Application of lean methodology to improve processes in the construction and demolition waste industry

The Ambisider Case Study

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Abstract – The construction industry is one of the largest consumers of natural resources and one of the main generators of construction and demolition waste (CDW). Thus, the incorporation of recycled aggregates in construction is fundamental in achieving sustainability, but this is only feasible if these are competitive in relation to new materials. Thus, lean management plays an important role in reaching efficiency of production processes within the CDW industry. This management paradigm, developed in the automotive industry, is currently one of the most used methodologies in improving production processes.

This dissertation focuses on Ambisider, a Portuguese company of the construction sector that manages the CDW generated by the demolition works, it performs with the objective of increasing efficiency of the production process of recycled aggregates. The fundamental aim is to propose the implementation of improvement actions based on lean management following the DMAIC cycle (Define - Measure - Analyze - Improve - Control) methodology, an organized and sequential method for solving problems using various tools and methodologies from the six sigma management philosophy.

The study of Ambisider recycling operations led to identify lean wastes, understand their root causes, and propose improvement strategies and respective forms of maintenance. The proposed improvements were designed in the future value stream mapping (VSM) showing improvements in production capacity, reduction of lead time and consequently improving the quality of aggregates, reducing production costs and increasing the organization level and competiveness of Ambisider.

Keywords: Construction and Demolition Waste, Lean, Six Sigma, Ambisider

1. INTRODUCTION

The efficient management of resources and the optimization of processes are two fundamental issues in environmental and economic sustainability. Over the decades there has been a considerable increase of economic activities that have contributed to the depletion of natural resources and natural ability to absorb and process the residues (Ferrão & Pinheiro, 2011). Thus, the need for optimization, rational and efficient use of resources in the various economy sectors is currently seen as a matter of citizenship.

As a result, the waste reduction and the efficient use of natural resources are two fundamental pillars of the general waste management regime established by the Portuguese Decree-Law (DL) nº 73/2011 of 17 June. This theme is extremely important that is also present in the “Portugal 2020” program, an agreement signed between Portugal and the European Commission, named Operational Program of Sustainability and Efficient Use of Resources for which it is intended a Community fund of 2,253 million euros

The construction industry is one of the largest and most active in the European Union (EU), absorbing over 50% of natural material resources and responsible for over 50% of the total produced waste. Every year 500 million tons of construction and demolition waste (CDW) is produced in the EU which represents 25 up to 30% of the total produced waste (Coelho & Brito, 2013). Despite the construction sector being an activity with centuries of existence, only in recent decades there has been a concern related to the CDW management (Botelho, 2010). Although the CDW has a specific legislative framework, published on the DL nº 46/2008 of 12 March, which establishes the CDW governing rules operations including its prevention, reuse and recycle operations, in Portugal the level of recycling and reuse of CDW is less than 10% unlike the Netherlands, which is over 90% (ETC/SCP, 2009).

Consequently, is needed an efficient management of CDW to reduce the consumption of natural resources and achieving sustainable construction. The incorporation of recycled materials is one solution, but is only feasible if these materials are sufficiently competitive in relation to new materials. Therefore, it is important to improve the processes related to CDW through the adoption of the lean management system along with the six sigma methodology. This management paradigm has revealed in companies from other sectors, considerable increases in efficiency and effectiveness of processes by improving product quality, reducing costs and production time and increasing customer satisfaction.

To conclude, this study is intended to assess lean principles and tools integrated with the six sigma DMAIC methodology in effort to apply an organized formula of approaching the case study in Ambisider, a Portuguese company that produces recycled aggregates from CDW originated by its demolition works. It is intended to improve the production process by proposing measures in order to create value for the company in terms of productivity, production capacity, lead time, organization, and value to customers.

2. BIBLIOGRAPHIC REVIEW

2.1 Lean

Lean production was originally started within the automotive industry with the implementation of the Toyota Production System (TPS) in 1950 in Japan. Taiichi Ohno and Eji Toyoda created the system combining the advantages of both mass production (high volume and low unit cost) and craft production (variety and flexibility) (Paez et al., 2004). The results of the new system have revealed obvious improvements in terms of production efficiency keeping focus in quality assurance and waste elimination (Holweg, 2007). Therefore, a study on lean production was initiated and became popular with the best-seller *The Machine That Changed the World*, which related the lean concept with Toyota methodologies and techniques (Womack, Jones, & Roos, 1990; Shah & Ward, 2003).

Later on, Womack and Jones (2003) demonstrated that lean production could be adaptable to other industries that aimed to improve their results. The term lean has become more embracing and is currently seen as a management philosophy which is governed by five main principles which aim to: specify value to the customer identify the steps in the value stream for each product family, eliminate those which do not add value, create a production flow toward the customer, and to create a system in which the consumer pulls the next activity. Finally, it is intended to seek for total efficiency (perfection) in which there is no waste, and a perfect value is created to the customer (Womack & Jones, 2003; LERC, 2015). Pinto (2009) has reviewed the lean principles by considering that the specification of value should take all stakeholders within the process, including the company's, employees', and customers' needs.

Waste is any activity in a process that does not add value to the consumer. There are seven main types of waste: over-production, waiting, transport, inventory, over-processing, motion, and defects (Pinto, 2009). In recent times, wastes such as making-do, skills and product maladjustment were added to the list. These "muda", as the Japanese call waste, should be reduced or eliminated by eradicating the corresponding root cause and not only focusing on the symptom having focus on the lean principles and value as perceived by the customers (Melton, 2005). According to Pinto (2009), only 5% of the activities add value for the customer, 35% are necessary non-value activities and 60% add no value at all. Thus, in order to eliminate the root causes various lean tools should be implemented. The keys tools are: 5S, standard work, five whys, value stream mapping, pull system, spaghetti diagram, visual control, just in time, single minute exchange of dies, takt time, *jidoka, heijunka*, one piece flow, *kanban*, etc..

According to Melton (2005) there are many benefits of being lean in terms of financial savings, customer satisfaction, quality improvements, empowered people and increased process understanding. While there is overwhelming evidence for the implementation of lean management principles, there are certainly obstacles that exist, such as the company culture and natural skepticism.

2.2 Lean Six Sigma (LSS)

In 1980, six sigma appeared as a new management paradigm within the Motorola Company in the United States. Six Sigma is defined as "an organized and systematic method for strategic process improvement and new product and service development that relies on statistical methods and the scientific method to make dramatic reductions in customer-defined defect rates'' (Linderman, Schroeder, Zaheer, & Choo, 2003). This management strategy also seeks for reducing process variability by avoiding the occurrence of errors and increase the efficiency of organizations through the quality of products and processes (Lin, Frank Chen, Wan, Min Chen, & Kuriger, 2012). The decrease in variability leads to a higher productive standardization and, therefore, better production control (Montgomery & Woodall, 2008). Six Sigma applies a structured approach to managing improvement activities that is represented by DMAIC cycle used in process improvement. DMAIC is a structured improvement procedure involving different management tools in each step which allows problem-solving and thus process improvements. Each DMAIC phase has proper objectives and tools. The Define phase is the problem selection. The Measure step translates the problem into a measurable form and assessment of the current situation. The Analyze phase is the identification of influence factors and root causes of the project problem. Subsequently, the Improve step designs and implements adjustments to the process. Finally, the Control phase maintains the gains in efficiency and monitors the improvements to ensure a continued and sustainable success.

Although lean and six sigma are two independent management philosophies, both seek for improvements within the processes and both require significant cultural changes to achieve them. According to Salah, Rahim & Carretero (2010) each five lean principles are related to the DMAIC phases (figure 1), making the lean six sigma (LSS) a set of powerful tools and techniques.

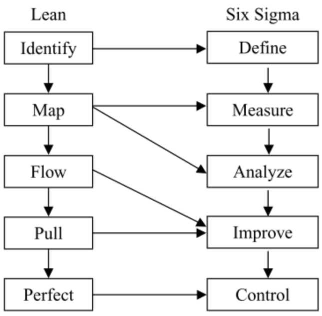

Figure 1 – Lean and Six Sigma phases relationship
According to Salah, Rahim & Carretero (2010)

3. CASE STUDY

The main objective of this case study is to give a proposal for improving the production process of recycled concrete aggregates of Ambisider by applying the DMAIC method based on LSS management philosophy. To better perceive the production process, a preliminary stage was carried out before applying the DMAIC method. This phase involved the action of "going and see" the actual process, asking questions and learning. This is a TPS key principle used to truly understand the problems and indicate immediate improvement opportunities at the *gemba*[1].

3.1 Preliminary Stage

Ambisider is a Portuguese company in the construction sector with three main activity areas (Ambisider, 2015):

1) Demolition and waste management;
2) Rehabilitation and material removal containing asbestos;
3) Project management.

The company core business is based on the first activity area mentioned before. The company practices selective demolition and building deconstruction and, as a licensed waste management operator, is responsible for the CDW treatment required by the Portuguese law. In order to do that, Ambisider has a Concrete Recycling Unit (CRU) and a Temporary Residues Storage Area (TRSA) where the residues are distributed according to their code specified in the European Waste List (EWL). The TRSA and CRU are represented in figure 2 with the residues code and other facilities (e.g.: repair and maintenance workshop and weighing control area). The production process which is going to be analyzed is focused in the CRU where the concrete (code 17 01 01) and mixture of concrete, bricks, tiles and ceramics (code 17 01 07) wastes are recycled and stored at the Tagus Bay Area (TBA), approximately 2km from Ambisider.

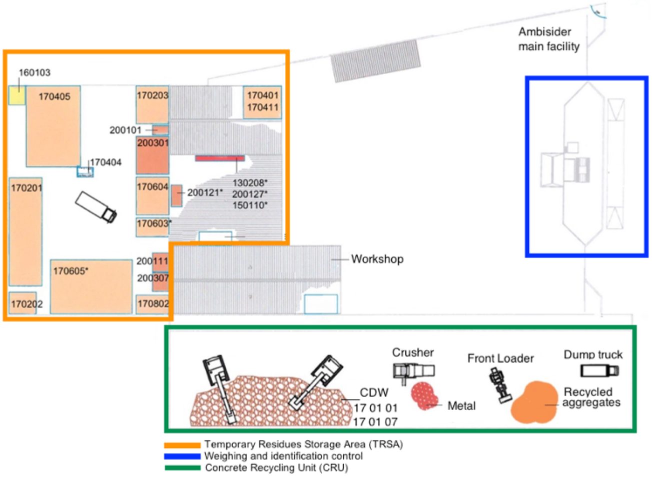

Figure 2 – Ambisider main facility layout

The CDW general recycling process is represented in figure 3 with the main process phases and the resulting products.

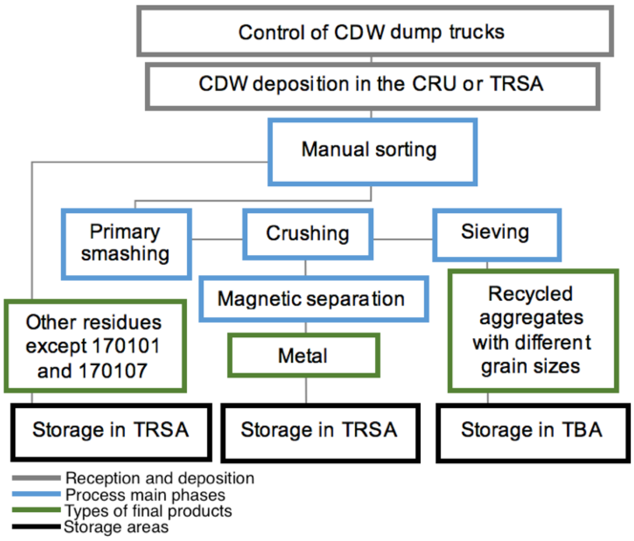

Figure 3 – CDW treatment process of Ambisider

Along the action "going and see" the following wastes were identified:

- **Waiting time** – crusher multiple breakdowns which leads to production stops during a long period of time;
- **Transport** – unnecessary transports when the residues are firstly stored in TBA when there is no space in the CRU;
- **Over processing** – inadequate machines;

[1] *Gemba*: A Japanese word meaning "the real place" or the shop floor where value is created.

- **Inventory –** high amount of CDW piles waiting for the recycling operations in the CRU reducing the available space to store;
- **Motion –** unnecessary movements of operators due to main facility layout organization;
- **Defects –** complaints from the potential customers about the quality of the recycled aggregates in terms of their dimensions, shape, and properties;
- **Making-do –** recycling operations begin with an insufficient number of operators;
- **Skills** – only few operators are specialized in handling the crusher machine;
- **Product maladjustment –** sieving operations are rarely executed leading to a non-competitive product.

3.2 Define

In this phase SIPOC tool was used to summarize the inputs and outputs of the process (figure 4). This acronym stands for Suppliers, Inputs, Process, Outputs and Customers and is used as an improvement tool to define the process and to give those who are not knowledgeable a macro overview of the process. The main suppliers are the construction owner or the contractor of the construction work who supply the CDW after a demolition/deconstruction operation and also the diesel and lubricants companies who supply the fuel and oil required for the machines functioning. The process consists of seven operations:

1. **CDW receiving –** weighing control of the dump trucks and identification of the residues;
2. **CDW storage** – CDW is deposited in its correspondent area (CRU or TRSA) according to the EWL;
3. **Manual sorting** – in the CRU, 17 01 01 and 17 01 07 construction debris are manually sorted to take other possible residues that can not be crushed. Those materials are then stored in the TRSA to be transferred to other authorized operators;
4. **Primary smashing** – the residues are smashed in suitable dimensions to fit in the crusher;
5. **Crushing** – the debris are crushed in a dimension established by the company and metal residues are excluded by magnetic separation;
6. **Sieving** – the aggregates are sieved in different grain sizes;
7. **Recycled aggregates storage –** the different aggregates sizes are stored in their correspondent pile in the TBA.

The outputs of the process are piles of 17 01 01 and 17 01 07 aggregates with different size grains and other residues manually sorted during the process which are sent to the TRSA waiting for other type of recycling treatments. The customers of this products are the building owner or contractor (the main customers) who paid for the demolition/deconstruction services and have to pay for the CDW recycling but also the recycled aggregates customers. The latter are potential customers resulting in an extra source of income.

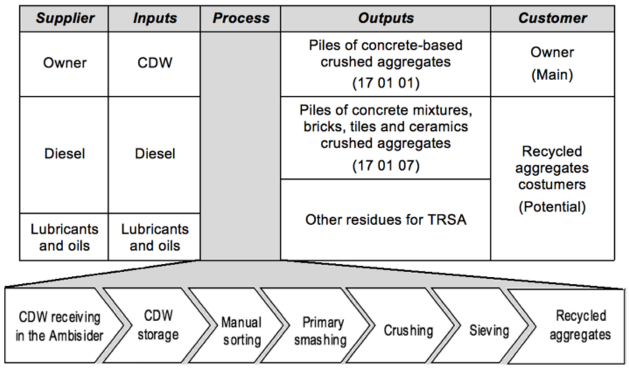

Figure 4 – SIPOC

After the contextualization of the production process is time to capture the customers and employees' requirements, needs and expectations. The voice of the customer (VOC) and voice of the employee (VOE) tools were used in order to specify value to all stakeholders involved in the process. According to Ambisider, the demolition and deconstruction market has been increasing not only in Portugal but also in the rest of Europe leading to greater demand of those works and an increasing production of CDW. As a result, in short time, the company will have to increase its productive capacity. From the employees' perspective, the process needs some improvement since the CDW waiting time for recycling operations is too long due to manual sorting and primary smashing that take too long. In their point of view, that time could be reduced if the demolition and deconstructions activities would be more efficient. They also complain about frequent stops due to breakdowns and lack of standard work.

To resume and decompose broad customers and employee requirements into more easily quantified elements, critical to quality tree (CTQ tree) was used and is shown in figure 5.

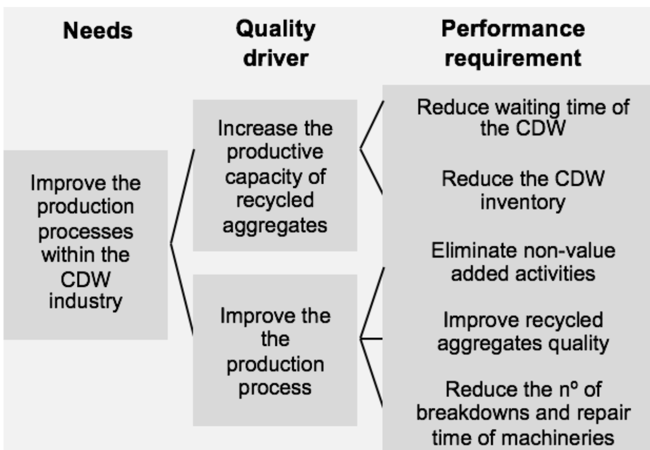

Figure 5 – CTQ tree

3.3 Measure

A spaghetti diagram enables a clear vision of the material flow throughout the plant. The image shows the material route from a building site to the company where the different layout facilities are designed as the background and delimited in two areas: the main facility with the CRU and TRSA and the TBA where the final products are stored. Figure 6 depicts the three production flows identified in different colors, the production phases and the final products either in temporary or permanent stocks. This design of material flow using a spaghetti diagram is important to design before the current value stream mapping (VSM) to have a clear vision of the production lines.

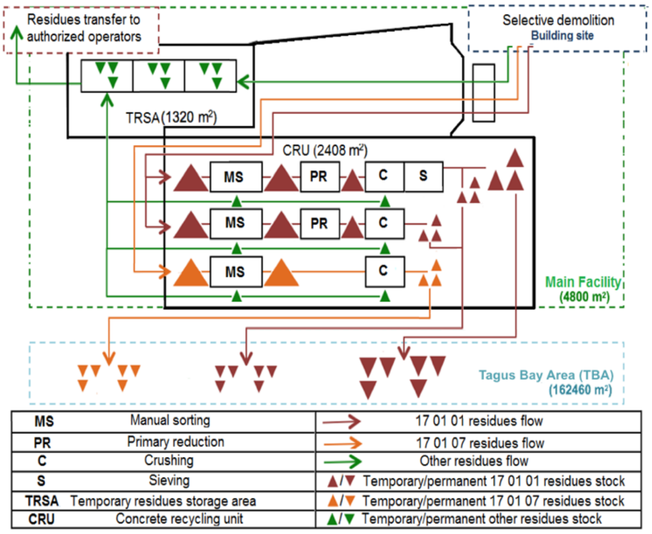

Figure 6 – Spaghetti Diagram

Later on, a current VSM was designed. A value stream consists of all the steps from the suppliers to the final product including the non-value added activities. It is a material and information flow mapping. Womack and Jones (2003) describe VSM as the process of visually mapping the current state and at the same time preparing a future state map with better methods and performance. The current VSM is depicted in figure 7 with improvement opportunities identified.

In summary, the key performance indicators (KPI) for this study were stablished as follows:

- CDW **waiting time** for recycling operations;
- CDW and recycled aggregates **inventories;**
- Machines **downtime** due to breakdowns;
- CDW **quality** parameters;
- **Lead time** and **value added time**;
- **Production capacity** of the process.

3.4 Analyze

The goal of DMAIC Analyze phase is to identify potential root causes for the problems. Having completed the Define and Measure phases, four main problems were defined as follows:

1st Problem – Waiting time of CDW to be recycled;

2nd Problem – Reduced quality of aggregates;

3rd Problem – Crusher breakdowns;

4th Problem – Occasional realization of sieving.

At this stage, several tools and techniques along LSS can be employed to verify the current root causes of waste and defects. In this case study, brainstorming technique, cause and effect diagram and 5 whys were used to conduct to a root cause diagnosis.

The brainstorming technique was used to analyze the problem related to the long waiting periods of the CDW to be recycled. Brainstorming is a group creativity technique by which efforts are made to reach the greatest number of innovative ideas for a specific problem in a short period of time. However, this tool can be used individually without consuming time to organize a group of people and has been shown to give greater freedom and is easier to achieve compared to group brainstorming. A brainstorming has revealed six potential root causes for the first problem identified:

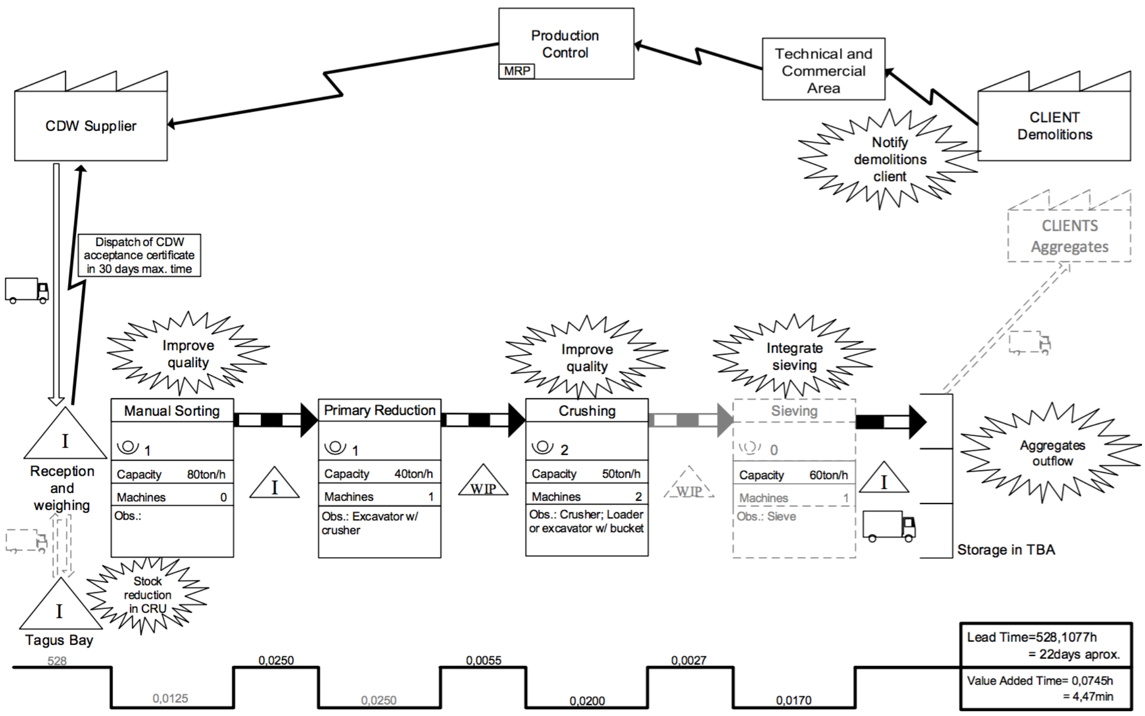

Figure 7 – Current State VSM

1. No control of CDW recycling operations by the contractor/project owner after the residues leave the demolition site;
2. High preparation time of CDW for crushing and sieving activities. The time spent during manual sorting and primary smashing could be reduced if those operations were done during the selective demolition at the demolition site;
3. Reduced number of specialized operators to handle the crusher;
4. Frequent breakdowns of equipment (especially the crusher);
5. Limited number of customers for the recycled aggregates;
6. There is no deadline for Ambisider completing the recycling process after the CDW reception.

To analyze the second and third problems two cause and effect diagrams were constructed. The cause and effect diagram, fishbone or Ishikawa diagram is a schematic tool which lists all the causes and sub-causes that undermine the process or cause the problem. Shaped as a fishbone, this technique enables the simple overview of many causes that can generate the effect or problem under study. Its structure comprises six leading causes related to the material, method, manpower, measures, machine and environment, the sub causes and effect (Werkema, 2006).

The cause and effect diagram related to the second problem in shown in figure 8.

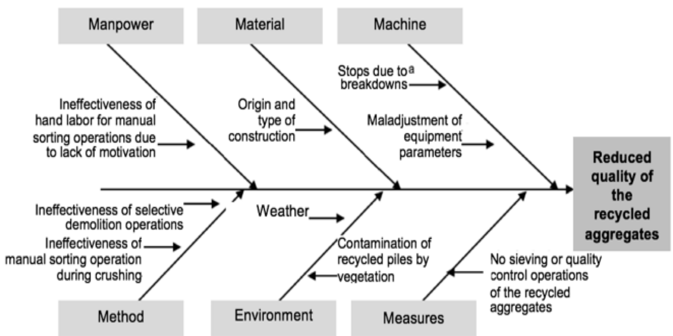

Figure 8 – Cause and Effect Diagram to analyze the reduced quality of recycled aggregates

Related to the manpower, the problem can be related to the ineffectiveness of hand labor during manual sorting activity, leading to a greater contamination of the final product. The material cause has to do with the origin and type of construction which is unavoidable (e.g. Pombaline[2] style structures). The machine category represents the stops due to breakdowns and maladjustments of the crusher parameters in terms of shape and dimension. The method points to ineffectiveness of the selective demolition and building deconstruction which lead to greater mixture of materials and ineffectiveness of manual sorting activities during crushing to extract possible contaminants. Although the CDW are mostly formed by inert materials which are neither chemically nor biologically reactive and will not decompose, the environment can still contribute to the concrete degradation (e.g. bacterial corrosion, carbonization, chlorides and sulfates) decreasing the quality of recycled aggregates. The company does not always perform the sieving phase because it is not required by law, and since there a limited number of customers interested in the aggregates there is no aim to separate them in different grain sizes. As a result, when the potential customers test the chemical and dimension properties, the product is not suitable to their needs.

The third problem was analyzed using the cause and effect diagnosis and it is depicted in figure 9.

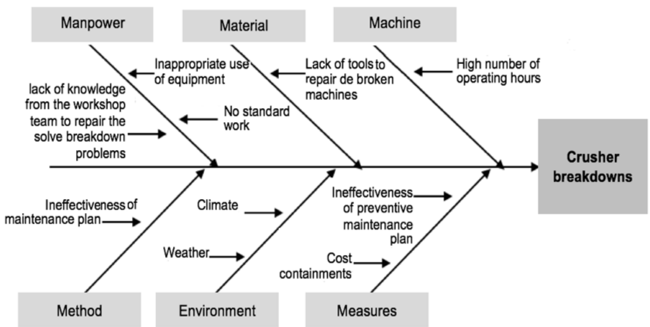

Figure 9 – Cause and effect Diagram to analyze crusher breakdowns

According to the manpower, the crusher breakdowns are frequent leading to greater downtime. In the manpower cause is suggested the lack of knowledge of the repair team to correct the anomalies. Furthermore, the nonexistence of standard work and the inappropriate use of the equipment can contribute to the crusher damages. According to the workshop, the crusher brand has no representation in Portugal, thus there are no specific material or tools available in the intern market to repair the problems. The high number of operation hours contributes to the crusher degradation and increases the probability to breakdown. According to the manual guide is required daily, weekly, 250h and 1000h maintenances. There is the chance of an ineffective maintenance control leading to defects. Despite the environment contributes for crusher breakdowns, the weather and climate still have a small contribution to its degradation. Ambisider has established cost containments despite their need to replace some equipment, especially the crusher. The company encourages preventive maintenance with regular controlling plans.

The fourth problem identified, related to the occasional realization of sieving activity, was analyzed using the 5 whys. This is an iterative interrogative technique by repeating the question "Why?" to determine the root cause of the problem. The "5" whys derives from an empirical observation of the number of iterations typically required to solve the problem. Table 1 shows the problem approach from two points of view: from the main and potential customers' view. The first why, common to both customers, reflects the lack of interest of the company to spend human, time and cost resources in a non-value activity which the main customer is not willing to pay, since the company only

[2] Pombaline style is a Portuguese architectural style of the 18th century which introduced anti-seismic design features by implementing flexible wood structures on the walls.

considers this customer's perspective. However, taking into account the lean principles, it is aim to satisfy every stakeholder involved in the business, thus the potential customers' point of view was taken into account during the application of the five whys technique for the next "Whys?".

On one hand, from the main customers' perspective, there is no interest in separating the final product into different grain sizes since it is not mandatory, although it is advised for a better recycling treatment, according to the Portuguese law. As a result, most of the time the process ends at the crushing stage. On the other hand, from the potential customers' point of view, the sieving phase represents value to the final product in terms of quality. However, the company does not see these customers as an opportunity increase profit and a way to reduce waste and contribute to the environmental sustainability due to reduced sales percentage of recycled aggregates. Although there are potential customers, after analyzing the aggregates characteristics with laboratory tests, the results do not comply with the Portuguese National Laboratory of Civil Engineering (LNEC) specifications. The reasons for that derive from flaws either in the demolition/deconstruction activities or in the recycling process.

Table 1 – Five whys technique for the occasional realization of sieving operations

Problem	Occasional realization of sieving	
1st W	From the standpoint of Ambisider sieving operations mean more human resources available, unnecessary time and cost consuming, adding no value to the company or the main costumer.	
	From the main costumers point of view (demolition/deconstruction costumers)	**From the potential costumers point of view (recycled aggregates costumers)**
2nd W	Because the company considers this an unnecessary step since it does not add value to the main client who pays for the CDW recycling operations.	Because the company considers this an unnecessary step, once there are no customers for recycled aggregates. If there were, the sieves would be used and in accordance with the customer specifications.
3rd W	Because, according to Portuguese law, it is only required the reduction of the waste dimensions. Thus, only sorting, primary reduction and crushing procedures are mandatory while the grains size differentiation is not.	Because the aggregates do not exhibit the desirable properties for the intended field of application.
4th W	-	Because the results of laboratory tests do not meet the technical specifications required by LNEC.
5th W	-	Because there are defects in selective demolition and during the recycling process.

3.5 Improve

Improve phase of LSS Project is the fourth phase. After opportunities for improvement were analyzed, in order to eliminate wastes and seek for lean principles, improvements for each problem were suggested.

Problem 1 – Waiting time of CDW to be recycled

- **More effectiveness during demolition and deconstruction works**

Whenever possible, manual sorting and primary smashing should be done at the demolition site, reducing defects in terms of rework and unnecessary transportations and movements in Ambisider main facility.

- **Advanced preparation of CDW**

As soon as the residues arrive at CRU without compromising other tasks which have greater priority, manual sorting and primary smashing should be carried out even if it is impossible to proceed with crushing. This action reduces the number of operators needed simultaneously for the entire process to occur and reduces the waiting time of the CDW to be crushed and sieved.

- **Set internal goals**

Since Ambisider is governed by green principles and has the mission to protect the environment by reducing the impact of its activity, the company should set internal goals once there are no deadlines for accomplishing the recycling process (e.g. establishing a deadline for recycling a particular amount of CDW).

- **Multitasking and flexible operators**

Educate all operators involved in the process. Only two operators know how to handle the crusher, as a result the process can be compromised. With multitasking operators, flow and flexibility are added to the process.

- **5S**

Implement 5S[3] methodology in CRU, TRSA and TBA. 5S consists in five phases: sort, straighten, shine, standardize and sustain. This is a system used to reduce waste and optimize productivity trough maintaining an orderly workplace (Al-Aomar, 2011). The first step consists in removing all unnecessary items (e.g. containers at the TRSA). The second action is to systematize, which means to put the necessary items in their place and provide easy access avoiding possible constraints. Thus, every machine, equipment, tool and stock needs to be in the correct place. Then the third step implies cleaning the workplace. As the company deals with CDW, a certain level of dust is allowed, however whenever possible watering the area and aggregate piles should be performed to reduce dirtiness in other surrounding areas such as the workshop. Standardize involves creating visual controls and guidelines for keeping the workplace organized, orderly and clean. Sustain, the last step, involves training people, motivating and disciplining them to ensure that everyone follows the 5S standards.

Problem 2 – Reduced quality of the recycled aggregates

- **Improve deconstruction and demolition works**

Educate workers about deconstruction and demolition skills. This will improve those activities leading to a greater amount of reusable material and better waste differentiation which provides better final product (less material contamination).

- **Calibrate the crusher parameters**

By calibrating the crusher parameters according to the potential customers' needs in terms of the aggregates granulometry, properties of the aggregates get closer

[3] 5S it is a workplace organization methodology that uses a list of five Japanese words: *seiri, seiton, seiso, seiketsu, shitsuke.*

to their expectations increasing the potential to commercialize them.

- **Operators motivation**

Involve all employees in the importance of manual sorting before and during crushing, removing most of the contaminants that can jeopardize the aggregates quality.

- **Standard work**

Create guidelines to perform each phase of the process in order to decrease defects or variability to the process.

- **Laboratory tests and pull system**

Execute laboratory tests of the recycled aggregates in order to meet desired properties and provide a better service to the potential customers. If the product quality can be measured, a KPI can be set. Those tests could be achieved by establishing an agreement with universities to promote practical studies for their students with no costs for the company working together as a synergy. By doing so, quality improves and the process turns into a pull system pulled by the recycled aggregates customers.

Problem 3 – Crusher breakdowns

- **Improve repair and maintenance operations**

Give training education to the workshop team in order to have a more effective repair and preventive maintenance service. This will contribute to professional growth and continuous improvement.

- **Improve better use of equipment**

Promote continuous training to employees involved in the crusher operation in order to prevent incorrect uses and ensure their commitment to best practice principles. This can reduce the risk of damage due to misuse.

- **Standardize work**

Create guidelines and standards to guarantee maintenance operations and reduce crusher breakdowns.

- **Invest in new equipment**

If the improvement actions aforementioned do not work and the crusher downtime is considerable, investment in the acquisition of new equipment is suggested. But only if it not compromises financial sustainability of the company in the future.

Problem 4 – Occasional realization of sieving

- **Seek for perfection**

Make an integrated waste management running all the steps underlying the aggregate production process. By including the sieve after the crusher does not increase the number of operators neither the temporary stock and the increase of costs are not substantial. This improvement creates flow and is important in terms of the process quality and avoid future rework in case some potential customer asks for grain size differentiation. Also, the grain sizes should be differentiated according to the market needs. To conclude with, sieving operation should be standardized with guidelines and specifications. This is an integrated approach which seeks for the process perfection. The future VSM state was designed englobing the proposed improvements and it is shown in figure 10.

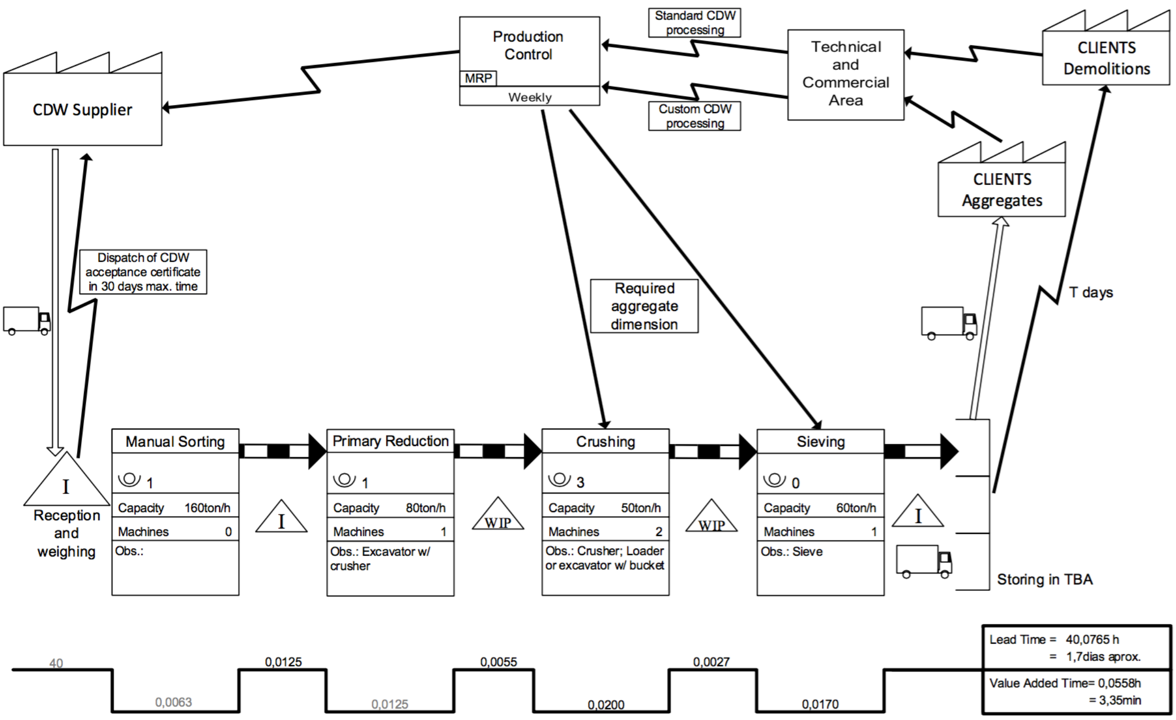

Figure 10 – Future State VSM

3.6 Control

The purpose of this step is to sustain the gains. However, since it was not aimed to implement the improvements proposed, control plans will be proposed as well to monitor the stability of the improvements over time.

- **Visual control**

Create a visual board visible to every employee indicating five main aspects: the company's mission, vision and main goals; lean principles and wastes; KPI with the correspondent values, statistics and graphics; highlight the best employees or areas (CRU, TRSA, TBA) that accomplish the goals and show best results during audits and finally an area for suggestions.

- **Standard work**

Create five standard sheets for the most important phases of the production process: manual sorting, primary smashing, crushing, sieving and storage. These rules will indicate the correct procedures and parameters that should be taken into account to better define each activity. To guarantee the crusher maintenance required by the operation instruction manual, checklists with the guidelines should be used. To register the breakdowns and equipment stops, a control sheet was developed to analyze the waiting time due to breakdowns.

- **Regular intern 5S audit**

A 5S audit form was developed in order to sustain the 5S standards set during the Improvement DMAIC phase. Audits should be done to all areas (CRU, TRSA, workshop area and TBA).

- **Training events**

Create familiarity with Lean and Six Sigma disciplines by training employees to implement improvements and integrate LSS into the company culture. In order to increase effectiveness either in demolition or recycling operations, continuous education in these areas should be given by the company to all employees.

- **Periodic review of KPI**

Control waiting time and inventory levels of CDW; machines downtime and quality parameters of the final product need to be periodically checked and updated.

4. CONCLUSIONS

The present work focuses on the proposal for implementation of lean methodologies in Ambisider, a Portuguese company specialized in building deconstruction and CDW management, with the aim to eliminate lean wastes, increase productivity and production effectiveness so as to become a more competitive and sustainable company. The methodology followed was based on DMAIC method, a structured and organized problem-solving tool as an integral part of six sigma initiative. The study began with a preliminary phase where the action "going and see" took place at the shop floor. This action allowed to truly understand the process and identify immediately some improvement opportunities.

The Define of DMAIC cycle was used to define the problem. Tools such as SIPOC, VOC, VOE and CTQ tree were used to have a high-level view of the process, understand the needs of both market and employees and finally determine the need, quality drivers and performance requirements. The Measure step was the second step which began with the design of the material flow analysis with a spaghetti diagram and after the design of the current VSM with the definition of the suitable KPI. Combining all lean wastes from the preliminary phase and current VSM, the analyze step took place to determine the root causes of variation. The defects were analyzed with the most suitable tool: individual brainstorming technique, cause and effect diagrams or five whys methodology. In the Improve step, opportunities for improvements were described and designed in the future state VSM.

Although the improvements were not implemented, the DMAIC phase was concluded with the Control phase by suggesting ways to sustain the suggested improvements.

In conclusion, the application of a structured and proven process such as the DMAIC cycle enable to understand the problems, find their root causes and effective countermeasures and design suitable results. As a result, the application of lean methodologies within the construction and demolition industries integrated with DMAIC method can be very efficient in obtaining improvements. Therefore, this study has contributed positively to this research area.

Throughout this work, some limitations were found. First of all, as a case study, this work presents some limitations and cannot be generalized to all CDW companies. In this particular study, this company has two types of customers, one at the beginning of the supply chain and other at the end. This makes it difficult specify value from the customers' perspective. However, this study uses a methodology that can be generalized and taken as a reference to other studies that lead with these particular characteristics. Secondly, all DMAIC phases were constructed taking into account the operators and engineers opinions since during this case study it was not possible to "see" the process due to the crusher breakdown. In the third place, there is lack of quantity information on the production plans which limits the detail of VSM in terms of lead and cycle times and value added time.

5. REFERENCES

Al-Aomar, R. (2011). Applying 5S Lean Technology: An Infrastructure for Continuous Process Improvement. *World Academy of Science, Engineering and Technology*, *60*, 1606–1611.

Ambisider. (2013). Relatório e Contas. Exercício de 2013. Retrieved 20-05-2015, from http://www.ambisider.com/

Botelho, M. (2010). *Resíduos de Construção e Demolição*. Lisboa: Verlag Dashofer Editora.

Coelho, A., & Brito, J. (2013). Economic viability analysis of a construction and demolition waste recycling plant in Portugal – part I: location, materials, technology and economic analysis. *Journal of Cleaner Production*, *39*, 338–352. Retrieved from http://doi.org/10.1016/j.jclepro.2012.08.024

Decreto-Lei nº 46/2008 de 12 de Março. Diário da República, nº 51 - 1ª Série. Ministério do Ambiente, do Ordenamento do Território e do Desenvolvimento Regional (2008). Lisboa.

Decreto-Lei nº 73/2011 de 17 de Junho. Diário da República, nº116 - 1ª Série. Ministério do Ambiente e do Ordenamento do Território (2011). Lisboa.

ETC/SCP. (2009). EU as a Recycling Society. Present recycling levels of Municipal Waste and Construction & Demolition Waste in the EU. *European Topic Centre on Resource and Waste Management*, (April), 1 – 73. Retrieved from http://scp.eionet.europa.eu/publications/wp2009_2/wp/WP2009_2

Ferrão, P., & Pinheiro, L. (2011). Plano Nacional de Gestão de Resíduos 2011-2020. Lisboa.

Holweg, M. (2007). The Genealogy of Lean Production. *Journal of Operations Management*, *25*(2), 420–437. Retrieved from http://doi.org/10.1016/j.jom.2006.04.001

Lean Enterprise Institute. (2015). Principles of Lean. Retrieved 01-07-2015, from http://www.lean.org/WhatsLean/Principles.cfm

Lin, C., Frank Chen, F., Wan, H., Min Chen, Y., & Kuriger, G. (2012). Continuous improvement of knowledge management systems using Six Sigma methodology. *Robotics and Computer-Integrated Manufacturing*, *29*(3), 95–103. Retrieved from http://doi.org/10.1016/j.rcim.2012.04.018

Linderman, K., Schroeder, R. G., Zaheer, S., & Choo, A. S. (2003). Six Sigma: A goal-theoretic perspective. *Journal of Operations Management*, *21*(2), 193–203. Retrieved from http://doi.org/10.1016/S0272-6963(02)00087-6

Melton, T. (2005). The Benefits of Lean Manufacturing. *Chemical Engineering Research and Design*, *83*(6), 662–673. Retrieved from http://doi.org/10.1205/cherd.04351

Montgomery, D. C., & Woodall, W. H. (2008). An Overview of Six Sigma. *International Statistical Review*, *76*(3), 329–346. Retrieved from http://doi.org/10.1111/j.1751-5823.2008.00061.x

Paez, O., Dewees, J., Genaidy, A., Tuncel, S., Karwowski, W., & Zurada, J. (2004). The Lean Manufacturing Enterprise: An emerging Sociotechnological System Integration. *Human Factors and Ergonomics In Manufacturing*, *14*(3), 285–306. Retrieved from http://doi.org/10.1002/hfm.10067

Pinto, J. (2009). *Pensamento Lean. A filosofia das organizações vencedoras* (3ª Edição). Lisboa: Lidel.

Shah, R., & Ward, P. T. (2003). Lean manufacturing: context, practice bundles, and performance. *Journal of Operations Management*, *21*(2), 129–149. Retrieved from http://doi.org/10.1016/S0272-6963(02)00108-0

Shah, R., & Ward, P. T. (2003). Lean manufacturing: context, practice bundles, and performance. *Journal of Operations Management*, *21*(2), 129–149. Retrieved from http://doi.org/10.1016/S0272-6963(02)00108-0

Werkema, C. (2006). *Lean Seis Sigma: Introdução às Ferramentas do Lean Manufacturing*. (W. Editora, Ed.). Belo Horizonte.

Womack, J. P., & Jones, D. T. (2003). *Lean Thinking: Banish Waste And Create Wealth In Your Corporation* (2ª ed.). New York: Free Press.

Womack, J. P., Jones, D. T., & Roos, D. (1990). *The Machine that Changed the World*. New York, USA: Harper Collins Publishers.