MFCA and Lean tools application in a production system – Proposal for a simplified approach

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Abstract:

Currently, the pressure to achieve quality products with a lower cost of production and environmental impact is increasing in the industry, which leads to the need to develop tools that sustain management decisions. There are different methods that provide this type of support. In the development of this thesis, a diagnosis was made with the aim of characterizing the current production system, based on the complementarities of MFCA method with Lean management tools. The diagnosis was applied to a case study developed in an industrial company in the metalworking industry. As the main objective of this dissertation was further developed and applied a simplified approach, that allows to combine the concepts of the MFCA methodology and Lean tools in a short period of time. This method seeks to identify the main problems and the root causes that are responsible for an inefficiency and ineffectiveness of the operational and economic of the production system in a simplified way,, and in short period of time comparing with a complete MFCA-Lean analysis. The MFCA is a method that analyses the material flows in physical and monetary quantities of the production system. The results are differentiated in production cost in relation to the final product and waste, thus allowing companies to accurately assess their economic and environmental performance. Lean tool-based analysis allows evaluating the efficiency and operational effectiveness of the production system, focusing on operational wastes occurring during production, enabling the use of problem-solving strategies for continuous improvement.

Keywords: Material Flow Cost Accounting, Lean manufacturing tools, Production Management, Continuous improvement

1. Introduction

For the last years, the environmental concern and worldwide economic instability indicates that the effectiveness of management of both environmental and economic matters is becoming vital for production companies. Manufacturing companies are under pressure to achieve higher productivity with the lowest environmental impact [1]. Accordingly, thought [1] and [2] some methods were developed to increase knowledge about the production system. To support management decisions in terms of production and economic effectiveness, without disregarding environmental issues and production volume. Beneath these conditions the integration of Lean thinking approach with the Material Flow Cost Accounting which is considered one of the major tools of Environmental Management Accounting (EMA) [2].

Material Flow Cost Accounting (MFCA) is an accounting method that allows companies to recognize the physical quantities of material wasted during production revealing the costs associated with these amounts of waste. This method offers to the companies the possibility of identifying material waste sources by enabling them to provide useful information.

Through the application of Lean tools, it is possible to identify other forms of waste, irregularities or productive overloads that cause constraints in the productive system. The ability to evaluate through the application of these tools allows enriching companies' information in relation to other types of waste that occur in production. However, these tools do not relate these wastes with costs, which does not allow to have a full assessment of the production system.

The complementarity in the application of the MFCA with Lean tools allows the interconnection of the capacities of the two diagnoses, thus enabling companies to obtain a single and complete diagnosis (MFCA-Lean) that evaluates the overall of their production system. This evaluation allows the obtention of quality results that reveal the economic and operational reality of the entire production system, though the union of these techniques and their application is long-term and demanding which hinders the process of replication and implementation of improvement measures.

The elaboration of this dissertation aims to propose and analyse the viability of a methodology that integrates the two techniques through a simplified approach and a faster application. However, there is a loss of rigor and detail in the results obtained, even so its application does not disable the analysis of identifying the main problems, nor the sources of waste of the production system. This approach is designated as quick-MFCA-Lean (qMFCA-Lean).

Both analyses were performed as a case study applied on a metalworking industry.

2. Bibliographic research

2.1. Historical development of MFCA

The MFCA arises with the need to respond to the changes imposed by the environmental protection system. The MFCA originated from an environmental management project carried out by a textile company in southern Germany in the late 1980s [3]. The MFCA concept, grown in the late 1990s, based on work developed at the German Institute for Environmental

Management (*Institut für Management und Umwelt*) [4]. In 2007 in Japan, ISO14000 was developed to support the companies in the method application. The ISO aims to standardize the concept and framework for all types of industry no matter the production's size[3], [5]. In 2011, the final and improved version of this standard was published with the designation of ISO14051 [6], [7].

2.2. Principles and fundamentals of MFCA

The MFCA method divides the entire production system into Quantity Centers (QC) i.e., sections or places of the production system. The QCs are the sub-divisions where the material is transformed and/or stored during the manufacturing process. In QCs are input and output of material, these must be quantified in physical measures and then converted into currency units. It is in QC that measurement's resources used occur and where it is possible to make a ratio between positive product and waste [1],[3] and [7]. The MFCA is based on the Mass and Energy Conservation law. Considering this concept, an individual balance should be made at each QC and then validated with an overall balance of the entire production system. MFCA considers the production as a system of material's flow, based on the mass balance. It distinguishes the movement of materials in [7]: (i) Desired material flow – Movement of material that intend to become part of the final product; (ii) Undesired material flow – movement of unintended materials output.

2.3. MFCA application

According to [3] the MFCA application must be considered as a step by step procedure. The procedures considered during the implementation in a production system should be:

1. Selection of the product to analyse;
2. Definition of boundaries and time of analysis;
3. Determination of the quantity centres;
4. Quantification of material and energy flow in physical units;
5. Quantification of the earlier flows in monetary units;
6. Identification of inputs and outputs;
7. Develop of a calculation model which compiles the collected information;
8. Communicate of the results to the company's managers;
9. MFCA summary and interpretation.

Subsequently, any production process requires several types of inputs. The analysis should consider all the costs involved in it. Consequently, the flow cost which must be assigned to the material's flow (physical units) include all costs which can be related or are caused by the material flow [3]. MFCA divides the several types of cost in: i) Material costs, ii) Energy costs, iii) Service costs, iv) Waste management cost. The system costs are related to the task of which QC performs, such as labour cost, operating cost, transportation, or maintenance and excludes the material and energy costs.
The calculation model should be developed by the company contemplating the principles of MFCA method. Thereafter the results must be presented and analysed by the company's managers to seek out improvements that could be implemented on production system.

2.4. Recent activity of combining MFCA and Lean Tools

The production wastes can be in large quantities and are related with the material and system resources [8].
In many industries system and production costs can have a large investment cost, especially in large scale production [2]. Integrating Lean and MFCA concepts into the production system has advantageous effects as it: can assist in improving productivity, resource efficiency and cost reduction, as well as environmental impact [2]. Some studies [2] and [10] suggest that the implementation of the MFCA method and Lean thinking should be focus in three fundamental steps:

1. Distinguish and cut Non-Added Value (NVA) activities through the concept of MUDA by rigorously examining the status of each process;
2. Use the Visual Stream Mapping (VSM) tool in combination with the material flow model - technique present in the MFCA that aims to determine the efficiency and environmental impact of each process present in the flow;
3. Improve the system to achieve continuous flow to maximize material efficiency and consumption and thereby reduce the environmental impact.

The advantages of integrating Lean with MFCA relate to the complete analysis of companies' waste of materials, energy and resources. These considerations are essential for improving a sustainable production because waste is considered in a way that is distinct from traditional waste, that is purely material waste. The insight that Lean offers allows to consider and integrate other types of wastes such as MUDA's in system waste [2].
This integration demands that more types of waste should be considered to implement solutions in compliance with the needs, such as:

1. Reduction of stocks;
2. Reduction of costs;
3. Reduction of rework;
4. Reduction of waste per process;
5. Reduction of production time;
6. Greater knowledge of manufacturing system.

Most of system and energy costs are related with some types of waste, that are mentioned above, and most of them are linked with the quantity of production time needed to finish the manufacturing in each QC [10]. Identifying the costs through MFCA application means numerous benefits from the point of view of evaluating and justifying improvement options developed in conjunction with the Lean analysis [2]
The implementation of a solution that was taken through the MFCA-Lean analysis could result in:

1. Reduction in cost with material;
2. Minimization of the waste with time production leading to a reduction of System and Energy costs;
3. Minimization of the consumption of material per production.

The application of a method such as MFCA with Lean management tools means to an increasing of efficiency in energy and material consumption and to a continuous improvement that lead to a reduction of costs per production [2] and [10].

3. Industrial environment and work's approach

One of the aims of the present work consists in the application and validation based in the literature study of the MFCA-Lean as a diagnostic tool. Subsequently based on this study the main goal of this dissertation entails the development of a method that allows integrate both, MFCA and Lean tools, however in a quicker way. After that, the quick method is applied and validated it the case study.

To achieve the dissertation goals, the work was performed in a metalworking industry, enabling the necessary data collection to perform the MFCA-Lean analysis. Additionally, when the MFCA-Lean is applied, it allows an easy identification of the benefits and the gaps of the integration of both methods, related to production management in a continuous improvement field.

The first phase consists in the application of the MFCA-Lean analysis to a production that follows a Make-To-Order strategy. A careful observation of the production system was performed as the data for MFCA and Lean analysis was gathered. This detailed analysis evidences the existence of some production problems that were only possible to identify using both methods of diagnosis. Subsequently, a study of similarities, benefits and gaps of this analysis was made, to access the viability of the development of a new method that leads to a similar result without the same level of precision and in a shorter period of time. Thereafter, a method that integrates MFCA and Lean tools on a quick version is developed, proposed, and tested. This method aims to keep the advantages of the MFCA-Lean analysis but turning into a quick tool for all types of industries. This tool results in MFCA mapping cost flows based on a detailed data gathering. On the other hand, the Lean tools which adds significant information about the efficiency of the production system and enables to have a specific tool for root-cause, and problem-solving analysis.

3.1. MFCA-Lean analysis application

The MFCA-Lean is applied to a production system which follows a make to order (MTO) strategy to appraise its current economic efficacy. This analysis is based on two methodologies, first method is MFCA and second is related with Lean management tools.

3.1.1. Case-Study characterization

In the first phase of this analysis according with [3] it was necessary to make a characterization of the production system in order to know the reality of the company. This characterization allows to define:

1. Which areas, processes, products, or procedures should be part of the analysis;
2. What is the period for data gathering and data analysis;
3. Determination of the quantity centre.

The product studied is entirely produced by the company, through the system characterization, the boundary and the limits of the manufacturing process that was defined. The product selection was based on its economic significance for the company. The analyzed product is divided into four components that were produced independently, only the budgeted quantities of components were produced in order to avoid stock accumulation.

Table 1-Characteristics of production's components

Product components	Material	Weigh [kg]
A	Aluminium	6,6
B	Aluminium	6,1
C	Aluminium	13,2
D	Aluminium	0,3

The analysis period was defined as the total production time of the selected product. This period allows the collection of reliable data, enabling the identification of the production's problems, as well as the comparison with company data. Once the limits and the period of the analysis are defined, the following step is defining the QC.

The ISO's 14051 [3] intent is to divide the production system into processes or parts that have a significant contribution, if this does not happen the process can be included in another QC. In every QC the material can be transformed, stored or stay on hold for the next QC. This analysis includes the identification and characterization of all production's activities, as well as the material movements that occur during the manufacturing process.

3.1.2. Material and Costs flows quantification

After the definition of the QCs, it is necessary to quantify the inputs and outputs of the system. The inputs should be divided between material and energy, and outputs between product and waste. However, this case-study will only consider the amount of material in the inputs of each QC, because the company does not have the necessary information regarding the amount of energy supplied in each QC. To quantify the material, the following steps were followed:

- Classification of all material involved in production;
- Data collection and material quantification in physical units.

In the present production system inputs have only one type of material which is used to produce the entire production. This material follows the entire production system and no other raw material is added to it. However, there are some auxiliary materials used during the production in some specific QC, however the quantities and the costs of it were neglected.

The quantification of input and output material should be made in physical units, in which case the raw material will be quantified in kilograms (Kg). It was necessary to consult the planning of material use that was approved by the preparation for production, so it was possible to obtain the volume of material used in the whole production. By measuring the volume, it is possible to obtain the mass of the material used. Thereafter, a mass balance within each QC and in the total production must be performed to confirm all the compiled information. The material input of each quantity centre and its inventory must be equal to the output, in terms of product and waste. Consequently, all cost that are associated or generated by the material flow must be distributed to the respective output flow.

Costs Quantification:

The material quantification in monetary units is calculated based on the amount of material and its cost per kilo. The system costs are the sum of the employees cost, the space cost, and the equipment cost. The employees and operation's cost are calculated individually per QC and it is based on the time that each employee spends performing each activity. Then, the space cost is calculated based on the space required to perform each activity and the respective rent cost. The company does not have the necessary information regarding the amount of energy consumed consequently the energy costs are neglected in this case study.

Allocation output:

The system costs are allocated to the material costs, i.e. the system costs in each quantity is quantified in monetary units and is assigned to the output flows in the proportion of the mass ratio between the products and the material losses.

3.1.3.Calculation model

The calculation model used in this case-study is based on the MFCA calculation model, this model organizes all the information previously calculated and exports the results as flow costs or cost matrix. This model should include all the resources used and the respective costs to assess the economic performance of the production system.

3.1.4.Lean Approach

The Lean analysis allowed to evaluate the efficiency of the same production system analyzed by the MFCA. This study is based on Lean visual process management tools and according with VSM logic. During the production it was carried out a task characterization that allows to distinguish the time that is assigned to NVA activities from the added value (AV) activities in each QC. Then a comparison is performed with the company records to verify the viability of the analysis.

3.2. MFCA-Lean analysis results

When the calculation model is completed it is possible to map a flow of quantities and costs of material. Through these flows it is possible to verify in which QCs were responsible for the emergence of wastes. From the analysis of the quantities flow map is achievable to analyze the efficiency of material consumption during the production.

Table 2-Material allocation

Total[kg]	Product[kg]	Product	Waste [kg]	Waste	Stock [kg]	Stock
425	279	65,6%	77	18,1%	69	16,2%

On the cost matrix, it is demonstrated which QC has the highest waste cost contribution during production. It is possible to check that in QC- "Corte por serrate" has 220€ of waste costs and 170,5€ of stock costs which represents 19% and 15% of the total invested in this QC. In a macro perspective it is possible to realize that the product has the value of 2098,99€ which represents 77% of the total invested in production, the remaining amount represents the value that is aggregated to the material that is in stock and to wasted material.

Moreover, it is analyzed and distributed the contribution of which type of cost.

The costs related with materials are 55% and the remaining 45% are related with system costs. The material cost occurs uniquely when the company purchases the raw material, for this reason the results focus on service costs. System costs differ from employee costs, and cost per operation has the greatest impact with weights of 35% and 9%, with the remaining 1% costs associated to space of each QC. Through the cost analysis in each QC it is possible to observe that the QC with higher system costs are the QC of "Soldadura" and "Serralharia". According to the cost flow and cost matrix analysis, an appreciation of the material throughout the production is identified.

Through the analysis of the mass flow it is possible to identify which QC has highest contribution to waste cost. In Figure 1 it is possible to observe that in this production system only the QCs "Plasma", "Serrote" and "Serralharia" has material waste. The first QC has the highest contribution to waste costs, because these QCs are where the material is cut, and this means the higher the quantity of material cut the higher will be the costs with waste.

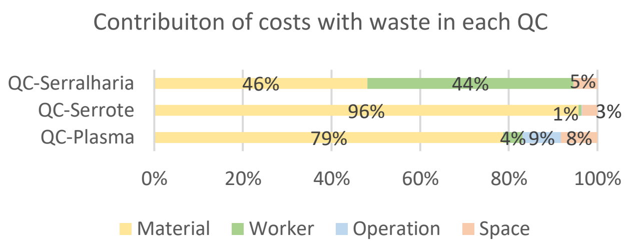

Figure 1-Contribuiton of costs with waste in each QC

Other source of waste identified is related with system resources. Only with a constant observation of the production and a characterization of the activities in each QC was possible to identify other sources of waste. The Figure 2 illustrates through a Yamazumi chart the results of the efficiency evaluation in each QC it is possible to understand that the QC- "Serralharia" has the worst performance of all QCs. Has 54% of the time production related with tasks with NVA N thus 38% are related to the task "marcação e medição" which is crucial to this QC. It is possible to concluded that this QC could be improved in 33% of his time production.

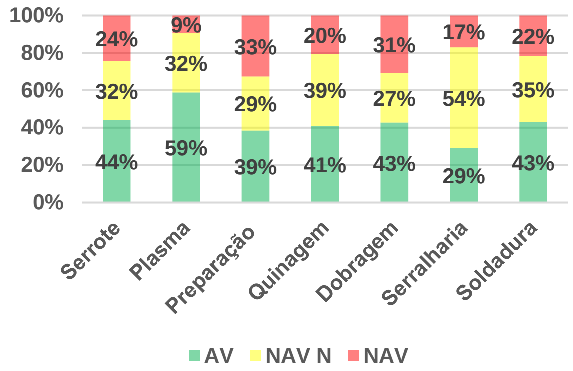

Figure 2-Yamazumi charts of each QC

By relating efficency analysis to cost analysis, it is possible to identify the cost associated with the tasks performed during production. The cost associated with NVA and NVA N activities is 285,98€ and 444,55€. The sum of this two, adding the value with cost with space of work-in-progress represents 62% of the total invested as system cost, which mean that only 38% of the invested as system cost is added value to the product.

It is concluded by combining MFCA and Lean management tools that is possible to achieve a more detailed view of the reality of the production system, combining an efficiency analysis with a cost analysis. Although this type of combination is advantageous, it is difficult to apply as it is a complex study. The application of this analysis needs a strong coordination of the various company sectors and a precise definition of the study boundaries. This type of analysis requires a very long-time interval.

Completed the analysis the benefits and limitations of the combination the two methodologies are evident. In Table 3-Benefits and limitations of MFCA-Lean analysis is demonstrated a brief conclusion about the application of this type of analysis.

Table 3-Benefits and limitations of MFCA-Lean analysis

MFCA-*Lean Analysis*
Benefits
• Evaluate the efficiency of each process: evaluate the productivity associated with production costs.
• Identify the amounts of material, system and energy waste; and a description of the costs involved.
• Analyse the waste of production time associated with NVA activities, and identify the costs added to those waste.
• Identify problems in the production flow, such as the existence of bottlenecks.
• Have a correct knowledge of the value of the product and its valuation at each stage of the production system.
• Analyse the actual status of production system.
• Through the accounting method of this analysis it is possible to have support in the various decisions for the implementation of solutions.
Limitations
• Extensive analysis and requires gathering meaningful information over a long time.
• Having a lot of data leads to a longer analysis time.
• Coordination of various sectors of the company to gather the best collection of data.
• Availability of company data for analysis.

4. Solution and improvement estimation of problems identified

From the analysis performed it was possible to conclude the root causes of problems found in the production system. In Table 4 a brief summary is presented of the root causes of the problems identified, and some measures of continuous improvement that could be implemented to minimize the limitations of production system.

Table 4-Summary of problems identified and improvements measures

Problems	Root causes	Improvements
Delay between process	•Ineffective productive planning;	• Creation of start-up mechanisms - minimize waiting times; •Redefinition of posts; •Centralization of consumables and utensils, reorganization of materials warehouse; • Layout redefinition; •Creation of map of works in progress and pipelines of works on hold - Definition of planning logic; •Daily / weekly meetings - Definition of the productive management logic; •Change of supplier or design of raw material. •Application of 5S tools to erase waste
Manufacturing operations performed at unsuitable stations	•Ineffective productive planning; •Unavailability of stations - productive overload; •Insufficient human resources;	
Rework and loop of material in production	•Inefficient layout configuration; •Insufficient of material completed by station; •No definition of productive flow; •Ineffective productive planning;	
Inefficiency of process	• Too much time spent NVA and NVA N activities); •Disorder of the stations on the shop floor; •Type of productive tasks (manual); • No tools required per workstation; •Ineffective productive planning.	
Wastes of material	• Quantity and design of order raw material - Supplier.	
High system cost in some QC	•Ineffective productive planning; •Shortage of human resources	

It is predicted that with a layout redefining measures and the promotion of production operation by a pull system, it will be possible to create new workspaces for new QCs.

Redefining layout coupled with a reorganization of existing material warehouse, as well as a redefinition of planning and productive management logic with the help of visual management elements, can reduce costs and the productive time of NVA activities about 36%. Which translates into a reduction of 103 € and 142 minutes, respectively.

The decision to change supplier or design of raw material is estimated to result in a 13% reduction in wasted material and stock which is a cost reduction of 212 €.

5. Quick-MFCA-Lean

The main aim of this dissertation is to develop a simplified approach of a MFCA-Lean diagnostic method designed to evaluate the production system. The results allow the identification of the critical points of the production and also serve as support for the implementation of improvement measures, implying a reduction of the effort of all involved in the diagnosis, and in a short period of time.

5.1. Quick-MFCA-Lean methodology development

The proposed methodology aims to create a rapid diagnostic method that use the complementarities of MFCA methodology with Lean tools, in order to obtain a quick and approximated analysis of the production system.

The application of this methodology should be performed by a team that has knowledge of the concepts MFCA and Lean. To meet certain criteria that allow a valid diagnosis to be obtained and that corresponds to the productive reality of the company. These criteria are as follows:

- Knowledge of the method and its capabilities;
- Collaboration between the company departments and the team that performs the diagnosis;
- Characterization of the productive system;
- Characterization of productive tasks;
- Measurement and data collection of QCs that are included in the defined production system;
- A careful analysis of the collected data.

To obtain a reliable diagnosis, the necessary criteria for the method must be fulfilled and the steps that constitute the quick-MFCA-Lean method must be followed. These are as follows:

- ➢ Definition of objectives and limits of the analysis;
- ➢ Methodology application and data collection;
- ➢ Process mapping and construction of accounting and performance model;
- ➢ Results analysis - Comparative analysis of analysis results.

The diagnosis ends as soon as the result analysis is performed. After this analysis conclusions are drawn the planning of implementation of corrective measures and improvement of the productive system begins.

After the implementation of improvement solutions, the method steps should be redone to revaluate the production system and, if necessary, to apply new complementary corrective measures in order to achieve the desired goals. Consequently, a new cycle of improvement begins focusing on continuous improvement of production incrementally, for this type of results the application of the PDCA cycle is fundamental.

5.2. Scope and boundaries definition

This definition is fundamental for the realization of this type of diagnosis, since this definition influences the duration of the analysis, the number of QC to be evaluated, the number of observations made, the periodicity of information collection from the shop floor as well as the planning for conducting the analysis. The definition of this goals in accord to the company's strategic planning is the first step in applying the method.

The company must also define where the method is applied, i.e. define the limits of the analysis for example: a QC, a production line, a specific production of a product or the entire production system.

5.3. Method application and data gathering

In the proposed method, the sequence of steps referred in the MFCA method is respected, however, there are intermediate steps that allow a synergy between them. The suggested steps for the proposed method are as follows:

- ➢ Involvement of company management areas
- ➢ Product system characterization
- ➢ QC definition
- ➢ Identification of inputs and outputs in each QC and characterization of operations performed during production.
- ➢ Quantification of energy and material flows in physical units and data collection on efficiency in each QC.
- ➢ Quantification of the costs related with the productive activity (mass and energy flux and tasks related to production).

The suggested way to collect data used to perform this analysis is presented in Table 5.

Table 5-Examples of the type and conducts of data collection from a production system

	Type of data	Technique suggested
MFCA	• Material quantity [kg] • Energy consumed quantity [kw] • Production time in each QC [h] • Material Cost [€/kg] • Energy Cost [€/kw] • System Costs: ○ Cost per worker [€/h] ○ Operation Cost [€/h] • Others	• If the company does not present a record of material or energy consumption, it is suggested to make a QC survey of the quantities of: ○ Material through volume measurements ○ Power consumption Reading • Observations on shop floor: ○ Estimate by measuring the volume of 5 to 10 components, the amount of material entering the QC and leaving.
Lean	• Production operations time [h or min]	• Observations on shop floor: ○ Observation and measurement between 10 to 30 productive

	• *Setups* and *changeovers time* [h or min] • Delay's time [h or min] • Number of delays • Others	cycles, if operations last a few seconds, the observation should be 1 hour per QC ○ Observation and measurement of 2 to 3 times of the changeover or setup change period. ○ Observation and quantification of waiting units or projects, minimum 1 time and if possible, repeat the observation 3 to 4 times over the analysis period. ○ Organizational observation of each QC, minimum 2 times during the analysis period. • Informal interviews with each employee involved in the productive system under analysis.

5.4. Process mapping and construction of accounting and efficiency model

The calculations were performed by combining the typical MFCA calculation model, with the characterization of the productive tasks and their productive time value.

For the elaboration of the calculation model the following procedures are suggested:

1. Material

a. Convert material quantities to currency units and add them as input to the 1st QC;

b. Distinguish input and output material costs in each QC according to the proportion of product quantity or waste obtained;

c. Calculate the ratio between product and waste;

d. Identify and calculate costs of auxiliary materials and assign them to each QC.

2. Energy

a. Calculate the energy cost consumed by each QC;

b. Allocation of the energy costs of each QC according to the ratio between products and waste.

3. System

a. Calculate the cost per worker in each QC;

b. Calculate the cost of space dedicated in each QC;

c. Calculate the cost of operation in each QC;

d. Allocate the system costs of each QC according to the ratio between product and waste.

4. Calculate the cost of waste and product.

5. Calculate the costs related with each QC efficiency.

a. Calculate the ratio of production time and the different types of tasks (AV, NAV, NAV needed);

b. Calculate the costs of each type of task in respectively QC.

Following this procedure, we obtain the cost and efficiency matrix associated with each QC. Repeating this procedure for all QCs it is possible to obtain the total cost matrix, and the overall efficiency of the production system under analysis.

Table 6-Exemple of a cost and efficiency matrix of a QC

QC - A					
			Per Production		
Input		Previous QC	- €		%
	New input	Material	- €	%	%
		Energy	- €	%	
		System	- €	%	
Output		Product	- €		%
		Waste	- €		%
Productive time			0,00 h		
NAV			0,00 h	- €	%
NAV N			0,00 h	- €	%
AV			0,00 h	- €	%

5.5. Analysis and results display

Through the diagnosis it is possible to extract several results that allow many conclusions. The way results are exposed is also a fundamental way of displaying the problems identified in the production system. So, a dashboard is suggested with all the information related with the analysis and the problems that were identified. The results presented in the dashboard are intended to demonstrate the quantities of material used, the amounts wasted, all costs involved in production, a summary of the allocation of production costs, the ratio of non-material costs in each QC, the valuation of the product over its lifetime production, efficiencies in the different QC through which production had to pass, and the number of wait occurrences and their causes found on the shop floor.

From the analysis of the results obtained through the procedure previously discussed, the analyst or the team responsible for the realization of the diagnosis can follow several strategies to interpret the results. The strategy suggested in this thesis is as it follows:

- ➢ Identify that QC with the highest associated costs even if they are not mainly related to waste;
- ➢ Identify that QC where the costs associated with NAV and NVA N tasks are high;
- ➢ Identify which QC with the highest cost of waste;
- ➢ Identify among which QC occurs a higher number of waits.

6. Quick-MFCA-Lean application

This section intends to present the application of the qMFCA-Lean approach, to a productive context. To identify its viability as a diagnostic method. The case study was developed during the production process in a metalworking industry

6.1. Definition of objectives and limits of analysis

The first stage of this diagnostic methodology is the definition of the objectives and limits of the analysis. This task is the responsibility of the company, which defined as the main objective the identification of material waste or human resources with the focus on its reduction. In order to achieve an increase in production profitability.

The parameters and limits of the analysis were then defined. It was identified the type of works that were relevant to be analyzed, according to the impact that their production has on the company. When the target of the analysis was found, it was immediately characterized the production system that begins in the processing of the raw material and ends with the delivery of the product to the customer.

6.2. Product and production system description

The type of works covered in this new case of study is once again a work produced exclusively in aluminum, it can still be subclassified as heavy beam this type of work is produced with relative frequency by the company. The entire production process runs within the company.

In the case study now under analysis, there are some differences regarding the processes involved in the production. These differences are found in the cutting QCs by guillotine and assembly that are not part of the production system previously analyzed. Otherwise the tube bending and plasma cutting stations are not inserted in this new system.

The processing of material starts in the cutting QC ("Serrote" and "Guilhotina"), then the material from the guillotine is folded at the "Quinagem" QC followed by the "Preparação" QC. The material coming from the "QC-Serrote" had already begun its transformation at this "QC-Preparação". As soon as the material is worked by the "QC-Preparação"., it goes to the "QC-Serralharia".

Once the operations carried out at the "QC-Serralharia" have been completed, the material goes to the "QC-Soldadura" where the component union is performed. After completing this process, the assembly of all constituent components of the product is started, and after the assembly operations are completed the product is available for delivery to the customer.

6.3. Quantification and data collection

In order to perform the analysis, it was necessary to obtain in detail all the available information of the production of a complete work, similar to the production of a work to be carried out during the same period of analysis. Figure 3 illustrates the mass flow model where inputs and outputs are identified and the distinction between material flows corresponding to the product, waste or stock. It is also possible to identify the definition of QC's.

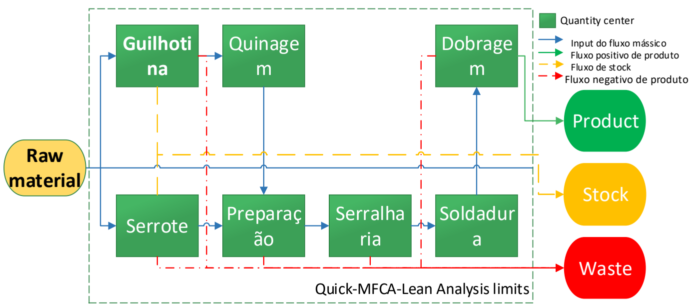

Figure 3-Material flow model

Once the inputs and outputs are defined in each QC, it is necessary to quantify them in physical units. In this case of study only 2 parameters were identified: material and system.

The quantities of material required for production were obtained through the planning designed by the company's production preparation department. The quantities wasted or stored in stock were measured in each QC.

The time dedicated by each employee and each operation corresponds to the system parameter. Obtained in each QC through production records.

For the efficiency analysis component, observations were made to the productive workstations of the productive system, in order to know all the operations performed in each of them. Once these operations are known, similar to what was done in the previous case study the tasks performed were characterized in: NVA, NVA N, and AV activities. Each QC of the productive system was observed during 1 hour through the timing method. In this way it was possible to obtain the times dedicated to each task of each QC, and thus obtain an approximation of the total productive time, in each QC during the production of the work under study.

The method of quantification of unitary units of material, followed was identic as followed in the previous case study. Similarly, to the process of quantifying the material, the method of quantifying costs is identical to the one that was used before. Information on the productive tasks of each QC was collected in the timekeeping observations. The duration of these observations was 1 hour per QC, thus allowing to associate the results of this observation with the total time in each QC in order to obtain an approximation to the productive reality.

6.4. Data processing

The quantification of the material flow in physical units, the conversion to material costs and the previous calculation of the remaining production costs per QC gathers all the conditions to initiate the processing of data in order to draw conclusions about the current productive system.

The following procedures were used for the development of the costing model of each QC:

1. Calculation of the costs of the material which will be considered the QC input according to the mass balance. For the first cutting QCs, the entry costs considered are the costs with the raw material;

2. Calculation of the system costs allocated according to the QC in the analysis;

3. Calculation of the relationship between the products and the waste in order to allocate a proportion to the resources used;

4. Cost allocation of the QC system based on the previously calculated reason;

5. Calculation of the output values of QC in analysis divided into product and residues;

6. Calculation of efficiency related with costs in each QC.

To obtain a complete analysis of the production system, these procedures should be performed for all QCs of the productive flow that constitute the case study. This analysis can be illustrated according to a cost flow, throughout the entire production process or, through a cost matrix where all analyses are compiled in an individual form of cost and efficiency of each QC.

6.5. Analyze results

By conducting a detailed analysis of the results obtained, it is possible to construct a dashboard that illustrates the productive reality found. In this way it is possible to present a series of results and problems that help outline the best action plan on the part of the continuous Improvement team.

Analyzing the results individually it can be obtained through the elaboration of a cost map of the identification of the QC that is most contributed to waste and stock costs. The QC that most contributes to the costs associated with the stock is the QC responsible for the initial cutting of raw materials, and simultaneously the QCs that most contributes to the waste of material.

According to the data provided by the company it was possible to create a map of mass flow according to production in analysis. In this map it is possible to observe the unit quantities of material that were initially requested by the production department in order to start production. It is possible to identify in which QCs occur waste, storage of material, and even their quantities. Through the mass balance it is possible to conclude the quantities of material that remain in production and which quantities are part of the final product. It is verifiable that a huge quantity of raw material in the form of sheet metal is required for this production and in large quantity. 60% of this same quantity was not used, consequently being in stock. Thus, contributing to a poor efficiency of consumed material.

Once all the costs involved on the production in analysis have been identified, as represented in the cost flow mapping, it is possible to distinguish the way in which each parameter influences the increase in production costs. As illustrated in Figure 4, it is represented as a percentage, the contribution of each cost to the total cost value in each QC. For example, the costs in “QC-Serrote”, had a weight of 87% with respect to the material, 10% with the cost of the worker and 3% with the cost of operation.

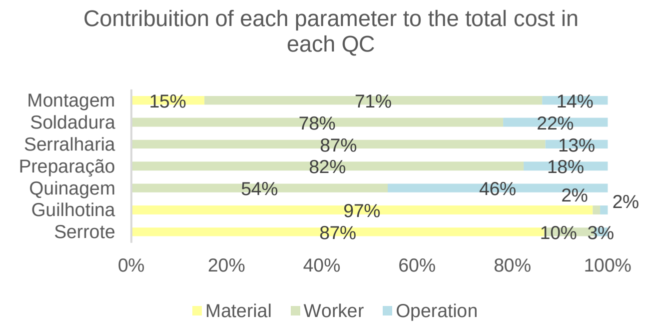

Figure 4- Contribution of each parameter for the total cost in each QC

In Figure 5 it is illustrated the evolution of the value of the product throughout the production system, it was found that the highest growth occurred at the “QC-Serralharia” corresponding to a valuation of 23%, to note that the final value of the product reached the 8,48 €/kg.

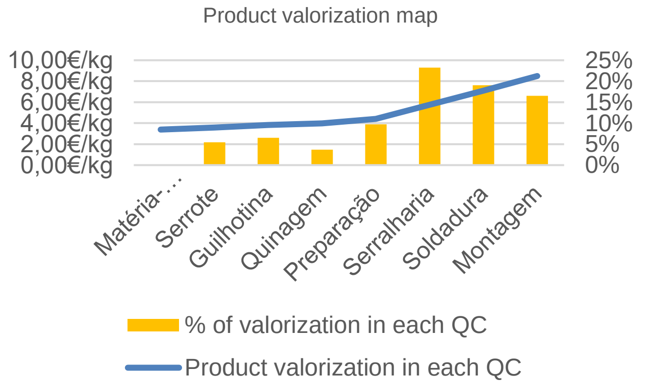

Figure 5-Material appreciation map

Once known and characterized the production system it is possible to construct a map according to the logic VSM which, allows to relate the total time dedicated in each QC with the performance found in each. The construction of this map allowed to show clearly in which positions of production occur delays, and the duration of the same. It also allows to obtain an evaluation of the productive lead time that considers only the efficiency of the productive time and an evaluation of the total lead time of the work, where the waits are considered.

6.6. Analysis conclusion

The application of the qMFCA-Lean methodology as a diagnostic tool made it possible to identify and distinguish the quantities of material used in the production of wasted quantities, relating them to the costs associated with production. The analysis focused on the identification of the sources of waste in production of material and temporal its origin, as well as the existence of other productive problems.

The simplicity and quickness that characterizes the diagnosis proves to be beneficial for the company because it allows to obtain knowledge on the level of waste with the material as well as the awareness of the cost of waste in NAV activities to the final product, quickly promoting a larger period for taking improvement measures. However, the accuracy of the information collected is lower than that of a complete and more detailed analysis, which can increase the margin of error of the results achieved. Thus, enabling the emergence of false positives regarding the performance efficiency evaluation of the production system. Through a comparative analysis of the diagnoses it is possible to understand the differences in the detail and accuracy of the results. In Table 7 it is illustrated a brief synthesis of problems found in both diagnoses. A comparison of the results obtained in both analysis evidences that the qMFCA-Lean analysis allows to identify the main problems of the productive system, although without the same detail and rigor that a complete analysis would allow.

Table 7-Problems identified in each diagnosis

MFCA-Lean	qMFCA-Lean
Problems	**Problems**
Wastes of material	Wastes of material
Inefficiency of QC	Inefficiency of QC
High system cost in some QC	High system cost in some QC
Delay between QC	Delay between QC
Manufacturing operations performed at unsuitable QC	
Rework and loop of material in production	

These results are due to the fact that the company is the same in both studies, which allows the conclusion that the quick methodology can be used in alterative to the most complete methods although losing quality in the results, allows to identify the main problems of the production system.

7. Conclusions

The application of a MFCA-Lean diagnosis enables companies to obtain a complete diagnosis through the complementarity of the two methods. The full analysis gives rise to a significant load on the collection of information and data, and availability for observations of the production system, which means that it is necessary to gather several factors to carry out this analysis making it a long-term diagnosis. This dissertation aims to propose a simplified approach to a MFCA-Lean diagnosis, maintaining the ability to analyze the production system, but in a simplified and brief way. Although the brevity of this method means loss of detail in the results achieved, there is no loss of identification capacity of the main productive problems. This new method designated as qMFCA-Lean allows through its application to shorten the period of data collection, while maintaining the capacity to evaluate and support the decision-making to implement improvement measures.

A series of procedures and suggestions were developed in order to guide and facilitate the application of the qMFCA-Lean method as well as the analysis of results. The development of this simplified approach followed the logic of the complete MFCA-Lean analysis aiming to maintain the complementarity of the methods. In order to make it possible and to decrease the analysis time, a set of changes were made in the format as the data were acquired, the duration of the observation period in each QC was reduced. The data extracted from this observation, as it is not the total time dedicated in each QC, is an estimate that was applied in order to obtain an approximate characterization of the total time dedicated in each, allowing to obtain approximate data from the total work. The simplified analysis obtained by compiling the data of all QC makes it possible to recognize superficially the production system analyzed, allowing to conclude where the highest waste, inefficiencies and other productive problems occur, as well as associated costs. Although the results achieved do not have the same level of detail as the results of a MFCA-Lean as, they still allow to identify the critical aspects that occur during production and that contribute to an increased waste and inefficiencies, and consequently an increase of production costs. This tool also enables the implementation and control of improvement measures.

The implementation of the qMFCA-Lean method allows to identify the main problems associated with the production observed in the case of study. These problems are related to the substantial amounts of wasted material, the high inefficiencies of some QC activities, high system costs in some QC and the delays between QC. As expected through the complete diagnosis MFCA-Lean, it was possible to additionally identify two problems: operations performed in inadequate QC and the occurrence of rework and loop of material in production. The amount of root causes found just as their detail differs equally to identifying productive problems. In this way the qMFCA-Lean method can act as a quick alternative to most complete diagnosis, as it allows to obtain a set of useful indications that allow you to start the process of change and improvement, even without the depth and detail of a complete analysis.

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