*IOSR Journal of Business and Management (IOSR-JBM)*
*e-ISSN: 2278-487X, p-ISSN: 2319-7668. Volume 23, Issue 5. Ser. III (May 2021), PP 56-71*
*www.iosrjournals.org*

# Management Culture
# The Integration of Lean Tools and Process Flow Cost Recording

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***Abstract***
***Objective:*** *The process flow cost recording is a precise method which asses the economic and environmental performance of the company, evaluating the physical flows in monetary units and presenting the results in terms of costs of the product itself and the waste. The Lean philosophy analyses, mainly, the physical flows and physical waste. Its methods/tools allow the diagnosis of different systems and uses problem solving strategies towards continuous improving. This study aims to integrate both methods considering their complementarities aspects.*
***Methodology:*** *This context motivated the proposal of a methodology which integrates the process flow cost recording and Lean management tools, taking advantage of their complementarities.*
***Findings:*** *Based on the root-cause information of the critical KPIs (Setup time) a problem-solving solution was applied, and its improvement results analysed. Firstly, a Gemba Walk was performed focused in the Injection Machine [where the Set-up occurs]. Then the Set-up process was observed and some wastes of the time were identified. Based on that identification, two different tools were applied, the 5S and SMED.*
***Value Added:*** *The industrial sector is under an increasing pressure to achieve quality products with the lowest possible cost and environmental impacts, leading to the necessity of developing methods to support management decision.*
***Recommendations:*** *This integration based on steps procedure allows the accomplishment of aimed results directly aligned with company's objective and scope. Process Flow Cost Recording-Lean methodology is able to present the real state of the production system in monetary units for manager's encouragement to re-evaluate their strategy and provide tools to recognise root-causes, support and improve employees' activities guiding efficiently their work. This methodology should be implemented as a continuous improvement cycle so the production process moves closer to the ideal optimized process.*
***Keywords:*** *Lean Management, Process Flow Cost Recording, Production Management, Continuous Improvement, Cost Structure.*
***JEL codes:*** *L11, L23, L25, M11, M41*

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Date of Submission: 06-05-2021 Date of Acceptance: 20-05-2021

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## I. Introduction

Nowadays, a modern, competitive and environmental concerned society is pressuring companies to achieve higher productivities with the lowest possible environmental impact (Kokubu & Tachikawa, 2013).

Thus, few alternative methods have emerged, to support management decisions in terms of economic performances and, simultaneously, considering the environmental impact and production volumes (Kokubu & Tachikawa, 2013), (Sygulla, Bierer & Götze, 2011).

Under the current circumstances, the Process Flow Cost Recording (PFCR) is considered as one of the main tools for Environmental Management Accounting (EMA) (Kokubu & Tachikawa, 2013).

Process Flow Cost Recording, according to ISO standard 14051 (2011), is a management tool fostering the transparency of energy and process flows and Time Driven Activity Based Costing (Kaplan & Anderson, 2007).

This method has been developed to support industrial companies to increase the efficiency of Business Processes and to support management decisions by presenting the effective value of the company's waste.

Lean Management is recognised as a solution for waste elimination. Its main goal is the identification and elimination of several types of waste allowing companies to achieve an efficient customer demand (Spear, 2019).

Firstly, Process Flow Cost Recording methodology is applied to an injection moulding system in a Portuguese company. Then, to support the hypothesis of integration, the Process Flow Cost Recording and Lean management complementarities and gaps are primarily observed to identify improvement opportunities in manufacturing system during the Process Flow Cost Recording application.

Further, to support the hypothesis of integrate Process Flow Cost Recording and Lean tools, their complementarities aspects and gaps of knowledge are studied based on scientific literature. Thereafter, a methodology to integrate PFCR and Lean management, is presented and preliminarily validated with a case study.

## II. Literature Review

The Process Flow Cost Recording is characterized for being a flow orientated accounting method that traces and quantifies in physical and monetary units all the material and energy flows. Furthermore, it compares the costs associated to the products and the material losses (Kokubu & Tachikawa, 2013). Once, the cost of waste is visible, it can drive managers to re-plan their strategy.

As soon as their strategy is implemented, the resources reduction can be achieved and consequently a reduction of the overall production cost and environmental impact (Schmidt & Götze, 2015). Thus, PFCR aims to support companies to enhance its environmental and economic performance through the reduction of resources usage (Christ & Burrit, 2016).

The original concept of the Process Flow Cost Recording was been developed in 2004 at "Harvard Business School", USA. Posterior few pilot projects were initialised in the world industry. Nevertheless, the first breakthrough of Process Flow Cost Recording was accomplished in Japan, by Toyota.

Due to the successful results of the first implementations the methodology was enhanced and published in September 2011 as ISO14051 included in Material Flow Cost Accounting procedures (Sygulla, Bierer & Götze, 2011), (Guenther, Jasch, Schmidt, Wagner & Lig, 2015).

### 2.1. Principles and Fundamentals of Process Flow Cost Recording

The Process Flow Cost Recording method divides the entire production system into Quantity Centres (QC). The QCs are parts or sub-divisions of the manufacturing system where the inputs and outputs must be quantified in physical and further in monetary units. Usually, these areas correspond to places where materials are transformed, or stocked (Kaplan & Anderson, 2007).

The QC is the starting point for data collection in physical units in terms of resources measurements. The base concept of the Process Flow Cost Recording, is the conservation law of material and energy.

Considering this principle, and to guarantee that all the flows are accounted, a mass balance should be performed to the production system per QC individually.

Process Flow Cost Recording considers the production of goods as a system of material's flow, based on the mass balance. It distinguishes the movements of materials in (Sygulla, Götze & Bierer, 2014).: (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.

The Process Flow Cost Recording application method must be considered as a step by step procedure. Its implementation in a production system can be performed based on the following steps (Kaplan & Anderson, 2007):

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

Since, any production process requires several types of inputs, the analysis should consider all the costs involved on it. Consequently, the flow cost which have to be assigned to the material's flow (physical units) include all costs which can be related or are caused by the material flow (Kaplan & Anderson, 2007).

Process Flow Cost Recording divides the several types of cost into: (i)Material cost, (ii)Energy cost;(iii) System cost; (iv) Waste management Cost.

The system cost includes the cost of 'all expenses incurred in the course of in-house handling of the material flows, except the material, energy and waste management cost (Kaplan & Anderson, 2007).

Thereafter, a calculation model should be developed to compile all the information required resulting in a Process flow map. Further, the flow map should be presented and analysed by the company's managers to seek for improvements (Kaplan & Anderson, 2007).

## III. Manufacturing Context And Approach

The main objective of the present work consists in the validation of the Process Flow Cost Recording's applicability as a diagnostic tool. Then, based on literary, a study to evaluate the Process Flow Cost Recording method and the Lean tools complementarities was performed.

Subsequently, based on this study, it aims to develop a methodology to integrate both, Process Flow Cost Recording method and Lean tools, and validated it by its application to a case study. To achieve the paper goals, the work was partially developed in an Injection Moulding company, enabling the necessary data collection to perform the Process Flow Cost Recording analysis and its calculation model.

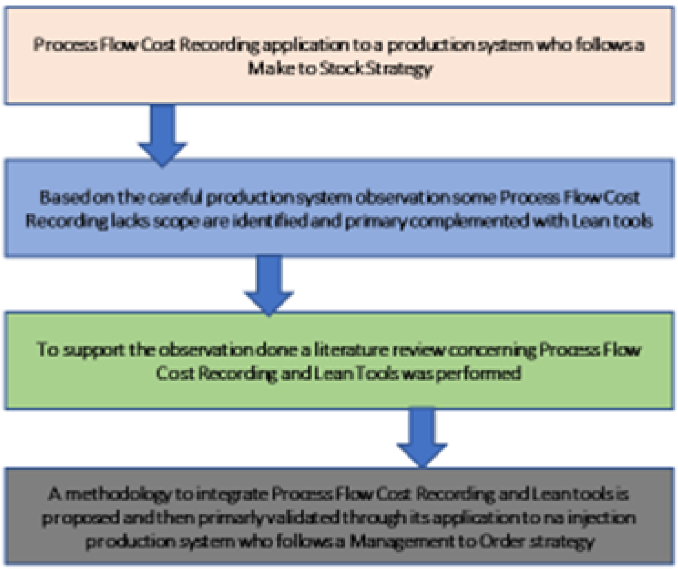
Moreover, when the Process Flow Cost Recording is applied, it not only allows an easily identification of the inherent Process Flow Cost Recording's gaps, but also, enables the recognition of the complementarity opportunities related to Production Management in continuous improvement domain.

The injection moulding process is the most adaptable process for the manufacture of plastic components.

Nowadays is considered as the preferable process to produce three-dimensional products with complex shapes (Kamal, 2009).

The following Figure 1 presents the approach followed to develop the work.

**Figure 1: Approach followed to develop the work**




Source: developed by the author

The first phase consists in the application of the Process Flow Cost Recording to an injection moulding unit which follows a Make-To-Stock strategy. Then, a careful observation of the same production system during the Process Flow Cost Recording data gathering was performed.

This detailed observation evinces the existence of some production problems that the Process Flow Cost Recording is not able to transmit clearly in its calculation output due to its nature. Subsequently, a study of similarities between the Process Flow Cost Recording and the Lean tools was performed to access the viability of their integration.

Thereafter, a methodology to integrate Process Flow Cost Recording and Lean tools is developed, proposed and further validated. This methodology aims to complement both method/tools taking advantage of each other.

In one hand, the Process Flow Cost Recording mapping cost flows based on a detailed data gathering and, on the other hand, the Lean tools adds significance information from the production system point of view and has specific tools for root-cause and problem-solving analysis.

## IV. The Process Flow Cost Recording In Practice

The Process Flow Cost Recording is applied to a production system which follows a Make to Stock strategy to appraise its current economic performance.

4.1. Case Study environment

The Process Flow Cost Recording methodology for application suggests that firstly, the production system must be characterised. The characterisation process includes a clear definition of the company's areas, the determination of the system boundaries and scope (Kaplan & Anderson, 2007):

1. Specify the boundaries and the product to be analysed;
2. Define of the time period of analysis and data collection;
3. Determine of the quantity centres.

The product studied is entirely produced by the company, thus the boundary was defined as the limits of the manufacturing system. The product analysed, was selected based on its economic significance for the company.

This product is divided in two components, which are produced separately although their production is synchronised to guarantee an equal production volume to manufacture the entire pair, avoiding unwanted stocks. The final product is assembled by an independent company.

The characteristics of the Product A are presented in the following Table 1.

**Table 1: Characteristics of Product A**

| Parts of Product A | Material | Weight (g) |
|---|---|---|
| Part 1 - Lid | Polypropylene | 2,3 |
| Part 2 - Cup | Polypropylene | 4,2 |

Source: Company data reports

The time period of analysis was defined as one month to allow the collection of reliable data, enabling the identification of the production's fluctuations, as well as the comparison with the logistic records which in turns are monthly organized.

Once the boundary conditions and the period of analysis are defined, the following step is the determination of the quantity centres. The Process Flow Cost Recording intends to divide the production system into processes or parts, the QC, in which the material is transformed, stored or contributes for the Work-In-Process. However, if a process does not represent a significant contribution, it can be included in another QC.

To support the QC definition, the production flow was analysed following the material flow within the manufacturing process. This analysis includes the identification and characterisation of all the activities as well as the analysis of the materials movements that occur during the manufacturing process.

4.2. Value for Process Flow

Once defined the quantity, the inputs and outputs of each QC should be identified. For the present case study, the energy and energy losses are included under the product and the material wasted respectively.

To quantify the material flow, a two steps procedure was used:

1. Determination and classification of all the materials involved;
2. Data compilation to quantify the flows in physical units.

The present production system inputs only one material, polypropylene, which is used to produce the entire product. This material follows the entire production system, and no other raw material is added to it. However, in the packaging and final product warehouse phases, there are auxiliary materials used to pack the product.

The cost of the auxiliary materials is allocated to the input flow of the QC and is part of the same QC product output. However, there are some quantity centres, where physical collecting data was not possible or easy to accomplish.

To overcome this issue an Auxiliary Calculation Model was developed for this specific case. The Auxiliary Calculation Model calculates the production volume and the material consumed to produce each part. It is based on: the data collected about material losses; the quality control records; the production time; the number of operational cavities per machine; and cycle time of each injection machine.

This last parameter is provided by a company's software programme that controls the production system. After the data collecting period, the global results were compared with the logistic and Warehouse records. The consistency of the obtained results allowed the validation of the auxiliary calculation model itself and the quantification of the material flows in physical units, for each QC.

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. The final step is the quantification of production inputs in monetary values. The production system cost includes all the monetary expenses incurred to perform the activity.

Consequently, all cost that are associated or generated by the material flow must be allocated to the respective output flow. The material quantification in monetary units is calculated based on the amount of material and its cost per unit. The same approach is followed for energy cost calculation.

The system costs are the sum of the employees cost, the space cost and the equipment cost;

The employees' cost is calculated individually per QC and is based on the time that each employee spends to perform each activity. Then, the space cost is calculated based on the space required to perform each activity and the respective rent cost.

Finally, the equipment cost is calculated based on its depreciation cost and the production time. The energy and system costs are allocated to the material costs, i.e. the energy consumed and 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.

4.3. Process Flow Calculation Model

The Process Flow Calculation model organises all the information previously calculated and at the end exports a flow map where the flow costs are specified. This model should include all the resources used and the respective costs to assess the economic performance of the entire production system. It ought to characterise the economic flow of each QC including the costs related to the previous ones and the internal costs. The present production system, works continuously during the entire year without significant variations during this period. Therefore, the obtained information can be extrapolated, obtaining the annual analysis of the manufacturing system.

4.4. Results

4.4.1. Process Flow Value Results

The flow map is the final output of the Process Flow Cost Recording analysis it presents the economic flow based on the resources consumed in each quantity centre. It is divided in QC and then each QC is sub-divided in Input cost, Energy and System cost and outputs which in turns differentiate the product and material waste cost.

Form the analysis of the Flow map is possible to analyse the process or processes within the total production system where the materials waste increases its cost. The Process Cost Recording flow map shows the single QC with the highest waste cost is the QC – Injection machine of Part 2 wasting 37k€ per year, followed by the Quality Control QC of Part 1 which wastes 36k€ per year and then the QC – Injection machine of Part 1 that generates a waste cost of 34k€.

Moreover, is possible to analyse the Part of the product which represents the highest cost contribution for the total waste cost. Following the waste flow individually of each part, the production system of the Part 1 wastes 81k€ per year and the production system of the Part 2 wastes 45k€ per year. Furthermore, is also possible to analyse the final cost of the production process per Part.

The product cost of the Part 1 production process is 1449 k€ per year and for Part2 is 2051k€ per year, these values are presented in QC-Final product (output-product) of Part 1 and Part 2 respectively. The analysis of the production system is performed based on Process Flow Cost Recording output. Moreover, to analyse the manufacturing system a complementary analysis is required.

The type of analyse or its scope is not specifically included in Process Flow Cost Recording standard or guidelines; only vague directions are provided (Kaplan & Anderson, 2007).

4.4.2. Complementary analysis

From the Process Flow Cost Recording direct results is possible to build a further analysis, which depends of the study aims and of the analyst/company needs. For this case study is important to analyse the primary causes of the material waste and its financial impacts.

The complementary analysis performed based on the Process Flow Cost Recording results together with the observation of the production system, allows the identification of some critical points and primary suggestions for their causes. The analysis of the overall results shows that 96.6% of the total cost is related to the production of parts with the required specification to deliver to the customer and 3.4% is related to material losses.

The production of Part 2 represents more 15.6% of the total cost than the manufacture of Part 1, this value can be a consequence of the Part 2 characteristic. Thus, a primary analysis to assess the cause of this difference pointed that the hopper dryer needs to supply more 1.85 grams of raw material to produce one Part2 than to produce one Part 1. The analysis identifies the cost contribution of each QC to the total production cost based on the cost increased in each within the total production cost (Table 2).

The results obtained, Table 2 pointed that the Raw Material is the QC where the product has the highest cost representing 67.9% of the total production cost, followed by the Part 2 Injection Machine, Part 1 Injection Machine QC, and QC Packaging of Part 1 and Part 2.

The Raw Material contribution cost value is pointed as a consequence of the fact that all material required for the product manufacturing is inputted in this QC. This cost represents approximately 98% of the total Raw Material QC cost which has a high influence in the production system economic performance. The followings QCs with the higher contribution cost are the Part 2 and Part 1 – Injection Machine, (Table 2) which is considered as comprehensible due to the type of production in study.

The difference between them is related to the amount of material injected into each production. Those two QC are also the ones that contribute more to the total waste cost. The material wasted in the production of Part1 and Part2 is distributed as 91% and 92% due to defective Part 1, and Part 2 produced respectively, and 9% and 8% with contaminated and discharges. Moreover, its cause is related with the material wasted after each maintenance stop.

**Table 2: Total Contribution Cost per QC**

| Flow Cost Recording | Both | Part 1 | Part 2 | Total Content |
|---|---|---|---|---|
| **Raw Material** | **67,90%** | | | **67,90%** |
| **Hopper Dryer** | 0,10% | | | 0,10% |
| **Injection Machine** | | **8,60%** | | **8,60%** |
| **Quality Control** | | 1,00% | | 1,00% |
| **Packaging** | | **6,00%** | | **6,00%** |
| **Waste Management (contaminated)** | | -0,003% | | -0,003% |
| **Waste Management (defective)** | | 0,10% | | 0,10% |
| **Final Product Warehouse** | | 0,70% | | 0,70% |
| **Injection Machine** | | | **9,20%** | **9,20%** |
| **Quality Control** | | | 0,90% | 0,90% |
| **Packaging** | | | **4,70%** | **4,70%** |
| **Waste Management (contaminated)** | | | -0,003% | -0,003% |
| **Waste Management (defective)** | | | 0,10% | 0,10% |
| **Final Product Warehouse** | | | 0,70% | 0,70% |

Source: Company data in process

The material inputted in the Quality Control of Part 1 results as material waste, and its high cost comes not only from the material wasted cost but also the fact that this process is performed by the employee once per hour.

Moreover, once per shift a quality technician performs the quality control test increasing its cost The Waste Management of defective components also contributes to the waste cost increase. This process is required from the customer for design confidentiality reasons, and the company is forced to grind all defective parts.

From the previous analysis some improvements are suggested: i. Reduce the number of mouldings rejected after stops; ii. Train the employees in order to eliminate the test performed by the quality technical, decreasing the QC cost. iii. Eliminate the Hopper-Dryer from the system – The material does not need to be dryer; iv. Schedule the moulds maintenance avoiding non-value-added activities.

## V. Methodology Integration

The Process Flow Cost Recording is a method to diagnose production systems based on the quantification of the material flows separating the material used to manufacture the products from the material losses (waste). It allows the identification of inefficiencies through the production system and presents the results regarding the product and waste cost flows separately.

During the development of the first case study, presented in the previous section, the Process Flow Cost Recording allowed the identification of the waste in each QC and the sources of that waste. Nevertheless, no information is provided about the critical level of those wastes (no target or benchmark is defined) neither the root causes are systematically identified. The Process Flow Cost Recording maps and quantifies the places (QCs) and the amount of resources consumed, as well as the material (and energy) losses.

However, does not include a procedure for supporting the subsequent phases of the diagnosis and implementation of improvement measures. Which includes: the identification of the critical QCs; the identification of the critical production steps or task in each QC; the identification of the root causes of unnecessary resources consumption and losses; and finally, the definition of the type of solution required.

Thus, as it was referred to the previous case study, the use of Lean Manufacturing related tools after Process Flow Cost Recording is recommended for the following reasons: (i)To identify the QC which has a critical value of waste (based on user experience and its sensibility to assess the results – e.g. the use of Key Performance Indicators (KPIs) could be useful); (ii)To identify the root causes (e.g. by applying 5 Whys);(iii)To develop a solution to improve the systems' performance (e.g. Kaizen events, Gemba walks for simple solutions; 8D problem solving, A3 report for more complex).

The necessity of applying Lean tools after the Process Flow Cost Recording analysis motivates this study and its validation. Despite most of the Lean thinking methods were suggested in the first case study; the impact and performance of these suggestions were not applied during the internship due to production's layout modifications and the transition phase of the manufacturing line.

Consequently, this context motivated the proposal of a methodology which integrates the Process Flow Cost Recording and Lean management tools, taking advantage of their complementarities. On the one hand, Process Flow Cost Recording aims to present to the managers the real monetary value of the waste and the QC within the manufacturing system that has the highest contribution to the waste value.

On the other hand, Lean Management tools goals are related to physical flow analysis and problem-solving solutions. From this arises the research question of the present paper: How to integrate Process Flow Cost Recording and Lean management tools for continuous improvement system? To answer this question, an integration methodology is proposed. Further, is validated through its application to a case study.

5.1. Process Flow Cost Recording and Lean Management Approach

Process Flow Cost Recording shows the performance of each QC, through the mapping of information related to each QC. This information allows the stakeholders to identify critical processes based only on the monetary aspect not being able to analyse the criticality level of the QC and its correspondent QC-Section.

This is due to the lack of indicators (within Process Flow Cost Recording indicators) able to identify single QC's and QC-Section's contributions for the Total Cost, or any parameter above the expected or the desired value (Kaplan & Anderson, 2007), From the Process Flow Cost Recording results the stakeholders are able to analyse different cases from that information; however, the Process Flow Cost Recording do not present directly those indicators.

Having performed the calculations of Process Flow Cost Recording, it is necessary to develop solutions and implement them. The literature on Process Flow Cost Recording largely neglects strategies for taking advantage of its detailed and monetary based diagnosis, as procedures of critical aspects' identification and strategies to develop solutions.

Lean has a different approach for diagnosis and critical aspects identification. While Process Flow Cost Recording is essentially a diagnostic tool and is concerned to make "visible" the monetary value of the production waste, Lean has a more incisive diagnostic, supporting the identification of critical processes/tasks, as well as the root causes and also including problem-solving tools/approaches (Spear, 2019).

Lean Management approach is divided in diagnostic tools, as Value Stream Map and Gemba Walk which analyse the production system in a macro perspective without a direct relation to the monetary value of the processes and/or the production cost (Spear, 2019) and (Basu, 2011).

Nevertheless, these analyses aim to identify the critical processes/tasks to launch continues improvement projects (based on Kaizen principles – Plan-Do-Check-Act). In fact, the main goal of Lean diagnosis tools is to identify non-value-added activities and analyse them. - Plan phase – aiming to eliminate waste regardless of its nature.

(8 MUDA (Spear, 2019)) The action-plan application accomplishes the effective waste elimination – Do phase – where the problem-solving tools as Kaizen events, A3 Problem Solving and 8D method (Sobek & Jimmerson, 2004) (from Lean and Kaizen inter-connection) are used to define cooperatively between the company collaborators. The intrinsic characteristic of these tools leads to the need of data collection tasks in physical units to analyse the results (sometimes with consecutive Gemba Walks).

These results are then shown regarding non-added value time (inefficiencies). During these problem-solving methods supporting tools for root-cause identification are used. Namely, 5Whys, 5W+1H, Is/Is not, among others (Basu, 2011). Then solutions are generated aiming to eliminate the root-causes, usually using good-practices of Lean tools like 5Ss, SMED, Kanban, Mizusumashi, among others (Basu, 2011).

The Kaizen process continues by assessing the impact of the implementation of the solution and by the comparison between the expected and achieved results. Usually Lean uses the Visual Management (VM) to access the production performance during the production time. In some cases, the VM displays KPIs to assess if the action-plan is allowing the performance previously defined.

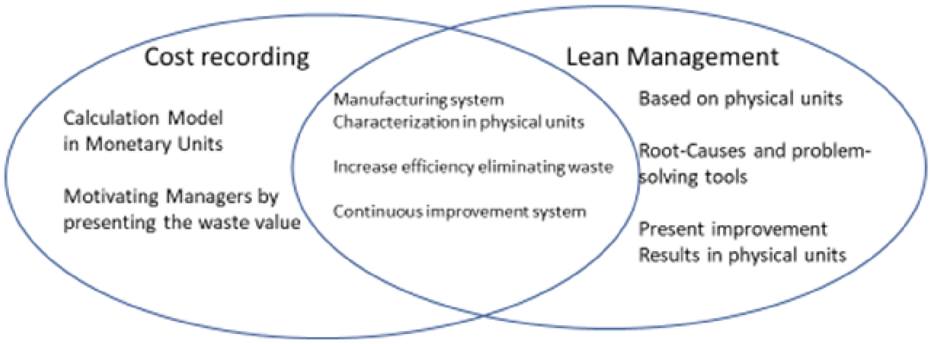
This procedure corresponds to the Check phase. After that, a beginning of a new procedure standardisation and identifying the next critical area and (in case) analyse the aspects of the difference between the expected and achieved results – Act and subsequent Plan phases. Despite different approaches to identify wastes and achieve better performance of production system, Process Flow Cost Recording and Lean tools have the same aim and starting point: both analyse the production flow in physical units and present the actual production performance status.

However, Lean is mainly concerned about reducing MUDAS and Process Flow Cost Recording is concerned about the waste economic impact and its reduction based on its cost. (Figure 3). On the one hand, Process Flow Cost Recording's goal is to demonstrate the improvement opportunity by showing the waste cost but is not primarily designed for problem-solving nor to present specific solutions.

On the other hand, Lean management aims at reducing all types of waste and uses the problem-solving methods and Lean tools to identify the root causes and to provide solutions. However, is not designed to present the results in monetary units – such as Process Flow Cost Recording.

Consequently, a methodology to integrate these two approaches is proposed taking advantage of their complementary aspects (Figure 2).

**Figure 2: Complementary aspects and integration opportunity**



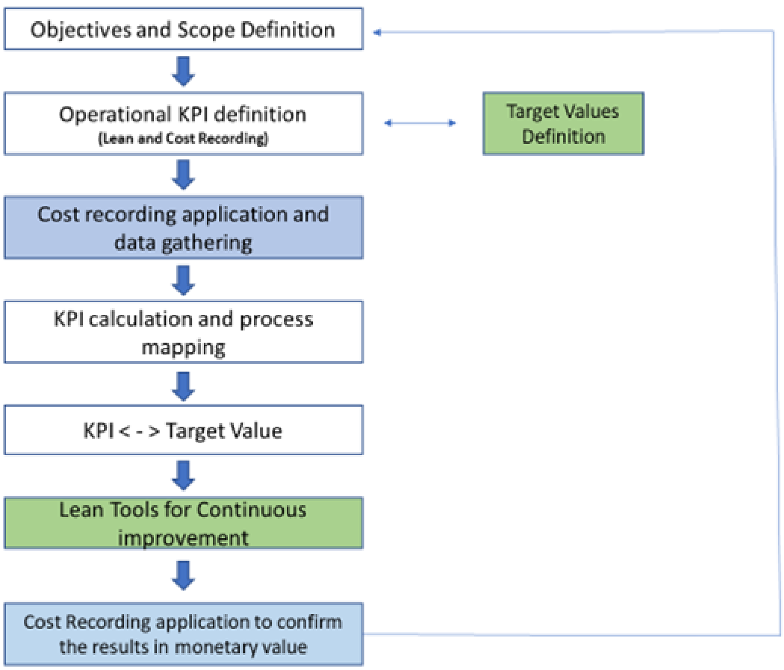

Source: Developed by the author

5.2. Process Flow Cost Recording and Lean Management

The proposed methodology integrates Process Flow Cost Recording structured phases with an adaptable application logic of Lean tools, i.e., the tools should be selected according to with the production issues. It also incorporates a very important rationale for the effective success of its implementation: The Kaizen continuous improvement foundations.

The Plan-Do-Check -Act cycle (Basu, 2011) is imbibed in the Process Flow Cost Recording - Lean methodology although is not explicitly mentioned in the methodology sequential phases. Figure 3 illustrates overview of Process Flow Cost Recording Lean methodology.

**Figure 3: Overview of Cost Recording and Lean integration approach**




Source: Developed by the author

Objectives and Scope Definition The first step of the integration approach is the definition of the objectives that should be aligned with the company's strategical planning. These "macro objectives" should be the translation of the strategic objectives in operational performance figures.

Furthermore, the scope definition will delimit the production system or part of it where the methodology will be applied. The objectives and scope definition will influence the application process of the proposed methodology. Operational KPIs definition The Process Flow Cost Recording and Lean-based operational performance indicators should be selected considering the objectives and scope.

The KPIs derived from Process Flow Cost Recording are "mandatory", the one from Lean are more dependent on the objectives and scope. Moreover, the Target Values for each KPI should be defined, according to with the company strategy. When Process Flow Cost Recording -Lean methodology is applied for the first time is possible that the company does not have the necessary information about the process to assign a Target Value to a specific KPI. Process Flow Cost Recording application and data gathering application of the Process Flow Cost Recording method, namely related to QC definition and related data gathering, as well as data gathering related to the information required for the Lean-based KPIs. KPI calculation and process mapping – KPI vs Target Value At this point the current state of the production system is well known, and the results can be analysed.

Aiming to facilitate the overall systems performance two types of dashboards are proposed (Figure 5) one for each QC and the other showing the total performance of the system. Both dashboards suggested have two main areas, one dedicated to the Process Flow Cost Recording indicators, and the other to the Lean indicators. They also have a column which connects each KPI with the Target Value.

The QC dashboard has more detailed information related to specific operation or tasks, if existent. This dashboard also shows the contribution of each QC to the overall production cost. The dashboard related with the total performance has the final Process Flow Cost Recording typical indicators of performance as well as the total cost involved. The contrast between the KPIs observed, and the Target Values indicates the current state of the process where improvement opportunities might be visible.

**Figure 4: Dashboard for Total Production System**

**Total Production System (TPS)**

| Flow Cost Recording | Per Production | KPIof TPS | Unit |
|---|---|---|---|
| Materials input | € | % | Kg |
| Energy | € | % | Kw |
| System | € | % | |
| Product | € | % | Kg |
| Waste | € | % | Kg |
| Total Production | € | % | h/parts |
| **Lean KPI´s** | | | |
| Material Waste | | | |
| Product Waste | Kg | % | |
| | Parts | % | |
| | | | **Auxiliar data** |

**QCI**

| Flow Cost Recording | Per Production | KPIof TPS | Unit |
|---|---|---|---|
| Materials input | € | % | Kg |
| Energy | € | % | Kw |
| System | € | % | |
| Product | € | % | Kg |
| Waste | € | % | Kg |
| Total Production | € | % | h/parts |
| **Lean KPI´s** | | | |
| QC associated cost | € | +- % | |
| Product Waste | Parts | % | |
| Total Production | € | % | h |
| Setup | € | | h |
| OEE | | % | |

KPI and TV Discrepancy

**Auxiliary data for KPI Calculation**

| | | | |
|---|---|---|---|
| Performance | % | Cycle time | % |
| Setup | % | Hours | h |
| Quality | % | Good Parts | Parts |

Source: Company data reports

Critical QC and KPIs and Lean tools application Then, the determination of the critical QC and the critical KPIs can be made by the analyst or the team through the observation and analysis of the dashboard. Several strategies can be followed, nevertheless, in the present work is suggested the following. (i) Identify the KPIs with "higher distance" to the Target Values, and consider them as critical; (ii) Identify the QC(s) with higher "QC associated cost" KPI and consider it(them) critical even though the distance to the Target Value is small;(iii) Identify in the critical QC(s) the KPIs that most contribute to the bad performance (waste-, time-, energy-related) and consider it as critical.

The selection of the critical QCs and KPIs allow for efficient and effective subsequent phases of root-cause analysis, and solutions development and its implementation. As proposed by the Kaizen philosophy, the continuous improvement process should be accomplished by a step-by-step approach, launching "only" a localised project with very specific objectives at the time. Hence, the critical QC or QCs must be analysed in detail to understand the reasons behind the crucial aspect through the application of the Lean diagnostic tools already mentioned.

Therefore, an improvement strategy can be defined through the appropriate problem-solving method. Finally, the Lean tools for continuous improvement should be performed and the improvement results confirmed. For example: If the issue is related with the OEE, then Availability, Performance and Quality performance should be analysed.

Moreover, if the problem is related to quality related KPI, the 5whys method should be used to achieve the root cause(s) for defective products and Kaizen events, A3 report or 8D problem-solving methods should be applied.

Furthermore, If the issue is related to the set-up time KPI, the SMED and 5s Lean tools can be implemented to eliminate wastes that result from a non-organized work area or even to convert the internal activities to external and eliminate non-essential operations creating a standardized set-up work. Concluding, a Kaizen based strategy provided by the application of Lean tools should be performed, and the improved results should be analysed by the reapplication of the proposed integrated methodology.

## VI. Integrated Methodology Application

This section presents the Process Flow Cost Recording-Lean Management methodology application to an injection moulding process which follows a Make to Order strategy.

### 6.1. Production System and Product Characterization

The production process in study is divided into four main steps. The first is the Injection Moulding process where the raw material is transformed into final product, then the product is subjected to a quality analysis and then packed.

Afterwards, the product is stored until be delivered to the client. To understand the calculation model and the methodology application the characteristics of the product are presented in, Table 3, as the moulding's constituents, the respective weight and the expected duration of each cycle, as well as the total production volume. For confidentiality reasons only, the necessary values are presented, and the part configuration cannot be displayed.

**Table 3: General dimensions of the production process and product**

| | Units | Weight |
|---|---|---|
| Parts per moulding | 4 parts | 2,12 g/ part |
| Runners per moulding | 1 | 4,1 g/moulding |
| Production lot size | 36000 | |
| | | |
| Theoretic cycle time | 12,3 sec/moulding | |

Source: Company data reports in process

### 6.2. Objectives, Scope and KPI´s Definition

The company defined as its main goal the increase of gain margin and the reduction of material, energy and human resources. Then, the scope was defined as the entire process from the material supply until the product delivered. The appropriate KPIs to analyse the current state of the production system considering the company's objectives is presented in Table 4.

Since one of the objectives defined was increase the gain margin, the Total Production Cost was selected as KPI to confirm and evaluate the actual cost. Then, considering the second goal, the material reduction, the waste material was selected to provide the current performance to evaluate the deviation between the real value and the expected to appraise improvement possibilities. To evaluate the possible reduction of human and energy resources and its impact three different indicators were selected: i) the Total System Cost since the human resources cost is included on it; ii) the OEE which evaluate the equipment performance and availability that is related to the energy consumption and employee's work duration due to the production time; iii) and the Set-up time which analyse directly the employee and equipment occupation during a period that no product is produced.

The following phase is the Target Value definition/attribution presented in Table 4. For this particular case, there is not yet a Target Value for the Total Production Cost and the Total System Cost because it was the first time the Process Flow Cost Recording was applied.

For the total amount of material waste, the 3% of Target Value represents an average value aimed by the company, including the material wasted due to discharges, material needed for replacement and parts needed for the quality control destructive test. The definition of the Target Value for Set-up time was based on an estimated value that has resulted from company's previous study.

Finally, the OEE is defined based on the company experience, and at this point the company aims to achieve at least 65%. This value represents what they consider as a reasonable value for this parameter.

**Table 4: KPI considering the company´s goals**

| Objective | KPI | Target Value |
|---|---|---|
| Increase Profif | Total Production Cost | Budget |
| | % Material Waste | < 3% |
| Reduce Resources Uses | Total System Cost | Budget |
| | OEE | > 65% |
| | Set-up time | < 1h30min |

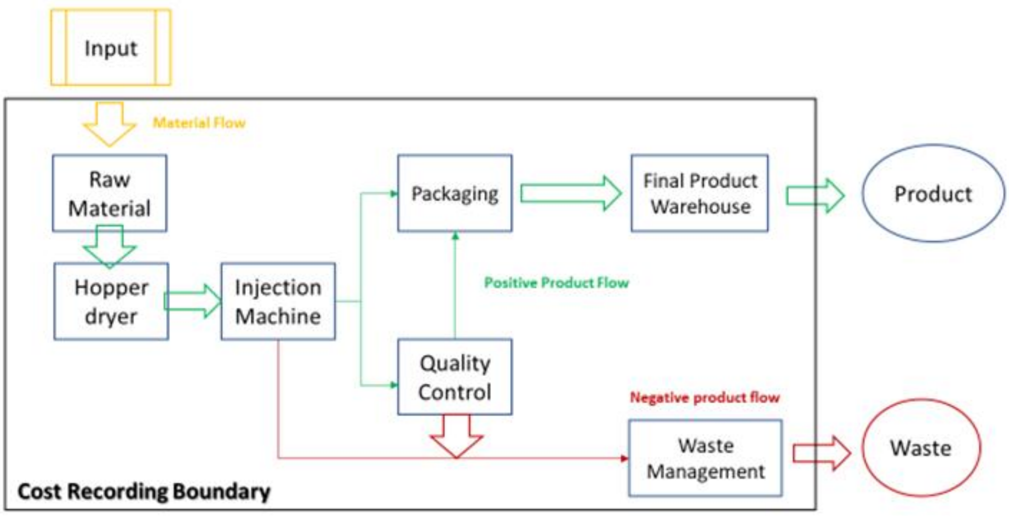
Source: Company data in process

The Target Values presented are used to evaluate the current state of the production system based on the aimed results, it will support the Check phase of the cycle. This evaluation is presented in the methodology dashboards for final results, section "KPI and Target Value discrepancy".

6.3. Application and Data Collection

To perform Process Flow Cost Recording analysis, the steps presented in section 4 were followed. Firstly, the data collection period was established as one production bunch, i.e. the time required to produce the total order (36 000 good parts). Then, the production system was sub-divided in QC, and the material flow was analysed. Figure 6, illustrates a material flow map, where the QC are identified as well as the inputs, positive product and negative product flows.

**Figure 5: Material Flow Model**




Source: Company data/performed by the author

Once defined the QC, the inputs and outputs should be quantified in physical units. As explained before each quantity centre identifies three different parameters, namely, the Material Stock, the Energy consumption and the System. Consequently, the material consumption and energy were measured. Then, the parameters of the third component, equipment and human resources, were allocated by the total dedicated time to this particular production.

The calculation criteria used to convert physical into monetary units were:

The material cost was calculated based on the amount of material required and its price;

The energy cost calculated based on the energy required and the energy prince;

Finally, the System cost of employee was calculated based on their cost and the time spent to perform each activity, the space cost was calculated considering the space required in each QC and the rent space cost; and the equipment cost was calculated based on its depreciation and production time.

Thereafter the energy and system costs are allocated to the material costs, i.e. The energy cost of each quantity centre should be assigned to the output flows in the proportion of the mass ratio between the products and the material losses.

6.4. KPI selection and Calculation

After the Process Flow Cost Recording application, the next step is the KPI calculation and the correlation criterion selection to incorporate in the original Process Flow Cost Recording calculation model. Per QC Considering the objectives exposed above, different types of evaluation can be selected. The first step is the calculation of each KPI of each QC. For the QC analysis was selected four costs related and two operational KPIs. Three of the cost related KPI appraise the contribution of each QC-Section within the total QC Associated cost. Thus, the Material, Energy and System contribution are calculated using Equation (1).

**Equation 1**

*Resource contribution QC = Resource Cost/QC Associated Cost*

The fourth KPI cost related presents the contribution of the QC within the Total Production and is calculated using Equation (2).

**Equation 2**

*QC contribution total Production Cost = QC Associated Cost/Total Production Cost*

The Set-up time is measured and expressed directly in the output dashboard in hours and the OEE calculated. (Basu, 2011). The analysis of the contribution of each QC-section and the OEE is then presented in the dashboard, “Lean KPIs” and the calculation of the OEE factors is presented in the dashboard section “Auxiliary data for KPI calculation”.

**<u>For Total Production System</u>**

The cost related KPIs (Material, Energy and System contribution) follows the same approach as the defined for the QCs. Thus, the cost contribution for the Total Production system is calculated using Equation (3).

**Equation 3**

*Resource contribution FP = Resource cost/Total production cost*

Then, were added two KPI only for the Total Production System, the Material Waste to evaluate the total amount of material lost in physical units and the Defective products to analyse the amount of parts rejected within the total production volume. Equations (4) and (5) respectively.

**Equation 4**

*Material Waste = Material Waste/Material Input*

**Equation 5**

*Defective Products = Defective products/Total production*

6.5. KPI target value

To evaluate the production performance by the correlation between the system’s KPIs and the correspondent Target Value two evaluation criteria were defined based on the KPI nature. The direct ratio between the Target Value and the KPI was selected to appraise the variation of the Total Production Time and the Set-up time.

The correlation criterion to calculate the discrepancy of the OEE and the defective products was the difference between the values (percentage points). Since the OEE and the Defective products are a percentage number, this criterion makes the discrepancy more perceptible.

6.6. Critical KPI identification

The analysis of results and identification of critical QC and KPIs is performed based on the methodology dashboard. It describes, not only, the costs per QC (input; output, product and waste) and per QC-section as the original Process Flow Cost Recording, but also, presents the actual performance of the process by the KPIs presentation.

Moreover, this Process Flow Cost Recording -Lean dashboard also presents the discrepancy between the KPI and the Target Value. Allowing the user to evaluate if the pre-defined plan was being fulfilled as planned. These properties make the MFCA-Lean dashboard more extensive than the original Process Flow Cost Recording flow map and more detailed and objective than Lean.

From the analysis of the dashboards, it is possible to find the critical KPIs which allow the identification of improvement opportunities.

For this specific case-study the criteria used to identify the critical KPI per QC were: (i) The KPI that presents the highest distance to the Target Value; (ii) QC which has the highest contribution to the Total Production Cost; (iii) The KPI which influences the critical QC contribution.

For the analysis of the Total Production System was also considered that an evaluation of (iv) the KPI that most contributes to the Total Production Cost was appropriate to assess the critical subsection.

The results obtained pointed that: Per QC (i) The Total Production Time is the KPI with the highest deviation to the respective Target Value. This corresponds to 12% more than the expected value which represents more than 74.01€ of the production costs; (ii)The QC with the highest associated cost is the Injection Machine. This QC represents 54% of the Total Processes Cost that corresponds to almost 116€. It is followed by the QC -Packaging that represents 33%. (iii)The KPI that contributes more to the QC- Injection Machine is the Material Waste which represents 37.58 perceptual points of the production which is translated in 237.58€. For the Total Production System (iv) The KPI that has the highest contribution to the Production system cost is the Material Input representing 72.4 perceptual points of the total costs, i.e. 515.37€. From the evaluation of the Total Production System is possible to assess that this value comes in part from the material wasted through the production system, 37.58%. However, 30.21% of that value corresponds to a manufacturing condition and is mandatory for the manufacturing process.

Thus, the critical KPI that most contributes for the Total Production Cost must be re-evaluated. The re-evaluation of the Total Production System results identifies as critical the System contribution for the entire production costs. Thus, an analysis of the QC-System of each QC that most contributes for the total System cost was performed. Its results show that the critical QC is the Injection Machine which represents 56% of the total system cost, i.e. 100,40 €, followed by the QC- Packaging that is 30% of the total system costs.

Attempting that the QC Injection Machine and Packaging are also pointed as critical once are the QCs with the highest associated cost a root cause analysis of these QC should be performed, and the most critical selected for further analysis.

### 6.7. Lean application tools

The Lean application tools is divided into: Lean tools for root cause analysis and, based on the results, the problem-solving solutions are applied and the results confirmed.

#### 6.7.1. Lean Root-Cause tools application

It was shown that the QC- Injection Machine and the QC Packaging were the QC that has the highest contribution for the QC-System of the Total Production System. Thus, a root cause analysis was performed to these two QC using the 5Whys and 5Ws diagnostic tools. For QC-Injection Machine: Combined 5Whys and 5Ws for root-cause analysis.

Statement: The QC-Injection Machine is the 1st QC that contributes more for the Total Production System Cost Why? - Because is the QC with the highest resource's consumption. Why? - Because of the Equipment and the Labours involved in this QC. - Root-cause achieved. Statement 1 –The Equipment cost is the reason behind QC- Injection Machine contribution cost. Why? - Because Injection Machine and the mould are equipment's with expensive depreciations. -Root-cause achieved Statement 2 –The labour cost is the reason behind QC Injection Machine contribution cost. Why? - Because this QC involves four different levels of employees.

Which employee has the highest contribution for the labour's cost? – Leader Supporter. Why? Because he is a specialized. What does he do? – He performs the Set-up- Root-cause achieved from the 5Whys analysis is possible to conclude that the root cause of the QC-System high value in the Injection Machine is due firstly the equipment and labours involved in the process. However, when the root-cause is analysed in detail is accessible that the Equipment value is a consequence of the machine depreciation.

However, the Labour cost is divided in Project manager (18%), Team Leader (31.6%), Employee (5.1%) and Leader supporter (45.3%). The Leader supporter main tasks are related to set-up activity and the raw material supply. Hence, the root-cause analysis, continuous to understand the reason behind that.

The specialisation level required to perform the set-up activity is directly related to his hour cost. Moreover, the set-up activity is also pointed as the second more critical concerning the KPI Target Value discrepancy presented in section 6.6. Based on the previous description, the set-up is considered the root-cause of the QC Injection Machine contribution for the total system cost. For QC-Packaging: 5Whys Root-cause analysis for System cost in QC-Packaging.

Statement- The QC-Packaging is the 2nd QC that contributes more for the Total System Cost. Why? - Labour is the sub-section of the QC-System in the QC-Packaging with the highest value. Why? - Because the packaging phase is the phase where employee spends most of the time. Why? - Because the product is packaged in concrete boxes that need to be tagged and this work is performed by the employee. - Root-cause achieved.
From the 5Whys analysis is possible to access that the contribution value which comes from the QC-Packaging is related to the time spent by the employee to perform that task. The packaging activity has specific requirements from the quality department, and the operator needs to perform this task following a determined procedure. Since QC-Packaging is dependent on the quality requirements and that the most critical QC has an operational cause, the QC-Injection Machine is selected for further analysis.

6.7.2. Lean Problem-Solving solutions application

Based on the root-cause information of the critical KPIs (Setup time) a problem-solving solution was applied, and its improvement results analysed. Firstly, a Gemba Walk was performed focused in the QC Injection Machine [where the Set-up occurs].

Then the Set-up process was observed and some wastes of the time were identified. Based on that identification, two different tools were applied, the 5S and SMED. During the Set-up observation, the following issues were identified:

i. The specific lubricant was not separated from the others and the employee wastes time looking for it.
ii. The cleaning material was not close to the work area and the employee wastes time measuring and transporting it.
iii. The new mould was far from the Machine. Consequently, the employee wasted time to look for it into the mould warehouse.
iv. The assembling and disassembling tools were not organised and identified for the change of the specific mould.
v. The new product folder warehouse is far from this machine and the employee wasted time.
vi. The Quality control team was not expecting the approval call, and they take longer to approve the product originating a waste of time and possibly of material since the production was already started.

Considering these issues, a 5S tool was applied focused in the tools organisation and the preparation of these accessories to obtain an organised and easy to access area. This tool application aims to reduce the issues i, ii and iv listed above. Firstly, the tools and consumables (lubricant and operating materials) were divided into the required ones for the mould change and the ones not needed.
Then, the necessary consumables were organised on the top of the tool cart close to the Machine and organised having in consideration the sequence of requirements. This sequence was selected based on the employee experience and the sequence of events observed.
Then, the additional equipment and materials were stored in the tool cart to promote a clean work area. In parallel with the previous tool, the SMED tool was also suggested to convert internal steps, into external steps of the process.
This tool's application goal is to reduce iv issues presented above when combined with the previously suggested tool. The activities selected to transform into external activities, i.e., the ones that should be performed before the mould change starts, includes the following:
1. The organisation tools, consequence of the 5S application, was performed before the end of the previous production;
2. Prepare the new mould and storage the mould cart close to the machine;
3. Bring the overhead crane close to the injection machine;
4. Prepare the cleaning material and store it close to the tool cart;
5. Bring the new mould folder and the robot accessories to the support machine table;
6. Notify the quality control team that the set-up is going to happen and they will be called in approximately 1hr30min.

The results presented in Table 5 shows that the Lean tools allowed a set-up reduction of 51%. After the application of the improvement solutions, the Process Flow Cost recording was reapplied to check the enhancement results based on the financial implications.
Table 6 presents the global results of the manufacturing system regarding the costs and the reduction after the application of the improvements.

**Table 5: Set-up time after Lean Tools Application**

| | Before Tools Application | Expected after SMED and 5S application | Real after SMED and 5S application |
|---|---|---|---|
| ***Set-up time*** | *3h 13 min* | *1h 25 min* | *1h 35 min* |
| ***Set-up reduction*** | | *-56%* | *-51%* |

Source: Company data in process

**Table 6: TPS Improvement Results after problem-solving tools**

| | Per Production | KPI of TPS | | Units |
|---|---|---|---|---|
| ***Energy*** | -0,53 € | -0,02% | -6,36 | Kw |
| ***System*** | -16,15 € | -1,72% | | |
| ***Product*** | -10,98 € | | | Kg |
| ***Waste*** | -5,69 € | | | Kg |
| ***Total Production*** | -16,68 € | -2% | -1,59 | h |
| ***Total Production time*** | | | -3% | |

Source: Company data in process

Through the analysis of the Total System Results obtained after the Process Flow Cost Recording - Lean methodology first application (Table 6) is possible to conclude that the improvements applied allowed not only, the Total System Cost and consequently the Total Production Cost reduction in 16.15€ (- 1.72%) and 16.68€ (-2%) respectively but also, the decrease of the energy consumed.

Thereafter the Process Flow Cost Recording-Lean Methodology should be re-applied to promote a continuous improvement cycle. A revaluation of the “new” critical factors and the reapplication of the entire methodology should be performed and in case of a lack of discrepancy between the Target Value and KPI a parameter's reformulation is suggested.

## VII. conclusions and future research lines

7.1. Conclusions

The present paper had two main objectives. The first one, related to the validation of the application of Process Flow Cost Recording methodology to a production system and the assessment of its benefits when applied as a diagnostic tool, to assess that information, during the Process Flow Cost Recording analysis a detailed observation was performed. Once understood the main advantages and limitations of its application concerning production flows, aimed at the development of a methodology which could integrate Process Flow Cost Recording method with Lean tools.

To accomplish these goals, a production unit which follows a Make to Stock strategy was used as a first case-study, then the Process Flow Cost Recording -Lean methodology was developed and applied to a production unit which follows a Make to Order strategy. This last was used as a second case-study to validate the Process Flow Cost Recording -Lean methodology.

The application of the Process Flow Cost Recording analysis through the direct application of Time Driven Activity Based Costing (Kaplan & Anderson, 2007) to a production unit supported the company to understand the magnitude of the resources used and flows in terms of product and waste costs.

The results obtained through Process Flow Cost Recording application reveals that the real waste percentage was three times higher than the company expected Hence, Process Flow Cost Recording proved to be an appropriate tool of diagnostic in terms of monetary values. i.e., the Process Flow Cost Recording is an effective tool to determine the resources used and transformed as a product or loss in terms of monetary performance.

It presents the real production cost of the production system based on an extensive data collected and allow the analyser to directly identify some obvious inefficiencies. Moreover, it could be a useful diagnostic tool to recognise some production inefficiencies during the analysis and data gathering period only if it is supported by a simultaneous careful observation.

As a primary conclusion, Process Flow Cost Recording analysis allow the accounting of all material and resources wasted based on an extensive data and system characterization but is not prepared to take care with inefficiencies from the manufacturing system point of view – as Lean tools. Process Flow Cost Recording-Lean methodology appears to overcome the Process Flow Cost Recording limitations presented. From the observation performed concerning Process Flow Cost Recording and Lean tools complementarities, a literature review of both was performed to support the Process Flow Cost Recording and Lean tools integration possibility. Then, the methodology was developed and successfully applied to an injection moulding production system which follows a Make to Order strategy. From the application results it was possible to conclude that the Process Flow Cost Recording -Lean methodology allows, not only, the understanding of the costs incurred in its production systems and its flow, but also highlights the critical KPI through its comparison with the aimed target values.

In addition, it provides specific Lean tools to evaluate the root-cause of the problem and uses problem-solving tools to solve the existent issues. Moreover, after the application of the proposed solutions the methodology allows the confirmation of results in monetary units due to the performance of the improvement activities, consequently the second aims of this dissertation are achieved. As final conclusions, the Process Flow Cost Recording method and Lean tools can be integrated.

This integration based on steps procedure allows the accomplishment of aimed results directly aligned with company's objective and scope. Process Flow Cost Recording -Lean methodology is able to present the real state of the production system in monetary units for manager's encouragement to re-evaluate their strategy and provide tools to recognise root-causes, support and improve employees' activities guiding efficiently their work. This methodology should be implemented as a continuous improvement cycle so the production process moves closer to the ideal optimized process.

7.2. Future Research Lines

Naturally, we understand some limitations in the study, as it is a specific case and in which there was a strong capacity and opportunity for improvement. Thus, we defined as future lines of research, two fundamental and converging options, which would be the possibility to compare the results over time with other industrial organizations and apply the study methodologies to companies in non-industrial sectors, such as logistics and services (Romana, 2016).

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Fernando Acabado Romana (Ph.D.). "Management Culture The Integration of Lean Tools and Process Flow Cost Recording." *IOSR Journal of Business and Management (IOSR-JBM)*, 23(05), 2021, pp. 56-71.