy adapts a simplified workflow with waste elimination goal, the agile strategy is tightly linked to responsiveness, and therefore it mostly relies on the planner's capability to schedule the operation and tactically adapting the local decisions for satisfying the market requirements proactively and reactively. This is the focal point for capturing the differences of the role of the planner/player within a lean or an agile BSC. In the agile BSC, the planner/player is in charge of managing with corrective actions the contingencies (or the market trends, extending the concept to the tactical and strategic levels), leveraging on his/her professional experience and using the data the BSC provides. In contrast, under the lean BSC, the planner/player deals with the upstream and downstream variability through strategic decisions, which makes the short-term planning of the BSC more automatic.

Under emergency conditions, the lean BSC player has more of a consultant role that is activating contingency plans for recovering the service continuity (?). Nevertheless, even if the player directly schedules orders in emergency conditions, it is noticed that such decisions do not alter the BSC production schedules or orchestration mechanisms, however they may alter a set of rules for managing the BSC, for example changing the blood group to be produced or modifying the safety stocks.

Issuing orders, as an agile supply chain player would do, is not the typical intervention of a lean BSC player, who instead mitigates the disruption consequences by modifying the supply chain configuration. To better simulate the agile and lean BSC strategies, two simulators are used, in this research, due to the critical differences in their conceptual approach to planning. The agile BSC requires a simulation tool that takes advantage of the central role of the player, whilst the lean one is better developed with a simulator that enhances the role of automated rules applied to the contingencies. In this study, the agile BSC simulation is run on an Excel sheet, while a Matlab script is chosen for the lean one.

Data Collection

The selected case study is the Italian BSC, specifically addressing the local supply chain operating in the Lombardy region (about 10 millions of citizens). The Italian BSC manages more than 3000000 units of whole blood per year, and the Lombardy BSC is in charge of approximately 450000 units/year. The region influences around the 15% of the overall supply chain results on a national level. The Lombardy BSC accounts for 53 facilities, 36 of them are big Immunohematology and Transfusion Medicine Service (SIMT) centres located over the Lombardy territory. After a network rationalization project in 2007, 8 centres were addressed as production hubs, while the operations of the other 28 were limited to the collection and transfusion activities. The 17 lasting facilities are mid-sized hospitals, under the local control of the larger ones. Real demand and supply data of Lombardy Region Blood Service in year 2016 was used for the calibration of both simulation models. Input data for the gaming sessions were randomly generated from the historical time series.

Gaming with Agile Supply Chain Strategy

The central and peripheral hubs are scheduled by a central planner/player, who directly releases orders to the entire chain’s stages. Despite in real life settings the agile strategy requires a planner for each hub, for the sake of simplicity in this research we merged the planners in a single central planner. Planners, manage the inflow of whole blood bags; they manage the arrival of donors spontaneously offering blood (donors push) and they also directly schedule the donors donating blood upon recall. The transfusion needs of patients are managed separately by personnel in wards.

Gaming with The Lean Supply Chain Strategy

The central and peripheral hubs are separately scheduled by two independent planners. The patients demand is fulfilled by releasing one or more blood bags from the finished goods supermarket, according to the status of inventories (e.g. stock availability, age of the inventories, etc.). The planner releases the patient orders to a demand leveller tool and it supports matching demand with supply. The leveller, which is basically an *Heijunka Box*, acts as a pacemaker, triggering the replenishment in pull *Kanban* logic for the upstream activities (i.e. Production Activities and Collection), once the reorder points are reached. All the donors are managed upon recall. The downstream activities (i.e. Transfusion) are managed in one-piece-flow logic without decoupling buffers.

Results and Discussion

Routine Scenario

The simulation of lean BSC strategy in routine scenario resulted in 0% stock out rate. The results highlight a huge drop (a negative peak at 0,0789) in the adherence performance in the peripheral hub. The average distribution age of the transfused blood is around 15 days. The wastages performances, over a one-year period, report 154 wasted whole blood bags (0,6% of the transfused bags). Eventually, the finished good waste are 81 bags. The stock position shows a different behaviour for the peripheral hub and the central hub. In the peripheral warehouse, the stock position of all the blood groups appears in control, especially for the Negative Rheseus factor groups. The Age of Inventory KPI, indicates an average value around 8 days. Detailed quantitative data are reported in table 1.

The simulation of agile BSC strategy in routine scenario resulted in 0% stock out rate. The wasted whole blood bags in a one-year period are 109 (0,4% of the transfused bags), no finished goods wastes are recorded. In terms of Adherence KPI, the registered value is 99,78%, presenting a singularity in the pattern with a throat value of 80%. The stock position shows peripheral hubs are in complete control, with zero variation in the stock position, while the central hub varies. The average age of the transfused blood is not directly measured by the agile simulator. By inference, since the agile simulator reflects the real data of the Italian BSC, it can be assessed as equal to the one measured in the real case. Thus, we assume that the average age of the transfused blood is 31 days.

Table 1 Resilience performance under pressure and shock disruptions

Disruption Scenario	Supply Chain Strategy	Stock-Out Rate Deviation Peak	Stock Position Average Deviation	Time-To-Disruption [days]	Recovery Time [days]
Cold Chain Interruption (A)	Agile	55%	-15%	Instantaneous	160 days
	Lean	0%	-17%	Instantaneous	Instantaneous
Terroristic Attack (B)	Agile	1%	-20%	Instantaneous	120 days
	Lean	0%	2%	Instantaneous	Instantaneous
Energy Blackout (C)	Agile	0%	-4%	Instantaneous	180 days
	Lean	100%	-26%	100 days	∞
Influenza Spread (D)	Agile	62%	-36%	20 days	30 days
	Lean	98%	-3%	116 days	78 days
Flood (E)	Agile	0%	-0,396%	Instantaneous	Instantaneous
	Lean	0%	-16%	Instantaneous	100 days
Cyber Attack (F)	Agile	Not affected			
	Lean	91%	-3%	83 days	108 days
Earthquake (G)	Agile	55%	-67%	Instantaneous	∞
	Lean	0%	-14%	Instantaneous	100 days

Resilience Performance under Shock and Pressure Disruptions

Overall, when a disruption affects the lean BSC, it induces more severe performance losses as compared to the agile BSC. However, while the agile BSC results demonstrate vulnerability to shock disruptions (e.g., the Cold Chain Interruption (A), a terrorist attack to the facilities (B), and the earthquake (G)), while it demonstrated greater robustness to direct and indirect consequences of pressure disruptions. In contrast, the lean BSC suffered higher performance losses in case of pressure crises (e.g., epidemic spreading among the donor population (D) and an energy blackout at the production stage (C)), but performed much better under all the types of shock crises. Furthermore, the dependability on the information system introduces further vulnerability for the lean BSC (i.e., cyber-attack disruption), which can result in severe operational consequences.

The lean BSC strategy is capable of delaying the disruption consequences for at least 30 days up till 116 days, regardless the type of disruption (i.e. shock or pressure). Whereas the agile strategy results in significant performance losses almost immediately (Fig.3).

The lean BSC strategy has a better recovery, even without any external support. Whereas, the agile one needs on average 100 days to bounce back to original performance (sometimes neither being able to fully recover autonomously, such as in the case of an earthquake event - G). The lean BSC bounce back to the point of original equilibrium (except for disruptions affecting the production phase) with recovery transients no longer than 100 days (Fig.4). Furthermore, as long as the lean BSC strategy primarily relies on a downstream protection tool (the *Hejiunka Box*), it demonstrates greater vulnerability to the disruption affecting the upstream side, such as the collection and the production stages, while the player in the agile BSC can arrange the schedules directly managing in a push logic for both sides of the SC.

Fig. 3. Stock-Out Rate Deviation in case of Influenza Spread (D)

The disruption starts in day 142 and lasts for 60 days. The agile BSC suffers damages during the influenza period; the lean BSC delays the damages up to 40 days.

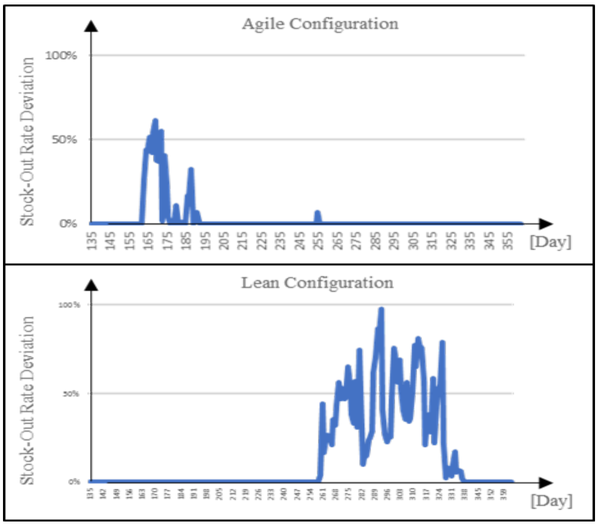
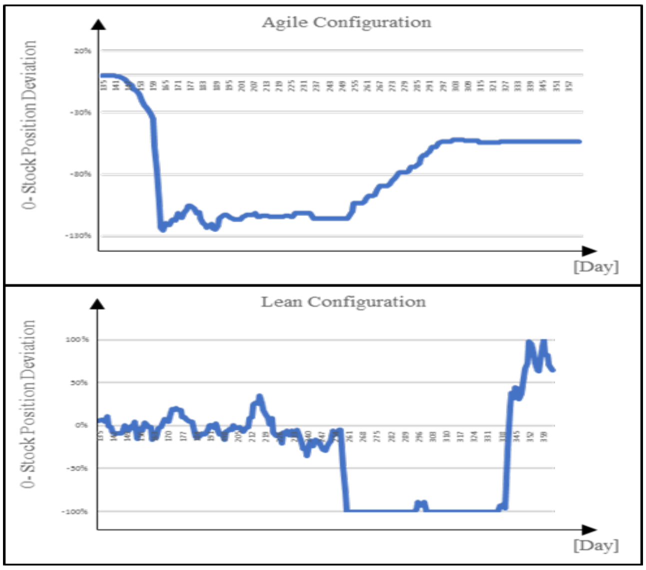


Fig. 4. Stock Position Deviation in case of Influenza Spread (D).

The disruption starts in day 142 and lasts for 60 days. The agile BSC retains 50% damage, for the 0- stock, with a recovery time of 100 days. The lean BSC fully recovers It in 84 days.



Conclusion

The critical review of prior empirical studies (see e.g., Birkie et al., 2016) reveal the appropriateness of adopting a lean supply chain strategy in high-uncertainty environments. The principal focus of our research was the systematic assessment and comparison of the performance of lean and agile strategies when applied to the Blood Supply Chain (BSC). Our analysis focused in particular on investigating the BSC resilience performance under different disruption scenarios.

The results of this research reveal that under normal and stable operating conditions, the lean strategy provides better performances in terms of quality and cost indicators, and in minimising the safety stocks. The lean BSC strategy reduces inventory by 31% compared to the agile one. This later issue heavily influences the population's welfare by increasing the "customer and supplier happiness". The lower values of waste the more the probability of retaining and enlarging the supply (donor) base, generating synergy in matching demand and supply. Nevertheless, the simulated data of waste under the agile BSC strategy shows the agile strategy better than the lean one in waste reduction. However, the lean BSC strategy guarantees 100% of service level (compared to the agile one), providing patients with blood bags of 15 days old in both the central and peripheral hubs (i.e., 15 days less than the agile BSC strategy which assigns on average 30 days old bags).

This research is one of the early attempts to address the resilience capabilities and performance of the BSC, under routine and emergency conditions. It provides multiple contributions, not only to the research and practice of BSC management field, but also to similar and comparable supply chain contexts with perishable goods, such as the fast moving consumer good (FMCG), or where efficiency (cost) and effectiveness (time, quality, safety) objectives are equally important, such as in pharma SC. Furthermore, the research applied a game-based approach, in which a researcher plays the role of a SC planner. To the authors' knowledge, this is a novel approach in SC resilience research.

The contribution, of this study, to practice is twofold. First, it provides healthcare managers with a lean model for BSC management, which could be used as a benchmark (?) for improving current practices. Second, the resilience profiles of the BSC, generated under different BSC strategies and disruption scenarios, can guide managers in selecting the most proper countermeasures. The research limitations mainly relate to the assumptions adopted for the simulations of both BSC strategies. The simulated decisions under the agile strategy might not fully reflect the real life situations, in which sub-optimal decisions could be made due to a lack of solid information. On the other hand, the lean BSC strategy was simulated relying on a realistic solution, i.e. feasible and stable, due to the lack of a corresponding real case. Avenues for future research may include investigating the optimization of the resilience performance of the BSC under lean strategy and aiming at deciding on dynamic arrangements that correspond to different datasets and disruptions with different intensity and latency levels.

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