A new fuzzy logic-based metric to measure lean warehousing performance

Nicolás Buonamico, Laurent Muller, Mauricio Camargo

A new fuzzy logic based metric to measure lean warehousing performance. A case study in wine supply chain.

Nicolás Buonamico[a,b], Laurent Muller[a] and Mauricio Camargo[a]
Université de Lorraine, ERPI, F-54000 Nancy, France
School ofEngineering, National University of Cuyo, CentroUniversitario,CC405(M5500AAT) Mendoza,Argentina

Abstract.
Lean manufacturing tools have been applied for several years to improve companies' internal logistics. However, lean warehousing (LW) is a relatively new subject in logistics, and for this reason there is still a lack of academic literature and implementation experiences about it, in particular regarding the manner of selecting the right indicators tomeasure the warehouse's leanness, taking into consideration the firm's own objectives and context. This paper's objective is to identify key indicators for facilitating the objective setting, monitoring and LW implementation, and then propose a lean warehousing key performance indicator (warehouse's global leanness (WGL)) by implementing an innovative lean warehousing scorecard. The proposed aggregated multi-criteriabased approach integrates seven indicators obtained from the crossing of three elements: the seven principal lean management variables identified after a Pareto analysis of the literature review, the eight lean wastes and the four main warehousing activities. The information gathered was organised in a systematic manner thanks to a functional analysis of the WGL index. The proposed tool is strongly oriented towards its practical industrial implementation. A case study is presented, in which the tool has been successfully introduced in a French-Argentinian winery's warehouse. Findings show that the use of this tool over a period of time favours the achievement of the lean warehousing management objectives, such as waste elimination (+6%, reducing inventory and number of stock keeping units and increasing inventory accuracy) and cross-functional teams and empowerment (+12%). By analysing the results, it is possible to observe an improvement in the WGL (+11%).

1. Introduction

Companies from different countries and diverse industrial areas have implemented lean manufacturing practices over the last decades. The lean philosophy has generated important benefits in the manufacturing field representing the key to success for many organizations (Melton, 2005). Many enterprises started to implement these practices and tools in their manufacturing plants, later they did the same with the administrative areas and processes. However, the application of lean practices to the supply chain processes is a very recent field of study. As stated by (Myerson, 2012), only over the last six or seven years, lean tools have been applied specifically for improving the logistic function with the objective of simplifying and optimizing these processes.
Despite the technological developments and new technologies emergence such as RFID tracking systems, automation process and robotics, there still a lot of work to do in the warehouse management. Indeed, implementing lean practices, specifically in the warehouse and distribution center management field, could have positive consequences for clients and also for companies themselves because on the one hand, "*it allows to minimize the number of non-value added activities from the client's point of view"* (Myerson, 2012) and on the other hand, it could be a

competitive advantage for the company because it promotes an efficient supply chain management.
Nowadays, supply chains are getting more and more complex and because of that, their management is more difficult than it was in the past. Warehouses are key elements in the supply chain because they are involved in every step: procurement, production and distribution of finished goods, raw materials, supplies and semi-finished goods (Rushton et al., 2010). The nodes from a supply network have a strong impact on its efficiency. Moreover, as stated by (Wyland, 2008) "*Warehousing (with transport and inventory keeping) is one of the three main logistics cost's components"*.

The trend over the last years has been to find ways to help warehouses to be more flexible to demand's changes, improve the inventory visibility, and optimize the logistics center operations, work efficiency and throughput. However, to start a lean implementation, it is necessary to establish objectives and key performance indicators to measure them. The lack of lean performance's understanding is a major reason for the failure of lean practices (Behrouzi and Kuan Yew, 2011). It is not possible to manage lean without measuring its performance. What is not measured is unknown and therefore it cannot be improved.

Lean warehousing (LW) is a relatively new subject (less than a decade) and that's why there are not many academic articles about the theme of selecting the right indicators to measure the warehouse's leanness, taking in consideration the firm's own objectives and problems. The expected LW implementation's results are: *stock reduction, productivity enhancement and an inventory record accuracy improvement, less picking errors, less stock-breakdowns, a health and safety improvement, the storage space's optimization and a transportation cost reduction* (Bartholomew, 2008), but also a higher workforce commitment, empowerment and team work.

This paper's objective is to propose a measuring tool and indicators for facilitating the objective setting, monitoring and implementation of LW. It is of course based on several aspects from recent scientific literature, but it is strongly orientated to its practical industrial implementation. A case study is also presented in this document, where the tool has been successfully introduced in a French-Argentinian winery's warehouse. This paper's proposal consists in obtaining a LW Key Performance Indicator (KPI) by implementing an innovative LW Balanced Scorecard (BSC).

The balanced scorecard is a graphical representation of a business strategy and selected performance indicators. It brings together objectives with indicators that measure them to allow a graphical interpretation of the strategies realization degree. By combining: the financial perspectives, customers, internal processes and innovation and organizational learning, the BSC helps managers to understand, at least implicitly, many interrelationships (Kaplan and Norton, 1992). The tool recognizes the importance of innovation in business management. There are BSC for mapping various strategic themes, such as logistics (Morana and Paché, 2000) and also innovation (Flores et al., 2009). Within the framework of the present paper, BSC is meant to give the warehouse's leanness degree, taking into account several parameters considered as lean and warehouse best practices.
The KPI is called Warehouse's Global Leanness (WGL). It is calculated considering seven main indicators which are obtained from the crossing of seven principal lean management variables, the eight lean wastes and the four main warehousing activities.
Because of their ability to deal with complex, uncertain and imprecise data, fuzzy functions are used for quantifying in an easy manner the proposed indicators and taking in consideration the firm's own objectives.

2. Overview of lean warehousing management and metrics.

Although *"lean thinking has become a very important dimension of implementing in the food supply chain"* (Ding, 2014), it is difficult to find scientific documents about measuring the warehouse's leanness or measuring tools to help in the lean warehousing management. It is even more difficult to find papers about LW in the Wine Supply Chain (WSC), but some important researches can be used as a base to start with the investigation.

Several authors have researched about measuring the WSC performance, for example García et al., (2009) who propose a modeling and measuring tool for the WSC but without focusing on warehouses or LW. Jimenez et al., (2012) applied Value Stream Mapping (VSM) and other lean tools to the wine production in Spain and determined several important lean variables in the wine industry. Overboom et al., (2010) have adapted an interesting questionnaire to measure the leanness degree for logistics providers. Azharul and Kazi Arif-Uz-Zaman (2013) developed a methodology for implementing lean manufacturing strategies and a leanness evaluation metric using continuous performance measurement in an assembly process, but it was not adapted yet to the warehouse environment. Khadem et al. (2008) developed a quantitative analysis framework and a simulation methodology to evaluate the lean metrics efficacy in production systems. Chen et al., (2013) focused on RFI D application in warehouse management and lean Supply Chain, they presented a case study on lean production and VSM in warehouse management.

Behrouzi and Kuan Yew, (2011) have proposed a measuring method for Lean manufacturing variables, using fuzzy functions, which allows to introduce particular objectives to the lean metrics. Other authors have proposed methods that are based on questionnaires, for example Myerson, (2012). These questionnaires are useful, but generally have a high subjectivity degree compared to a performance measure based approach.

Using a BSC specifically for LW management is an original proposition in the context of wine warehouse management. However, the proposed methodology is adaptable and applicable to other organizations in the WSC or other industrial or service sectors, because fuzzy functions make possible to set LW objectives regarding the warehouse's present state and the enterprise's global strategy. The WGL indicator can also be used to carry out benchmarking activities regarding LW implementation.

2.1. Lean Manufacturing traditional metrics and Lean Warehousing.

In a lean warehouse context there would be no bottlenecks in the basic processes, no disruptions in the work-in-progress flow, no unnecessary material transportation, workers movement, finished products in excess or picking errors. The reason for this is that the objectives in LW are, of course, the same as in lean manufacturing: to accelerate the material flow, eliminate waste and reduce inventory. However, "*applying Lean practices in a warehouse is not the same thing that applying them in a manufacturing plant. Of course, the principles and practices do not change, but here Lean is used to transform the specific warehouse processes"* (Bartholomew, 2008), i.e. general objectives in LW and in Lean Manufacturing are the same, but particular objectives are different because specific warehouse's processes are different too. That is the reason why non-warehousing-adapted traditional lean metrics could fail in describing the warehouse's true state.
One interesting example of metrics is the case of Overall Equipment Effectiveness (OEE). According to (Charaf and Ding 2015): "*For manufacturing processes, OEE is considered a relevant performance measurement lean tool which is able to take into account a machine's availability, performance and quality"... "It is useful in high volume manufacturing process where capacity utilization is of high priority and stoppages or disruptions are expensive in terms of lost capacity"* but *"the OEE metric is not universally applicable"*.
In low volume or batch processes, OEE fails to indicate the true performance because *"the unscheduled production time is high and thus planned maintenance can take place then. Also, the failure of one machine does not have a big impact because production can be re-routed to another machine. The change-over time is not relevant since set-up can be done on one machine as*

production continues on the other" (Pintelon and Nganga Muchiri, 2008). This statement is also true in many warehouses where picking is not the only critical activity, because other important logistic operations are performed with cross-functional employees. In many cases OEE could be an acceptable KPI, but in other ones this metric does not represent the real performance and it is just another lean tool that could be applied for specific logistic process but not as a global warehousing KPI. It is necessary to find other LW performance indicators which fit better warehouse's specific activities.

2.2. The seven main lean management variables.

Several authors have researched about the lean manufacturing main variables. In Behrouzi's research, waste elimination and Just in Time (JIT) are identified as the most important Lean performance elements because they have received more attention in the scientific literature (Behrouzi and Kuan Yew, 2011). But they also focus on perfection and the zero defect theory. (Bayou and Korvin, 2008) have chosen JIT, continuous improvement and quality control as lean management attributes. Most of the literature emphasizes waste elimination as an important matter: *"The main objective is to eliminate waste using Lean techniques and tools"* (Mohammed Hamed, 2013). De Visser, (2014) made a comprehensive review of the literature regarding LW and lean performance. He states that *"LW is a powerful tool to improve quality by reducing errors"*. According to the principles of lean management, there are eight types of waste: transportation, inventory, motion, waiting, overproduction, over processing, defects or errors and underutilized employees (Shabeena Begam et al., 2013). These wastes exists in any process: production, administration or even in the supply chain and logistics.
Other researchers have used a larger number of variables to define Lean. Hodge G., has developed a conceptual model of lean tools and principles, based on a review of the literature, *"main tools were grouped into six categories: Visual Management, Policy Deployment, Quality Methods, Standardized Work, Just-In-Time and Improvement Methods"* (Hodge G., et al. 2011).
Several authors attach importance to the practical application of lean manufacturing tools like VSM, the 5S method and visual management for organizing the workplace. For example, (Bartholomew, 2008) thinks that *"besides kaizen events or continuous improvement and VSM, a lean warehouse uses other lean tools such as 5S for work organization and visual controls to support improved business processes among others"*. For (Detty and Yingling, 2000) key tenets of lean philosophy include: standardized work, JIT, quality-at-the-source, visual control and continuous improvement among others. For (Jim Wu, 2002), *"key lean manufacturing techniques include pull systems, continuous flow, level production, preventive maintenance, built-in quality, and frequent changeovers"*. According to (Dotoli et al., 2012), all lean warehouses should use the VSM tool to search and reduce waste. *"VSM is the most simple and effective tool to identify and reduce waste by improving process control"*. Other researchers, such as Bose and Sinha or Dubouloz emphasize the Lean's human aspect. The first ones show that employee empowerment and decision making participation, cross-functional teamwork, job rotation and collaboration are very important for the lean implementation success (Bose and Sinha, 2012) and the second one states that *"In Organizational Innovations such as Lean Management, internal barriers, particularly those linked to human resources are the most important"* (Dubouloz, 2013).
A Pareto analysis of scientific literature, highlights seven important practices among those considered as lean management activities: JIT, Waste elimination, Continuous improvement, Perfection, zero defects and quality, Lean tools application (VSM, 5S, etc.), Cross-functional teams and empowerment and Supplier management.

2.3. The four main warehousing activities.

Warehouses are key elements in the supply network. *"The warehouse is playing a more vital role in the success (or failure) of businesses today than it ever has"* (Frazelle, 2002). "*Warehousing is one of the most important and critical logistic activities in industrial and service systems"* (Manzini, 2012). Each one of them could have different objectives and its own particularities but

they share things in common, "*even when warehouses can be used for quite different purposes, most of them share the same general pattern of material flow"* (Bartholdi and Hackman, 2011). So, there are four activities that take place in warehouses which are the most important ones for these supply net nodes: receiving and put-away, storage, order picking and shipping. Reception includes the group of activities related to the orderly arrival of all materials coming into the warehouse and put-away is the act of placing the items in the warehouse. *"Storage is the physical containment of merchandise while it is awaiting a demand"* (Frazelle, 2002). *"Order picking is the process of retrieving items from storage to meet a specific customer order"* (Park, 2012). Expedition consists essentially in loading the trucks or any other kind of transport and the related control and document preparation.

2.4. The eight lean wastes in the warehouse.

There are eight types of waste: Inventory, Transportation, Motion, Waiting, Over-production, Over-processing, Defects or errors and Underutilized employees. Much of the scientific literature agree about its definitions.
The inventory is a buffer between suppliers, manufacturers and customers and it is necessary to compensate different problems in the supply chain, for example late deliveries and variability in the system, scrap, quality issues, etc. The second type of waste includes material and information transportation. Motion waste is any movement that does not add value to the product or service, for example searching for tools or materials placed too far away. The fourth waste is the time waiting on materials, supplies, information, and people that are needed to complete a task. In warehouses and distribution centers, the products are waiting between the various stages of the process. Overproduction is the act of manufacturing or treatment of something before it is needed. This results in larger inventories and higher storage costs. In the warehouse, over-production may be for example, preparing an order earlier than it is needed. Over-processing happens when too much time or effort is utilized to do something that is not seen as added value by the client. It may include the use of more expensive, complicated, or accurate equipment than the one that is actually required to perform the operation. Defects or errors are waste themselves but also because they produce a repairing or reworking need. And the last waste, is not using properly the employee's creativity to eliminate the other seven wastes. To achieve continuous improvement's goals, empowerment and a working team culture are needed.

2.5. Fuzzy membership functions. Basic Concepts.

Behrouzi and Kuan Yew, (2011) proposed a lean manufacturing measuring method using fuzzy functions called self-benchmarking. This method is based in part on the Bayou and Korvin's research. They used fuzzy logic to make lean-benchmarking between two automotive companies. To build the lean BSC, fuzzy membership functions, are utilized to take in consideration the firm's own objectives and for quantifying more easily the lean BSC's indicators. *"Fuzzy models use fuzzy sets to represent the non-statistical, uncertain and linguistic values"* (Behrouzi and Kuan Yew, 2011). *"A fuzzy set is a class of objects without a precisely defined criterion of membership. Such a set is characterized by a membership function which assigns to each object a grade of membership ranging between zero and one"* (Zadeh,1965), representing a range from "definitely not in the set" to "completely in the set."
Most concepts used in lean warehousing's everyday language, such as waste elimination or continuous improvement are not clearly defined and that is why by using fuzzy functions, KPIs can be more easily calculated.
"A fuzzy set A is defined by a set of ordered pairs:
$A = \{(x, \mu A(x)) / \in A, \mu A(x) \in [0,1]\}$
Where $\mu A(x)$ is a function. It is called membership function and specifies the grade in which an element x belongs to the fuzzy set A. A membership function of a triangular fuzzy number is defined by:

$$\mu A(X_i)=\begin{cases} 1, \text{ if } Xi \le a \\ 1 - [(X_i-a)/(b-a)], \text{ if } a<X_i<b \\ 0, \text{ if } X_i \ge b \end{cases}$$ (Bojadziev and Bojadziev, 2007; Behrouzi and Kuan Yew, 2011)

To build the BSC, for every not clearly defined lean variable, metrics are fuzzified using the fuzzy functions and points "a" and "b" as the worst or the best lean performance of each metric. The importance of a fuzzy function is its ability to transform data into numbers between 0 and 1 or between 0% and 100%. For a better understanding of how fuzzy functions help in the KPI's calculation, an example is shown in section 4.

3. Proposition of the fuzzy based metric

3.1. The Lean-Warehousing-adapted Balanced Scorecard.

The seven main lean variables, the four main warehousing activities and the eight lean wastes in the warehouse formed the basis for structuring the WGL index. In order to set up this metric a functional analysis was carried out, enabling us to identify the 19 elements of environment of the index to be proposed, as shown in Figure 1. Then, the sub-indicators that will constitute the criteria to be integrated in the WGL index were defined in a systematic manner. Thus, the subsequent hierarchical structure of the WGL is shown in Figure 2. The WGL scorecard is the graphical representation of the selected performance indicators and the warehouse's performance related to the enterprise's business strategy.

The WGL indicator is calculated as the mathematical average of the seven main indicators. This means that, in this case, each one of the seven variables has the sam importance. This simplification has been adopted because the interrelationships between lean variables are a field of investigation itself. It is necessary to determine in a next step which variable is more important than the others by analyzing the interrelationships between them. As stated by Shah and Ward (2007), 'Lean production is an integrated system composed of highly inter-related elements. Researchers frequently rely on the statistical significance of the empirical results but that is not a sufficient condition to explain the interrelationships
in a system.'
Indicators should be described by a series of attributes that define each function and mode of use (Suclla Fernandez et al. 2012). These attributes are name of the attribute, purpose, calculation formula,
frequency of measurement, area that is responsible for its measurement and the business needs. The
attributes are shown in Table 1 for the WGL index. In the same manner, the attributes for each KPI and
sub-indicator were developed. As an example, Table 2 shows these attributes for the KPI WE and its constitutive sub-indicators: finished products inventory (FPI), semi-finished products inventory (SFPI), supplies inventory (SI), inventory accuracy (IA) and number of articles with a positive quantity (APQ). To obtain the sub-indicators, for every unclearly defined lean variable, metrics are fuzzified using the fuzzy functions and points a and b as the worst or the best lean performance of each metric. These points a and bare set based on historical data, experience and LW objectives.

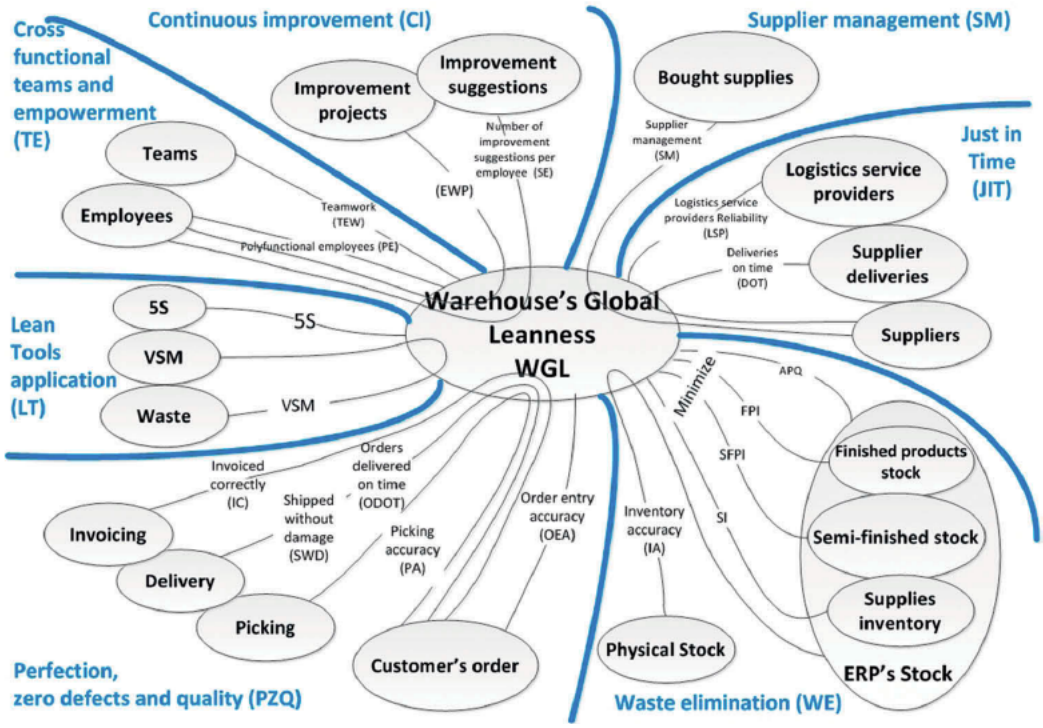


Figure 1. The Lean Warehousing Balanced Scorecard's KPIs.

For calculating the sub-indicators is necessary to consider organization's specific objectives and the warehouse's actual state. For clarifying, a KPIs' Functional analysis has been made (Figure 2).

Name	Warehouse's global leanness (WGL)
Objective	Measure the WGL
Formula	WGL = (JIT + WE+ PZQ + LT + TE + CI + SM)/7
Frequency	Quarterly
Responsible area	Warehouse
Business needs	Logistics costs and inventory reduction, logistics quality improvement (for the external and the internal client).
Warehousing activity	Receiving and put-away, storage, order picking and shipping

Table 1. The attributes for WGL Index

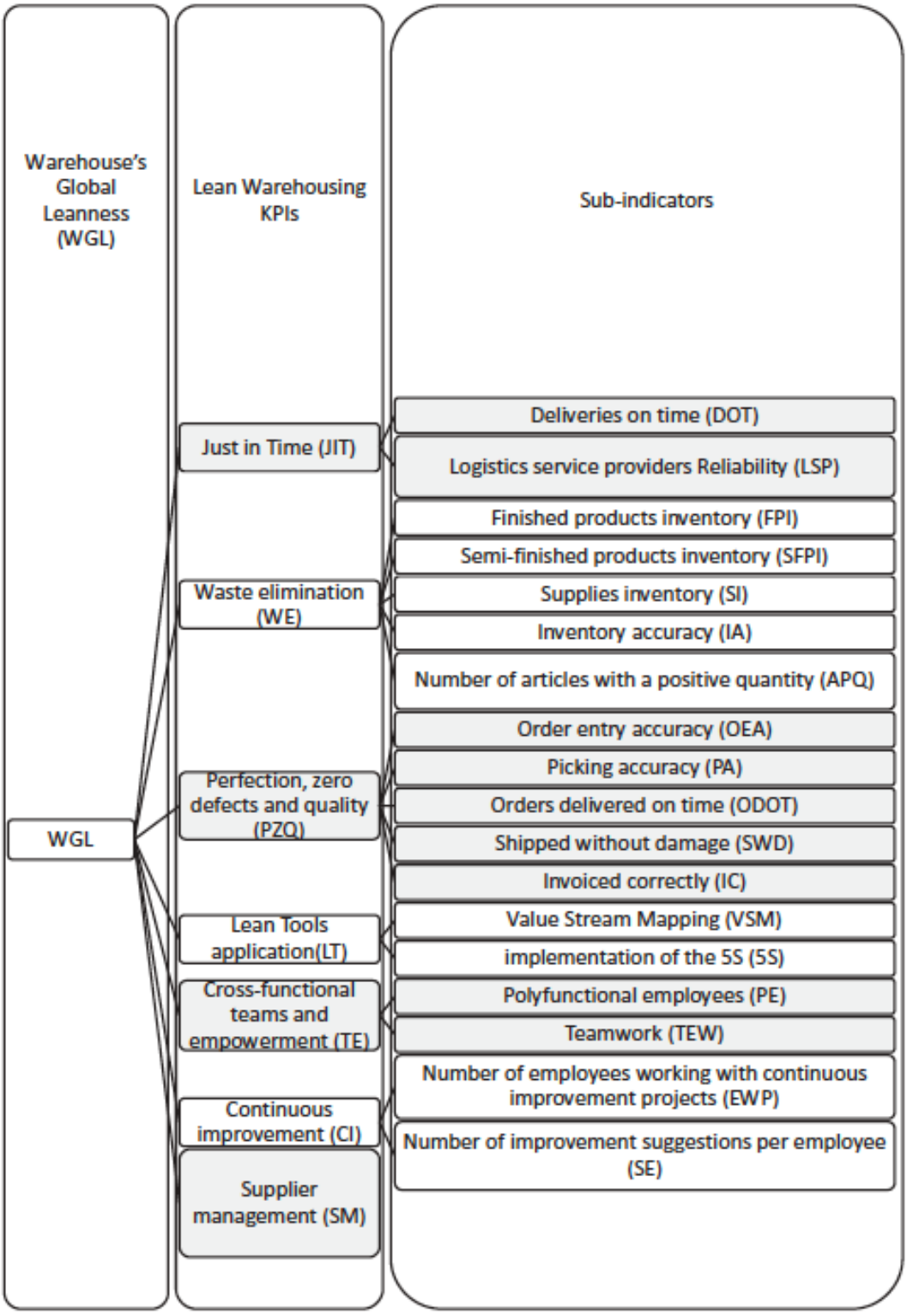


Figure 2. Lean Warehousing KPIs' Functional analysis.

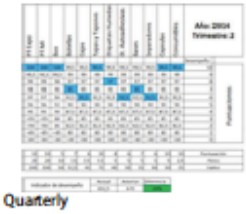
Name	WE
Objective	Measure inventory levels and accuracy
Formula	$we = \frac{\sum_{i=0}^{n} \frac{m_i}{n} + \sum_{i=0}^{n} \frac{m_i}{n} + \sum_{i=1}^{n} \frac{m_i}{n} + IA + APQ}{5}$
Frequency	Quarterly
Responsible area	Warehouse
Business needs	Minimise inventory by ensuring the level of service and reduce costs
Warehousing activity	Receiving and put-away, storage, order picking and shipping
Name	**Finished products inventory (FPI)**
Objective	Measure FPI levels
Formula	$FPI(X_i) = \begin{bmatrix} 1 & \wedge X_i \leq a \\ 1 - \left[\frac{X_i - a}{(b-a)}\right] & \wedge a X_i b \\ 0 & \wedge X_i \geq b \end{bmatrix}$ **a = Desire inventory b = Maximum operational over – stock tolerance**
Frequency	Quarterly
Responsible area	Warehouse
Business needs	Minimise FPI by ensuring the level of service
Warehousing activity	Storage, order picking and shipping
Name	**Semi-finished products inventory (SFPI)**
Objective	Measure SFPI levels
Formula	$SFPI(X_i) = \begin{bmatrix} 1 & \wedge X_i \leq a \\ 1 - \left[\frac{X_i - a}{(b-a)}\right] & \wedge a X_i b \\ 0 & \wedge X_i \geq b \end{bmatrix}$ **a = Desire inventory b = Maximum operational over – stock tolerance**
Frequency	Quarterly
Responsible area	Warehouse
Business needs	Minimise SFPI by ensuring the level of service
Warehousing activity	Storage
Name	**Supplies inventory (SI)**
Objective	Measure SI levels
Formula	$SI(X_i) = \begin{bmatrix} 1 & \wedge X_i \leq a \\ 1 - \left[\frac{X_i - a}{(b-a)}\right] & \wedge a X_i b \\ 0 & \wedge X_i \geq b \end{bmatrix}$ **a = Desire inventory b = Maximum operational over – stock tolerance**
Frequency	Quarterly
Responsible area	Warehouse
Business needs	Minimise SI by ensuring the level of service
Warehousing activity	Receiving and put-away, storage, order picking (for the intern client)
Name	**Inventory accuracy (IA)**
Objective	Measure IA. Reach IA level = 99.5%
Formula	
Frequency	Quarterly
Responsible area	Warehouse
Business needs	Minimise inventory by ensuring the level of service
Warehousing activity	Storage
Name	**Number of articles with a positive quantity (APQ).**
Objective	Eliminate obsolete and slow moving inventories
Formula	$APQ(x_i) = \begin{bmatrix} 1 & \wedge X_i \leq a \\ 1 - \left[\frac{X_i - a}{(b-a)}\right] & \wedge a X_i < b \\ 0 & \wedge X_i \geq b \end{bmatrix}$ **a = Goal quantity of items in the inventory b = Historical or actual quality of items in the inventory**
Frequency	Quarterly
Responsible Area	Warehouse
Business needs	Decrease the inventory by looking obsolete and slow moving items
Warehousing activity	Storage

Table 2. The attributes for the waste elimination (WE) KPI and its related sub-indicators

In the following sub-sections each selected KPI will be explained. The whole set of KPI and sub-index attributes are detailed in Appendix.

3.2. Just in time (JIT).

The suppliers' evaluation is a capital issue for every organization because they have a key role in the supply chain and due to the outsourcing of processes that are not part of the know-how of the company (Suclla Fernandez et al., 2012). Therefore, it is essential to measure the supplies and material on-time deliveries and also the logistics service providers' reliability. "*A logistic provider is a company that offers the logistics activities realization on behalf of a manufacturer or a large retailer"* (Fulconis et al., 2014). It is possible to consider any logistic provider. The indicator purpose is to measure the on-time deliveries of supplies and the logistics service providers' reliability.
It is calculated as the average of two sub-indicators: Deliveries On Time (DOT) and Logistics Service Providers reliability (LSP). The indicator DOT is calculated by the Enterprise Resource Planning (ERP). The LSP indicator is calculated by using a fuzzy function. The point "b" is the total quantity of services requested and the point "a" is the tolerable quantity of services requested unfulfilled according to the warehouse's present state and objectives. Here, services can include outsourced logistics personnel and activities, transport services, etc.

3.3. Waste elimination.

Although there are eight different types of waste, the most important is the inventory. The Lean management considers it as garbage. "*Inventory is the most visible waste and it is simultaneously the final result of other wastes"* (Myerson, 2012). That is why the waste elimination indicator must focus on supplies, semi-finished and finished product inventories. It must consider the amount of obsolete items and the inventory record accuracy because they are the tools to ensure inventory's visibility. *"Lean companies keep less inventory of any type"* (Demeter, 2011).
The Waste Elimination KPI (WE) is calculated on a quarterly basis. It is the result of the average of five indicators that are very important to understand the behavior of stocks in warehouses: Finished Products Inventory (FPI), Semi-Finished Products Inventory (SFPI), Supplies Inventory (SI), Inventory Accuracy (IA) and the number of Articles with a Positive Quantity (APQ).
The Finished Products Inventory (FPI) is the quantity of finished products measured in days of stock, according to the sales forecast. From a Lean perspective, the inventory is waste, and so this number should be theoretically almost zero, but from an operational point of view a minimum amount of inventory is always necessary. Baker's research results indicate the importance of buffer inventory in international supply chains (such as WSC) and suggest that it is very difficult to eliminate the need for such inventory completely (Baker, 2007). When the company uses a push-production system this is also different because the enterprise produces for maintaining stock levels that are considered the best to satisfy the estimated demand without stock-outs. This is true in most of the beverage industry because these enterprises use a mixed system between push and pull production according to the market. Thus, fuzzy functions are used to consider in the KPI the estimated "best inventory level" according to the enterprise's objective. In this case, point "a" is the desired inventory level depending on the enterprise's stock policy and point "b" represents the operational over-stock tolerance.
Semi-Finished Products Inventory (SFPI) and Supplies Inventory (SI) are calculated in the same way.
"The inventory accuracy (IA) is the degree to which the physical count of inventory corresponds with the records" from the ERP (Enterprise Resource Planning) (Muller, 2003). The IA indicator is calculated by using an Omax matrix (Buonamico, 2015), which has been proposed by (Balkan, 2011) to measure productivity in service sectors. *Any company that has a 95% inventory accuracy can be considered as a company with accurate inventories and it is part of the 20% most accurate*

companies in the world (Brooks and Wilson, 2007). The number of Articles with a Positive Quantity (APQ) is also important because its minimization implies a periodic review of inventory turnover and the places where an article is used. This indicator is highly dependent on business objectives but it is essential to measure and analyze its variations.

3.4. Perfection, Zero defects and Quality (PZQ).

The SCOR model provides the perfect order measure, which calculates the rate of every stage of a purchase order without error, it can be used as an indicator of perfection in the supply chain (SCOR Model 2011) (Myerson, 2012). Particularly, it can be used to measure the warehouse leanness because they are the supply chain's nodes. This KPI should capture every stage in an order's life.
The SCOR model proposes five indicators to measure the order's perfection. The five stages that this indicator considers to get a perfect order are: Order Entry Accuracy (OEA), Picking Accuracy (PA), Orders Delivered On-Time (ODOT), orders Shipped Without Damage (SWD) and orders Invoiced Correctly (IC).
The first KPI is the Order Entry Accuracy (OEA). It is calculated as the ratio between the amount of Orders without errors and the total number of orders. Second, the Picking Accuracy (PA) is the ratio between the number of orders picked without errors and the total number of orders. Then, the Orders Delivered On-Time (ODOT) is the ratio between the amount of delivered on-time orders and the total number of delivered orders. Finally, the orders Shipped Without Damage (SWD) and Invoiced Correctly (IC) measure the shipping performance and are calculated in the same way as the last KPIs.

3.5. Lean Tools application (LT).

Another important subject to measure is the degree to which the tools provided by lean management are applied into warehouses. According to (Dotoli et al., 2012), all lean warehouses should use the VSM tool to search and reduce waste. *"The VSM is the most simple and effective tool to identify and reduce waste by improving process control"*. Also, there are several key tools in lean management that according to the scientific literature are considered basic tools to apply in a lean warehouse, such as visual management, work standardization and the 5S method implementation.
So, the Lean Tools application (LT) KPI is calculated as mathematical average of two sub-indicators: Value Stream Mapping Implementation (VSM) and the implementation of the 5S method, visual management and work standardization (5S).
The VSM implementation degree depends largely on each company's objectives, but the best thing to do is to map the overall warehouse flow and all the key processes. Undoubtedly, the VSM project must include all warehouse's main operations: Receiving and put-away, storage, order picking and shipping. The maps should be periodically reviewed. VSM is a diagnostic tool for process improvement. The 5s implementation degree also depends on the enterprise's objectives and that is why it is generally measured by using an overall 5S assessment. In the case of study, a particular questionnaire was applied. It consists of a checklist for each one of the 5s: Sort, Set in order, Shine, Standardize and Sustain.

3.6. Cross-functional teams and empowerment.

"*Companies where Lean becomes part of the culture tend to get greater, longer-lasting results. Much more progress can be made and maintained if Lean is part of everyone's job, rather than just a few"* (Myerson, 2012). The development of a work team is a main issue for the improvement program's success and sustainability and for that reason this KPI is very important for the objectives' achievement.

The Cross-functional Teams and Empowerment indicator (TE) is calculated as the mathematical average of two sub-indicators: Poly-functional Employees (PE) and TEamWork (TEW).
To be considered as a poly-functional employee, it is required that the employee was trained and prepared to develop at least two workstations' functions. He or she must have the expertise and knowledge to be able to replace at least another collaborator without losing performance or productivity. For calculating the EP KPI it is necessary to consider how many of the warehouse's employees can perform the tasks from at least two workstations.
Teamwork is playing a major role in business nowadays and from a lean perspective, where processes are managed transversely, it is even more important. Teamwork is a really difficult measure to quantify. A simple way is to list the warehousing key tasks that are made as a team. A team is joined by two or more people cooperating with coordination to achieve a common goal.

3.7. Continuous improvement.

It is also important to maximize the number of employees involved in improvement teams. These projects could be simple or complex, but it is essential to get the warehouse's employees commitment to perform activities in a better way and get new ideas that will improve the warehousing service quality and conditions of their own daily work. To calculate the Continuous Improvement (CI) KPI, two sub-indicators must be taken into account: Number of employees Working with continuous improvement Projects (EWP) and Number of improvement Suggestions per Employee (SE).
Firstly, the number of employees who are actively involved in warehousing continuous improvement projects should be measured. This number needs to be increased. Secondly, the employees' participation in terms of proposing and developing warehouse's improvement initiatives should be encouraged and measured. Employees are those who face warehousing problems daily and they should come up with ideas to solve them. Recording and monitoring new ideas and solutions to daily problems is critical to the achievement of a true continuous improvement process, and this must be a part of everyday work. The warehouse supervisor and the company must give their collaborators the means to carry out improvements.

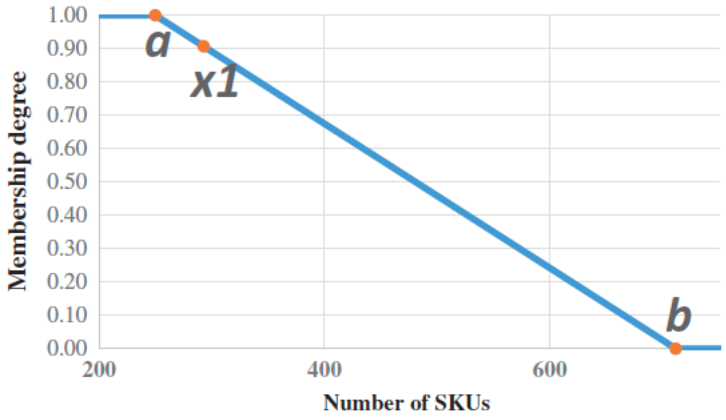
3.8. Supplier management.

Lean management seeks to minimize inventories in different ways. One of those ways is perfection, and therefore it is essential to have reliable suppliers and long-term relationships. The enterprise must work together with its suppliers to optimize the supply chain. "*Production systems are becoming organized in complex networks resulting from subcontracting in cascade. That is why, the core companies of these networks must manage multiple suppliers*" (Brun and Guérin, 2014).
Suppliers must deliver their products in accordance with technical specifications and quantities of the purchase order. Nonconforming received items should be minimized. To do that, the company must be proactive and attack defects before the supplies entry to the plant. Nonconforming supplies not only generate nonconforming finished products, they also increase the amount of reception, control and return tasks, due to nonconforming Supplies. The supplier management KPI is generally calculated by the QSED sector (Quality, Safety, Environment and Development) and through the use of fuzzy functions, it can be integrated to the logistics BSC.

4. Case study application.

The Lean BSC's first application has been done in a French-Argentinian winery's warehouse. It is one of the warehouses from the Argentinian subsidiary of a leader enterprise in the premium spirits drinks industry.
The BSC has been used to make a LW performance diagnosis to start a LW process. This tool will also serve as a warehousing best practice because it sets the framework to apply LW and measure the impact of its implementation in the company. The organization's specific objectives

and present state should be considered to set the starting goals. By calculating the proposed indicators, the BSC should be completed to get the initial WGL.
Calculations have been made by using observation, field data collection and enterprise's real data during a three quarters period (Q0, Q1 and Q2). Thanks to the implementation of a spreadsheet, it is possible to load the data for calculating the KPIs and obtaining a simple graphical representation.
For a better understanding of how fuzzy functions help in the KPI's calculation, an example is shown (Figure 3). For calculating the Number of articles with a positive quantity indicator (APQ) it is necessary to consider historical data and the enterprise's policies among other aspects. According to lean philosophy, inventories should be minimum. But it is not possible to have zero stocks in a real case, because when an enterprise is operating and producing, it needs inventories for several reasons. Sometimes, slow moving and obsolete items in the inventory can be really important, not only in unitary costs but also with many "hidden costs" such as the space they occupy in the warehouse. If the enterprise has problems in avoiding obsolete stock and acting to eliminate it when it is already produced, this articles can reach a high quantity. The wine industry is particularly prone to obsolescence, especially in labels due to legal constraints (each country has different regulations and specifications) and because of the harvest (generally wine labels show the harvest's year). In this case, 250 Stock-Keeping Units (SKU) with a positive quantity would be the desired situation (objective) (a=250). The historical worst case was 712 different articles (b=712). For the Q0's calculation, warehouses have already been working in this field and the result obtained was 293 items (x=293). Then, APQ = 0,907 or 90,7%.

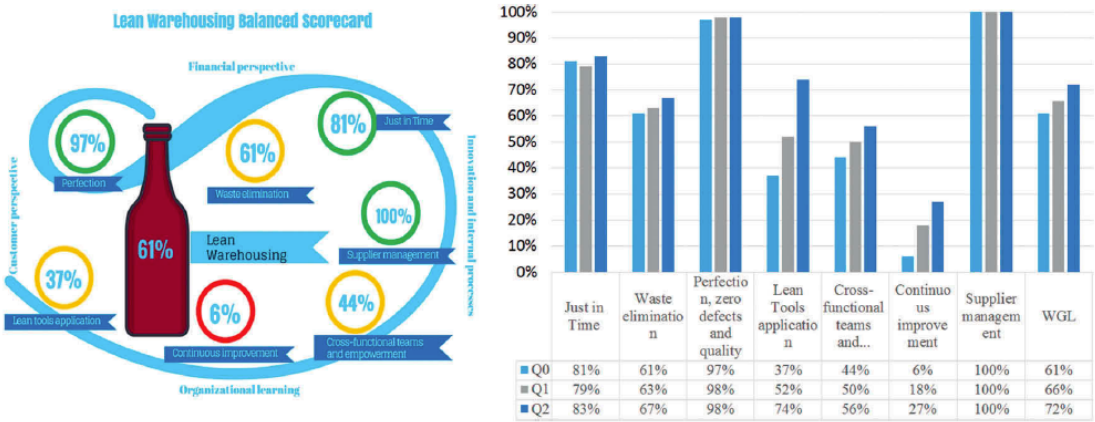


$$APQ(X_i)=\begin{cases}1 & \wedge\ X_i \le a\\ 1-\left[\dfrac{(X_i-a)}{(b-a)}\right] & \wedge\ a<X_i<b\\ 0 & \wedge\ X_i \ge b\end{cases}$$

a =Goal quantity of items in the inventory (SKUs)
b =Historical or present quantity of items in the inventory (SKUs)

Figure 3 APQ calculation using fuzzy functions.

By analyzing the Balanced Scorecard's evolution (Maton and Zelinschi, 2012) and these KPIs, a graphical representation is recommended in reference to Deming's circle. In the image, each indicator helps to increase the WGL index (Figure 4). The graphical representation is important because it helps everyone to get a better understanding of how their efforts and the daily improvements allow to reach the goal. This is especially critical when the work force is starting their Lean training. Graphical representations are the ones that were applied in the warehouse but because of confidentiality reasons, some design details have been modified or removed.
Results for the first quarters (Figure 4), show an increment in the WGL, mainly due to the LT, TE and CI KPIs. These results confirm that the tool is relevant in the enterprise's LW management by facilitating the objective setting, the monitoring and the lean warehousing implementation and obtaining a LW KPI. They were initially the ones that had the lower values and they also depend more on the warehouse's own efforts than the others KPIs. JIT, WE and PZQ show a positive performance, but with a slower increment than the other ones. This is probably because they represent the main lean principles which depend on a work philosophy change and not only Warehouses are involved in this subject but it also requires the whole enterprise commitment. In this particular case, Lean Tools application is the KPI with a greater growth due especially to the VSM implementation and that is a very positive aspect because VSM is the main tool to find and eliminate waste and identify improvement opportunities in warehouses.
KPIs also show a bigger employee participation and empowerment. These indicators should present in the medium-term lasting impacts on other indicators, because they are part of a change in the work culture. WGL shows a +11% increment.



	Just in Time	Waste eliminatio n	Perfectio n, zero defects and quality	Lean Tools applicatio n	Cross-functional teams and...	Continuo us improve ment	Supplier managem ent	WGL
Q0	81%	61%	97%	37%	44%	6%	100%	61%
Q1	79%	63%	98%	52%	50%	18%	100%	66%
Q2	83%	67%	98%	74%	56%	27%	100%	72%

Figure 4 Lean Balanced Scorecard application and KPIs Evolution.

5. Result's discussion and implications.

Firs, it is necessary to highlight that the LW implementation is a matter that requires time and effort because the results will only be sustainable in time, if a real work culture change happens. For this reason, the results presented show only a partial progress because of course in a

continuous improvement development, the measurement period should be larger to make sure that improvements will continue in the future in spite of employees rotation and other changes.
It is necessary to continue measuring the performance to see if the progress achieved generates a positive synergy. Lasting results will only be achieved if the project leaders and collaborators manage to persuade other sectors to reach these objectives.
The proposed scorecard allows us to measure the improvements generated by the lean projects that are under development and the use of fuzzy functions allows us to set higher targets in the future. As mentioned in Section 3.1, there was the simplification of not considering interrelationships between lean variables within the framework of the present paper. A future study must be done in this sense to improve the WGL index's relevance.
Interesting approaches have been applied in the supply chain field, such as the DEMATEL-FuzzyANP method (Senvar, Tuzkaya, and Kahraman 2014) or the fuzzy measures- based Choquet integral method (Wang, Lu, and Chen 2010).
Perhaps one missing aspect in this LWS is environmental sustainability and energy management in the logistics field. This aspect was initially considered but it was not integrated into the dashboard because of its added complexity. It could be one of the next steps.

The challenge of this scorecard is its implementation in warehouses of other industries and firm sizes, and even in other actors of the same supply chain.

6. Conclusion

A lean logistics journey can start in warehouses, spreading later to other areas involved.
This first version of the Lean Warehousing BSC is the first tool for facilitating the objective setting, the performance monitoring and Lean Warehousing implementation applied on the Argentinian wine industry. It helps to reconcile the improvement objectives based on Lean principles and Warehousing key activities with the present state and enterprise's objectives and policies. The BSC also allows to measure lean project's improvements that are under development.
By its conception, which is based on current trends in Lean Management, Warehouse and Supply Chain Management, it is easily applicable to other organizations and thanks to the use of fuzzy functions, it can be adapted to each company's objectives.
One of the most complicated aspects to realize the Lean BSC was identifying indicators to be used to represent the main lean variables in warehouses, because companies apply many different KPIs. The selected indicators give a general idea of a warehouse's leanness, but they could be removed or replaced by others that fit better to a particular case.
Perhaps one missing aspect in this Lean BSC is environmental sustainability and energy management in the logistics field. This aspect was initially considered but it was not integrated into the dashboard because of its added complexity. We believe it could be one of the next steps.
The challenge of this scorecard is its implementation in other industries, warehouses and even in other links of the same supply chain.
The balanced scorecard could evolve into a wider tool for measuring the performance of a complete lean supply chain, based on the performance of its nodes (network's warehouses), though this requires further study in this regard.

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