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Analysis Of An Order Fulfilment Process At A Metalwork Company Using Different Lean Methodologies

José António Dias[a], Luís Pinto Ferreira[a,*], Maria A. Gonçalves[a], F. J. G. Silva[a], Enrique Ares[b]

[a]ISEP – School of Engineering, Polytechnic of Porto, Rua Dr. António Bernardino de Almeida, 431, Porto 4200-072, Portugal.
[b]Department of Engineering Design, School of Industrial Engineering, University of Vigo, Spain.

Abstract

This article presents the analysis of a process by using four distinct approaches, each of them recurring to different Lean tools in order to get a detailed and multidimensional overview of the process. The primary objective of this study was to identify activities which add value in the order fulfilment process of a metalwork company. In this context, one also addressed issues such as waste, problems and their causes, in order to define intervention priorities and select actions capable to enhance the performance and efficiency of the process. The secondary objective was to evaluate and compare the results of the analysis made through different mapping techniques. From this study results the proposal of a tool to identify perceived micro-inefficiencies, as well as the impact of these on the production sub-process. Designated as Perceived Waste Mapping (PWM), this method allowed one to estimate that the ratio between the value-added hours and the total number of work hours at the company will be approximately 30%, far from the figure of 84% registered in the existing time and production records.

Keywords: Lean waste; Process mapping; Value stream mapping; Perceived waste mapping.

1. Introduction

Currently, the creation of value in a company is promoted by intangible factors such as process improvements, innovation, knowledge and staff. Tangible resources deliver increasingly fewer competitive advantages in the long term [1]. New technologies and the competition of global markets have forced companies to continuously review their processes in order to ensure greater efficiency and success when meeting their clients' requirements [2]. Lean thinking has allowed the achievement of long-term improvements through the use of its tools of systematic analysis, as well as its Kaizen philosophy, which is based on the PDCA cycle (plan, do, control, act) [3]. The first objective of this study resides in the collection, processing and analysis of information pertaining to the current state of the order fulfilment process. This procedure is fundamental in supporting decision-making during the subsequent phases of planning and the implementation of changes, which will lead to performance improvements. The second objective of the work at hand consists of evaluating and comparing the results of the analysis of a random process by using different

* Corresponding author. Tel.: + 351 228 340 500; fax: + 351 228 321 159.
E-mail address: lpf@isep.ipp.pt

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methods of analysis. The purpose of this exercise is to acquire a greater knowledge of the degree of convergence and complementarity of the information obtained, or if this presents diverging results. This study is divided into six sections. The first of these consists of the introduction; the second describes the used methodology; the third presents a brief literature overview; the fourth section describes the collection and analysis of information related to the process; the fifth section discusses the tools used and the results obtained; the sixth section presents the final conclusions and suggestions for future studies.

2. Research methodology

The methodology used in this article consisted of a case study. A previous approach allowed obtaining further knowledge about the company's activity, its organizational mindset and the views held by senior management. The selection of the order fulfilment process for this study is due to the fact that it encompasses the production process, as well as the upstream and downstream stages of activities. This activity produces a great impact on order flow like, for instance, the quotation process. Subsequently, a review of literature related to the objectives of the study was undertaken. One then proceeded by using four methods based on Lean thinking to collect and analyze the data pertaining to the order fulfilment process. Through each method, it was possible to typify the process and detect existing problems. One then defined the intended future project, as well as the priorities of intervention to achieve the required improvements. These elements will constitute the basis of future works which will involve the selection and implementation of actions to improve the process.

3. Literature review

The analysis of a process implies a sound knowledge of its purpose and manner of operating. Through the mapping of its stages and flows, one acquires a better perception of its input and output, and which sub-processes, resources, rules and activities are involved in the process. This will enable comparing the current state with the way in which it should operate [4]. Quality tools constitute an example of the techniques which make it possible to order and synthesize quantitative or qualitative data pertaining to a process, thus controlling its quality [5]. They contribute to the identification and resolution of problems, provide support for decision-making and allow one to monitor and stabilize the processes in question [6]. The seven main quality tools are: the Histogram, Cause-and-Effect Diagram, Check Sheet, Pareto Chart, Flowchart, Control Charts, and the Scatter Diagram [7]. Lean tools, most of them created by the Toyota Production System, also enable the mapping and analysis of a process, allow the introduction of changes and the monitorization in order to reduce waste and improve efficiency [8]. Lean tools can be divided into different categories according to various criteria [9], depending on their focus [10], following Lean principles [11], or in compliance with the PDCA cycle. In the last case, the tools used in the analysis of processes consists of: VSM (Value Stream Mapping), SIPOC (Supplier, Inputs, Process, Outputs, and Customer), Pareto analysis, the Ishikawa Diagram, Flowcharts, Histograms and the Spaghetti Diagram [12]. Other tools designed to support Planning include: Hoshin Kanri, KPIs definition, PDCA and FMEA (Failure Mode and Effect Analysis). In addition, there are tools which promote operation changes: 5S, Kaizen events, Kanban, Poka-yoke, and SMED (Single Minute Exchange of Die). Finally, there are tools to monitor the processes' performance: Control Charts, the Scatter Diagram, Six Sigma, OEE (Overall Equipment Effectiveness) and Time Analysis [13]. There are many examples of the practical implementation of these tools. The flowchart, for instance, has proved to be very useful in different circumstances [14]. It can represent the programming of a single machine, explain a sustainable production system [15], even provide a greater understanding and improvement of the quality of a health service [16], or describe a certain work methodology [17]. Through the VSM and the subsequent implementation of SMED in the process of a company in the cork sector, tool changeover time was reduced by 43% [18]. The integration of SIPOC and VSM generated a new tool, and reduced the time needed for a recruitment process from 69 days to 25,5 days [19]. Some limitations have been detected in VSM; they are related to the impossibility of mapping complex processes or industries which have thousands of references just by using a pencil and paper. As an alternative, the Process Mining method was proposed: by crossing the data processing with the Lean waste identification, one will obtain useful information about the process and its performance [20]. In Lean thinking, the Value for the client is the quality of a product or service delivered within the deadline, and which meets the customer's requirements [21]. Waste refers to everything that adds no value to the product; namely, when cost and time are added but the client is unwilling to pay for them [22]. The seven types of waste identified by the Toyota Production System consist of: Excessive Transportation, Inventory and Motion, the existence of Waiting Time, Rework, Overproduction and Defects [23]. Current studies have pointed out new additional types of waste such as the underutilization of employees' skills [24, 25] and environmental impact [26]. Within the perspective of Value, one can classify process activities as being Value-Added Activities (VAA) when these operations transform the product or service, but the client is willing to pay for them. In the case of Activities of No Added Value but Necessary (ANAVN), these should be minimized. Lastly, there are the Activities of No Added Value which are Unnecessary (ANAVU). These consist of tasks resulting from failures in the process or the company's inefficiency, which must be eliminated or reduced [21, 27]. At a textile company, the production process of an article was mapped through VSM and different types of waste were detected. By using software to support decision-making and prioritize the waste in question and, after drawing up a future VSM version, several actions were proposed to eliminate priority waste [28]. Another study sought to identify the reasons for delays in communication between surgeons and doctors at a hospital. By resorting to flowcharts, as well as the Ishikawa Diagram and XY matrix, the causes of delays were identified. In this case, the proposals put forward included redesigning the processes and creating a smartphone application, so that the parties involved could view the treatments prescribed for each patient. Errors in communication were thus reduced and processing time dropped from 97 hours to approximately 11 hours [29]. Another case demonstrated that, by analyzing the process with the support of quality tools and the FMEA tool, it was possible to improve an existing process which provided support for retained students at a university [30]. The constant revision of technical drawings in a special machinery manufacturer often led to the existence of outdated versions being used in shop-floor causing severe problems. The problem was studied and, by using information technologies and digital support devices accessible to all those involved, drawings were updated in real time, thus reducing defects the required time for project and production [31].

4. Mapping and analysis of the order fulfilment process through different approaches

The four analysis methods selected, which are described in Fig. 1, identify value, flows and waste in accordance with the Lean perspective.

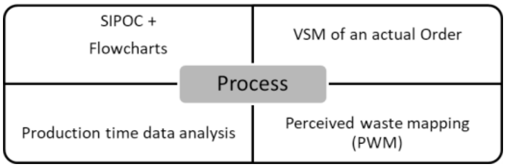

Fig. 1. Four selected methods for process analysis.

4.1. Mapping of the process and analysis of its components using sipoc and flowcharts

The analysis of the process was undertaken by itemizing the different components which usually constitute a process on a SIPOC map, as is presented in Table 1. Data collection was carried out through a questionnaire which was made to the participants in the process, and it was based on the 5W2H technique (What?, Who?, When?, Where?, Why?, How?, How long?) [9]. By going to all the locations where the process activities took place, and where its resources interacted, one was able to characterize the process and its elements, as well as draw up a flowchart of its flows.

Table 1. SIPOC map for the order fulfilment process.

Suppliers	Inputs	Process	Outputs	Customers
External entities Suppliers, Clients, Companies from the holding **Internal entities** Warehouses, Employees, Production Sections, Planning, Commercial Department	**Materials** Raw materials (steel, aluminium, technical plastics and mechanical components), Customers' materials and subsidiary materials **Services** Subcontracts, sandblasting, painting, heat treatments, **Information** Manufacturing orders, verbal instructions, Drawings, shipping documents, invoices	**Subprocesses** Recording of a request for quotation, Sorting, Budgeting, Opening of work, Preparation of materials, Preparation of manufacture, Supplies, Production, Recording of times, Evaluation, Dispatch and Billing **Resources** The organization, staff, machines, Facilities, layout, Warehouses, Logistics, information systems **Activities** Register, calculate, transport, milling, grinding, turning, welding, boring, packing, deburring, painting, etc.	**Materials** Finished mechanical components, welded structures, repaired components, another waste scrap **Services** Assemblies, Engineering Projects **Information** Shipping and billing documents, dimensional inspection records, material certificates	**External entities** Customers, Companies from the holding **Internal entities** Warehouses, Employees, Production Sections, Planning, Commercial Department

The representation of the process through flow charts revealed the absence of continuous flow and standardized procedures. It also allowed for the identification of the principal sub-processes and resources, as well as their main problems (Table 2).

Table 2. The identified sub-processes and their main problems.

Sub-process	Problem description
Recording of Customer's Request	• The recording of requests consists of too many stages, which demand considerable time and effort to execute.
Assessment and Screening	• Screening is carried out intuitively, since there are no specified criteria
Quotation	• The current system is slow and rejects complex quotations or with many references
Record of work and Issuing of Manufacturing Orders	• The issuing of Manufacturing Orders (MO) is a lengthy task, and contains little information • The Work and its respective MO are not integrated within a Production plan
Preparation of Materials	• Material requirements are not registered in the ERP (Enterprise Resource Planning), thus complicating inventory management and the processing of orders to suppliers
Supplies	• Material received or which circulates internally is completely unidentified • There is no registration of material or tool movement between warehouses and production
Planning of Work	• Tardy definition of the manufacturing method and resources required
Production	• Manufacturing management is not centralized, thus causing failures in deadlines • There are no procedures in place to ensure dimensional control and quality checks
Record of Times	• Handwritten production times are often illegible or incorrect • The spreadsheet allows incorrect data to be recorded, which misrepresents real work results
Results of Work	• Lack of a system to provide a quick calculation of real results and deviations for each work
Shipping and Billing	• There is no employee responsible for the logistics of shipping and the reception of materials

After an analysis of process, Resources was undertaken, it is pertinent to highlight the information contained in Table 3.

Table 3. Problems detected in process resources.

Resource	Problem description
Internal Organization	• There is no organization chart, no description of task duties, and no responsibility for some activities
Staff	• Insufficient number of human resources possessing adequate technical and academic training
Production Equipment	• Outdated machine pool, which requires maintenance • Many of the machines are not used or seldom used
Premises and Layout	• The premises are in a state of disrepair, thus affecting the performance of resources • Obstructed corridors in the sector for welded structures
Logistics and Warehouses	• Specific area not allotted for the storage of handling equipment • Finished products, raw material and scrap are jumbled and untidy • Disorganized tool warehouse
Information Systems	• Computers and production machines are not connected to an internal network • The absence of a production management system which includes a record of times

Before the implementation of improvement actions, the information gathered through this method allowed one to draw up flowcharts for the process and sub-processes, with a view to the future expectations of activities.

4.2. Mapping the value stream of an actual order

For the second method, one proceeded with the VSM of an actual order starting the analysis by distinguishing the features of orders produced by the company for the year 2016. The processed orders were found to be rather heterogeneous: by using histograms and the Pareto analysis it was able to conclude that 79% of the orders took up 23% of the total number of hours, and that just 1% of the work manufactured consumed 24% of production time. It was also determined that approximately 80% of the work carried out involved between one and four distinct operations. One then decided to plot an order of greater complexity, which had been produced in 2017 and was already concluded so that the observation would not interfere with the process. The chosen order was the manufacture of a base for a tool to control automotive parts which implied the execution of seven added-value operations. One then collected estimated and real data relating to production: dates, production times and used resources. Subsequently, one proceeded with the drawing up of a planned and real chronogram of work, which is presented in Fig. 2.

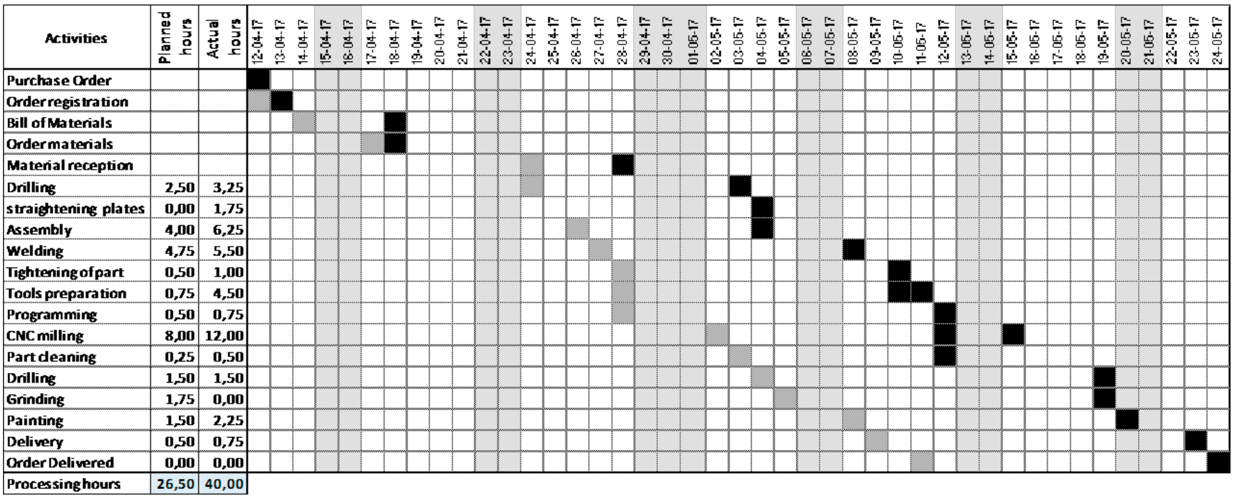

Fig. 2. Lead time chronogram: Planned time (grey) and actual time (black).

After consulting the employees who participated in this job process, the VSM was drawn to identify Value and the main interactions involved in the process. Once Fig. 2 and Fig. 3 were analysed, it was able to conclude that there had been an increase in production time: from the 24,5 expected hours to 38,25 hours. Predicted Lead time was set at 30 days, and increased to 42 days, which was largely due to longer waiting times between operations (from 61 to 96 hours). The arrival of material was not transmitted, thus delaying the start of manufacture, and the operation of rectification thus was not executed. In addition to this, the raw material was warped. It was corrected internally instead of being replaced by the supplier. With regard to the creation of value, 28% of the Lead time (38,25 hours) was considered to constitute added value, whereas the remaining 72% of the time was spent on no value-added activities. A cause-effect diagram was subsequently used to identify the causes of the problems, which was then concluded with the drawing up of an expected VSM.

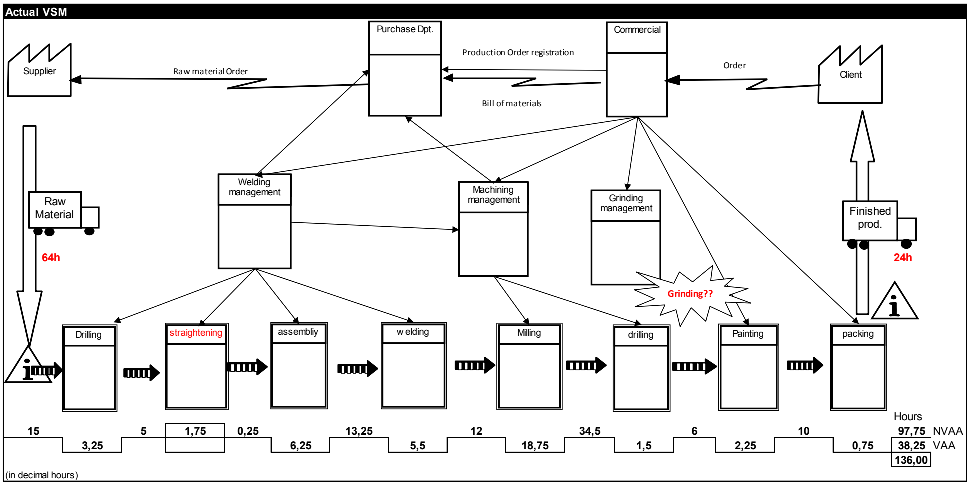

Fig. 3. Value stream mapping of the order as it was produced.

In Fig. 4, the most considerable change resides in the appointment of a Production manager, who will coordinate all the sectors. Furthermore, systems have been adopted to support Planning and Production control which, besides collecting the predictive and real data of orders, will also carry out planning for each of the Manufacturing orders.

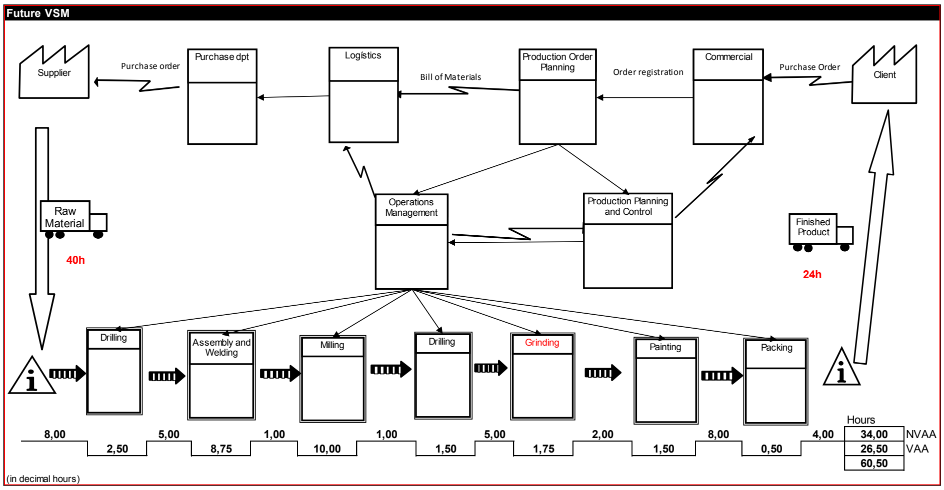

Fig. 4. VSM of the expected future state of processing for the work analyzed.

4.3. Analysis of the creation of value for the process through an analysis of production times

A record of production times constitutes an important data source when analyzing the Production sub-process. It includes flows, the creation of value and the performance of all the intervening parties – Employees, Machinery and Tasks. In this context, one evaluated the reliability of the existing data by analyzing records from the year 2016. By doing so, one concluded that there were problems in the data itself due to its absence or mistakes in the inserted codes. Incorrect records amounted to approximately 22% of a total sum of 28.360 working hours. This number must be taken into account when drawing conclusions related to value creation. In a second phase, one sought to identify the time spent by the company both on value-added activities, as well as on those which are considered wasted time.

Table 4. Classification of times and activities relating to the creation of value.

Type of value	Task description	Hours	%
Added-Value Activity (AVA)	Milling, grinding, welding, drilling, turning, painting, …	23.746	84%
No added-value activity necessary (NAVAN)	Maintenance, tool setup, parts setup, workplace cleaning	3.295	12%
No added-value activity unecessary (NAVAU)	Waiting for work, idle time due to failures, …	1.023	4%
Without task or with errors	Other non-specified	296	1%
	Hours worked in 2016	28.360	100%

According to the presented data in Table 4, the no added-value time amounted to 16%, and the time spent on added-value activities corresponded to 84% of total hours. However, these percentages seem to be rather optimistic: they do not reflect what was observed on the shop-floor and do not coincide with operators' reports. The company possessed 27 machines in the year 2016. Analyzing the production times of each machine one discovered that five of these did not operate at all and 14 were used for only 864 hours. Near 52% of the machines represented only 3% of the working hours. This information reveals efficiency problems chiefly due, namely to obsolete machinery, machines that must be repaired, while others are used only as a support for maintenance.

4.4. Examination of micro- Inefficiencies through perceived waste mapping (PWM)

Observing the company's activity on the shop-floor it was able to conclude that some of the activities that do not add value to the process were not registered by employees on the manufacturing times due to their short duration. For a better study of this subject, a tool was developed to enable mapping micro-inefficiencies in detail. The tool is based on information provided by each operator regarding his perception of potential problems, their rate of occurrence and the time estimated for each event. Named as Perceived Waste Mapping (PWM), this tool analyzes activities at a specific workstation and consists of the following steps:

- Identify the stages of the production process at a workstation;
- Identify, for each stage, the problems which may arise;
- Obtain an estimate of how often each problem occurs;
- Obtain an estimate of the average time spent when each problem occurs;
- Calculate how many hours each operator spends on each problem over a one-year period;
- Analyze the results obtained, and compare these to similar workstations or to previous time periods.

Table 5. Perceived Waste mapping and calculation of a milling workstation.

			Year	Months	Weeks	Days	Failure average time (minutes)	Hours / Year
			1	12	46	230		
Stage	**Problem location**	**Problem description**	Times per year	Times per month	Times per week	Times per day		
Before milling	Production Orders coordination	The new PO forces the interruption of ongoing work		2			20	8
		The operator was idle while waiting for a new Order		3			30	18
	Drawings and Instructions	The Operator waits for clarification of technical queries			8		20	123
	Machine programming	The operator waits for the machine program			2		20	31
		Technical Problems affects Machine Programming		2			30	12
	Making Tools Available	The operator must move to obtain tools				3	5	58
		The operator has to look for tools that are off site			3		10	23
		Tightening tools or jigs must be manufactured		2			120	48
		The operator waits for tools to be delivered by the supplier	2				480	16
		The operator waits for tools to become available		6			30	36
	Transport and materials placement	The operator waits for supplies		4			60	48
		The operator must move to obtain materials			4		5	15
		Awaiting for transporting equipment to move cargo			6		10	46
		Transportation equipment is not on his place			5		4	15
		Long path or obstacles delays transportation			5		5	19
		Unsuitable or damaged equipment delays operation			4		3	9
During milling	Material to be processed	The material has unexpected surpluses, hardness or bends		8			10	16
		Material is not clean or deburred on arrival			3		20	46
		Defective material requires its replacement	5				60	5
		Unsuitable material results in longer operations		1			20	4
	Machine performance	Unsuitable machine results in longer operations		3			20	12
		Machine problems delays manufacture			5		15	58
		Machine malfunctions - the operator awaits for repairing		4			120	96
	Tools performance	Less appropriate tools delay manufacturing			3		10	23
		Poor tool quality or poor condition			6		15	69
	Operator performance	The operator has difficulty in some operations		6			15	18
		Operator errors require rework	6				180	18
	Technical support	The operatorstpsmanufacture to clarify queries			3		12	28
	workplace conditions	Worstation location and dimension delays operations				1	3	12
		The lack of cleanness and order affects operations				2	3	23
After milling	Dimensional Control	The tools are not on their place		6			8	10
		The operator awaits the availability of the tools			2		15	23
		Damaged or uncalibrated control tools	4				30	2
	Removing the processed product	Awaiting for transporting equipment to move cargo			3		10	23
		Transportation equipment is not on his place			5		5	19
		Long path or obstacles delays transportation				3	2	23
		Inadequate or damaged transport equipment delays operation		5			8	8
							Total hours/year	1.059

In the example presented in Table 5, the tool was used to analyze the performance of a milling workstation. Through observation and collaboration with the operator, one was able to determine the stages of the process, as well as the problems which could occur during each of these stages. Subsequently, one identified 13 main stages as well as 38 of the problems which occur most often during the execution of tasks in this process. One then established the frequency of occurrence for each problem, according to the operator's opinion, and the average time of each event in minutes. This rate can be determined annually, monthly, weekly or daily, and is calculated for periods of 1 year, 12 months, 46 weeks or 230 working days. Despite depending on the operator's perception of events, this tool allows to identify which tasks are No Value-Added Unnecessary activities (NVAU) and thus generate most waste, as well as the number of hours they potentially consume on an annual basis. For this example, one calculated a figure of 1.059 annual hours of waste per operator. This means that the remaining 781 hours are dedicated to Value-Added Activities (VAA) and No Value-Added Necessary activities (NVAN). Using this value as a reference, and the 12% of NVAN hours obtained for the year 2016, one might extrapolate that the operator will need to spend 94 hours on these activities. In addition, the time required for value-added activities is estimated to be 687 hours. One can thus determine that the efficiency ratio for the milling workstation will be 37% (687/1.840 hours). This means therefore that the existing system omits many aspects of inefficiency mainly because the operator does not register a few minutes keeping them mostly hidden in the Value-Added hours. Analyzing the data and chart of Fig. 5 one can conclude that it is a priority to intervene in activities such as the tools availability, internal transport and machines performance.

stage	Step	Hours	Hours
Before processing	Manufacturing coordination	26	525
	Drawings and Instructions	123	
	Machine programming	43	
	Making Tools Available	181	
	Transport and materials placement	153	
During processing	Material to be processed	71	427
	Machine performance	166	
	Tools performance	92	
	Operator performance	36	
	Technical support and monitoring	28	
	Workplace conditions	35	
After processing	Dimensional control	35	108
	Withdrawal of the processed product	73	
	Annual wasted hours	1.059	1.059
	Annual predicted working hours	1.840	
	Waste ratio	57,6%	
	Added Value ratio	42,4%	

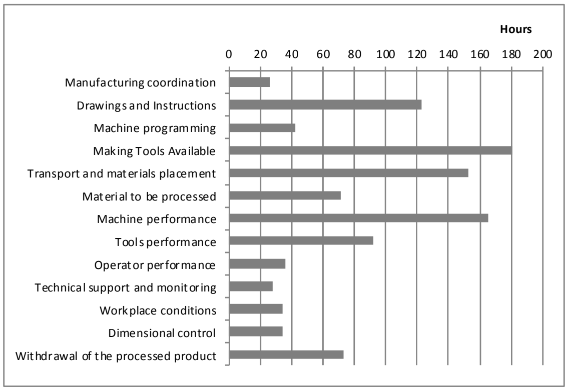

Fig. 5. Perceived waste analysis.

5. Discussion of the results obtained and tools used

The examination of the results obtained through each of the four methods used enables one to assert that they are complementary. The information produced is not redundant, provides varying degrees of detail and allows one to build a multidimensional picture of the process studied, all of which can be seen in Table 6.

Table 6. Description of the features of the information obtained from each analysis method.

Method	Type of information
SIPOC, Flowchart	Qualitative information based on the observation and opinion of the intervening parties. Evaluates problems related to the organization and process structure, state of resources, and identifies the need for rules and procedures to enable flow improvements
VSM	Quantitative information concerning the process, with a greater focus on the identification of value across the process and the improvement of Lead time
Production time data	Quantitative information based on actual data with a great focus on the production sub-process. Allows for an assessment of the company's information system and the quality of the information.
Perceived Waste Mapping	Quantitative information based on the subjective opinion of the operator regarding the process at his workstation, thus identifying micro-problems which affect performance. Allows one to establish standards and schedules which, when implemented periodically, will generate a performance indicator for each workstation. This will also enable a comparison with real data or with other workstations.

Three of the methods used allowed one to quantify the creation of value and the level of efficiency of the process. In this case, efficiency is understood as the ratio between the number of Value-Added hours and the number of total or available hours worked. As can be observed in Table 7, the percentage of Value-Added work hours differs considerably in method 3 (84%); this is explained by the errors and problems in the sub-process which records production times. The other two methods present data that is closer to the result obtained (28% and 37%), and will act as future indicators in the assessment of efficiency.

Table 7. Percentage of the process efficiency according to each method.

Activities linked to the creation of value	Method 1 SIPOC, Flowchart	Method 2 VSM	Method 3 Production time data	Method 4 Perceived Waste Mapping (PWM)
Value-Added Activity (VAA)	N.A.	28%	84%	37%
No value-added activity Necessary (NVAN)	N.A.	1%	12%	5%
No value added-activity Unecessary (NVAU)	N.A.	71%	4%	58%
Total time in %		100%	100%	100%

6. Conclusions and suggestions for future studies

The four methods selected and used in the process of mapping and analyzing the order fulfilment process led to distinct contributions, which are relevant to the description of the process characteristics and problems detected therein. One was thus able to consider these from various perspectives and at different levels, making it possible to detect the problems and causes in the order fulfilment process from different angles. By means of VSM and PWM, one was able to demonstrate that the efficiency ratio of 84%, namely the comparison of value-added hours with the hours worked, which had been determined by production time records at the company, was incorrect and that effective efficiency points to a figure closer to 30%. Consequently, one recommends testing and optimizing the PWM tool in order to gain a better understanding of its potential in mapping and analyzing process performance in the context of a workstation, as well as complementing these methods with other Lean tools such as FMEA and VSM. Future studies relating to the process would include defining priority issues and the manner of addressing these. In addition, various solutions and ways of intervening in the process should be identified, with the subsequent selection and incorporation of measures considered to be the most efficient. These must then be integrated within a structured plan which would, finally, be implemented and duly monitored.

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