Productivity improvement in solid waste recycling centres through lean implementation aided by multi-criteria decision analysis

Structured Abstract

Purpose: This paper aims at investigating, through a comparative analysis, the applicability of Lean Manufacturing practices, such as value stream mapping, for productivity improvement in recycling centres aided by multi-criteria decision analysis.

Design/methodology/approach: The study is carried out in five recycling centres that sort the municipal solid waste of Porto Alegre, one of the main cities in Brazil. Since all of the centres present their labour composed by poor communities' members, cultural and social characteristics may represent an incremental challenge for lean implementation. Further, these centres are organized in cooperatives, in which decisions are taken through a participatory way and all their members are entitled to vote, undermining and retarding the decision-making process.

Findings: The integration of a multi-criteria decision-making tool to the lean practices enables the prioritization of improvements, complementing the final stage of value stream mapping. In particular, this contribution becomes especially important in cooperatives managed by community, where decisions are often complex and time-consuming. Finally, despite the increasing pressure for better performance of recycling centres, the existent mindset is still far from the private sector, where lean practices were conceived. Further, our findings suggest that, despite processes similarities, it is not feasible to declare the existence of a one-best practice to such scenario.

Originality/value: In theoretical terms, we demonstrate through a multi-case study the adequacy of AHP as a decision analysis tool complementary to the value stream mapping,

enabling a broader perspective about this subject. Concerning the practical contribution, the comprehension of the adaptation needs for lean practices implementation within the production context of solid waste recycling centres provides a framework with guidelines for this sector, when incorporating lean activities. Lean practitioners and eventual municipal authorities involved in improving productivity of community-managed recycling centres might benefit from this framework, since they will be able to emphasize the development of recommended and already tested lean practices that tend to improve their operational performance.

Keywords: Lean Manufacturing; Multi-criteria Decision Analysis; Productivity; Solid Waste Recycling Centres.

1. Introduction

Solid waste management has been an integral part of every human society (Shekdar, 2009) and is one of the most challenging issues in urban cities, which are facing serious pollutions problems due to the generation of huge amount of solid waste (Kumar et al., 2009). The influence of improper management practices for municipal solid waste (MSW) has attracted the attention of various entities, professionals and researchers in recent years (Catapreta and Heller, 1999; Agarwal et al., 2005; Mondelli et al., 2007; Taylan et al., 2008; Parrot et al., 2009), since these can cause serious threats to the public health and environment. MSW is the most complex solid waste stream, as opposed to more homogeneous waste streams resulting from industrial or agricultural activities (Troschinetz and Mihelcic, 2009). According to the Brazilian Institute for Geography and Statistics (IBGE, 2002), Brazil produces about 125,281 tons of MSW per day, 30.5% of which are disposed off in garbage dumps, 22.3% in controlled dumps and 47.1% in sanitary landfills. Although, the selectiveness of garbage disposal has improved in recent years, 63.6% of Brazilian towns still dispose off their solid waste in dumps.

Effective planning of solid waste recycling programs is currently a substantial challenge in many solid waste management systems (Li et al., 2008). Despite some effort in order to develop sustainable solutions for municipal solid waste management systems (Shekdar, 2009), the management of MSW is going through a critical phase, due to unavailability of suitable facilities to treat and dispose of the larger amount of MSW generated daily in metropolitan cities (Sharholy et al., 2008; Taylan et al., 2008; Parrot et al., 2009; Chamizo-Gonzalez et al., 2016). Specifically in the case of Brazil, the existent technology for the recycling of MSW is simple and labour intensive (Nunes et al., 2007). While developed countries typically apply curbside recycling programs to collect and sort wastes for recycling processing (Troschinetz and Mihelcic, 2009), developing countries, such as Brazil, utilize the social sector known as scavengers to handle such activities, who are citizens with low-to no-income that collect materials either dispersed throughout the city or concentrated at dumpsites (Medina, 2004; Wilson et al., 2006; Fei et al., 2016).

Furthermore, Nunes et al. (2007) report on their study that the majority of recycling centres in Brazil are badly administered by public authorities and their viability depend on continuity of operation and reaching expected production volumes. According to Krook and Eklund (2010b) there is a lack of affordable and accurate monitoring for providing the recycling centres with the necessary facts for improving waste. Javied et al. (2014) also mention that, among several critical success factors for improving efficiency at recycling centres, four main points are worth noticing: (*i*) proper funding for MSW management system, (*ii*) awareness and training of workers and people, (*iii*) increased pay of workers and related staff and (*iv*) proper production practices for daily activities' demand. Thus, as the trend towards recycling grows, so does the need for increasing the effectiveness of recycling centres (Hemphala et al., 2010; Lino and Ismail, 2013). One way of doing this is to adapt ideas, theories, strategies, philosophies, and principles from the area of operations management (Sundin et al., 2011), such as lean manufacturing (Liker, 2004; Thanki et al., 2016), to enhance the performance and efficiency of recycling centres.

Lean manufacturing is widely adopted and is claimed to increase productivity, decrease lead time and costs and enhance quality, through a systematic reduction of waste (Womack and Jones, 1996). Nevertheless, it is important to distinguish the meaning of the word 'waste' in lean manufacturing context, in which it refers to losses in productive systems such as overproduction, waiting and transportation (Ohno, 1988); from its meaning in the environmental and recycling context. Previous studies (Sundin et al., 2011; Krook and Eklund, 2010a and 2010b) have presented initiatives to adapt such industrial production practices into recycling centres systems. However, they all emphasize that, from a manufacturing perspective, there is clearly a challenge when it comes to interpreting and implementing this industrial mindset into recycling centre culture (Krook and Eklund, 2010b). Among the available lean practices; Value Stream Mapping (VSM) is one of the most implemented and studied practices outside manufacturing environment (Duggan, 2012; Seth and Gupta, 2005). This practice allows the identification of systematic opportunities within material and information flows and the creation of a shared future state for the organisation's main value stream in order to improve productivity and reduce lead time (Rother and Shook, 1999).

Thus, this paper aims at investigating, through a comparative analysis, the applicability of LM practices, such as VSM, for productivity improvement in recycling centres aided by multi-criteria decision analysis. Due to the generation of sub-optimal solutions with different pros and cons, the process of mapping and determining future states for value streams becomes critical to assure the organization's efficiency and flexibility, especially within facing different market scenarios. In this paper we propose the use of multi-criteria decision support tools in conjunction with LM practices implementation, in particular in choosing and prioritizing the improvement opportunities derived from VSMs. Finally, performance indicators are identified to assist in the evaluation of efficiency in the application LM practices. The study is carried out in five recycling centres that sort the MSW of Porto Alegre, one of the main cities in the Southern region of Brazil. Besides the obvious environmental benefits, such centres are managed by poor community cooperatives, in which decisions are taken based on a participatory way and all members are entitled to vote, undermining and retarding the decision-making process. The more productive these centres become the higher the income of their workers will be. None of them has had previous experience with any of the LM practices, entailing a huge potential for productivity improvement in their production systems. Further, since all of them present their labour composed by poor communities members, cultural and social characteristics may be an incremental challenge for an assertive decision-making process with regards to LM implementation.

The contribution of this article is two-fold. First, in theoretical terms, it contributes to the existing body of literature on LM implementation since it proposes the integration of AHP (Analytic Hierarchy Process; Saaty, 1980) into the prioritization of improvement opportunities step of the VSM. The literature on LM only suggests the use of multi-criteria analysis techniques in the selection of lean practices, without further detail. Therefore, literature evidences are still scarce with narrow contributions with regards to the integration of multi-criteria decision tools to support lean implementation (Yang and Lu, 2011). In this article, we demonstrate through a multi-case study the adequacy of AHP as a decision analysis tool complementary to the VSM, enabling a broader perspective about this subject. Second, concerning the practical contribution, the comprehension of the adaptation needs for lean practices implementation within the production context of solid waste recycling centres provides a framework with guidelines for this sector, when incorporating lean activities. Lean practitioners and eventual municipal authorities involved in improving productivity of community-managed recycling centres might benefit from this framework, since they will be able to emphasize the development of recommended and already tested lean practices that tend to improve their operational performance.

This rest of this paper is structured as follows. Section 2 gives a brief overview of the literature on LM and multi-criteria decision tools. Section 3 describes the proposed method, with results of its application in five MSW recycling centres presented in section 4. Section 5 addresses the discussion of the research outcomes, and Section 6 closes the paper presenting conclusions and future research opportunities.

2. Background

2.1.Lean Manufacturing

The main principles that characterize LM (lean manufacturing) have been defined similarly by different studies. Womack and Jones (1996), for example, define LM as a superior way to manufacture products using fewer resources to generate greater value to customers. For Lewis (2000) and Albino et al. (2016), LM is an integrated set of activities designed to achieve high-volume production using minimal inventories of raw materials, work-in-process, and finished goods. More recent studies usually define lean as a management system formed by two levels of abstraction: principles and practices (Hines et al., 2004; Shah and Ward, 2007; Pettersen, 2009; Bhamu and Singh Sangwan, 2014). The principles represent the ideals and laws of the system, such as encouraging employees' participation in continuous improvement activities, eliminating waste, producing according to the pull of the customer, and continuous flow production (Liker, 2004; Marodin and Saurin, 2013). These practices operationalize the principles and some of the most well-known are the use of kanbans, cellular manufacturing, and value stream mapping (Rother and Shook, 1999; Shah and Ward, 2003; Pettersen, 2009).

Several manufacturing, service and governmental organizations are adopting Lean Manufacturing (LM) to achieve the flexibility needed to meet new competitive challenges (Shetty et al., 2010). Although the use of LM by manufacturing companies started in the late 1980s, only a few succeeded in reaching a truly lean system (Anvari et al., 2010). LM can be implemented in a part or at the entire shop floor as well as at the whole supply chain, including product development, procurement, distribution and service (Hines et al., 2004; Karim and Arif-Uz-Zaman, 2013). Nevertheless, it is more common to start by applying LM practices at the shop floor (Shah and Ward, 2007; Bhamu and Singh Sangwan, 2014), as they serve as a way to gradually introduce the lean principles at a corporative level.

Many western companies unsuccessfully tried to import Japanese manufacturing techniques to their production systems. However, existent socio-cultural factors involved in the change process were neglected, which led to limited benefits (Longoni et al., 2013). Further, the understanding of the company's current context is fundamental for the appropriate LM implementation (Pavnascar et al., 2003). According to contingency arguments, organizations should use LM practices that are effective in their context (Anvari et al., 2011). Therefore, the contingency approach assumes that it is the contextual variables that, in the long run, determine the organizational responses in the LM implementation (Desai, 2011).

Marodin and Saurin (2013) comment that regardless the fact that LM has been used for decades, generalizable implementation steps have not yet emerged. An exception may be the VSM which seems to be present in any lean implementation roadmap, whose purpose is to minimize waste that prevents a smooth, continuous flow of product and information throughout a value stream (Jimmerson et al., 2005; Parthanadee and Buddhakulsomsiri, 2014). A value stream displays the set of activities involved in creating a product or providing a service, and their relative importance (Braglia et al., 2006; Karim and Arif-Uz-Zaman, 2013). VSM has been successfully used in different contexts and applications, from manufacturing to healthcare organizations (Lummus et al., 2006; Cookson et al., 2011). However, practitioners should be aware of some important distinctions between contexts when applying VSM (Shah and Ward, 2003; Tortorella et al., 2016). While manufacturing typically consists of linear flows of material and information, processes within other contexts may flow in linear, parallel, or even reverse direction (Larson, 2013). By applying VSM, it is possible to avoid doing random improvement initiatives that do not bring any results to the bottom line (Sim and Rogers, 2009). VSM provides structured continuous improvement that leads into a lean value stream and entails a continuous improvement culture within organization (Stone, 2012). Further, VSM enables the creation of a shared perspective of both the current issues and the future vision for the value stream, trespassing departments' limits and providing a horizontal improvement of processes.

Generally, VSM is performed in the following manner: (*i*) select a product family, (*ii*) create a current state map, (*iii*) create a future state map using lean practices, (*iv*) create an implementation plan for the future state, and (*v*) implement the future state through structured continuous improvement activities (Rother and Shook, 1999; Duggan, 2012; Seth et al., 2017). Specifically at this final step, VSM usually results in an implementation plan comprised of several improvement opportunities with different characteristics, such as technical and financial feasibility, level of impact on operational performance, and even staff expertise with regards to a particular problem (Vinodh et al., 2011; Bertolini et al., 2013). Thus, it is reasonable to integrate some multi-criteria analysis tool to enable prioritization of these improvements in order to achieve the best results with minimal time and resources.

2.2.Multi-criteria decision analysis applied to LM implementation

Despite the fact that LM implementation has become a topic of great theoretical and practical relevance, the literature related to methods for evaluating and prioritizing improvement opportunities is relatively limited. The evaluation of an improvement opportunity consists in investigating its characteristics under real conditions of time, resources and performance impact. Thus, indexes that allow measuring those characteristics are required in order to make the objective evaluation of the feasibility of an improvement opportunity (Anand and Kodali, 2008a; Thanki et al., 2016).

A few researches have focused on integrating multi-criteria decision tools to the problems underlying the LM implementation. For instance, Anand and Kodali (2008a) present the application the application of PROMETHEE in making a strategic decision of implementing LM as a part of an organisation's manufacturing strategy. Further, Anand and Kodali (2008b) report the application of a multi-criteria decision-making model named the Performance Value Analysis (PVA) for a case situation in which managers must choose between implementing the following two alternatives: LM and CIMS (Computer Integrated Manufacturing Systems). Yang and Lu (2011) combine multiple attribute decision-making and value stream mapping in order to implement lean continuous flow that can satisfy both a high service-level and low inventory cost. Simultaneously, the authors consider sophisticated variability, such as multi-products, random setup, random breakdown, yield loss, and batch processes, and other contingencies. Vinodh et al. (2012) presents a study that applies the AHP approach for evaluating five different LM concept alternatives concept for implementation in an Indian organization. Cabral et al. (2012) propose an integrated LARG (Lean, Agile, Resilient and Green) analytic network process (ANP) model to support decision-making in choosing the most appropriate practices and KPIs to be implemented by companies in a supply chain. Overall, Lu et al. (2011) highlight that not all lean implementations have produced the desired results because of not having a clear implementation procedure and execution guide. Furthermore, Singh et al. (2006) add that it is widely deemed that VSM provides various tools for data collection and analysis, and identifies the wastes occurring in different stages of manufacturing process. However, to select the detailed mapping tools for the identification of waste and improvement opportunities at micro level is a much more complex decision making problem, and much research still needs to be carried out to properly fill this gap (Gurumurthy and Kodali, 2008; Seth et al., 2017).

In particular, Guglielmetti et al. (2005) conducted a comparison between the AHP and other multi-criteria analysis methods, such as Electre and MAHP. The methods were evaluated according to their performance characteristics in the input data, output data and interface between decision maker and method. Seven aspects were considered to carry out the comparison: (*i*) consistency, (*ii*) logic, (*iii*) transparency, (*iv*) ease of use, (*v*) number of practical applications and scientific publications, (*vi*) time required for the process of analysis and (*vii*) availability of software. Following these criteria, it was decided to adopt the AHP as multi-criteria technique, since it has desirable attributes for the realization of our study, such as (Tortorella and Fogliatto, 2008; Schmoldt et al., 2013): (*i*) a structured decision process that can be documented and repeated, (*ii*) applicable to situations that involve subjective judgments, (*iii*) utilization of both quantitative and qualitative data, (*iv*) provision of the preferences consistency measures, (*v*) wide documentation of its practical applications in the literature and (*vi*) suitable for decision-making groups. The AHP is based on three basic steps (Saaty, 1980; Saaty and Vargas, 1984): (*i*) problem organization in a hierarchical structure that reflects the relationship between the decision criteria and the candidates alternatives; (*ii*) pairwise comparison between elements positioned in a hierarchical level in relation to elements in the adjacent upper level; and (*iii*) analysis of the comparisons matrix generated in (*ii*) by calculating maximum eigenvalues and eigenvectors, and derived performance indicators, such as levels of consistency ratings.

3. Method

The proposed method is comprised of 7 steps, which are shown in Figure 1. The method aims at adapting a multi-criteria decision tool (i.e. AHP) into the application of VSM in five recycling centres in order to identify improvement opportunities for productivity enhancement, and assumes no previous knowledge on the tool.

Figure 1: Research method

In step 1 we propose an extensive data collection with emphasis to the type of organisation targeted in the study. Such data enable the identification of the current contextual condition of each one of the recycling centres, in addition to common difficulties faced by those during their daily operational tasks. Another objective in this step is to gather knowledge regarding the human factors involved in the productive processes, and comprehend the socio-technical management systems. For that, the following conditions are desirable: commitment of leaders to follow the improvement approach, willingness to share operational data (Slack et al., 2010), and willingness to actively participate in process improvement initiatives (Kidwell, 2006). The recycling centres in which VSM will be applied are determined in this step. For that, historical data concerning quality and productivity indicators should be analysed. Individual interviews with process experts for data collection of the recycling centres are performed. Finally, an improvement team should be put together, including knowledgeable employees. A team leader with experience in lean and its tools is also recommended, however not mandatory.

Step 2 is carried out analysing products and services offered by each centre and their production processes. The aim is to determine families of products/services, such that items in a family present similar processing needs. Grouping the items in families will simplify the mapping activities in Step 3. A product family matrix, in which processes are in the columns and products are listed in the rows, can help to identify product families. It can be a simple visual tool (Duggan, 2012) or a complex mathematical model (De Lit et al., 2000; Eppinger and Browning, 2012), depending upon the application. Due to the low complexity of process flow in our study, we apply a visual matrix that correlates products and processes, which are grouped according to a minimum of 80% of processes similarity, as suggested by Rother and Shook (1999). The steps of the method to follow should be first implemented for the product/service family with greatest impact on total demand or revenue.

In step 3 the team will draw the current state map for each centre. For the development of this step, four approaches may be applied in parallel: (*i*) oriented visits to the shop floor, (*ii*) observation, (*iii*) semi-structured interviews and (*iv*) focused groups with the improvement team. As aforementioned, such task will be initially carried out for the most important product/service family. The current value stream is drawn starting from the downstream to upstream processes, as follows: (*i*) shipping, (*ii*) weighting, (*iii*) housing, (*iv*) pressing, (*v*) sorting, and (*vi*) supplying of sorting. Such approach allows the understanding of the value stream from the customer (internal or external) perspective, enabling the proper identification of waste in each process (Vinodh et al., 2011). Such identification of waste, either in material or information flows, is vitally important to target for improvement opportunities in the future state (Herrmann et al., 2008). One way to prioritize these opportunities is measuring the impact of the waste reduction on the average production lead time of the product family under analysis (Duggan, 2012). To consolidate the current state map, processes data are gathered, such as: cycle time, inventory level, work-in-process, changeover time, number of workers, machine downtime, information flow, etc.

Step 4 determines the future state value stream for each studied recycling centre. Designing this future state allows the definition of improvement opportunities that maximize waste elimination and sustained benefits (Womack and Jones, 1996). Waste elimination becomes easier when problems are identified using a team-based approach rather than the narrow scope of an individual or department (Miller et al., 2010). Such design should be grounded on four principles: (*i*) increase system's flexibility to allow rapid adaptation to changes in demand; (*ii*) eliminate waste; (*iii*) minimize inventories producing only when required; and (*iv*) increase efficiency of materials and information flows (Rother and Shook, 1999). Therefore, mapping was developed following the eight guidelines for the lean value stream as proposed by Rother and Shook (1999), and Duggan (2012); they are: (*i*) define *takt* (i.e cycle) time, (*ii*) define finished goods strategy, (*iii*) implement continuous flow, (*iv*) establish FIFO (first-in, first-out), (*v*) implement pull supermarket, (*vi*) create one-point scheduling, (*vii*) establish interval, and (*viii*) define pitch. Once reaching the aimed state for the value stream, several inferences on ways to improve value addition are likely to be outlined based on practical experience registered through the application of focus group method (Krueger and Casey, 2014).

Step 5 applies AHP in order to rank and select the improvement opportunities listed on the previous step. In this sense, the evaluation criteria for the improvement opportunities must be defined. Since the recycling centres are financially supported by the City Hall, performance objectives are previously established by the municipal system; they are: (*i*) minimize lead time, (*ii*) minimize process time, (*iii*) maximize number of involved personnel, (*iv*) maximize monthly commercialized waste/person, (*v*) maximize monthly income/person and (*vi*) minimize the percentage of rejected material. Further, due to the complexity of current information flow within the recycling centres, we suggest to add "number of production scheduling points in the value stream" as another criterion for evaluation. Figure 2 shows the proposed hierarchical structure for multi-criteria analysis. At the highest level, it is placed the main objective of the multi-criteria analysis, which was to determine the best improvement opportunity for each recycling centre. The evaluation criteria are set as the second level of the hierarchy. Finally, in the last level there are all improvement opportunities, denoted as o_n (n = 1,..., N), inferred from the recycling centre future state map.

Figure 2: Hierarchical levels for the multi-criteria analysis in each recycling centre

To analyze this hierarchy it is required eight matrices of pair wise comparisons. The first matrix lists the levels 1 and 2 of the hierarchy. It is a matrix in which the comparisons were evaluated using opinion of the improvement team of each recycling centre. Each pair of items (i, j) has been evaluated in importance using a discrete scale from 1 to 9, where 1 denotes a scenario where items i and j are equally important, and 9 denotes a scenario in which the item i is extremely more important than item j. Intermediate values show commitment and reciprocal values situations (e.g. 1/9) denote situations where the item i is less important than item j. Further, an importance weight vector is obtained for the elements listed in the rows of the matrix, thereby defining the ranking of importance of the evaluation criteria. The importance weight vector corresponds to the main eigenvector of the matrix with normalized values, such that the sum of weights is equal to 1.0. The other comparison matrices relate levels 2 and 3 of the hierarchy. Each of these matrices brings the pairwise comparisons of the N improvement opportunities for each criterion of level 2. The comparisons that generated the data in the matrices were performed adopting a similar procedure of the first matrix, which was based on the improvement team's opinion. Similarly to the first matrix procedure, it is obtained the importance weight vectors for each criterion according to the improvement opportunities. The consistency of qualitative assessments carried out in levels 2 and 3 of the hierarchy generates the CR (Consistency Ratio) values. CR values lower than 0.10 indicate that improvement team's opinion provided a consistent assessment (Saaty, 1980). For the final weight vector, which assigns an importance weight to each improvement opportunity, we calculate the weighted average of the ratings obtained for each opportunity for each criterion. The weighting factors are the importance weights assigned to each criterion, which is given by the importance weight vector of the evaluation criteria matrix.

Further, this information allows comparing the obtained results in order to rank the improvement opportunities and highlight achievements and share best practices among recycling centres. However, in the comparison carried out in step 6, it is worth noticing the existent contextual factors in each case study, so the differences and limitations among them are taken into account. Our proposed method closes with Step 7, in which lessons learned during the value stream analysis and future developments are proposed, so that guidelines may be provided for further implementations. In addition, this is when the organisations are ready to adopt *yokoten*, i.e. a process in which learning is shared throughout the organisation by adapting best practices and improvement ideas to problems arising in other areas or departments (Azevedo et al., 2012; Liker, 2004).

4. Results

Solid waste collection in Porto Alegre involves 150 neighbourhoods, with a population of more than 1.3 million. More than 60 tons of solid waste are collected per day and distributed to eighteen recycling centres, in which only 18% of total solid waste generated in the city is recycled. The collection and distribution of the solid waste are performed by DMLU (Department of Urban Sanitation), while the recycling centres are managed by cooperatives, whose members are mostly poor and not part of the mainstream economy. In these centres, the solid waste is separated, appraised, stored, and commercialized. The profit remains with the cooperatives, making it an important income source (about R$ 812/person/month) for more than 500 workers, who present an average monthly productivity of 1.9 ton per person

(DMLU, 2013). These recycling centres must be designed to minimize process lead time and maximize the output rate. Another design parameter is sorting quality; it must be easy to discard the waste in the correct waste fraction container. The importance of this is highlighted by Krook and Eklund (2010a and 2010b).

The main data was collected through observations, questionnaires and interviews with workers at the five recycling centres. This data collection was conducted during March and December 2014 during different days of the week. Also, additional data was gathered at the DMLU in order to complement initial information. There are many categories of MSW such as food waste, rubbish, commercial waste, institutional waste, street sweeping waste, industrial waste, construction and demolition waste, and sanitation waste. Table 1 shows the amount and mix participation of each MSW category received by each one of the five studied recycling centres (RC). Product families were grouped according to the process similarities based on a visual incidence matrix, in which products are listed in the rows and processes in the columns, as aforementioned. Plastic, paper, cans and dry waste present the same process flow, and together comprise the largest amount of MSW (from 60 to 85% of total material) and, in terms of revenue, these materials represent from 75 to 90% of total monthly income, entailing a major product family. Thus, given its importance, this value stream was selected to be mapped its current state in all recycling centres, considering both information and materials flow.

Table 1 – Mix distribution of received MSW in each recycling centre

In Step 3, the value stream's current state was mapped and analyzed by the improvement team. Participants brainstormed ideas and identified specific steps in the process that could be eliminated or consolidated. To complete the current state map for all centres, eight 4-hour meetings were carried out, in addition to several oriented visits to the recycling centres' shop floor to visualize the processes *in loco*. Table 2 depicts the current state characteristics of the five studied RCs, displaying information emerged from the current state map analysis.

Production lead time among RCs varied from 6.1 to 13.6 days, at RC5 and RC3 respectively; of those, only 179 minutes were effectively devoted to the processing of solid waste. A minimum of 5 and maximum of 12 scheduling points were identified in the value streams with unclear scheduling decision criteria, mostly based on supervisors' expertise. Regarding the sorting quality, high levels of rejected material were found in the recycling centres, with special attention to RC1, which presented the value of 66% of received material rejected in sorting process. Further, the sorting process presented significant differences among RCs. While RC1 and RC5 present electric conveyors, where MSW is moved through workers distributed along these conveyors, similarly to assembly lines; RC3 and RC4 have four tables with four workers each, where MSW is disposed and sorted. Finally, RC2 present 12 individual workbenches, where the sorting process happens in parallel and independently from each other.

The size of the RCs varied from 22 (at RC5) to 100 (at RC1) involved personnel, denoting the recycling capacity of each RC. Further, the average productivity among RCs was measured in terms of "monthly commercialized waste per person". This indicator is directly correlated with average "monthly income per person", since RCs work as cooperatives and all revenue is equally distributed among personnel. RC5 presented the highest productivity and income per person, with 2.4 ton/person and US$ 370/person, respectively. Despite showing the lowest percentage of rejected material (20%), RC4 presented the lowest productivity and monthly income per person, with 1.4 ton/person and US$ 169/person, respectively.

Information flow from customers to RCs was not standardized and informal. Actually, customers' demands are set and parameterized with DMLU, which defines the licensed customers, the expected amount and kind of recycled waste distributed to each one of these. Therefore, there is no demand forecasting or information system involved in this process. Instead, RCs are supposed to inform customers whenever a new truck load of a specific recycled waste is available for being collected. Consequently, the distribution process to customers is in charge of themselves, and RCs do not get involved with it. Moreover, since DMLU is responsible for delivering MSW to RCs, RCs do not inform any supplying needs. DMLU presents a weekly delivery routine, which is defined with RCs based on their expected outcomes and, thus, characterizes the only superficial connection with suppliers.

Participants faced some difficulties while performing the current state analysis. The first one was related to processes data. System information was inexistent and several processes were informally performed. Moreover, cycle times were extremely sensitive to workers' expertise and commitment, imposing difficulties in the analysis of current data. Prior to the current state mapping RCs used to estimate cycle times based on past experience; the same applied to the definition of the centres' production capacity, which was estimated from past performance knowledge. Thus, part of the improvement team was given the task of random sampling processes' cycle times in order to provide more reliable information for the value stream analysis. Since labour may change among workstations, for each workstation it was selected, where available, the most experienced worker and 30 samples were collected for each process, and average times were used as input to the maps. The lack of quality control of sorted materials by the RCs was also viewed as another opportunity for improvement during mapping. Finally, two additional improvement opportunities were considered noteworthy; they were related to: (*i*) the lack of process indicators and formal process management routines, and (*ii*) unbalancing of labour distribution (and therefore production capacity) across workstations.

Table 2 – Comparison of current state characteristics of studied recycling centres

In Step 4 of the research method, the improvement team drew the value streams' future state map. The construction demanded six additional 4-hour meetings, which took place in a two-month timeframe. Some objectives and assumptions were set before drawing the future state map. First, a six-month implementation horizon was targeted for the future state map, so that team members could reasonably work on the proposed improvements without losing focus of daily activities yet not losing the improvement *momentum* created so far. Second, improvement ideas that demanded capital expenditure should be limited, since the study was carried out in cooperatives supported by local government with limited budget. Improvements demanding acquisition of additional instruments, new machines or costly layout changes should be initially disregarded. Several improvement actions were elicited towards the desired future state of each centre, generating an improvement portfolio of more than 50 different opportunities and various implementation points along the value streams.

For the development of Step 5, each member of the improvement team was asked to establish values from 1 to 9 for the first matrix (levels 1 and 2 of hierarchy); the median of responses from individual interviews was adopted in order to avoid extreme values in the answers, which are likely to be outliers. The consolidated matrix is depicted in Figure 3. Then, the same procedure was applied to other seven matrices which consolidated the pairwise comparisons of improvement opportunities according to each criterion of level 2. Additional importance weights vectors were generated according to each criterion and all CRs were lower than 0.10, denoting consistency in the qualitative assessments provided by the improvement team. Finally, an overall scores vector was established based on the weighted average of the ratings obtained for each opportunity for each criterion. To better compare these scores and remove scale effects, we created a differentiation index that gives the number of standard deviations of each improvement opportunity score with respect to the total average. Standardized scores displaying values larger than 1.0 are highlighted in Table 3, and they indicate the most critical opportunities for improvement.

Figure 3: Matrix of pairwise comparisons of the evaluation criteria

Table 3: Overall scores vector for improvement opportunities portfolio

Among the opportunities, 10 main actions were defined as displayed in Table 4. It is worthy to notice that, regardless the process and RCs' characteristics, these actions were commonly applied. For instance, the implementation of visual management, review packaging and batch sizes and balance workload among processes were the main improvement deployment for all RCs. No actions were addressed to improve information flow with customers and suppliers, since it was understood that it belongs to local government's scope. Further, MSW distribution to RCs and delivery of finished goods to customers remain the same way as current state, since the improvement horizon was six-month implementation and these improvements demand a longer time. Thus, future state analysis mainly focused on the simplification and standardization of internal processes. Table 5 depicts future state results for each RC after implementation of identified improvements.

Table 4 – Main processes' improvement opportunities for future state maps

Table 5 – Future state results for each recycling centre

Regarding the future state results for RCs, the average lead time was approximately 3 days; with a minimum of 1.3 at RC1 and a maximum of 6.2 days at RC3. Also, process time has been reduced, varying from 56 to 120 minutes at RC1 and RC5, respectively. Further, information flow within RCs was simplified, since the number of scheduling points was reduced to 1 in all RCs. Therefore, due to the implementation of visual management practices (e.g. first-in, first-out) along the value streams, clear production decision criteria were defined to connect processes, reducing information misunderstandings, errors or need for supervisors' intervention. Another evidenced outcome was related to quality, since there was a significant reduction on the percentage of rejected material in each RC. Such improvement was basically grounded on the implementation of visual management procedures and redesign of workload balance of sorting processes. The redistribution of tasks in sorting processes allowed workers to focus on specific materials, enabling work specialization and standardization, and reducing the learning curve of workstations through greater assertiveness in tasks.

In terms of productivity, the outcomes of the future state map analysis were obtained through small, systematic and short term improvements in value streams, denoting a huge potential for processes optimization if more time and capital were invested in each RC. Practices such as change over reduction, and packaging and batch size review strongly benefited transportation and inventory management within RCs. Further, re-layout opportunities were identified and implemented, especially in the sorting processes, whose production capacities were revised based on cycle times and workload balance definition. Another process that strongly contributed to results was "supply of sorting", where improvement practices focused on visual management implementation and inventory sizing. These practices allowed a homogeneous and continual feeding of sorting processes, which are denoted as productive bottlenecks, avoiding lack of material and loss of systems' productivity. Thus, the implementation of these practices resulted in significant improvements in tons of commercialized waste per person in all RCs, and, consequently, an enhancement in personnel monthly income, regardless the increase in the number of involved personnel.

5. Discussion

Our results denote some interesting points with regards to the productive systems of solid waste recycling centres and lean implementation, summarized in Figure 4. First, despite a careful sample selection process in order to ensure the uniformity of characteristics among the studied RCs, some contextual variables presented differences that may influence the results. For instance, size of the RC, which can be compared based on the number of involved personnel, vary from 22 at RC5 to 100 at RC1. A few studies (Dora et al., 2013; Ates, 2004) state that the larger the size of the plant the worse the information flows, which negatively affects the production scheduling process. However, RC1, which is the largest recycling centre, currently presents nine scheduling points, as shown in Table 2, while others that are smaller present ten or twelve such as RC2 and RC3, respectively. Further, large size also implies the availability of human resources that facilitate adoption and implementation of change management practices (Foster et al., 2007; Herron and Braiden, 2006). Nevertheless, our findings show that smaller centres have presented significant changes with adoption of lean practices, such as RC5 and RC2, whose productivity improvements were approximately 112% and 105%, respectively, comparing current and future states. Thus, although literature evidences that contextual variables impact the adoption and implementation of lean practices in solid waste recycling centres (Hemphala et al., 2010), results indicate that the direction of the effect is not always as predicted.

Secondly, the current state results indicate the existence of a significant amount of waste incorrectly sorted, which in turn influences the environmental and productivity performance of the waste management system as a whole (Wilson et al., 2006; Campos, 2014). Due to its heterogenic line of business, the waste sector involves several agents with varying incentives for sorting waste. For instance, two of the RCs presented more than 50% of rejected material and only one achieved the target of 20% of rejected material established by the municipal legislation (DMLU, 2013). However, future state achievements show the percentage of rejected material of four RCs aligned with the target. RC1 presents a particular contextual variable, which may justify its result of 37% of rejected material. Among all RCs, RC1 is the only one that receives and sorts medical waste (21% of total material) due to agreements with local hospitals. This kind of waste usually presents a more problematic and specific materials for manual sorting than domestic waste, which, consequently, affects the quality of sorting (Krook and Eklund, 2010a). Krook and Eklund (2010b) also mention that this problem could possibly be addressed by product design limiting the extensive mixture of different materials in products and enhancing the ability for dismantling. Thus, the waste origin may influence the quality of sorting at RC1, and, although its productivity has already increased, it could potentially be enhanced without such issues.

More specifically, regarding the implementation process of lean practices (e.g. VSM) in recycling centres it is worthy to note a few points. In general, solid waste recycling centres are often poorly run and operate to low standards. However, there are some main differences between recycling centres and an ordinary industrial production system. For example, it is the function of the recycling centres to receive and take care of visitors' waste, characterizing a push system, while industrial production systems normally order the incoming material from their suppliers, denoting a pull system. Thus, some lean principles such as "*let the customer pull value from the producer*" (Slack et al., 2010) needed to be adapted to this scenario based on municipal arrangements with DMLU and the future productivity planned for each centre in order to review and establish new patterns of MSW collection frequency and distribution quantities. Such outcome corroborates to the contingency approach, in which organisations should use and adapt lean practices and principles that are effective in their context (Anvari et al., 2011; Desai, 2011). As a consequence, the adoption of a "best practice" approach becomes brittle, since the diversity of as its major theme of study the identification of the best practices associated with alleviating these problems.

Finally, a recycling centre can be viewed as a combination of a service and a production operation (Sundin et al., 2011). While it is supposed to perform an environmental role through the sorting and compacting of MSW in order to become raw material for other businesses, it contributes as a socio-economic service. Specific socio-economic conditions prevail in many economically developing countries, including rapid population growth, migration to urban areas, lack of sufficient funds and affordable services, poor equipment and infrastructure and generally a low-skilled labour force (Parrot et al., 2009). The promotion and development of recycling centres is a means of upgrading living and working conditions of rag pickers and other marginalized groups (Sharholy et al., 2008). Such service can be denoted by the increase in the number of involved personnel from the current to future state. Considering the five studied RCs, despite the obtained productivity improvements, 48 people were added to the centres, resulting in an increase of 22% in employment opportunities. Moreover, the average monthly income per person presented a significant increase that varied from 56% to 126%, at RC3 and RC2 respectively. Therefore, not only the employment level has improved but also the financial condition of these workers has increased, contributing to a local socio-economic inclusion.

Figure 4: Summary of variations and uncertainties for lean implementation in community-managed RCs

6. Conclusion

MSW management is a major problem in most economically developing countries. This research suggests two major findings. First, while VSM theory brings valuable information to managers and facilitators, the most important benefit comes from actually applying the tool. During the mapping process insights grow, paradigms are shifted, and consensus is built. Not only the mapping activity leads to better and leaner processes, but also brings consensus that enables and enhances lean implementation in contexts other than manufacturing. Second, the integration of a multi-criteria decision-making tool to the VSM methodology characterizes an important contribution to the area. VSM provide means to identify several systemic wastes and, hence, address improvement actions. However, due to the large amount of identified opportunities over several targeted objectives, the integration of AHP as a multi-criteria decision-making tool enables the establishment of criticality scores and prioritizes the improvements. Therefore, AHP complements the final stage of VSM by ranking opportunities and facilitating the priorities decision within improvement teams. In particular, this contribution becomes especially important in cooperatives managed by community, such as RC, where decisions are often complex and time-consuming. Sundin et al. (2011) reinforce that the studied context usually presents certain reluctance in adopting formal controlling and management practices. Personnel training in recycling centres (whenever it exists) is usually task focused and do not emphasize the development of managerial skills. Due to their socio-economic condition, labour force usually comes without technical background and low educational level, which hinders the implementation of more complex management practices. Thus, incorporating a decision-making tool helps to address such issues. However, AHP might not be the proper tool choice if a larger amount of opportunities is identified, due to its operational characteristics. Further studies may investigate more practical multi-criteria analysis in order to overcome this barrier.

Finally, despite the increasing pressure for better performance of recycling centres, the existent mindset is still far from the private sector, where lean practices were conceived. While in the private sector managers must improve and optimize resources to financially sustain their businesses, solid waste management systems are usually supported by governmental institutions, whose primary objectives do not necessarily involve attaining financial profit or business performance. However, this fact is somewhat contrary to a recycling centre reality. Since most of the recycling centres in Porto Alegre work as cooperatives, their income is directly associated with their level of productivity. Therefore, the expected mindset should be in favour of lean implementation and the provided improvements in their management and productive systems.

There are some limitations due to the nature of the study that must be highlighted. First, with respect to the data collection we used historical average values to map the current state at each recycling centre. This limitation neglects potential variation in terms of time, inventory, processes, people, among others. In fact, this kind of approach is inherent to VSM methodology, and may undermine the decision-making process disregarding improvement initiatives that aim to reduce variation. Therefore, further studies that include methods for approaching process uncertainty may fulfil such gap, providing a more robust improvement portfolio and allowing managers and practitioners a more assertive prioritization. Further, the social impact arising from the improvements was poorly investigated. Since lean implementation embraces a socio-cultural change, the effect of these improvements might entail different behavioral outputs, specially under this scenario (recycling centres). Thus, another opportunity for future research comprises the investigation of the social impact of lean implementation on centres that are managed by poor community cooperatives, which may raise new contextual paradigms regarding LM.

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Table 1 – Mix distribution of received MSW in each recycling centre

Mix of received MSW	RC1		RC2		RC3		RC4		RC5	
	kg/month	%	kg/month	%	kg/month	%	kg/month	%	kg/month	%
Broken glass	76,852	18%	16,560	26%	6,508	13%	8,770	26%	6,645	12%
Mixed paper	60,230	14%	5,160	8%	8,832	18%	3,910	12%	5,867	11%
Corrugated paperboard I	53,074	12%	4,760	7%	9,017	18%	2,490	7%	9,496	18%
Journal	37,445	9%	5,400	8%	3,121	6%	2,144	6%	4,250	8%
White paper	37,450	9%	3,210	5%	4,292	9%	2,480	7%	4,200	8%
Corrugated paperboard III	27,230	6%	3,200	5%	3,313	7%	656	2%	4,520	8%
Low-density polyethylene (LDPE)	19,894	5%	1,558	2%	1,501	3%	520	2%	2,143	4%
Metal scrap	20,722	5%	8,000	13%	2,001	4%	1,230	4%	800	1%
Polyethylene (PE)	16,789	4%	2,320	4%	1,547	3%	1,688	5%	3,123	6%
Publication paper	17,924	4%	3,280	5%	1,906	4%	2,920	9%	2,210	4%
Tetrapack	14,698	3%	2,320	4%	1,374	3%	1,020	3%	2,168	4%
High-density polyethylene (HDPE) Transparent bottle	8,394	2%	2,140	3%	773	2%	1,115	3%	2,281	4%
LDPE film	9,522	2%	904	1%	1,209	2%	920	3%	1,618	3%
Aluminium can	3,627	1%	481	1%	458	1%	414	1%	457	1%
HDPE colour bottle	5,492	1%	830	1%	551	1%	643	2%	1,370	3%
HDPE bag	3,719	1%	608	1%	441	1%	515	2%	1,160	2%
Polyethylene (PE) green	4,184	1%	480	1%	404	1%	502	2%	0	0%
Polypropylene (PP)	3,217	1%	360	1%	343	1%	0	0%	512	1%
PP transparent	4,206	1%	425	1%	506	1%	370	1%	387	1%
Others	6,232	1%	1,626	3%	967	2%	979	3%	463	1%
Total	430,900		63,622		49,066		33,286		53,670	

Table 2 – Comparison of current state characteristics of studied recycling centres

Current state indicators	RC1	RC2	RC3	RC4	RC5
Lead time	7.4 days	12.4 days	13.6 days	13.4 days	6.1 days
Process time	86.4 minutes	134 minutes	179 minutes	168 minutes	145 minutes
Number of scheduling points	9	10	12	7	5
Number of involved personnel	100	30	35	28	22
Monthly commercialized waste/person	1.6 ton	2.1 ton	1.4 ton	1.4 ton	2.4 ton
Monthly income/person	US$ 200	US$ 234	US$ 177	US$ 169	US$ 370
% of rejected material	66%	34%	53%	20%	28%
MSW sorting type	2 Conveyors (28m) with 28 workers each	12 Individual Workbenches	4 tables with 4 workers each	4 tables with 4 workers each	1 conveyor (11m) with 12 workers
Does it sort medical waste?	Yes (21%)	No	No	No	No

Table 3 – Overall scores vector for improvement opportunities portfolio

Improvement opportunities	Overall score	Differentiation index
o_1	0.015	-0.46
o_2	0.023	0.33
o_3	0.033	1.32
o_4	0.019	-0.06
o_5	0.030	1.02
o_6	0.008	-1.15
o_7	0.019	-0.06
o_8	0.012	-0.76
o_9	0.031	1.12
o_{10}	0.006	-1.35
o_{11}	0.011	-0.85
o_{12}	0.017	-0.26
o_{13}	0.004	-1.55
o_{14}	0.024	0.43
o_{15}	0.013	-0.66
o_{16}	0.002	-1,74
o_{17}	0.021	0.13
o_{18}	0.024	0.43
o_{19}	0.027	0.73
o_{20}	0.019	-0.06
o_{21}	0.008	-1.15
o_{22}	0.028	0.83
o_{23}	0.032	1.22
o_{24}	0.016	-0.36
o_{25}	0.019	-0.06
o_{26}	0.022	0.23
o_{27}	0.016	-0.36
o_{28}	0.009	-1.05
o_{29}	0.010	-0.95
o_{30}	0.025	0.53
o_{31}	0.005	-1.45
o_{32}	0.036	1.62
o_{33}	0.011	-0.85
o_{34}	0.039	1.91
o_{35}	0.027	0.73
o_{36}	0.008	-1.15
o_{37}	0,017	-0.26
o_{38}	0.035	1.52
o_{39}	0.026	0.63
o_{40}	0.017	-0.26
o_{41}	0.023	0.33
o_{42}	0.009	-1.05
o_{43}	0.014	-0.56
o_{44}	0.041	2.11
o_{45}	0.028	0.83
o_{46}	0.013	-0.66
o_{47}	0.006	-1.35
o_{48}	0.038	1.81
o_{49}	0.016	-0.36
o_{50}	0.034	1.42
o_{51}	0.016	-0.36

Table 4 – Main processes' improvement opportunities for future state maps

Implementation process	Improvement opportunities description
Supply of sorting	o_3- Sizing the receiving inventory to keep an uninterrupted flow between waste delivery. o_5- Using gravity to facilitate receiving process. o_9- Using visual management at receiving in order to allow supervisor's anticipation before running out of material.
Sorting	o_{23}- Balancing workload and defining cycle times
Transportation	o_{32}- Review of batch sizes and packaging for transportation o_{34}- Implementing visual management for stock before pressing
Pressing	o_{38}- Reducing batch size for pressing o_{44}- Improving pressing change over o_{48}- Defining standardized work for workers procedure
Housing/storage	o_{50}- Implementing visual management for finished goods

Table 5 – Future state results for each recycling centre

Future state (6 months) indicators	RC1	RC2	RC3	RC4	RC5
Lead time	1.3 days	3.4 days	6.2 days	4.1 days	1.4 days
Process time	56 minutes	88 minutes	82 minutes	87 minutes	120 minutes
Number of scheduling points	1	1	1	1	1
Number of involved personnel	100	39	44	40	40
Monthly commercialized waste/person	3.4 ton	4.3 ton	2.1 ton	2.3 ton	5.2 ton
Monthly income/person	US$ 419	US$ 530	US$ 276	US$ 288	US$ 792
% of rejected material	37%	20%	20%	20%	20%
Improvements in sorting resources	2 Conveyors (28m) with 36 workers each	17 Workbenches	5 tables with 6 workers each	5 tables with 6 workers each	1 Conveyor (20m) with 22 workers

Macro-steps
1. Preliminary data collection and contextualization
2. Analysis of product/service offered by the organization and their production processes
3. Drawing of current state maps and deployment of improvement actions to attain future state
4. Drawing of future state map and creation of improvement opportunities portfolio
5. Multi-criteria decision analysis and ranking of improvement opportunities
6. Results comparison and framework with guidelines
7. Analysis of lessons learned and future developments

Figure 1: Research method

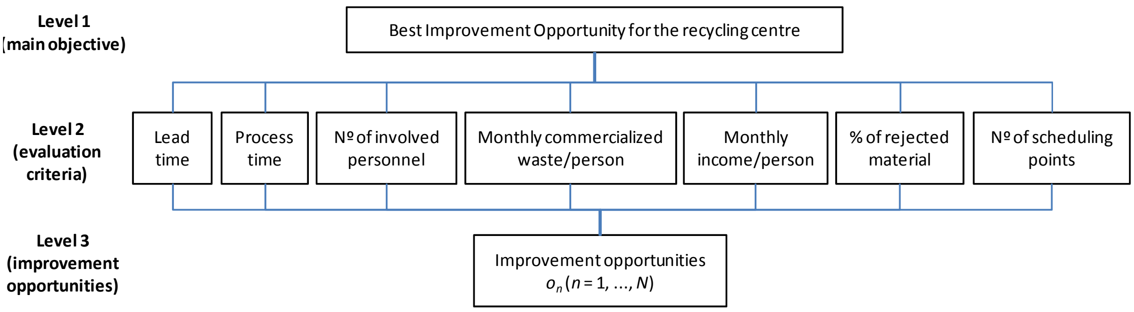

Figure 2: Hierarchical levels for the multi-criteria analysis in each recycling centre

CRITERIA	Lead time	Monthly income/ person	Nº of involved personnel	Monthly commercialized waste/person	Process time	Nº of scheduling points	% of rejected material	Importance weight
Lead time	1	1/3	1/2	1/5	3	4	2	0.105
Monthly income/person	3	1	2	3	6	5	4	0.315
Nº of involved personnel	2	1/2	1	1/3	4	5	3	0.161
Monthly commercialized waste/persor	5	1/3	3	1	5	6	4	0.268
Process time	1/3	1/6	1/4	1/5	1	2	1/2	0.045
Nº of scheduling points	1/4	1/5	1/5	1/6	1/2	1	1/3	0.034
% of rejected material	1/2	1/4	1/3	1/4	2	3	1	0.072
CR								**0.06**

Figure 3: Matrix of pairwise comparisons of the evaluation criteria

Category	Specific issues
Diversity of the supplied products	Usage of toxic material Uncenrtainty in supplied quantities and mix Delivery routines are set by suppliers
Complexity in process planning and operations management	Extreme obsolete or inexistence of technology in equipments Production takt time is set according to suppliers' delivery No product structure Low capabilities and limitations of detection technique No demand forecasting or medium and long term planning Inexistence of a disassembly sequence plan Long and decentralized decision-making process Lack of disassembly process parameters Unstructured information flow
Labour	Poor ergonomics aspects taken into consideration High variation among processes' cycle times Excessive manual labour Absence of formal leadership and hierarchies Low skilled labour
External factors	Market driven factors Precarious condition of building infrastructure Prices are totally set by customers Socio-economic role of RCs in municipal areas

Figure 4: Summary of variations and uncertainties for lean implementation in community-managed RCs