# Application of Value Stream Mapping and Monte Carlo Simulation in a University Hospital

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## Abstract

This study aims at proposing a method that combines value stream mapping (VSM) and Monte Carlo simulation for identifying improvement opportunities in the flow of value, taking into account the inherent variability of the uncertainty sources. A cross-functional team was involved to draw the current and future state maps. Moreover, leaders were interviewed to define the most critical uncertainty sources of the value stream, whose variability was verified through a thirty-day in loco data collection in a university-hospital. These variability data were inputted into the simulation model in order to comprehend how the uncertainty sources impact lead time. Findings show that the proposed approach allows the identification of opportunities for improvement that are not taken into consideration in traditional application of the VSM, providing a more realistic condition of the current state.

## Keywords
Lean production; Value stream mapping; Monte Carlo methods

## 1. Introduction

Lean Production (LP), term coined in 1990s by researchers at the Massachusetts Institute of Technology, refers to the management philosophy of increasing customer value through more efficient use of the organization's resources (Greef et al., 2012). LP implementation comprises five principles (Womack and Jones, 2010): specification of value from the customer's point of view; identification of the flow of value; make the value flow; pull value according to customers demand; and seek perfection. Many companies have been aiming the implementation of LP as a response to an increasingly competition in a global market (Abdulmalek and Rajgopal, 2007; Woehrle and Abou-Shady, 2010). Results obtained from LP implementation have consistently demonstrated its benefits, such as productivity improvement, lead time reduction, increased customer satisfaction, and others (Jimmerson et al., 2005). Nevertheless, there may be drawbacks in LP implementation with regard to social and human resources aspects, which are vital for the success of Lean Production (Martínez-Jurado and Moyano-Fuentes, 2014).
Among the existing LP practices, Value Stream Mapping (VSM) aims to identify all the activities involved (value-added or not) along the material and information flows of a specific product family (Womack and Jones, 2010). In this sense, VSM supports a systemic continuous improvement implementation in order to make the value stream more flexible (Jimmerson et al., 2005). VSM provides a structured method to analyze the flow of value and ensure that the improvement actions will be carried out at the points where there are greater opportunities and bring real benefits to the business (Duggan, 2002). However, it is important to highlight some limitations involved in the use of this practice. Tortorella et al. (2017), Tyagi et al. (2015), and Dickson et al. (2009) show the approach the VSM usually base their information and data collection on a deterministic perspective. In other words, along the value stream there are several uncertainty sources, such as inventory, processing and setup times, among others, which add variability to manufacturing processes (Standridge and Marvel, 2006) and undermine production management. One

of the consequences of a productive scenario with high variability is the increase in inventory levels as a countermeasure to mitigate the effects of uncertainties. The addition of inventories increases lead time and costs, besides masking the main problems underlying the uncertainty sources (Mapes et al., 2000).
Additionally, to address improvements from deterministic perspective can lead to isolated benefits that will not impact the business performance as a whole (Standridge and Marvel, 2006). Quantitative methods that consider process stochastic allow a more realistic view of existing variability, identifying means to mitigate such uncertainty sources. Thus, in order to complement VSM, previous studies have integrated it with other techniques. Braglia et al. (2009) apply VSM and through fuzzy logic and probabilistic methods treat the variability within in the processes. Woehrle and Abou-Shady (2010) present the use VSM and Lean Accounting in conjunction with simulation to address uncertainty and financial aspects of LP implementation. The incorporation of this variability into the VSM allows reducing management uncertainties, resulting in lower inventory levels, lead time and operational costs (Flynn et al., 1995). In this situation of greater variability, the solution usually employed is to use the lowest and highest values to find the worst case scenarios in the lead time estimation (Braglia et al., 2009). In this sense, the approaches commonly found adjust the characteristics of the productive processes based on trial and error (Standridge and Marvel, 2006), which usually implies a greater time to make really significant improvements to the productive system. Hence, the use of simulation together with the VSM might serve as a solution to this problem (Lian and Van Landeghem, 2007).
In this context, this work aims at proposing a method to identify improvement opportunities that combines Monte Carlo simulation and VSM. The contribution of this study may include the identification of the main uncertainty sources in the flow of value and the definition of the impact of their variability on the lead time through the consideration of their probability distributions. This novel approach allows the identification of improvement opportunities under a more realistic perspective of value streams. Such benefit is especially important for contexts subjected to high variability and complexity, such as healthcare processes. In this sense, the proposed method is illustrated from an application in a flow of supplies in a Brazilian public hospital-school. This paper is organized as follows. Section 2 presents a literature review and section 3 describes the proposed method, whose results and analysis of the practical application are presented in section 4. Finally, the section 5 brings about the concluding remarks and recommendations for future work.

## 2. Literature Review

### 1.1 Value Stream Mapping

The flow of value involves any action necessary to transform the raw material into finished product (Rother and Shook, 1999). VSM is used to map a process or a supply chain considering not only the material, but also the information flow that controls the production and transportation (Braglia et al., 2006). VSM is developed in order to clearly present the processes under study and their main characteristics, evidencing the existing problems and opportunities (Tyagi et al., 2015). Such opportunities may support the waste reduction in order to more significantly impact the bottom line of the company (Forno et al., 2014). VSM application also provides systemic guidelines for improvement, which is why it is one of the most widely adopted LP practices (Marodin and Saurin, 2013), and serves as the basis for the implementation of other LP practices (Seth and Gupta, 2012).
VSM is comprised by four main steps (Rother and Shook, 1999): (i) define the product family to be mapped; (ii) draw the current state map; (iii) elaborate a future state map; and (iv) develop an action plan to address the improvement opportunities that will allow the achievement of the future state. An important part of VSM is the understanding of the relationship between material and information flows (Singh et al., 2011). Unlike most mapping techniques that only document the material flow, VSM records key data, such as inventory, scheduling points and information frequencies. In addition, it is also possible to visualize important aspects of the processes, such as cycle and processing times, hence complementing conventional mapping techniques (Tyagi et al., 2015).
Despite the evidenced benefits, VSM presents some limitations and challenges in its implementation. According to Hines et al. (1998), one of the difficulties faced in applying VSM is the limited dissemination and understanding of the LP and its principles across the company as a whole. In this sense, the application of VSM without reconciling it with the company's strategy leads to operational gains, but without significant financial return. Braglia et al. (2006) state that in companies where there are multiple value streams that overlap and share resources, VSM application becomes more difficult. Forno et al. (2014) affirm that when there are multiple products with similar importance to the business, one of the challenges is the definition of the product family to be mapped. Woehrle and Abou-Shady (2010) argue that one of the first wastes to be identified and eliminated is the excess of inventory. However, the simple reduction of these inventories without actually implementing consistent improvements in the flow can

negatively affect company's operational performance, discouraging the adoption of the LP. Further, VSM does not provide means to precisely predict the benefits and impacts of the implementation of the future map (Detty and Yingling, 2000; Lian and Van Landeghem, 2007). Such limitation undermines the acceptance of the improvements, and emphasizes the need to develop an alternative that presents quantitative data to support the decision-making process (Abdulmalek and Rajgopal, 2007).

The deterministic feature of VSM limits its modelling capacity and makes it difficult to map systems with dynamic behavior (McDonald and Van Aken, 2002), which present a high degree of variability. Variability is propagated and extended throughout the processes directly impacting its performance (Braglia et al., 2009; Forno et al., 2014). Thus, complementary techniques were developed to broaden the application scope of VSM. Such techniques can be separated into two groups: simulation and detailed mapping. The first group (simulation) has an interface oriented to the creation of models, capturing the dynamic aspects of the productive systems to be analyzed. Through simulation it is possible to develop future models and compare them to the current state. The combination of computational capacity and the visual aspects of VSM allows LP adoption to be faster and the resistance lower (Woehrle and Abou-Shady, 2010). Abdulmalek and Rajgopal (2007), for instance, adapted LP principles to a continuous processing industry using simulation to compare the current and future states from the VSM. Lian and Van Landeghem (2007) develop a modular structure for VSM simulation that can be fed by company's management system.

The second group of techniques (detailed mapping) comprises new mapping methods that complement VSM. Braglia et al. (2006) propose a new approach for VSM application in high-variety companies through an iterative process that uses timed bill of material, allowing the identification of the critical path of production and then suggesting a new one. Hines and Rich (1997) suggest seven techniques for dealing with value stream analysis, most of which are adaptations of techniques already present in other areas, such as logistics, system dynamics and operations management. Braglia et al. (2009), in turn, propose two methods for the incorporation of the variability to VSM. The first is to obtain Beta distributions of the process times using as input data the minimum, average and maximum values of each process. The second method is through fuzzy logic, with triangular distributions of probability, which is simpler than the first one.

### 1.2 Uncertainty Sources in a Production System

The search for uncertainties reduction in productive processes is key for companies' survival in a highly competitive scenario (Du et al., 2010). These uncertainties have a great impact on costs and may lead to several different forms of waste (Braglia et al., 2009), such as idleness, overcapacity and inventories, in order to compensate for variability (Van der Vorst and Beulens, 2002). Therefore, it becomes necessary to identify these sources, which is generally challenging in manufacturing processes with multiple variables. Process variability can also affect efficiency and, consequently, impair production planning (Arbós, 2002). In addition, lower variability levels in lead time allow the prediction of delivery times, facilitating the coordination of plant activities and reducing the buffers needed in the process (Lu et al., 1994).

Uncertainties can be found throughout the entire value stream (Wu et al., 2006). The greater the uncertainties, the greater the need for integration between processes of the value stream (Wong et al., 2011). Simangunson et al. (2011) identify different types of uncertainties and classify them into three groups: (i) internal uncertainties of the organization, (ii) supply chain uncertainties, and (iii) external uncertainties. The first group consists of uncertainties that occur within the organization's sphere of control, such as manufacturing and control processes, and behavioral characteristics of the organization. Production machines are one of the ways by which uncertainty can be observed within the organization (Jamshidi and Esfahani, 2015). In addition, particularly in automated processes, factors such as machine maintenance can directly affect its effectiveness and reliability (Samat et al., 2012). For manual processes, the main risk is the reduction of productivity due to dissatisfaction with work or absenteeism. In this sense, it is necessary to implement policies that reduce the risk to which the operator is exposed, promoting a safe and healthy working environment (Miller, 1992). Simangunson et al. (2011) present some strategies to deal with this type of uncertainty, such as the automation of processes to reduce the influence of manpower and quality strategies. Among these strategies, Du et al. (2010) highlight control charts, which allow the detection of anomalies and trends in process variability.

The second group refers to uncertainties within the supply chain, such as customer demand, supply delivery and quality control mechanisms. Demand from the end consumers may vary according to seasonal factors and changes in their preference. According to Wong et al. (2011), supplier-related uncertainty is directly linked to the tier level. The greater the integration, collaboration and exchange of information, the lower the level of uncertainty with regard to suppliers (Simangunson et al., 2011). Van der Vorst and Beulens (2002) list some strategies that can be used in

supply chains, such as relocating facilities, establishing an infrastructure for information exchange between agents, and reducing tier levels. Further, Graves and Tomlin (2003) indicate that companies with flexible processes may respond to demand variations more efficiently.
Finally, the third group lists uncertainties that are beyond the control of the supply chain, such as economic regulations, government policies, macroeconomic issues and disasters. Miller (1992) comments that some macroeconomic aspects can directly affect company's operational performance, such as exchange rate and interest rate variations. Rao and Goldsby (2009) state that when buying from offshore suppliers (import) it is important to evaluate the political context of the country in order to avoid supply problems later. It is also important to highlight cultural aspects that affect the behavior of supply chain agents (Van Der Vorst and Beulens, 2002). Some strategies to deal with these uncertainties are (Simangunson et al., 2011): purchasing insurance, financial risk management, and collaboration among companies from the same industry sector.
In general, it is up to managers and business leaders to redesign the value stream to deal with their uncertainties and mitigate them in order to optimize their performance (Van Der Vorst and Beulens, 2002). Moreover, it should be considered that these uncertainty sources may present interdependence, and it is necessary to evaluate the impact of the reduction of one in relation to the others (Simangunson et al., 2011). Table 1 summarizes the existing uncertainties from these three groups. Research methods are described next.

Table 1. Uncertainty sources in a production system

| Category | Uncertainties |
|---|---|
| Organization | Machine cycle time<br>Machine uptime<br>Quality performance<br>Labor productivity<br>Absenteism<br>Accidents |
| Supply chain | Customers demand<br>Suppliers delivery<br>Costs variation<br>Material availability |
| External | Governmental policies<br>Macroeconomic issues<br>Social trends<br>Natural disasters |

## 2. Research Methods

The proposed method is comprised by 6 steps: (i) identify the product family, (ii) map the current state of the value stream, (iii) raise and collect data of the critical uncertainty sources of the current value stream, (iv) critically analyze the flow as a whole and list improvement opportunities, (v) draw the future state map, and (vi) consolidate priority actions to improve flow.
Step (i) consists of identifying the product family to be mapped. To do so, it is necessary to define the products that make up each family and their respective processes. In this sense, Duggan (2002) suggests the use of a matrix of products and processes that identify which products follow the same processes. Products of the same family are those with a minimum process similarity of 80%. Thus, among the identified families, a few criteria for prioritizing their analysis may be their participation in revenue, production volume, among others (Tortorella et al., 2017).
Step (ii) draws the current state map of the selected product family. The icons and methodology to be used in this step were proposed by Rother and Shook (1999). The current state map allows the visualization of wastes throughout the processes and the identification of improvement opportunities. In order to approach the flow from customers' perspective, the mapping is done from finished goods to raw material (Forno et al., 2014). To establish an interdisciplinary team contributes to enriching the analysis (Bhami and Sangwan, 2014). It is noteworthy that this step disregards the existing uncertainties in processes.
Step (iii) identifies the main uncertainty sources related to the value stream through semi-structured interviews with leadership. Interviews of this type have a set of previously defined questions in order to guide the discussion and broaden the collection of information. Nevertheless, there is freedom for the interviewer to conduct the conversation, allowing a greater wealth of obtained information. The uncertainties listed in the literature review

were presented in interviews by using a 0 to 10 scale (0 is 'insignificant' and 10 'being an absolutely critical uncertainty'). Historical data about the critical uncertainties were obtained directly with the company under study. Uncertainty sources whose accumulated sum of the average criticality values totalizes 80% (uncertainties type 'A') have their variability studied and inserted into the analysis of the current state map.
Step (iv) applies a stochastic analysis of the current state is performed using Monte Carlo simulation (MCS) as supporting method. MCS is used as a way of quantifying the existing variability in probabilistic scenarios through the use of computational simulation (Kentel and Aral, 2005). MCS allows understanding how variability of critical uncertainty sources influence lead time.
Step (v) consists of mapping the desired future state of the value stream. This future state map aims at removing wastes with a focus on both the nominal values of processes and variability of the critical uncertainty sources. The used icons in the future state map are similar to the ones used in the current state map, with the insertion of some icons showing the suggested improvements. Rother and Shook (1999) propose a set of questions about the future state in order to aid in its construction: (a) what is the takt time?; (b) will finished products be stocked or will they be shipped immediately?; (c) where can continuous flow be applied?; (d) is there a need for a supermarket-type pulled system in the value stream?; (e) what will be the scheduling point in the value stream?; (f) how will the production levelling be adjusted to the required pace? (g) what is the minimum production unit?; (h) what kind of process improvement will be needed?. Moreover, uncertainty sources that were not addressed in this first cycle of improvement have their current variability levels maintained for the future state map. However, when consolidating the new lead time, all critical uncertainties are considered through MCS, analogously to step (iv).
Finally, step (vi) developes an action plan in order to achieve the desired improvements for the future state map. This plan should have its goals, activities, and responsibilities clearly defined as well as deadlines. Furthermore, in order to ensure the implementation success, follow-up meetings should be performed with team members. The required resources for the implementation of the future state map should also be taken into account.

## 3. Findings

The proposed method was applied to the supplies of a Brazilian public university-hospital, which has been in operation for 37 years. For products family definition, a meeting with hospital management was carried out. It was defined that the orthoses and prostheses supplies (OPS) would be studied due to their high value and lack of inventory policies. These materials are obtained through a bidding session with one year period and stored on a consignment basis. The warehouse has a storage capacity of approximately 1,500 units and currently manages 300 different items. The agreed delivery time with suppliers is five days. Moreover, suppliers have a contractual obligation to exchange the consigned items that are within the expiration date. The average demand for this product family is 215 units per month, considering the period from January 2016 to June 2017.
The second step corresponded to the drawing of the current value stream from a deterministic perspective (see Figure 1).

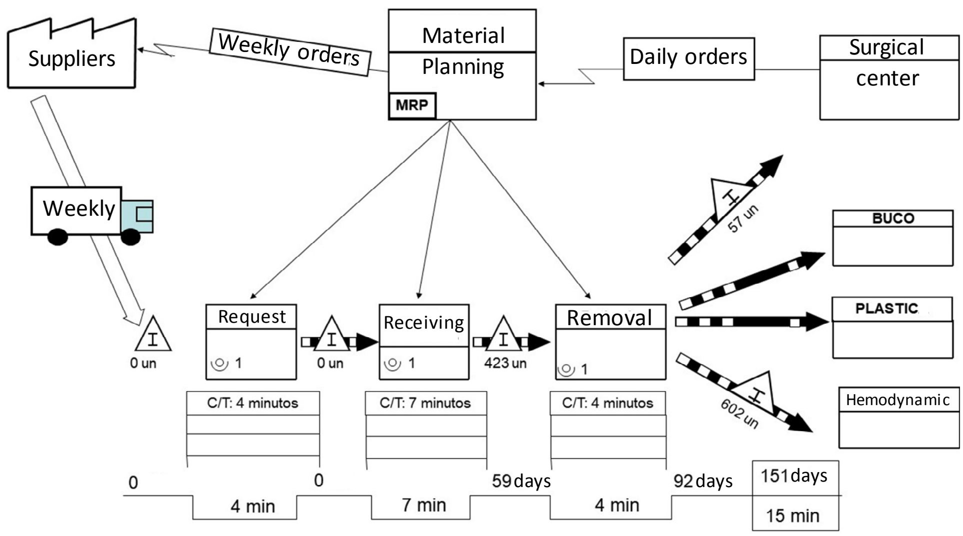


Figure 1. Current state value stream map

To develop the map of Figure 1, an interdisciplinary team was invited, composed of employees from hospital's material planning sector as well as members of all sectors for whom the OPS are distributed (internal customers). To draw this map, three meetings of approximately two hours each involving the members of this team were held. It is worth noting that the data collected for the elaboration of this map were based on a random sampling available at the time of the mapping activities and, hence, do not indicate the variations that occur over time in this flow. Currently, these materials do not have a systematic policy for requesting delivery orders with suppliers. This request is done based on the experience of the warehouse supervisor. When OPS are received, an inspection is performed through a sampling process. Then, the material is registered in the system and forwarded to the stock. There is no systematic way to manage queues in inventory, and occurrences of products that reach their shelf life are observed without utilization. As previously mentioned, in this situation suppliers are contractually responsible to exchange the item without additional charge to the hospital.

OPS are sent to several hospital units, such as hemodynamics and surgical center. The material requests from each of unit do not follow a standardized form, being done in various ways, such as email, physical request, or telephone call. Once these orders are received, the items are separated waiting for be withdrawn in a specific removal area in the warehouse. In addition, a certain level of inventory remains in some of these units (internal customers). Throughout the flow of value there are three scheduling points: on the request, receiving, and removal processes. After utilization, a medical report is required to certify and to ensure traceability of the material. The total lead time observed in for this value stream was 151 days, while the process time totalized only 15 minutes.

Once the current state map was drawn with data collected in a timely manner, the existing variabilities were raised. As this process is fundamentally focused on materials management and information flow, uncertainties such as machine, maintenance, and macroeconomic issues could be disregarded. In this sense, through interviews with three leaders of this value stream (warehouse supervisor, material planning coordinator, and surgical center coordinator), uncertainties had their criticality levels classified on the 0-10 scale, previously mentioned. Table 2 presents a summary of the results obtained with the interviews. The uncertainties of 'customers demand', 'suppliers delivery' and 'labor productivity' comprise the A-type uncertainties, which were considered as critical and hence incorporated into the analysis. Therefore, data collection of these uncertainties was performed during a period of thirty days, in which processes time and inventory levels were registered. For the request, receiving and removal processes, time measurements were made with the purpose of studying the variability that occurs in worker productivity. For the other uncertainties, inventory levels in both warehouse and hospital units were verified. Based on these 30-day data, histograms were generated and the probability distributions were identified for each uncertainty source (see Table 3). For probability distributions determination, ®Easyfit software was used.

Table 2. Uncertainty sources criticality

| Uncertainties | Criticality level | % of participation | Accumulated % | Classification |
|---|---|---|---|---|
| Customers demand | 7 | 35% | 35% | |
| Suppliers delivery | 5 | 25% | 60% | A |
| Labor productivity | 3 | 15% | 75% | |
| Material availability | 2 | 10% | 85% | B |
| Accidents | 1 | 5% | 90% | |
| Absenteeism | 1 | 5% | 95% | C |
| Quality performance | 1 | 5% | 100% | |
| Machine cycle time | 0 | 0% | - | |
| Machine uptime | 0 | 0% | - | |
| Costs variation | 0 | 0% | - | |
| Governmental policies | 0 | 0% | - | |
| Macroeconomic issues | 0 | 0% | - | |
| Social trends | 0 | 0% | - | |
| Natural disasters | 0 | 0% | - | |
| Total | 20 | 100% | | |

Through the application of MCS a critical analysis of the current state was performed. Issues such as lack of a standard material request with suppliers and from internal customers, and lack of systematic management of inventory queues could be verified through the deterministic analysis approach of the value stream. In addition, based on the stochastic analysis it is possible to identify other improvement opportunities. Results in Table 3 indicate that internal customers' inventory contributes with the largest amount of the lead time (67.31%). However, its variation coefficient is the smallest one (3.5%), suggesting that customers' demand does not add great variability to the flow. When considering absolute values, the standard deviation of suppliers' inventory was the one that presented the highest value, which is closely related to the variability of suppliers' delivery. This variability implies that suppliers have a delivery frequency and/or quantity that show great oscillation. Therefore, it was necessary to address improvement actions with suppliers in order to reduce such variability. Overall, when analyzing from a stochastic point of view it is possible to observe that the largest inventory (located at internal customers) has a lower variability and, hence, can be significantly reduced.

Table 3. Characteristics of probability distributions for each uncertainty source

| | Request | Receiving | Removal | Suppliers inventory | Customers inventory |
|---|---|---|---|---|---|
| Probability distribution | Johnson SB | Generalized Pareto | Generalized Extreme Value | Johnson SB | Burr |
| Parameters | γ=0.907<br>δ=1.44<br>λ=0.133<br>ε=0.0323 | K=-0.382<br>σ=0.142<br>μ=0.0067 | K =-0.348<br>σ =0.019<br>μ =0.053 | γ=0.436<br>δ=0.759<br>λ=798.27 | k=7.419<br>α=37.806<br>β=3393.7<br>γ=0 |
| Average (hours) | 0.080 | 0.108 | 0.059 | 1,543.03 | 3,177.93 |
| Standard deviation | 0.019 | 0.077 | 0.018 | 193.95 | 110.45 |
| Variation coefficient | 23.7% | 71.6% | 31.3% | 12.6% | 3.5% |

Considering the proportionality of variability, the receiving process is the one with the greatest variation coefficient (71.6%). Variability for receiving process times can lead to difficulties in balancing labor among working shifts. This variability can occur for a number of reasons, such as the way orders are conceived, employees' experience level, quantity of items delivered by suppliers, and lack of receipt patterns. Moreover, data in Table 3 can be used to validate team members' perceptions. For instance, one of the issues raised by team members was the lack of demand planning by the units that are internal customers of OPS. However, this lack of planning was not verified in customers' inventory, which is closely related to customers' demand variation.

Then, for each uncertainty source five thousand random data were generated based on the parameters of the corresponding probability distribution. Summing up the random values generated at each occurrence, five thousand values were obtained for the total lead time of the value stream, which allowed the establishment of its probability distribution and accumulated probability distribution, presented in Figures 2 and 3, respectively. Table 4 summarizes the obtained lead times and the respective main probabilities, emphasizing the importance of the stochastic analysis of the value stream. It is noteworthy that the lead time found with the usual deterministic VSM is lower than the minimum value found according to the probabilistic distribution, which corroborates with the assumption that the deterministic approach represents an unreal condition of the value stream. Moreover, for a 99% probability the corresponding lead time is 44% higher than that predicted in the deterministic approach. It is also worth observing that an increase of approximately 7% in the total lead time increases the attendance probability from 70% to 99%. Therefore, these results indicate that, while a lead time of 196 days is feasible in half of the cases, considering a value of 217 days allows a more reliable estimation of lead time.

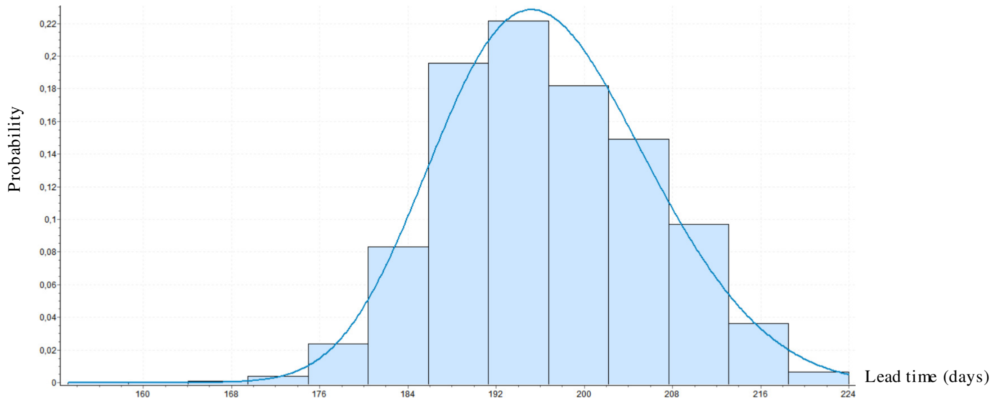


Figure 2. Probability distribution of lead time

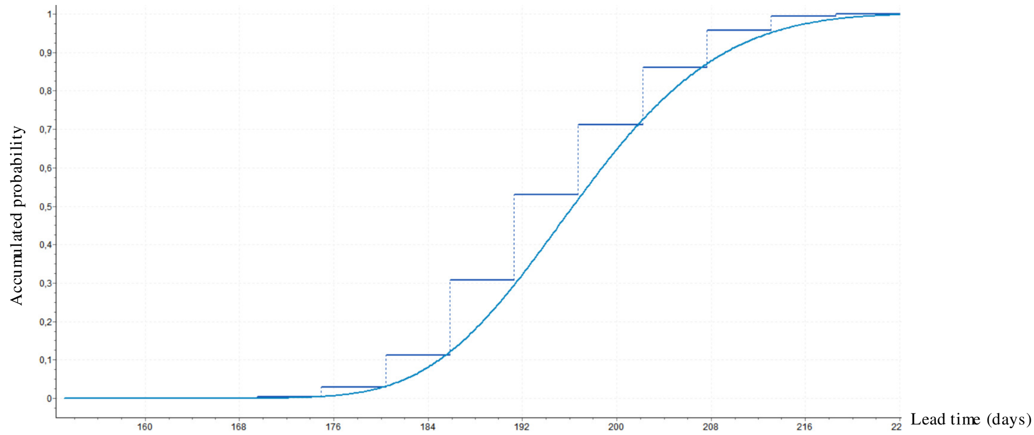

Figure 3. Accumulated probability distribution of lead time

Table 4. Lead time and corresponding probability values

| Scenarios | Lead Time | Probability | Difference in relation to Deterministic scenario |
|---|---|---|---|
| Deterministic | 151 | - | - |
| 1 | 196 | 50% | 30% |
| 2 | 202 | 70% | 34% |
| 3 | 210 | 90% | 39% |
| 4 | 213 | 95% | 41% |
| 5 | 217 | 99% | 44% |

After that, the same team was involved with the purpose of developing a future state map for this value stream, taking into account the aforementioned improvement opportunities. The future state map includes improvements that were identified from both the deterministic and stochastic analysis of the VSM. From the deterministic approach, the main opportunities were (represented by the darker kaizen bursts in Figure 4): (1) elaboration of a system to define material request orders with suppliers; (2) definition of a systematic for managing inventory queues so that products with longer shelf lives are not used before those with shorter ones; (3) standardization of internal customers' material requests; and (4) definition of a specific removal area for each customer. The stochastic analysis allowed the identification of additional improvements (lighter kaizen bursts in Figure 4): (5) standardization of the receiving process in order to increase its predictability and allow a better balance of the workload; (6) reduction of inventory levels in internal customers due to low demand variability; and (7) revision of suppliers' delivery policies in order to reduce their variability and positively impact suppliers' inventory. Finally, an action plan was established defining deadlines and responsible for the implementation of the defined improvements. Based on these arguments, an estimated 80-day lead time for the future state was aimed and a total of 9 minutes for processing times.

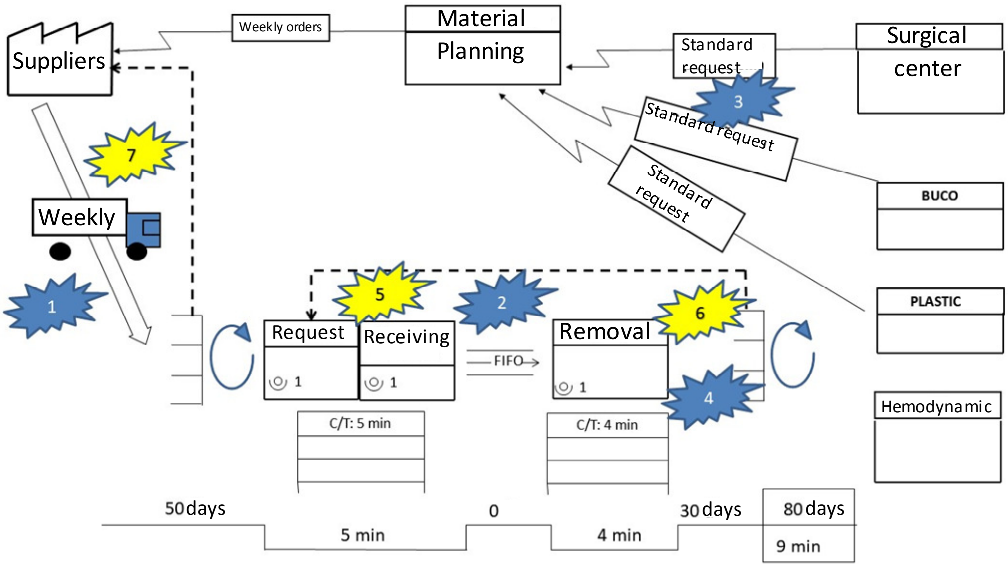


Figure 4. Future state value stream map

## 4. Conclusions

This study proposed the integration of a stochastic analysis of the VSM, taking into account the dynamic aspects usually neglected in the usual approach. The proposed method combined MCS and VSM and it is illustrated on a practical application in the flow of OPS from a public university-hospital. Implications of this study were two-fold: from the theoretical and managerial perspectives.

First, from the theoretical point of view, the proposed method presented a complementary approach to those available in the literature to deal with variability in value streams. Such integration allowed the consideration of a more realistic scenario that drives more assertively opportunities for improvement. Furthermore, the qualitative analysis of the uncertainty sources criticality enabled the adaptation of the method to the contextual condition of the value stream under study. Second, concerning managerial contributions, the simple application of the proposed method might be appealing for practitioners, especially in companies whose value stream's data are easily collected and pinpointed with the support of information technology. Moreover, the identification of the effects of the critical uncertainty sources on lead time provides managers means to systematically address variability in the value stream. Such improvements might entail other benefits than the ones usually foreseen by the usual VSM application.

Among the limitations of this study, it is worth noticing that the method used to identify the uncertainty sources criticality can be further improved. The use of managers' perception may be restricted to their level of understanding of the value stream, which mitigates the visualization of other potential uncertainties that are atypical, e.g. uncertainties related to non-cyclical decisions. The proposed method for considering the uncertainties also constitutes a limitation itself, since only MCS was used to consider the uncertainties and variability of the value stream. Thus, other methods that could have similar or better results were not addressed in this work. In addition, relatively to data collection, a used 30-day basis may have limited the analysis. Future studies that consider larger periods or samples could provide more extensive analysis and, hence, outcomes. Furthermore, it is suggested to apply the proposed method in different scenarios in order to extend its limits beyond the presented context.

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