A systematic literature review on the stochastic analysis of value streams

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Abstract

Value stream analysis is a very useful approach in the identification of non-value adding wastes and developing a systemic plan for achieving process improvement. However, traditional value stream mapping fails in considering the inherent variability of processes, hence reinforcing improvements that might not lead to significant results. In this sense, the uncertainties associated with value streams become an issue that can be curbed with the integration of stochastic methods. By conducting a systematic literature review, this research evaluates the level of integration of stochastic methods into value stream analysis and identifies those stochastic methods that are widely adopted to address uncertainties in the value stream analysis. Results from the review indicate that the application of the existing stochastic methods into value stream analysis is still at its infancy and is not systematically integrated. Additionally, the few studies that consider stochasticity of value streams weakly examines the effect that uncertainty sources entail on each other.

Keywords: Value stream analysis, Stochastic methods, Uncertainty Sources, Systematic literature review.

1. Introduction

Lean Manufacturing (LM) provides a strategic and operational approach to increase the level of value aggregation from customer's perception, thereby systemically reduces the non-valve adding waste (Womack & Jones, 1996; Hines et al., 2004). LM implementation fosters the development of companies by allowing the identification of improvement opportunities that will entail more efficient processes and, hence more flexible value streams (Seyedhosseini & Ebrahimi-Taleghani, 2015). In this sense, one of the most popular LM practices is the Value Stream Mapping (VSM), which comprises a structured method to analyze the flow of value and to identify critical improvement needs that will possibly impact on company's bottom line (McManus et al., 2002; Duggan, 2012).

Although VSM is useful to identify waste, it does not consider the dynamic aspect of production systems. Thus, according to Solding et al. (2009), some drawbacks of using VSM are: (*i*) only one stream of a product or product family is analyzed, (*ii*) the current state map only provides a snapshot of the value stream at a specific time, (*iii*) VSM traditionally entails a deterministic approach, which represents a huge simplification of the real situation, and (*iv*) it is difficult to conduct experiments with the proposed improvements through the future state map. Standridge and Marvel (2006) complemented that there are several uncertainty sources throughout a value stream such as setup and processing times, which introduce variability in processes and undermine management decisions.

Previous studies (e.g. Braglia et al., 2006; Abdulmalek & Rajgopal, 2007; Weston et al., 2009; Swallmeh et al., 2014; Seyedhosseini & Ebrahimi-Taleghani, 2015) have investigated the effect of variability in value stream analysis. Nevertheless, there is still a lack of studies that systematically integrate the variabilities related to uncertainty sources comprised in a value stream, regardless of the context of analysis. Most studies narrowly approach the stochasticity of value streams, either because they aim at a specific set of uncertainty sources (Serrano Lasa et al., 2009; Tortorella et al., 2017) or due to the fact that they do not provide user-friendly solutions for such integration (Seth et al., 2017). Therefore, in this research, we will be answering the below-listed research questions:

(*i*) What are the main uncertainty sources in a value stream?

(ii) What are the stochastic methods that can be integrated into the value stream analysis?

To answer both these questions, this study carries out a systematic literature review considering the main uncertainty sources and stochastic methods associated with the value stream analysis. A systematic literature review is an efficient method to reinforce the proposed research problem and reorganize the existing knowledge, identifying gaps and opportunities for further studies (Paré et al., 2015). Therefore, due to the exploratory nature of the methodology, this research generates knowledge and highlights future research directions.

2. Background

2.1. Value stream analysis

Value stream analysis has been a popular topic of research in the operations management field. The steps to conduct a value stream analysis have been coined in the widely deemed work by Rother and Shook (1999). Basically, there are four main steps to map a value stream. The first step, product families' identification, aims at grouping products/services according to their process similarities. The second step refers to mapping the current state of the value stream, enabling the examination of improvement opportunities and a common vision of the problems. The third step comprises the design of a future state, which aims at reducing waste and increasing the flexibility of the value stream. Final and fourth step consolidates the improvement opportunities and establishes an implementation plan to achieve the designed future state. These steps have been thoroughly followed by many researchers (e.g. Parthanadee & Buddhakulsomsiri, 2014; Ben Fredj-Ben Alaya, 2016; Tortorella et al., 2017; 2018), which indicates their academic acceptance and practical relevance.

In fact, over the past decades, several academicians (e.g. Seth & Gupta, 2005; Ben Fredj-Ben Alaya, 2016; Tortorella et al., 2018) and institutions (e.g. LEI and Prosche) have differently approached this topic and its practical and theoretical intricacies. Despite such differences, most of them agree that value stream analysis is a key activity to better comprehend the business and to provide a common and shared vision for improvement opportunities. Some literature reviews were also performed on the subject, such as Singh et al. (2011), De Steur et al. (2016), Shou et al. (2017), among others, which emphasized the benefits and challenges related to value stream analysis in different sectors, contexts and processes. However, the stochasticity nature of value streams has been poorly discussed in those literature reviews. Such gap entails the need for a literature consolidation on value stream analysis and the stochastic methods used to verify the impact of uncertainty sources on flow performance.

2.2. Uncertainty sources

Uncertainties associated with a value stream may present significant differences in terms of their nature and criticality (Wu et al., 2006; Wong et al., 2011). Simangunson et al. (2011) proposed the classification of these uncertainties into three groups: (*i*) internal uncertainties, (*ii*) supply chain uncertainties, and (*iii*) external uncertainties. We discuss below these three uncertainty groups and explain in detail how they impact the value stream analysis. The first group comprises of uncertainties related to information and production processes encompassed within the organization boundaries. For instance, maintenance operations such as setup and equipment repair are included in this group of uncertainties. Supply chain uncertainties concern aspects such as suppliers' deliveries and quality (Wong et al., 2011), and customers' demand

(Graves and Tomlin, 2003), among others. To mitigate these uncertainties, Van der Vorst and Beulens (2002) suggested some strategies that can be adopted at a supply chain level such as relocation of facilities. Finally, the third group includes uncertainties that can significantly affect the effectiveness of value streams and go beyond the company or supply chain management control such as economic regulation, government policies (Rao & Goldsby, 2009), macroeconomic issues (Miller, 1992), and natural disasters.

As the application of VSM can vary in different levels of an organization (Duggan, 2012), the uncertainty sources that impact the value stream are also subject to change according to the analysis. VSM that is more focused on flow within the organizational boundaries are more likely to be affected by either internal or supply chain uncertainties. When considering a VSM that involves processes and activities that go beyond such boundaries, external uncertainties are more prone to present a relevant effect due to the broader scope of analysis. In opposition, internal uncertainties, for instance, tend to lose their relevance at broader application levels of VSM. Therefore, it becomes important to take into account all groups of uncertainty sources so that a holistic analysis of VSM application is conducted.

3. Method

The proposed research method follows three steps adopted by Augusto and Tortorella (2019): (*i*) consolidation of research axis and definition of literature portfolio (LP), (*ii*) bibliometric analysis, and (*iii*) theoretical lenses discussion. These steps are detailed in the following sub-sections.

3.1. Consolidation of research axis and definition of LP

The establishment of a LP involved three main activities: (*i*) preliminary selection of the articles, (*ii*) adherence test of keywords, and (*iii*) filtering process. Considering that the research objective of this study is related to the identification of the main uncertainty sources and stochastic methods associated with value stream analysis, we sought for studies that fit within this topic. As suggested by Augusto and Tortorella (2019), the following databases were used: Web of Science, Science Direct, Emerald Journals, Scopus, and EBSCO. No delimitation related to articles' year of publication was considered.

For our study purpose, three research axes were established: value stream analysis, uncertainty sources and stochastic methods. Hence, keywords were combined to retrieve publications according to titles, abstracts and/or keywords. To validate the utilized keywords, we performed an adherence test. This test was carried out by randomly selecting five articles out of the 2,276 identified in the initial search and comparing their keywords with those used in the research axes. This comparison evidenced that the keywords initially used were part of the set of keywords included in the five articles, suggesting an alignment with the research topic and disregarding the need to incorporate additional keywords to our search (see Table 1). During the filtering process, publications were analyzed according to the following criteria: (*i*) duplicate articles, (*ii*) titles and abstracts alignment with the research topic, and (*iii*) full article analysis and alignment with the research topic. The EndNote X7® software was used to support the filtering process. First, 91 articles were removed due to duplicate versions and then, 2,080 articles were eliminated as their titles and abstracts were not aligned with the research topic. Finally, the remaining 53 articles were considered as part of the filtered LP (see Appendix).

Table 1. Consolidation of research axis and definition of LP

Keywords					Database	Initial result	Remaining publications after each filtering criteria		
							(*i*)	(*ii*)	(*iii*)
"value stream analysis" OR *"value*	AND	"*uncertainty*"	AND	*"stochastic approach"* OR *"stochastic method"* OR	*Web of Science*	823	2,185	105	53
					Science Direct	40			

stream mapping"	*"stochastic perspective"* OR *"stochastic"*	*Emerald*	783
		Scopus	118
		EBSCO	512
		Total	2,276

3.2. Bibliometric analysis

The bibliometric analysis facilitates the identification of trends of scientific production in different research fields (Tranfield et al., 2003; Crossan and Apaydin, 2010; Lazzarotti et al., 2011). This analysis firstly considered the 'basic variables' of the LP such as the most prominent journals and authors on the topic, and the evolution of publications through time. Then, we performed a content analysis with respect to the following 'advanced variables': (*i*) uncertainty sources for value stream analysis, and (*ii*) stochastic methods applied in value stream analysis. These variables provide support for integrating variability into value stream analysis and were assessed both quantitatively and qualitatively.

3.3. Theoretical lens

The analysis and discussion of theoretical lenses intend to evidence opportunities for knowledge development on the studied research context. Thus, a critical evaluation from the selected lenses helps to identify research gaps that can be further investigated in other studies on the subject. The analysis via theoretical lenses also allows a better understanding of the current theory, shedding light to aspects that are not yet explicitly evidenced in the literature (Harmancioglu et al., 2009). In this study, two theoretical lenses were chosen: (*i*) value stream levels and (*ii*) types of flow. According to Duggan (2012), value stream analysis can occur in different levels of an organization (e.g., micro, macro and mega), demanding specific tools and techniques for its improvement. Thus, understanding how stochastic methods have been used to support value stream analysis in each of those levels helps to approach problems more assertively. In terms of types of flow, value streams may significantly differ depending on the kind of value that is being mapped. The characteristics of a material flow, for instance, may completely change if compared to information or services flows. In this sense, not only the uncertainty sources may vary among types of flow, but also the stochastic method to be applied to the value stream analysis can differ.

4. Results and Discussion

4.1. Analysis of basic variables

From the 53 articles in the LP, 174 authors were identified and only three of them co-authored three publications each. As for scientific journals, Table 2 shows the distribution of publications from the LP. *International Journal of Production Research* stands out with four publications. Figure 1 displays the year of publication of the articles from the LP, which indicates that the topic has gained relevance over the last few years.

Table 2. Number of publications from authors and number of publications per journal of the LP

Authors	Publication Count
Braglia, M./ Frosolini, M./ Zammori, F./	3
Badri, H./ Ghomi, S. F./ Hejazi, T. H/ Seyedhosseini, S. M./ Ebrahimi-Taleghani/ Wang, T. K./ Yang, T./ Chan, F. T. S	2
Other 163 authors	1
Journals	**Publication Count**
International Journal of Production Research	4
Business Process Management Journal *Industrial Management & Data Systems* *The International Journal of Advanced Manufacturing Technology* *Journal of Manufacturing Technology Management*	3
European Journal of Operational Research *International Journal of Computer Integrated Manufacturing* *International Journal of Lean Six Sigma* *International Journal of Production Economics*	2

Mathematical Problems in Engineering	
Omega	
Other 25 journals	1

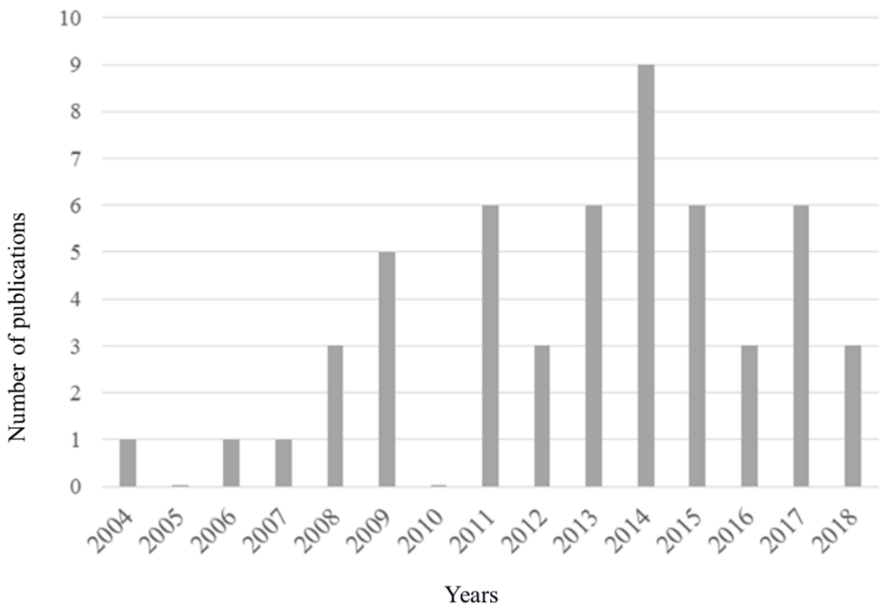

Figure 1. Evolution of the publications over time

4.2. Analysis of advanced variables

For the identified uncertainty sources for value stream analysis, Table 3 indicates s_1 (demand) as the main cause of variability in a production system, being mentioned by more than 70% of the LP articles. Moreover, s_1 may be associated with seasonality issues (You & Grossmann, 2008) and its analysis can be hampered by the absence of historical data, leading to potential forecast errors (Jauhari & Saga, 2017). This difficulty is even higher when considering the demand for new products with unknown demand profiles. In operational terms, demand variability usually leads to excess inventory, which increases costs and undermines organization's cash flow (Lugert et al., 2018; Ait-Alla et al., 2014). In this sense, uncertainties arising from demand variation end up undermining the scheduling of production processes, entailing the propagation of uncertainties through the value stream and hampering the sequencing of production orders (Seyedhosseini & Ebrahimi-Taleghani, 2015). In turn, uncertainty sources with the lowest citation frequency were s_{10} (machine maintenance), s_{11} (natural disasters), s_{12} (infrastructure) and s_{13} (government policies). Despite their lower acknowledgement level within the LP, these uncertainty sources cannot be neglected since they can generate risks of temporary or permanent interruption of value streams.

Regarding the stochastic methods applied in value stream analysis, Table 4 shows the consolidation of the main methods that appear in the LP. Among the 11 methods, m_1 (stochastic simulation) followed by m_2 (fuzzy approach) seem to be more frequently integrated into value stream analysis. In turn, other stochastic methods, as m_9 (systems dynamics), m_{10} (multi-period stochastic planning model) and m_{11} (nonlinear mixed-integer multi-period programming), appear to be less frequently used for value stream analysis.

Particularly, the main advantage of m_1 is the error risk reduction entailed by the prediction of the stochastic behaviors from key value-stream parameters such as supply lead time. This in fact increases the reliability of the planned inventory levels, for instance Kim et al. (2014), while enables a thorough approach for considering variables that present different probability distribution functions (Shararah et al., 2011). Complementarily, m_2 is usually applied to variabilities inherent to production processes when designing future state maps for value streams. Braglia et al. (2009), for example, used this method to consider variability into VSM. More specifically, they evaluated the effect of different ranges on production cycle times from a probabilistic perspective. The main advantage of the fuzzy approach is the possibility of propagating the effect of uncertainties along the considered value stream, representing the stochasticity of parameters by their respective probability distribution functions (Abdo & Flaus, 2016).

Table 3. Citation frequency of uncertainty sources over the years

Uncertainty Sources	Group	Year															Total
		2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	
s_1 – Demand	Supply Chain	-	-	1	-	3	4	-	3	3	2	5	5	3	5	4	38
s_2 – Processing Time/Cycle	Internal	-	-	-	-	-	2	-	4	-	5	6	4	1	1	-	23
s_3 – Setup Time	Internal	-	-	1	-	-	1	-	5	-	2	1	1	-	1	-	12
s_4 – Inventory	Internal	-	-	-	1	-	2	-	1	1	-	3	-	1	1	-	10
s_5 – Supplier Delivery Lead Time	Supply Chain	-	-	-	1	-	1	-	2	-	2	-	-	-	1	-	7
s_6 – Distribution Logistics	Supply Chain	-	-	-	-	1	2	-	-	-	1	1	-	-	-	-	5
s_7 – Selling Prices	Supply Chain	-	-	-	-	1	-	-	-	-	-	-	-	2	2	-	5
s_8 – Quality of the Raw Material	Supply Chain	-	-	-	-	-	-	-	2	-	1	-	-	-	1	-	4
s_9 – Employee Productivity	Internal	-	-	-	-	-	-	-	1	-	1	-	-	-	1	-	3
s_{10} – Machine Maintenance	Internal	-	-	-	-	-	-	-	-	1	-	-	-	-	1	-	2
s_{11} – Natural Disasters	External	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
s_{12} – Infrastructure	Internal	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	1
s_{13} – Government Policies	External	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Total		2	0	2	2	5	12	0	18	5	14	16	11	7	14	4	121

Table 4. Citation frequency of stochastic methods over the years

Stochastic Methods	Year															Total
	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	
m_1 – Stochastic Simulation	-	-	-	1	-	1	-	3	1	2	1	3	1	1	-	14
m_2 – Fuzzy Approach	-	-	-	-	-	1	-	-	-	2	-	1	-	1	-	5
m_3 – Stochastic Programming in Two Stages	-	-	-	-	-	-	-	-	-	-	-	1	2	1	-	4
m_4 – Monte Carlo Simulation	1	-	-	-	-	-	-	-	-	-	-	-	-	1	-	2
m_5 – Optimization Models	-	-	-	-	-	-	-	-	-	-	1	-	-	-	1	2
m_6 – Stochastic Mixed-Integer Linear Programming	-	-	-	-	-	-	-	-	-	-	1	-	-	-	1	2
m_7 – Stochastic Dynamic Programming	-	-	-	-	-	1	-	-	1	-	-	-	-	-	-	2
m_8 – Central Limit Theorem Application	-	-	-	-	-	1	-	1	-	-	-	-	-	-	-	2
m_9 – Systems Dynamics	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-	1
m_{10} – Multi-period Stochastic Planning Model	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	1
m_{11} – Nonlinear Mixed-Integer Multi-Period Programming	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	1
Total	1	0	0	1	2	4	0	4	3	4	3	5	3	4	2	36

4.3. Theoretical lens

Value stream levels

Value stream analysis can be performed from three mapping levels: mega, macro, and micro. The mega level involves processes and activities that go beyond organizational boundaries, expanding the analysis to supply chain agents. VSM at this level has been adapted and denoted as extended value stream mapping (EVSM) (Womack & Jones, 2002; Duggan, 2012). When the value stream analysis is concentrated within the company boundaries (door-to-door stream), it is called a macro analysis. The macro analysis enables the understanding of the main streams of materials and information that occur across company's departments and production units; it is the most common level of analysis (Rother & Shook, 1998; Singh & Sharma, 2009). Finally, the value stream analysis at a micro level usually includes processes and activities specific to a sector or productive area, enabling the detailed comprehension of aspects such as cycle times and sequencing of activities. Based on the articles from the LP, Table 5 (see the Appendix for information on the reference code) shows that nine publications focused on a mega level, 20 studies were related to the macro level, and four were oriented to the micro level.

At the mega level, two out of the nine studies used a two-stage stochastic programming in their analysis, which shows a slight tendency to apply this method in more complex value stream analyses such as supply chains (Behrouzi & Wong, 2013). In general, value stream analysis at this level lacks data and information that are more difficult to collect since they involve several agents (firms). Therefore, a mega value stream analysis implies the knowledge of variables subjected to non-deterministic behaviors such as transportation times, customers' demand, and shipment and dispatch of goods' waiting times. Badri et al. (2017), for instance, applied this method in a multi-commodity supply chain involving three tiers. However, a barrier for applying two-stage stochastic programming, especially at the mega level, is that the probability distribution functions of the uncertainty sources need to be well-known (Sahling and Kayser, 2016).

Regarding the macro level, nine out of the 20 studies applied stochastic simulation to, for example, balance processing capacities according to customer demand (Abdulmalek and Rajgopal, 2007), as well as to provide significant inventory reductions on the value stream (Gurumurthy & Kodali, 2011). This method is useful for analyzing the variability of production rates and workload balance (Wang et al., 2014) as it allows to test different scenarios in which parameters can vary (Villarreal et al., 2016; Aziz et al., 2017). In general, most of the articles reported studies conducted in manufacturing contexts, in which the effect of uncertainty produces negative impacts on operational performance (Braglia et al., 2009).

At the micro level, studies mainly approached the reduction of variability in production cells and lines (Deif, 2012), or specific sectors and departments (Xie & Peng, 2012) in manufacturing or services companies, respectively. The stochastic method most frequently used was a stochastic simulation, since it allows carrying out experiments without altering the structure of the system under analysis and verifying how the variability of the uncertainty sources affects performance (Wang et al., 2015).

Overall, it is clear from the literature that the development and application of more robust stochastic methods are likely to occur in mega and macro levels, where the intrinsic higher levels of complexity may justify the integration of more sophisticated techniques. However, the implicit variability in value streams at the micro level cannot be neglected, resulting in the need for simpler stochastic analysis methods whose application can be easily integrated. This is aligned with Deif (2012), who emphasized the importance of a proper evaluation of the value stream at the micro level to support more assertive decisions for the organization.

Types of flow

As different types of flow may influence on the approach chosen to complement the value stream analysis, we checked the LP to verify the prominence of the integration of any particular stochastic methods throughout different application contexts. The articles included in the LP were analyzed according to five types of flow as suggested by Borges et al. (2019): (*i*) flow of information, (*ii*) flow of materials, (*iii*) flow of processes, (*iv*) flow of patients, and (*v*) flow of equipment. The flow of information refers to the course that documents, data, emails, etc., need to go through so that processes within an organization can be undertaken (Vamsi & Sharma, 2014). Similarly, the flow of materials is related to the path taken by a raw material from the moment it is received until it becomes finished goods and is delivered to the end consumer (Singh & Sharma, 2009). The flow of processes represents sequences and activities that compose a process under analysis (Braglia et al., 2009). The flow of patients refers to the path taken by patients in healthcare environments (Xie & Peng, 2012). Finally, the flow of equipment concerns the cycle that a piece of equipment must follow under a specific operating condition (Aziz et al., 2017).

It is noteworthy that most of the studies are related to the manufacturing context and no specification of the type of flow is provided. However, 30 studies analyzed the flow of information. Possible delays in the transfer of documents, forms, emails and data usually result in potential delays in the subsequent operations and processes (Vamsi & Sharma, 2014). This type of flow evidences the alignment between different departments within an organization, since information is a central element for decision-making and, hence, must be delivered in a fast and adequate manner. Such a need is increasingly important in view of the dynamic nature of consumer markets (Mohanraj et al., 2015).

23 studies in LP discussed the aspects associated with the flow of material. Within organizations, waiting times for materials end up increasing the uncertainty level of the productive chain (Basu & Dan, 2014) and thereby delaying production. Such delays generate a misalignment between productive capacity and *takt* time (production rate demanded by customer) (Singh & Sharma, 2009). In general, visualization of problems arising from inefficiencies in this flow is more evident to the managers, since the accumulation of material stocks or their lack are perfectly verifiable in productive environments. In addition, the propagation of variability between information and material flow can be perceived, for example, in the production planning and scheduling (Jonsson & Ivert, 2015).

Another important type of flow comprises the flow of patients in healthcare organizations. Three articles from the LP approached this context. For Xie and Peng (2012), the utilization of stochastic simulation is beneficial in the search for a reduction in patient waiting times, which is fundamental to increase the competitiveness of healthcare organizations. This was also reinforced by Wang et al. (2014; 2015), who studied the harmful effects of the high variability in patient care times using stochastic simulation. The reduction of waiting times through the consideration of the probabilistic characteristics of healthcare also depends on the concomitant analysis of the flow of information within hospitals. In other words, delays in medical records and requisitions between departments often lead to longer waiting times for medical procedures (Michael et al., 2013). Thus, despite the relevance of healthcare quality and service, the consideration of stochasticity on the flow of patients is still scarce in the literature.

Table 5. Theoretical lenses

Value stream level	Type of flow	Stochastic methods	Articles in LP (listed in appendix)
Mega	Information/Materials/ Processes	m_3 – Stochastic Programming in Two Stages	7, 8
		m_1 – Stochastic Simulation/ m_2 – Fuzzy Approach	10
		m_6 – Stochastic Mixed-Integer Linear Programming	42

		m_{11} – Nonlinear Mixed-Integer Multi-Period Programming	51
	Information/Processes	m_4 – Monte Carlo Simulation	19
		m_1 – Stochastic Simulation	24, 36
		m_5 – Optimization Models	34
Macro	Information/ Materials/Processes	m_4 – Monte Carlo Simulation	1
		m_1 – Stochastic Simulation	2, 21, 23, 28, 41, 43, 47
		m_2 – Fuzzy Approach/ m_8 – Application of the Central Limit Theorem	11
		m_3 – Stochastic Programming in Two Stages	14, 38
		m_5 – Optimization Models/ m_6 – Stochastic Mixed-Integer Linear Programming	25
		m_7 – Stochastic Dynamic Programming	26, 29
		m_2 – Fuzzy Approach	33, 49
	Processes	m_{10}– Multi-period Stochastic Planning Model	5
	Information/Materials/ Equipment/Processes	m_1 – Stochastic Simulation	6
	Processes	m_2 – Fuzzy Approach	44
	Information/Patients/ Processes	m_1 – Stochastic Simulation	46
Micro	Information/Patients/ Processes	m_1 – Stochastic Simulation	3, 48
	Information/ Materials/Processes	m_9 – Systems Dynamics	18
	Processes	m_8 – Central Limit Theorem Application	52

5. Future Research

The objective of this study was two-fold: (*i*) to identify the main uncertainty sources in a value stream and (*ii*) to examine the stochastic methods that are commonly integrated into the value stream analysis. For the first objective, our research identified 13 uncertainty sources that were categorized into three different groups according to the root of their occurrence, as suggested by Simangunson et al. (2011). With respect to the second objective, 11 stochastic methods were found in the literature. These methods were grouped based on the level of application on value stream (micro, macro and mega) and the type of flow addressed in the literature evidence (see Table 5).

The analysis derived from the achievement of both objectives allowed the suggestion of three main research directions related to stochastic value stream analysis: (*i*) identification of uncertainty sources criticality, (*ii*) verification of variability propagation along the value stream, and (*iii*) systemic incorporation of uncertainty sources into a more practitioner friendly value stream analysis. These research directions are subsequently discussed.

5.1. Identification of the uncertainty sources criticality

As evidenced, uncertainty sources can significantly vary in terms of their nature and impact on the value stream. Additionally, the scarcity of organizational resources may limit the capacity for addressing all improvement opportunities in a value stream. Hence, it is fundamental to properly prioritize managerial efforts so that performance is benefitted and maximized with minimum efforts. In this sense, future studies could use hierarchical methods (e.g. analytic hierarchy process; Saaty, 1980) and multiple-criteria decision analysis (MCDA) (De Azevedo et al., 2013) to rank the uncertainty sources and identify the ones with the greatest impact on the value stream. These hierarchical methods allow the ranking of certain alternatives against multiple previously established analysis criteria. Such prioritization would support managers' decision-making process through the establishment of criticality levels for each uncertainty source. Additionally, the identification of criticality levels for uncertainty sources could be later used as a comparative and evolutionary parameter for the incremental variability reduction in value streams. At the same time, the creation of such criticality parameters allows comparisons between uncertainty sources of different value streams, allowing the establishment of benchmarks and providing arguments to comprehend the reasons for different operational performance levels between value streams.

5.2. Verification of variability propagation along the value stream

There is a lack of research related to the combined effect of different uncertainty sources on value streams, especially at a mega level which tends to be more complex. Value streams with higher complexity levels are more likely to be affected by variability propagation issues, since characteristics such as extension and linearity of the flow tend to be more critical (Seyedhosseini & Ebrahimi-Taleghani, 2015). Therefore, there is a need to integrate uncertainty sources in order to observe how their variability propagation can affect the design of leaner value streams.

In this context, the combination of stochastic methods such as optimization models (Alem and Morabito, 2015) or Monte Carlo simulation with sensitivity analysis can be an alternative to check the effects of the variability propagation along the value stream. The verification of multiple scenarios would enable to test how different levels of key uncertainty sources' variability impact performance indicators such as lead time and delivery service level (Aamer, 2017). This could be especially important for better understanding of uncertainty sources that are less extensively assessed in the value stream literature such as human factors (Xie & Peng, 2012).

5.3. Systemic incorporation of uncertainty sources into a more practitioner friendly value stream analysis

The incorporation of variability derived from various uncertainty sources into value stream analysis has increasingly motivated researchers to search for new stochastic methods and techniques. Such methods, as observed in our literature review, can vary in terms of complexity and approach and usually require high mathematical skills to be applied. Although those methods may present a certain level of acceptance within academia, their translation to practice (i.e. organizations in general) is not as smooth as one might assume. In fact, most practitioners still struggle with the application of those stochastic methods, which becomes a barrier for their actual utilization in the real world. This leads to the utilization of oversimplified deterministic value stream analysis, which presents a number of flaws and does not represent the real performance of the flow of value.

In this sense, we argue that future research could aim at developing stochastic methods that systemically incorporate relevant uncertainty sources into value stream analysis, but through a more practitioner-friendly perspective. Such studies would provide practitioners means to better capture their current states through the understanding of stochasticity and its effects on value stream performance; hence, leading to more realistic analysis. The challenge in conceiving such practitioner-friendly methods relies on considering the stochasticity of value streams while avoiding complex mathematical computations that inhibit a popular utilization. One way to overcome such challenging issue is the development of software or applications that support practitioners to map the real situation of their current states in a simple and intuitive manner. Future studies could also comprise the integration of more sophisticated digital technologies (e.g. Internet of Things and cloud computing) to facilitate a systematic incorporation of uncertainty sources into a more practitioner friendly value stream analysis.

6. Conclusion

This paper aimed to identify the main uncertainty sources and stochastic methods considered in value stream analysis. For that purpose, a systematic review of the existing literature was conducted by adopting content and bibliometric analysis. Further, this analysis allowed the verification of the evolution of this research topic, reinforcing its relevance to achieving more efficient value streams. This literature review allowed the identification of research gaps, whose fulfilment is suggested through the development of a research agenda.

This research has a few limitations. First, findings were restricted to publications available at certain databases. Although these were widely deemed ones, there may be important studies that were not indexed in these databases. Thus, future research could enlarge the number of consulted databases so that a wider set of journals is considered. In addition, the insertion of other keywords in the initial search could lead to complementary insights on the topic. In this sense, an advanced combination of keywords could bring other stochastic methods that were not included in this search.

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APPENDIX – Final LP

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