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Research Article

Healthcare supply chain risk assessment KPIs: an empirical study using PLS-SEM

Pedro Senna[a*], Augusto Reis[a], Julio de Guimarães[b], Lino Guimarães Marujo[c], Ana Carla de Souza Gomes dos Santos[d,a], Eliana Andrea Severo[b]

[a]Centro Federal de Educação Tecnológica Celso Suckow da Fonseca, Rio de Janeiro, RJ, Brasil

[b]Universidade Federal de Pernambuco, Recife, PE, Brasil

[c]Instituto Alberto Luiz Coimbra de Pós-Graduação e Pesquisa de Engenharia, Rio de Janeiro, RJ, Brasil

[d]Instituto Federal do Rio de Janeiro, Nilópolis, RJ, Brasil

*pedro.senna@cefet-rj.br

Abstract

Paper aims: This study has the objective of mapping and empirically validating KPIs that can be used to assess healthcare supply chain risks.

Originality: We combined two methodological approaches: i) we conducted a systematic literature review to identify the healthcare supply chain risk assessment KPIs and ii) We grouped these KPIs into five constructs and validated their relations using PLS-SEM.

Research method: This is the only study that presents a systematic literature review to identify KPIs that measure healthcare supply chain risks, groups the KPIs into a theoretical framework, and presents a PLS-SEM validation. This study used data from Brazil, from a variety of healthcare supply chain organizations (suppliers, OEMs, clinics, and hospitals), therefore we cannot guarantee that the study can be generalized.

Main findings: The systematic literature review identified 27 KPIs which were grouped into five constructs. The structural model supported by the PLS-SEM technique revealed that reliability, responsiveness, costs, and agility are antecedents to healthcare supply chain quality.

Implications for theory and practice: Managers may rely upon this study to understand that healthcare supply chain reliability and responsiveness are antecedents to healthcare supply chain costs and agility, which are antecedents to healthcare supply chain quality.

Keywords

KPI. Healthcare supply chain risk management. Supply chain resilience. PLS-SEM.

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1. Introduction

The academic literature provides many examples of risks that led to disasters, on the other hand, little information is available concerning Healthcare Supply Chain Management (HCSCM) (VanVactor, 2011). Supply Chains (SC) are often vulnerable to multiple high-magnitude risks (Kouvelis et al., 2011). Furthermore, supply chains are increasingly exposed to operational and disruption risks that threaten their business continuity. When these risks are in an Healthcare Supply Chain (HCSC) context, it often means that a medicine or a bandage is missing, the wrong treatment is applied or even the team was unable to save the patient's life (Khalili et al., 2016). Recently, the COVID-19 outbreak highlighted that healthcare supply chains must be even more resilient than regular market-oriented supply chains.

Therefore, it is crucial to identify, measure, and mitigate not only Healthcare organizations' risks, but risks concerning their SC as well. In this sense, Performance Management becomes a crucial feature for risk mitigation. Performance Management systems are usually introduced to monitor goal achievement and are considered a challenge frequently confronted by public service managers (Arnaboldi et al., 2015). In addition, there are dreadful outcomes associated with poor use of Performance Management systems in public services, including negative effects on staff morale. The implementation of indicators can even generate behavior change. The lack of quick answers and solutions to improve Performance Management makes this task complex and critical for public service managers (Arnaboldi et al., 2015). Most of the poor Performance Management in Healthcare organizations is aggravated due to the lack of good Key Performance Indicators (KPI), jeopardizing Supply Chain Risk Assessment since managers become unaware of which tasks to prioritize. In areas such as finance, insurance, crisis management, and Healthcare, the importance of considering risk is acknowledged, creating a proper environment to develop heterogeneous concepts and approaches for risk management (Heckmann et al., 2015). Healthcare disasters strike Healthcare organizations of all types and designs, making resiliency actions crucial for crisis mitigation (VanVactor, 2011).

Several studies have focused on Supply Chain Risk Management KPI (Heckmann et al., 2015; Wu et al., 2010) and present indicators such as standard deviation, VaR (Value – at - Risk), and CVaR (Conditional Value – at – Risk). The literature also provides KPI related to healthcare, most of them clinic KPI (Cavalcante et al., 2016) or more general and operational KPI (Kanamori et al., 2016). However, this research detected that studies that aim to identify KPI measuring risks in HCSC are lacking. Our study aims to fill this gap and extends the literature on Supply Chain Risk assessment by identifying groups of KPI and their relationships, moreover, this study investigates how reliability, responsiveness, costs, and agility impact HCSC quality. To the best of our knowledge, there is no other study that presents a systematic literature review to identify KPI that assess healthcare supply chain risks and validate a theoretical framework using Partial Least Squares Structural Equation Modeling (PLS-SEM). This study used data from Brazil, from a variety of healthcare supply chain organizations (suppliers, OEMs, clinics, and hospitals) and provide a first guide to managers to which KPI to design to develop supply chain risk assessment.

2. Literature review

This section summarizes our theoretical framework that served as the basis for our hypotheses.

2.1. Supply Chain Risk Management (SCRM)

Competition and customer demands are constantly increasing while almost all industries have witnessed fiercer competition and globalization effects on markets (Fan et al., 2011). The last two decades showed evolution concerning process integration (Kannengiesser et al., 2016). The next step of integration was at the Supply Chain level, which led to identifying Supply Chain main processes (Croxton et al., 2001), how to model a Supply Chain (Saen et al., 2016; Lehoux et al., 2016; De Meyer et al., 2016; Senna et al., 2016) and KPI concerning a Supply Chain (Coelho et al., 2009; Fang & Weng, 2010; Cai et al., 2009; Santos et al., 2022).

Lately, with process integration inside and outside companies, the theoretical framework for these subjects was complete and formed the required backbone for Supply Chain Risk Management to gain relevance (Norrman & Jansson, 2004; Lavastre et al., 2012; Thun & Hoenig, 2011; Pujawan & Geraldin, 2009). Neiger et al. (2009) show that supply chains that include sometimes thousands of companies over several tiers present significant risks. Firms and researchers are paying close attention to this subject, which is notably triggered by the frequency and intensity of catastrophes, disasters, and crises that seem to have increased on a global scale (Fang & Weng, 2010).

There are considerable differences between operational risks and disruption risks (Fang & Weng, 2010). Operational risks refer to uncertainties such as customer demand, supply, and costs. Disruption risks are concerned with major disruptions severely influencing the whole chain. In Healthcare organizations, such risks often mean that medication will not be available, or a more expensive (and often better) medication may not be provided to patients. Given its importance, SCRM has emerged as a topic within the domain of SC resilience (SCRes). There are four basic constructs within SCRM: risk sources, risk consequences, risk drivers, and risk-mitigating strategies (Jüttner et al., 2003). The focus of SCRM consists in understanding and trying to avoid the devastating effects that disasters or business disruptions can have in a SC (Norrman & Jansson, 2004). In this sense, companies should not only focus on their risks, instead, they must also focus on risks in other links in their supply chain (Souter, 2000). In general, companies implement organization-level risk management and there is still little evidence of SC level Risk Management implementation (Juttner, 2005). Considering Healthcare organizations, there are still few papers which mention Healthcare Supply Chain Risk Management (HCSCRM) studies (VanVactor, 2011).

2.2. Supply chain resilience

Disturbances in SC are becoming an increasingly important issue, mostly due to the growth in both length and management complexity (Barroso et al., 2010). Such complexity, which is hard to manage (Mason, 2006) creates the need for methods and frameworks to manage changes in their supply chains (Pettit et al., 2013). The multidisciplinary concept of resilience arises in this context, being also a subject of scientific research in different subjects such as psychology, ecology, and economy. Resilience can also be found in emerging interdisciplinary fields such as emergency management, sustainable development, and SCRM (Torabi et al., 2015). The concept of resilience is closely related to the capability of a system to return to a stable state after a disruption (Bhamra et al., 2011). Resilience is defined as the ability of the system to maintain its identity in facing internal change and external shocks and disturbances (Fiksel, 2007). SCRes is concerned with the system's ability to return to its original state or to a new, more desirable, one, after experiencing a disturbance and avoiding the occurrence of failure modes (Carvalho et al., 2012). The goal of SCRes analysis and management is to prevent movement to undesirable. System resilience can be defined as the ability to reduce effectively both the magnitude and duration of the deviation from targeted system performance levels (Vugrin et al., 2011).

A framework for enhancing resilience is based on pillars such as flexibility, adaptability, collaboration, visibility, and sustainability (Soni & Jain, 2011). These are intangible dynamic SC capabilities that can hold SC disruptions as well as generate competitive advantage (Soni & Jain, 2011). Resilience is also very hard to reach, mostly due to specificities of each supply chain allied to the uncertain environment in which they operate, which do not allow to determine which is the most appropriate strategy to mitigate the negative effects of a likely disturbance (Barroso et al., 2010). While the literature provides great examples of preparedness and how companies dealt with all sorts of risks, little information is available concerning Healthcare supply chain management (VanVactor, 2011; Senna et al., 2020). While the literature provides great examples of preparedness and how companies dealt with all sorts of risks, little information is available concerning Healthcare supply chain management (VanVactor, 2011; Senna et al., 2021; Senna et al., 2021).

2.3. Healthcare supply chain risk management

A hospital is much more than a mere link in a very complex SC (Chan & Green, 2013). Hospitals are structured around clinical departments such as emergency, intensive care, oncology, cardiology or coronary care, the catheterization laboratory or cath lab, and surgery (Chan & Green, 2013). A Healthcare SC model is described by Chan & Green (2013) with the following tiers: i) External chain – Vendors, Manufacturers, Distributors; ii) Hospital's internal chain - Hospital central storeroom, Nursing units, Points of care.

The literature on risks presents a wide range of techniques scarcely adapted to the needs of HCSC (Khan & Burnes, 2007). In the last years, SCRM has been largely studied with many different approaches and applications. However, specific healthcare HCSCRM applications are not so frequent. These papers can be sorted into two types, papers that explicitly use SCRM applied to HC organizations and papers which eventually discuss solutions to problems that consist of major risks and may cause service rupture. Concerning papers that approach HCSCRM, VanVactor (2011) highlights the importance of disaster mitigation to prevent SC breakdown and draws attention to crisis mitigation concepts. Thus, based on VanVactor (2011) Healthcare Supply Chain Resilience (HCSCRes) can be defined as a capability to be responsive to disasters, as well as SC breakdowns and still being able to provide a full continuum of services to all patients arriving at a care facility. Studies developed by Zepeda et al. (2016) highlight the risks concerning mismatch between supply and demand and discusses risks of higher inventory costs. Other articles shed light upon issues that may indirectly contribute to measure and mitigate risks as is the case of Eiro & Torres Junior (2015), which present cases of Healthcare organizations that implemented Total Quality Management (TQM) and Lean through the implementation of tools like Value Stream Map (VSM) and Failure Mode and Effect Analysis (FMEA). Such tools, techniques and concepts are process improvers and generate KPI that mitigate undesired effects. Healthcare supply chain managers must deal with the tradeoff of risk-mitigating costs versus the costs caused by the risks, moreover, managers should minimize costs while keeping the best care for the patients (Senna et al., 2021; Senna et al., 2022).

3. Methodology

The methodology of this paper consisted of two major phases: i) A thorough systematic review and the reading of SCOR 12.0 to identify the main HCSCRM KPI; ii) We developed a questionnaire validated via PLS-SEM. Our methodology workflow is shown by Figure 1.

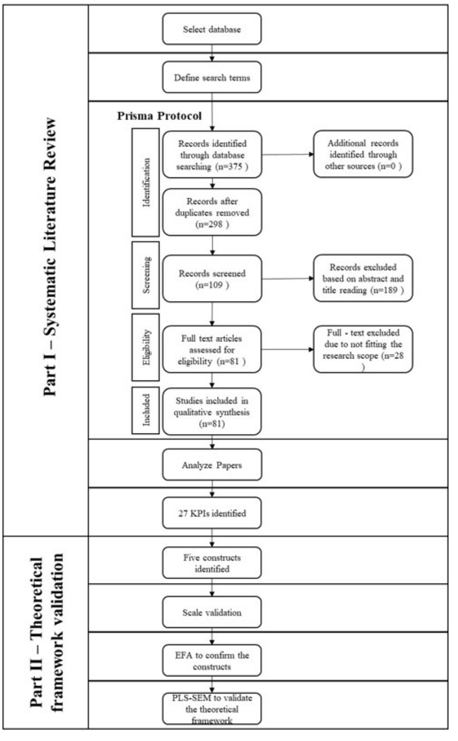

Figure 1. Systematic literature review of KPI.

3.1. Select database

The database chosen for searching the research terms were Scopus and Web of Science. Scopus is the largest database of peer-reviewed literature and Web of Science can recover documents from 1945 to the present days.

3.2. Define search terms

The search strings were based in consolidated Supply Chain Risk Management and Supply Chain Resilience terminologies as shown in Table 1.

Table 1. Search strings.

Strings	*Ocurrences*	
	SCOPUS	Web of Science
“SUPPLY CHAIN” AND “RISK” AND “INDICATOR”	261	68
“LEAN HEALTHCARE” AND “INDICATOR”	5	1
“SUPPLY CHAIN RISK MANAGEMENT” AND “INDICATOR”	18	2
“SUPPLY CHAIN RESILIENCE” AND “INDICATOR”	13	4
“SUPPLY CHAIN RISK MANAGEMENT” AND “HEALTHCARE”	0	0
“SUPPLY CHAIN RESILIENCE” AND “HEALTHCARE”	1	1
“HEALTHCARE” AND “LEAN INDICATOR”	0	0
“SUPPLY CHAIN RISK MANAGEMENT” AND “KPI”	0	1
Total	298	77

3.3. Select papers

The search took place in December 2021 and resulted in a total of 375 publications. Then, after duplicate removal, there were 298 documents. An initial screening of publications that consisted in checking titles and abstracts was performed, aiming to discard those that did not fit within the scope of this research, resulting in 109 articles ranging from the years 2002 to 2021. The last step was full-text reading which generated a final list with 81 papers that were analyzed to compose the KPI list.

3.4. Survey design

This study used a web-based survey to collect data from healthcare supply chain professionals in Brazil. A survey pre-testing was realized with four healthcare supply chain management professionals. The constructs used in the paper were identified from the literature and adapted to fit the supply chain context. All the experts evaluated the questionnaire's content validity. The items were measured using a five-point Likert scale ranging from (1) "strongly disagree" to (5) "strongly agree."

3.5. Sample and data collection

Samples were restricted to HCSC professionals in Brazilian companies. The survey was distributed using the snowball methodology, asking for the professionals to distribute the survey to other professionals. Therefore, we obtained a total of 135 responses. To ensure the absence of bias in the survey, we tested for non-response bias comparing responses of early respondents (the first 25%) with late respondents (the last 25%), and we did not detect any response bias across the variables. In addition, a full collinearity assessment to address the issue of common method bias (CMB), indicated that in our study, this was not an issue.

4. Theoretical framework and hypotheses

The adopted performance measures in healthcare organizations look to draw a picture of quality, equity, and efficiency of the medical care at different levels: caregiver, hospital, local health authority, region (Antonelli & Bruno, 2015). Additionally, health institutions have adopted methods of evaluating their services based on indicators (Silva et al., 2009). The literature shows a good number of papers comprising clinic indicators including Cavalcante et al. (2016) and Minami et al. (2016). However, there are not many papers where Healthcare indicators are related to SCRM (Gu & Itoh, 2016; Zepeda et al., 2016; Eiro & Torres-Junior, 2015).

In healthcare organizations, high-risk exposure can lead to life losses, thus, it is essential to identify, assess and mitigate risks. Measuring resilience is a questionable task, so there is still scope to identify and develop sustained metrics (Cardoso et al., 2015). Sometimes the indicators were identified without a direct citation in the paper. The papers often mentioned important factors to be measured leading to the decision of registering a correspondent KPI. Indicators that measure performance to assess the quality of care are often chosen arbitrarily (Jones et al., 2014).

In this sense, the first list of KPIs was generated from the Systematic Literature Review. The pre-test Consisted of 3 sub-phases: i) 4 HC professionals analyzed the indicators text and suggested exclusion and inclusion of KPI, ii) a sample of 20 HC professionals analyzed the KPI importance and made suggestions concerning text, inclusion, and exclusion, iii) The reading of SCOR 12.0 validated some KPI and revealed new ones. Therefore, a final list of 27 KPI was generated to be statistically validated by HCSC professionals. Figure 2 shows the validation methodology. Figure 2 shows the identification and validation process.

Decision support systems in the form of dashboards, present crucial graphical information, to assist senior management to make the right decisions to achieve strategic goals within this complex environment (Erdem et al., 2016). Information visualization can accelerate perception, provide insight and control of valuable data to gain a competitive advantage in making business decisions (Al-Kassab et al., 2014).

The questionnaire made from Table 2 includes only one affirmative (The following indicator is important). This affirmative should be evaluated in each KPI, and the respondent must choose from a Likert scale from 1 (Totally disagree) to 5 (Totally agree).

Based on the experts and in SCOR 12.0, we have grouped the KPIs into five dimensions (constructs) that function as building blocks of Healthcare Supply Chain Risk assessment. Healthcare supply chains are as reliable as their hospitals and clinics since these organizations are the interface with the clients, which are responsible

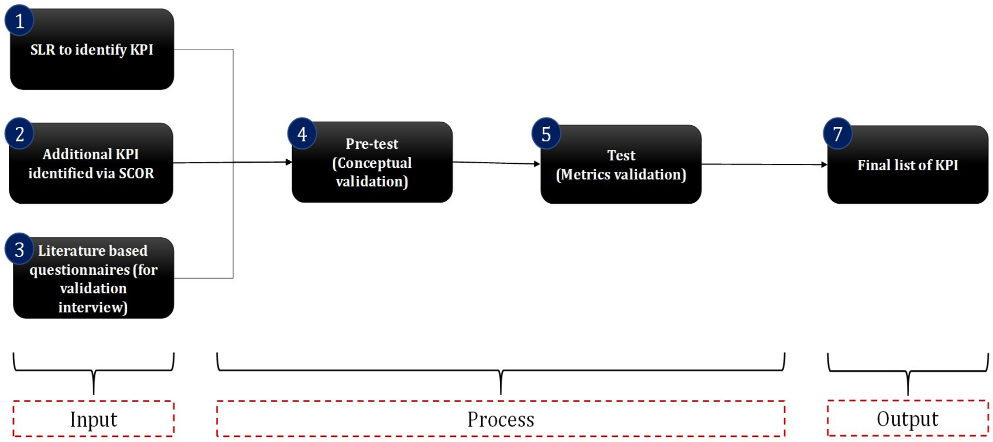

Figure 2. KPI list validation process. (SCOR: Supply Chain Operations Reference).

Table 2. Questionnaire - final list of KPI.

Construct	Variable	Reference
Reliability	REL1 - Bed ocupancy	Gu & Itoh (2016)
	REL2 - Monthly number of inpatients	Gu & Itoh (2016)
	REL3 - Monthly number of outpatients	Gu & Itoh (2016)
	REL4 - More visited diagnosis centers (visited by the patients)	Gu & Itoh (2016)
	REL5 - Number of operations procedures	Experts
	REL6 - Outpatient waiting time	Gu & Itoh (2016)
	REL7 - Wait time in ER/clinic	Gu & Itoh (2016); Günal & Pidd (2011)
Costs	COS1 - General costs	Gu & Itoh (2016); Reijula et al. (2014), Robinson et al. (2012); Díaz et al. (2012),
	COS2 - Human Resources Costs	Li et al. (2015); VanVactor (2011); Khalili et al. (2016); Gu & Itoh (2016); Reijula et al. (2014); Sedevich-Fons (2014); Díaz et al. (2012)
	COS3 - Inventory Costs	Experts
	COS4 - Maintenance repair costs per m^2	VanVactor (2011); Zepeda et al. (2016); Díaz et al. (2012)
	COS5 - Mitigation costs	SCOR 12.0
Quality	QUA1 - Quality: Improvement initiatives and innovation	SCOR 12.0
	QUA2 - Supply Availability	Minami et al. (2016); Gu & Itoh (2016); Habidin et al. (2015); Yildiz & Demirors (2014); McIntosh et al. (2014); Aoun & Hasnan (2013)
	QUA3 - On time delivery	McIntosh et al. (2014); Aoun & Hasnan (2013)
	QUA4 - Investments	Habidin et al. (2015)
	QUA5 - Maintenance efficiency	McIntosh et al. (2014); Aoun & Hasnan (2013)
	QUA6 - Continuous Education	Shohet (2006)
Responsiveness	RES1 - Contract approval and issue time - personnel	Crema & Verbano (2015); Cavalcante et al. (2016); Minami et al. (2016); Efe & Efe (2016); Hammadi et al. (2015)
	RES2 - Contract approval and issue time - materials	Rajesh (2016), Experts
	RES3 - Environmental impact	Rajesh (2016), Experts
	RES4 - Order Fullfillment	Kolotzek et al. (2018)
	RES5 - Order compliance	SCOR 12.0
Agility	AGI1 - Employees error rate	Rajesh (2016)
	AGI2 - Amount of Debt	Li et al. (2015); Gu & Itoh (2016); Reijula et al. (2014); Rajesh (2016)
	AGI3 - Overtime	Gu & Itoh (2016)
	AGI4 - Paid leave	Gu & Itoh (2016)

for the entrance of revenue in the supply chain. Therefore, these organizations must be reliable, provide efficient services to patients while being cost-efficient, and have a good relationship with the upstream organizations (Senna et al., 2022, 2023). In this sense, we formulated the hypothesis H1a:

H1a – Healthcare supply chain reliability has a positive impact in healthcare supply chain costs

Healthcare supply chain agility can be attained through an adequate number of beds (Gu & Itoh, 2016) in addition to other indicators that help dimension the operation port with precision, avoiding, for instance, unacceptable waiting times (Gu & Itoh, 2016; Günal & Pidd, 2011), allowing the patients to trust the organizations, knowing they will be attended when needed. In this sense, we formulated the hypothesis H1b:

H1b - Healthcare supply chain reliability has a positive impact in healthcare supply chain agility

The capability of a supply chain to be responsive can be measured by the agility of contract approval (Crema & Verbano, 2015), which may potentially generate fines and surplus of inventory (Cavalcante et al., 2016; Minami et al., 2016; Efe & Efe, 2016; Hammadi et al., 2015; Kahraman, 2021). The capability of how fast the healthcare supply chain can fulfill orders can also impact costs and must be dimensioned using good data and statistical tools (Kolotzek et al., 2018). In this sense, we formulated the hypothesis H2a:

H2a – Healthcare supply chain responsiveness has a positive impact in healthcare supply chain costs

The capability of being responsive can directly impact the agility of which services are provided. If the supply chain has a good responsiveness level, they can diminish the employee's error rate (Rajesh, 2016), reduce the need for overtime, and paid leave (Gu & Itoh, 2016). In this sense, we formulated the hypothesis H2b:

H2b – Healthcare supply chain responsiveness has a positive impact in healthcare supply chain agility

Companies always seek to increasingly reduce their costs while maintaining service-level performance. In this sense, the company may incur costs with risk mitigation (SCOR 12.0), maintenance, and human resources (Li et al., 2015; VanVactor, 2011; Khalili et al., 2016; Gu & Itoh, 2016; Reijula et al., 2014; Sedevich-Fons, 2014; Díaz et al., 2012), that are related to service quality. In this sense, we formulated the hypothesis H3:

H3 – Healthcare supply chain cost control has a positive impact in healthcare supply chain quality

Quality can also be measured by how agile the healthcare supply chain can provide its services. For example, the excessive amount of debt can cripple quality investments (Habidin et al., 2015), delay the delivery of the equipment and jeopardize the whole supply availability (Minami et al., 2016; Gu & Itoh, 2016; Habidin et al., 2015; Yildiz & Demirors, 2014; McIntosh et al., 2014; Aoun & Hasnan, 2013). In this sense, we formulated the hypothesis H4:

H4 – Healthcare supply chain agility has a positive impact in healthcare supply chain quality

Our theoretical framework is shown in Figure 3.

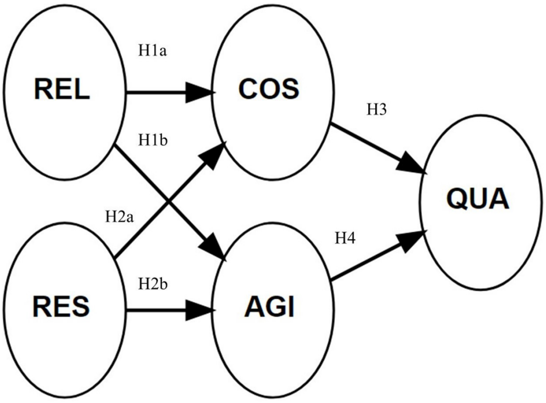

Figure 3. Theoretical framework.

5. Results

We used the PLS-SEM to test the research model; data analysis was performed using the SeminR package (Hair Junior et al., 2021) in Rstudio. First, the measurement model is estimated using confirmatory factor analysis (CFA) to confirm the reliability and validity of the constructs, then, the structural model examined the hypothesized relationships in the research model.

5.1. Measurement model

We used the Mahalanobis distance, eliminating values greater than 40, therefore, eliminating 29 forms that were considered outliers. There were no forms filled with a single alternative, nor forms in blank due to the mandatory form filling out process for all sections, therefore, the final sample was constituted with 106 forms.

The verification of the combination of observable variables in factors (Constructs) occurred through an Exploratory Factor Analysis (EFA) between blocks, preceding the PLS-SEM. The factorial loads (Table 3) show values above 0.5, as recommended by Hair Junior et al. (2013), to measure the contribution of each observable variable in the construction of the construct. In the EFA process and in addition to factorial loads, other important indexes were verified. Based on Mardia (1971), Hair Junior et al. (2013), Kline (2011), Lorenzo-Seva et al. (2011) and Tavakol & Dennick (2011):

Table 3. Loadings.

Reliability (REL)	Factorial loads	Communality	Mean	Standard deviation
REL1 - Bed ocupancy	0.850	0.803	4.235	0.990
REL2 - Monthly number of inpatients	0.820	0.743	4.226	1.007
REL3 - Monthly number of outpatients	0.730	0.651	4.047	1.054
REL4 - More visited diagnosis centers (visited by the patients)	0.880	0.779	4.216	0.975
REL5 - Number of operations procedures	0.890	0.882	4.396	0.922
REL6 - Outpatient waiting time	0.750	0.733	3.962	1.137
REL7 - Wait time in ER/clinic	0.770	0.693	4.188	0.996
Mean 4.182; Standard deviation 1.012; Cronbach's alpha 0.910; Composite reliability 0.933; KMO 0.847				
Costs (COS)				
COS1 - General costs	0.870	0.789	4.075	1.020
COS2 - Human Resources Costs	0.860	0.732	4.056	1.012
COS3 - Inventory Costs	0.880	0.796	4.169	0.909
COS4 - Maintenance repair costs per m^2	0.850	0.747	3.971	0.940
COS5 - Mitigation costs	0.850	0.697	4.113	0.908
Mean 4.077; Standard deviation 0.958; Cronbach's alpha 0.932; Composite reliability 0.934; KMO 0.871				
Quality (QUA)				
QUA1 - Quality: Improvement initiatives and innovation	0.690	0.534	4.301	0.863
QUA2 - Supply Availability	0.830	0.800	4.292	1.013
QUA3 - On time delivery	0.780	0.669	4.245	1.002
QUA4 - Investments	0.830	0.775	4.226	1.026
QUA5 - Maintenance efficiency	0.870	0.859	4.207	1.092
QUA6 - Continuous Education	0.650	0.555	4.349	0.915
Mean 4.270; Standard deviation 0.986; Cronbach's alpha 0.918; Composite reliability 0.898; KMO 0.878				
Resilience (RES)				
RES1 - Contract approval and issue time - personnel	0.790	0.848	4.047	0.898
RES2 - Contract approval and issue time - materials	0.890	0.842	4.047	0.919
RES3 - Environmental impact	0.610	0.336	4.028	1.081
RES4 - Order Fullfillment	0.520	0.575	4.075	0.847
RES5 - Order compliance	0.630	0.585	4.150	0.881
Mean 4.070; Standard deviation 0.925; Cronbach's alpha 0.910; Composite reliability 0.822; KMO 0.763				
Agility (AGI)				
AGI1 - Quality: Employees error rate	0.700	0.507	3.933	1.197
AGI2 - Amount of Debt	0.750	0.566	3.915	1.096
AGI3 - Overtime	0.710	0.648	3.952	0.950
AGI4 - Paid leave	0.740	0.701	3.849	1.136
Mean 3.913; Standard deviation 1.095; Cronbach's alpha 0.851; Composite reliability 0.814; KMO 0.778				

KMO: Kaiser-Meyer-Olkin.

The measurement model analysis includes the assessment of reliability, convergent validity, and discriminate validity. All the composite reliability values exceed the recommended value of 0.70, indicating acceptable construct reliability (Hair Junior et al., 2017).

Table 4 presents the convergent validity assessment. The loadings of all items at the significant level of 0.01, with average variance extracted values exceed the recommended cut-off level of 0.50 (Hair Junior et al., 2017). These results support convergent validity. We also present that the squared root of AVE is higher than the correlation among the constructs (Fornell & Larcker, 1981) further confirming adequate discriminant validity. Hence, it is concluded that the proposed model had acceptable reliability and validity.

Table 4. Average variance extracted and discriminant validity.

	REL	COS	QUA	RES	AGI
REL	0.792[a]				
COS	0.594[b]	0.752[a]			
QUA	0.518[b]	0.646[b]	0.857[a]		
RES	0.560[b]	0.571[b]	0.640[b]	0.773[a]	
AGI	0.510[b]	0.677[b]	0.638[b]	0.490[b]	0.807[a]

[a]Square root of Average Variance Extracted (AVE) – Convergent Validity (CV). [b]Correlation between constructs – Discriminant Validity (DV).

5.2. Common method bias

This study used the Harman's single-factor test examines whether a single factor emerges from principal component analysis, or if one factor represents most of the covariance among the variables in an unrotated factor analysis. The results indicated that more than one factor emerged to explain the data variance. Hence, CMB was not a problem for the current research. The proportional variance found was 0.41, less than the threshold of 0.5

5.3. Structural model

This section shows the results obtained in the structural model, that were used to test the hypotheses. We evaluated the model's quality, using the amount of variance explained (R^2 value) in the endogenous variables. An R^2 = 26% is considered substantial (Cohen, 1988), moreover, the results revealed that the R^2 of all the endogenous variables are above this threshold, ranging from 0.519 to 0.586, indicating that the model has a good explanatory model. Additionally, we assessed the predictive relevance of the model by calculating the Q^2 value. The results show that the Q^2 values for all endogenous variables were greater than zero (0.270), therefore, supporting the predictive relevance of the model (Cohen, 1988). The complete structural model is shown by Figure 4:

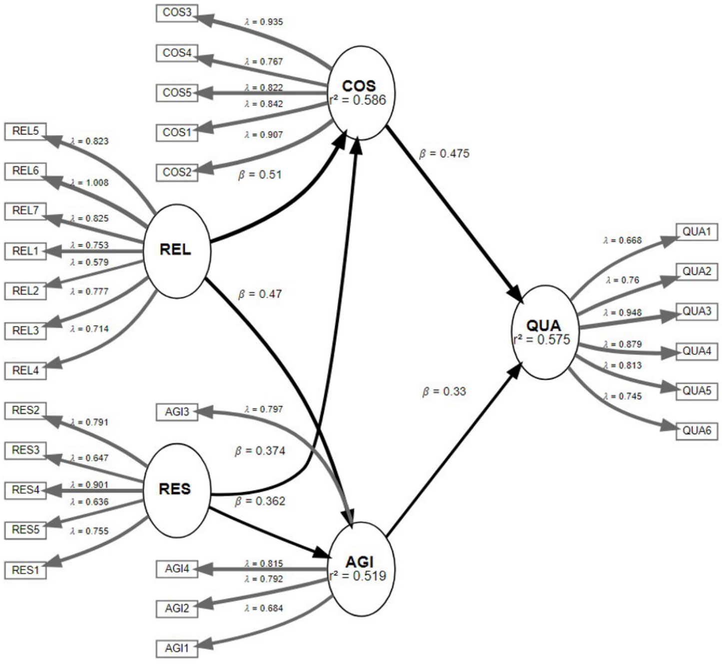

Figure 4. Structural model.

Regarding reliability, the healthcare supply chain reliability has a positive influence on healthcare supply chain costs (β = 0.510, $p < 0.05$), and has a positive influence on healthcare supply chain agility (β = 0.470, $p < 0.05$), therefore, hypotheses H1a and H1b are supported.

Concerning responsiveness, the healthcare supply chain responsiveness has a positive influence on healthcare supply chain costs (β = 0.374, $p < 0.05$), and has a positive influence on healthcare supply chain agility (β = 0.362, $p < 0.05$), therefore, hypotheses H2a and H2b are supported.

We note that the healthcare supply chain costs construct has a positive influence on healthcare supply chain quality (β = 0.475, $p < 0.05$). Healthcare supply chain agility has a positive influence on healthcare supply chain quality (β = 0.330, $p < 0.05$), thus, hypotheses H3 and H4 are supported. In addition, the standardized root mean square residual (SRMR) is 0.081, which less than 0.1 is considered a good model fit (Hair Junior et al., 2017). Table 5 summarizes these findings.

Table 5. Loadings and test of hypotheses.

	Loading	Hypotheses
H1a - REL → COS	0.510*	supported
H1b - REL → AGI	0.470*	supported
H2a - RES → COS	0.374*	supported
H2b - RES → AGI	0.362*	supported
H3 - COS→ QUA	0.475*	supported
H4 - AGI → QUA	0.330*	supported

*p<0.05. Standardized root mean square residual (SRMR) = 0.081.

6. Discussion

This study provides relevant theoretical implications to the literature. First, this study helps filling the gap in respect to healthcare supply chain risk assessment, to the best of our knowledge, there are no papers that map healthcare SCRM KPI. In addition, we used empirical data from 106 professionals from Brazil. Our study found support for the theoretical model, proposing a framework to enable healthcare supply chain risk assessment based on KPI found in the literature.

For managers, this study provides several practical implications about the KPI that can be used to assess healthcare supply chain risks divided into five main blocks. Managers may rely upon this study to understand that healthcare supply chain reliability and responsiveness are antecedents to healthcare supply chain costs and agility, which are antecedents to healthcare supply chain quality. To implement these KPI, managers should first build a team with the capabilities of collecting and handling the data to calculate the KPIs and should provide appropriate training methods to educate healthcare supply chain professionals and highlight the importance of these initiatives. Moreover, this study suggests that we can measure HCSC quality through responsiveness, reliability, costs, and agility, which is a very strong premise. In this sense, more empirical studies should be conducted to verify whether this premise is always correct or other frameworks can be more suitable.

We showed a first validated draft concerning SC risk/resilience KPI, nevertheless, there is still much discussion to be done concerning this result. A relevant question would be, which of these KPI are relevant to which company/tier? This question needs another robust quantitative study to be answered. The objective of this mapping is to find KPI relevant to HCSCRM, nevertheless, how far can one consider clinical KPI as strictly clinical and affirm they have no impact in SC whatsoever? This question must be addressed through many thorough case studies which will then be able to highlight details that a general review cannot. Some KPI even are written in a way that consists of jargon of a specific sector, nonetheless, this study validated with experts and tried to minimize these problems by writing a text that is as understandable as possible.

In terms of the literature, the KPI we listed and validated can be related to the work of Chan & Green (2013), however, further studies are needed to map which KPI can be more suitable to each supply chain tier (External chain – Vendors, Manufacturers, Distributors; Hospital's internal chain - Hospital central storeroom, Nursing units, Points of care). A robust set of KPIs is the path to identifying possible disasters and building HCSCRes and mitigation strategies following the work of VanVactor (2011). Some KPIs can directly mitigate the mismatch between supply and demand, helping to address the gaps identified by Zepeda et al. (2016).

There are still many challenges remaining considering these KPI implementation. HC organizations should analyze whether they have or not professionals trained to measure and compile these indicators. Another important challenge is systems integration, where do the information will come from? HC organizations will have to hire more management-related professionals with solid data management formation and sensitize HC professionals of the KPIs' importance (even if indirect) in saving patients' lives.

7. Conclusion

This paper had the objective of map and empirically validate KPI that could be used to assess healthcare supply chain risks. To fulfill this objective, our study conducted a systematic literature review where we identified 27 KPI from a shortlist of 81 papers which were grouped into five constructs (reliability, responsiveness, costs, agility, and quality) to assess healthcare supply chain risks. We used PLS-SEM to empirically test the following hypotheses: i) H1a – Healthcare supply chain reliability has a positive impact in healthcare supply chain costs; ii) H1b - Healthcare supply chain reliability has a positive impact in healthcare supply chain agility; iii) H2a – Healthcare supply chain responsiveness has a positive impact in healthcare supply chain costs; iv) H2b – Healthcare supply chain responsiveness has a positive impact in healthcare supply chain agility; v) H3 – Healthcare supply chain cost control has a positive impact in healthcare supply chain quality; vi) H4 – Healthcare supply chain agility has a positive impact in healthcare supply chain quality. The results reveal that the proposed framework has theoretical and empirical support. Our research used multivariate data analysis, composed of the tests of normality, variability, and reliability contributed to the validation of the observable variables that were grouped in constructs. These tests are crucial to reduce the impact of limitations, such as the risk of using the Likert type, which is made up of levels and with no other source for data triangulation (opinions of respondents only), which may cause the formation of response biases. Another limitation of the study is related to the data collection that was conducted using the Snowball technique, which can lead to similar characteristics among respondents since the sample's origin is the researchers' contacts. Based on this study, new research questions arise related to the investigation of other socio-environmental behaviors influenced by the Pandemic situation, such as: Are there other constructs that can contribute to healthcare supply chain risk assessment? Are there other KPI that can measure these constructs? In a general way, healthcare supply chain risk assessment literature is very scarce, and both researchers and practitioners should develop more risk assessment studies in order to prioritize, mitigate and monitor supply chain risks.

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