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Waste Identification Diagram and Value Stream Mapping: A Comparative Analysis

Abstract

Purpose – The aim of this paper is to compare the well-known Value Stream Mapping (VSM) with a recent tool named Waste Identification Diagram (WID), regarding the capacity of information representation and easiness of interpretation.

Design/methodology/approach – The work begins with a brief literature review comparing the main tools for representation of production units, with special emphasis on VSM and WID, in terms of ability to identify several types of waste. Then, the authors developed the VSM and the WID of a specific production unit and after that several groups composed by students of Industrial Engineering (IE) and/or professionals from industry were asked to analyse / interpret only one of these diagrams. Finally, a questionnaire with closed and open questions was applied to the groups in order to evaluate the analysed tool.

Findings – In general, the results revealed that WID is more effective than VSM and participants recognized that most of the WID elements are relevant. Specifically, a measure coined overall effectiveness was applied (based on the response time and percentage of correct interpretations), indicating a clear advantage of WID (22% of correct interpretations per minute) compared to VSM (9% of correct interpretations per minute). The main drawback pointed to the WID is the lack of representation of the information flow.

Originality/value – This work contributes to the IE field by revealing WID as a new promising graphical tool for representation of production units, especially in terms of identification / quantification of wastes. The tool was quantitative and qualitatively evaluated by persons both from academia and industry.

Keywords - Lean manufacturing, Performance measurement, Production improvement, Questionnaires, Value Analysis

1. Introduction

The identification and evaluation of all forms of production waste, i.e. non-value adding activities (Ohno, 1998; Coimbra 2009), is a crucial element for the process of improving the companies' competitiveness. In fact, that allows a more effective selection of the improvement opportunities that lead companies towards their goals, in a systematic way. However, while identifying the current state of production units in an a accurate way, one is often confronted with the need to have an adequate tool to represent where production waste occur in the plant and how large they are. Thus, the great motivation of this work is the study and analysis of tools to represent waste in productive processes, in order to add value to the body of knowledge inherent to both academic and industrial community working in this area.

From all the existing tools able to represent production units and provide aid in identifying production wastes, the most popular in the context of lean manufacturing is the Value Stream Mapping – VSM (Rother and Shook, 1999). However, VSM has some limitations (section 2.2) and thus an alternative tool called Waste Identification Diagram (WID) was proposed by Dinis-Carvalho *et al.* (2014). WID was specially designed not only to overcome some of the VSM drawbacks but also to be more effective in the representation of production wastes and performance.

The general objective of this paper is to compare the VSM and the WID diagrams in terms of the speed and correctness of the interpretation of the data represented, based on a questionnaire applied to industrial engineering students (IE) and IE professionals (section 3). Other aspects are addressed, namely the ability to (i) identify and assess production wastes related to people and (ii) represent the available capacity, production layout and key characteristics (e.g. setups and bottlenecks).

The paper is divided in 5 sections. After this introduction (section 1), section 2 presents a brief literature review about representation tools in general, for the manufacturing systems area, and VSM and WID in particular. Section 3 describes the methodology adopted in this work. Section 4 presents and discusses the achieved results. Finally, on section 5, the main conclusions are outlined.

2. Literature review

Womack and Jones (1996) defined five principles that underpin the Lean Production concept: (i) creation of value; (ii) identification of the value stream; (iii) continuous production flow; (iv) implementation of a pull system; and (v) pursue of perfection. All those principles push forward the fundamental need for waste elimination and continuous improvement. The concept of shop floor waste (muda in Japanese) is defined as any activity that does not add-up to the products' value, and for that reason is very unlikely that the customer is willing to pay for it (Ohno, 1988; Shingo, 1989; Womack & Jones 1996). All forms of waste intrinsically relate to the concept of value, therefore in order to recognize the occurrence of wastes it is fundamental to identify and separate the activities that add value from those that do not.

2.1. Production systems representation tools in general

To add value to products and services, organizations rely on processes and activities (Hunt, 1996), that must, obviously, be properly managed using adequate techniques. These techniques should allow the analysis, diagnosis and improvement of important aspects of processes and activities, namely: (i) cost, (ii) cycle time, (iii) quality, (iv) flexibility and (v) reliability. Several graphical tools are available to assist the analyst in the process of representing, analysing and diagnosing production units, but they are usually dedicated to specific aspects. Some tools are primarily focused on the representation of production layout and routes, others are intended to represent the worker's movements, while others are just focused on the production flow of particular products or particular product families (Dinis-Carvalho et al, 2014). The identification of waste is a crucial step towards waste elimination or at least waste reduction. In fact, the reduction of cost through waste eliminations was stated by Sugimori, Kusunoki, Cho, and Uchikawa (1977) as one of the two most important concepts of the Toyota Production System. Table 1 presents the main graphical tools, found in the literature, for production units' representation, indicating the waste types that each one is able to represent in the context of the seven classic waste types defined by Ohno (1988). Only these types of wastes, typically found in the production of goods, are considered in the context of this work, although other important types of waste relevant to the services area (Gupta, Sharma, and Sunder, 2016; Sunder, 2016) could also be considered.

Table 1. Main graphical tools for representation of production units.

Tool	**Types of waste represented**
Flow Process Chart (ASME, 1947)	Transportation; Inventories.

Flowchart Map (Barnes, 1968)	Transportation; Inventories; Motion.
Spaghetti Diagram (Neumann & Medbo 2010)	Transportation; Motion.
Model of Supply Chain and Waste (Hicks et al, 2004)	Transportation; Defects.
Process Activity Mapping (Barnes, 1968)	Transportation; Inventories; Motion; Waiting; Overproduction.
Supply Chain Response Matrix (New, 1993)	Inventories; Overproduction.
Production Variety Funnel (New,1974)	Inventories.
Quality Filter Mapping (Hines & Rich, 1997)	Defects.
Demand Amplification Mapping (Forrester, 1958)	Inventories; Overproduction.
Decision Point Analysis (Hoekstra e Romme, 1992)	Inventories; Overproduction.
Physical Structure (Miles, 1961)	-
Value Stream Mapping (Rother e Shook, 1999)	Transportation; Inventories; Overproduction.
Waste Identification Diagram (Dinis-Carvalho et al, 2014)	Transportation; Inventories; Motion; Waiting; Defects; Overproduction.

2.2. Value Stream Mapping

Lean manufacturing professionals often use a specific diagnostic tool to identify production wastes and to help them in the establishment of a plan of improvement actions. The objective is to eliminate, or at least reduce, activities that do not add value to the product (i.e. wastes) and, obviously, the customer is not willing to pay (Rother and Shook, 1999). In most cases the applied tool is the VSM, which assists the visual identification of productive resources, their use and inherent wastes (Tapping et al, 2002).

The VSM is an adaptation of the original technique from Toyota named "materials and information flow diagram", being used to represent and analyse all processes and activities (both “adding” and “not adding” value), allowing the quantification of production time and the identification of opportunities for improvement (Rother and Shook, 1999). An important characteristic of the VSM is its visual nature, allowing for a quick assessment of the state of the production process.

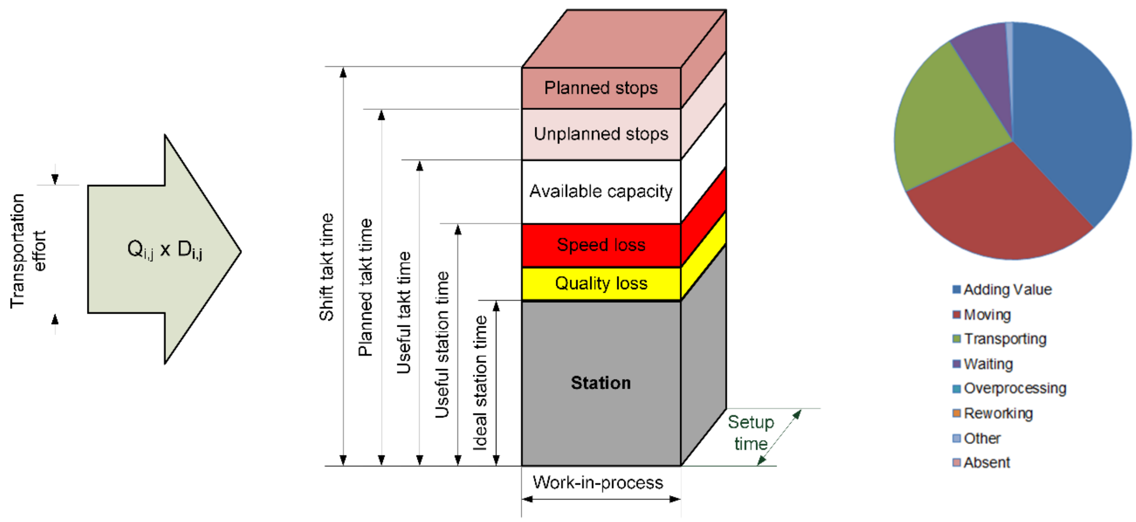
Several authors, e.g. Womack et al. (2004), Abdulmalek and Rajgopbal (2007), Rahani and Muhammad (2012), Teichgraber and Bucourt (2012) and Sá et al. (2011), point out the importance of VSM in the context of lean manufacturing implementations. However, other authors, e.g. Lian and Van Landeghem (2007), Serrano et al. (2008), Xinyu and Jian (2009), Kemper et al. (2010), Singh et al. (2011), and, Teichgraeber and Bucourt (2012), consider that VSM has also some limitations. More specifically, Sá (2010) and Nogueira (2010), refer: (i) inability to represent different production flows, (ii) difficulty of being used by those who are not familiar with the tool, (iii) absence of graphical indicators for transport, queues and movements due to the layout, (iv) absence economic indicators, (v) absence of layout representation, and, (vi) does not reflect the bill-of-materials of the product.

2.3. Waste Identification Diagram

The WID is a new tool, aiming to overcome some of the VSM drawbacks, being developed at the Department of Production and Systems, School of Engineering, University of Minho - Portugal. The WID uses an innovative approach, which includes the use of the physical size of the symbols to transmit relevant information about the state of the production unit, in a very quick and intuitive way (Dinis-Carvalho et al. 2014). The proposed initial challenge was to develop a tool able to:

- Represent all the production flows in the production unit (not just the flow of a particular family of products).
- Show and evaluate all types of waste in a visual and intuitive manner.
- Provide effective visual information.
- Provide information on performance.
- Be a reference tool for continuous improvement.

The WID is essentially composed by blocks, arrows and a pie chart. The blocks represent stations (workbenches, machines, equipment or even sectors), the arrows represent the transport effort required for moving the parts from one station to another (Sá, Carvalho and Sousa, 2011), and the pie chart depicts the workforce activities, i.e. how the workers spend their time (Figure 1).



(a) (b) (c)

Figure 1. Main symbols of a WID: (a) transportation effort (arrow), (b) station (block), (c) workforce occupation (pie chart).

Figure 1 shows how the dimensions of the station symbol (block) are employed to represent different types of information, more specifically:

- Work In Process (*WIP*)
- Shift Takt Time (S_{TT})
- Ideal Station Time (I_{ST})
- Setup Time (S_T)
- Planned Takt Time (P_{TT})
- Useful Takt Time (U_{TT})
- Useful Station Time (U_{ST})

The WIP can be measured in parts, Kg, currency, etc. Note that the difference between UTT and UST provides a measure of the idle capacity of the station. Furthermore, according to Little's law (Litlle, 1961), the frontal area of the bottom part of block represents the ideal lead time inherent to the station. According to Dinis-Carvalho et al. (2014), the useful takt time UTT is calculated by:

$$U_{TT} = \frac{S_T-(P_S+U_S)}{Q} \quad (1)$$

where S_T represents the shift time, P_S the planned stops, U_S the unplanned stops, and, Q the shift demand. The proposed calculation for the useful station time U_{ST} is:

$$U_{ST} = \frac{I_{ST}}{Q_L \times S_L} \quad (2)$$

where I_{ST} represents the ideal station time (standard time), Q_L the quality loss (%), and, S_L the speed loss (%).

The width of the arrow symbol represents the transport effort required for carrying parts and products between different stations. The length of the arrow has no meaning. The transport effort between station i and station j is denoted by $TE_{i,j}$ and, typically, it is obtained multiplying the quantity of products transported $Q_{i,j}$ by the distance travelled $D_{i,j}$ (Figure 1). However, the transport effort can also be quantified in terms of currency as well as through some metric of the energy consumed.

Lastly, the pie chart depicts the occupation of the workforce according to the following classification of activities: (i) motion, (ii) transport, (iii) setup, (iv) help co-worker, (v) non-added value activity (general), and, (vi) added-value activity (general). The values are obtained using work sampling techniques (Barnes, 1968).

3. Methodology

The methodology adopted in this study can be observed in Figure 2 and involves three types of stakeholders: researchers (the authors), Industrial Engineering (IE) students and IE professionals. Several groups were created (in Portugal and Brazil) and each group might have IE students and IE professionals. However, each group is dedicated to the evaluation of only one of the tools: VSM or WID.

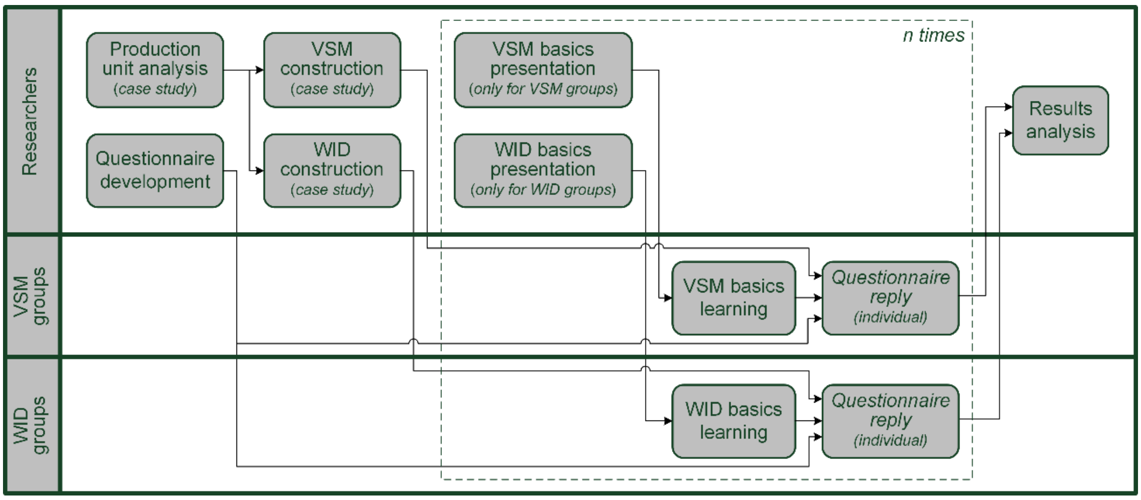


Figure 2. Adopted methodology.

The production unit selected as case study was the assembling section of copper tubes of an air conditioning equipment manufacturer, located in the Manaus industrial area, Brazil. The researchers built the VSM and the WID of this production unit in order to allow the subsequent comparison of those tools performance, through an individual questionnaire applied to the elements of specific groups (VSM and WID groups) previously introduced to the fundamentals of VSM or WID (respectively). The developed VSM and WID are represented in Figure 3 and Figure 4, respectively.

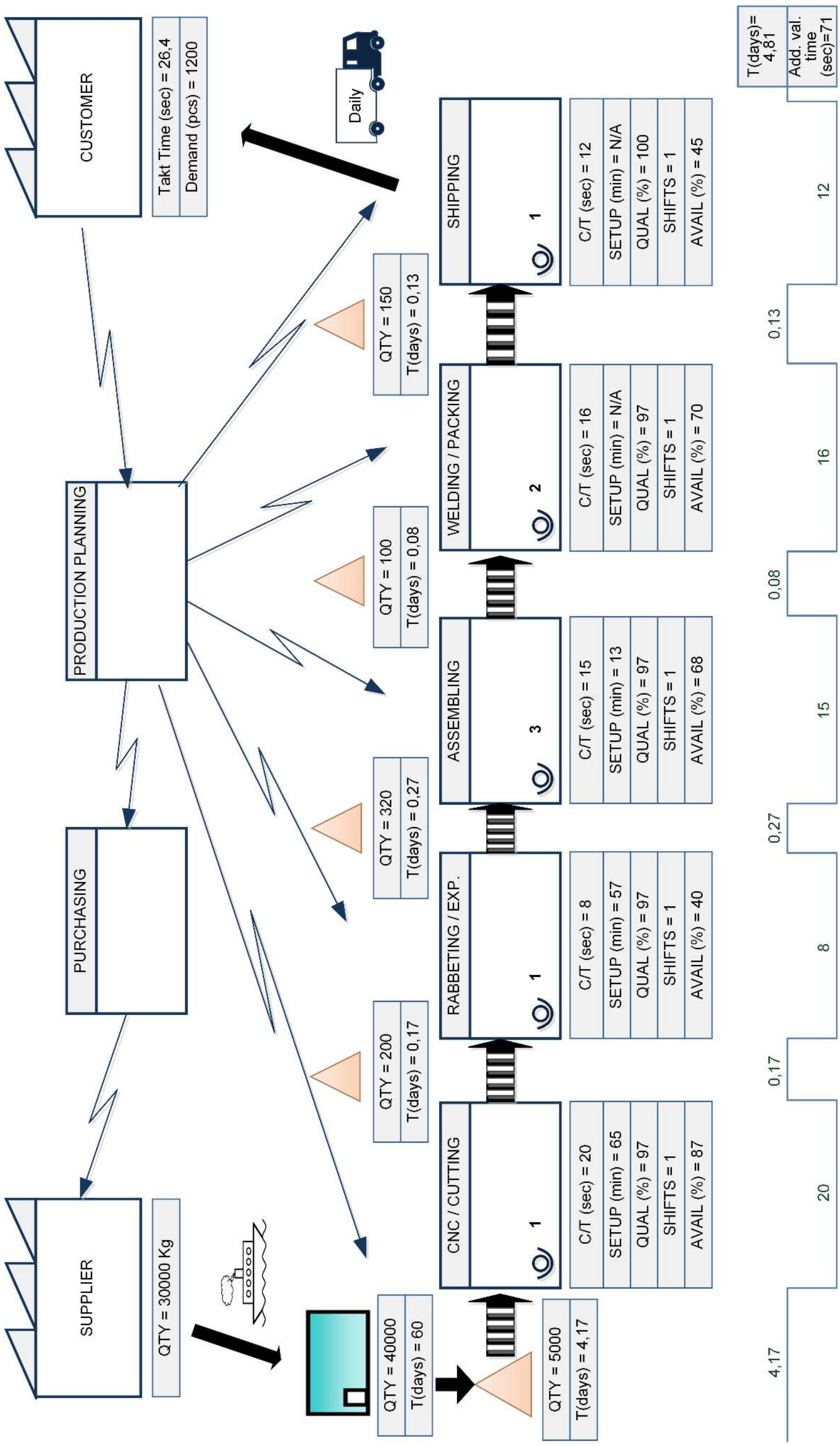


Figure 3. Value Stream Mapping (VSM) built for the comparison case study.

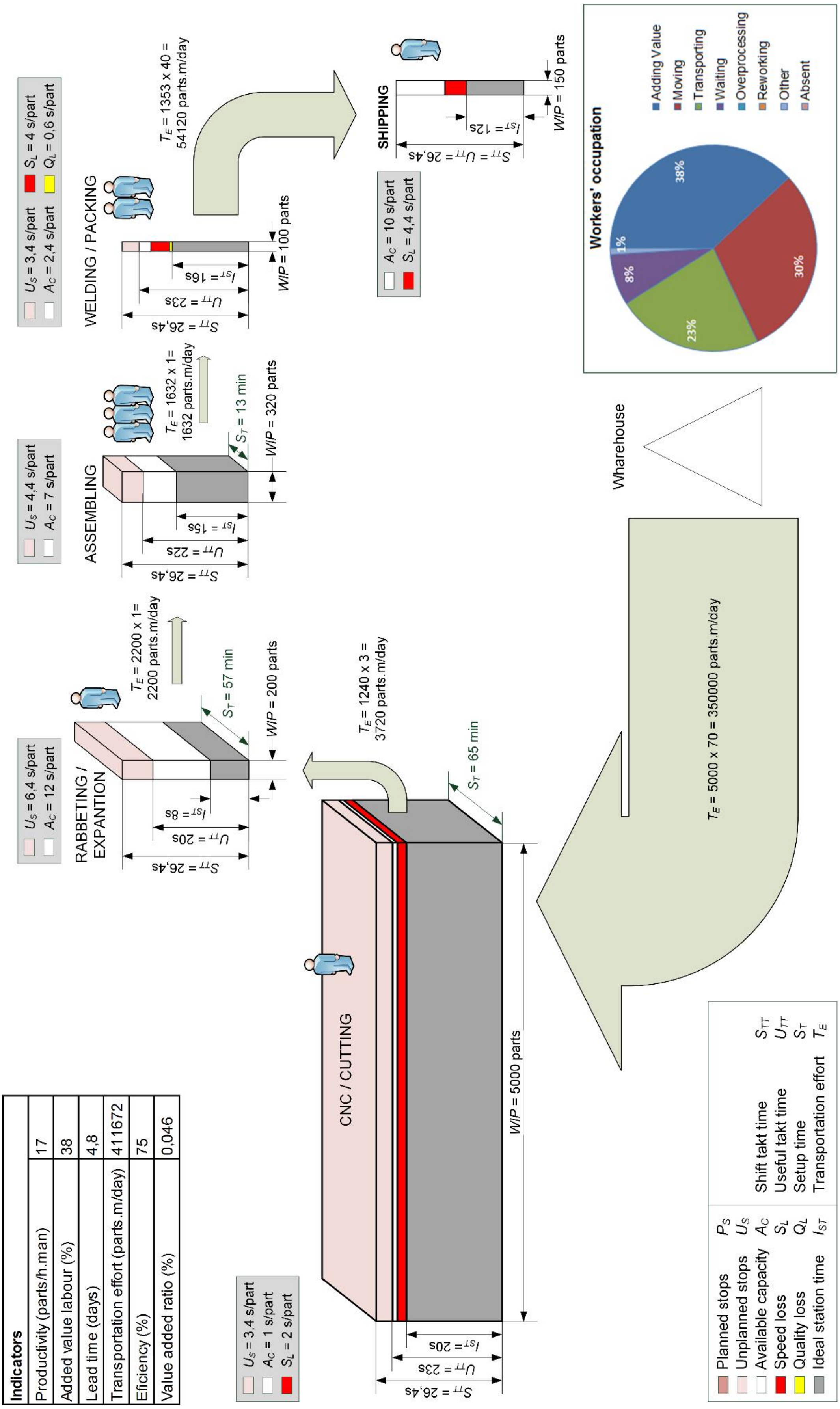


Figure 4. Waste Identification Diagram (WID) built for the comparison case study.

The questionnaire was developed in three stages: (i) design of a preliminary version, (ii) pre-test of the preliminary version and subsequent analysis of comments and incorporation of suggested improvements, and (iii) development of the final version. Besides a short initial part about participant characterization (IE student or IE professional, evaluation of VSM or WID, and, VSM knowledge level), the final version of the questionnaire has two main parts: (A) a set of eight questions concerning the quality of the interpretation of the diagrams' contents (VSM or WID) and (B) a set of eight questions only about WID (based on a 5-point Likert scale, where: 1 - “Strongly Disagree”, 2 – “Disagree”, 3 – “Neither agree nor disagree”, 4 – “Agree”, and 5- “Strongly Agree”, except question B8).

For the Part A the participants (VSM group or WID group) should record the aggregate response time and the set of questions is:

- A1. How many processes are represented?
- A2. How many workers are involved?
- A3. Identify the process(es) with more workers.
- A4. Identify which process(es) is (are) the bottleneck.
- A5. Identify the process(es) with the highest inventory.
- A6. Identify the process(es) with the highest available capacity.
- A7. Identify the process(es) with the highest setup time.
- A8. Identify the process(es) with more planned stops.

The Part B concerns only the WID group and the set of questions is:

- B1. Do you find relevant the inclusion of layout information?
- B2. Do you find relevant the inclusion of information about transportation waste?
- B3. Do you find relevant the inclusion of information about workers’ related waste?
- B4. Do you find relevant the inclusion of information about waste’s costs?
- B5. Do you find relevant the graphic information about cycle times, thickness of transportation arrows, etc.?
- B6. Do you find relevant the inclusion of the table with performance indicators?
- B7. Do you see any advantage on including the workers icons?

- B8. Identify other advantages/disadvantages of WID. Please include relevant comments.

Following the methodology depicted on Figure 2, each group of participants (VSM group or WID group, composed by IE students and/or IE professionals) attended a presentation which included a brief description of the research purpose (evaluation of two representation tools for the manufacturing systems area) and a 15 minutes session about the fundamentals of one of the tools (VSM or WID). Then, the questionnaire was provided to each participant and, according to the type of group, the VSM (Figure 3) or the WID (Figure 4) was projected in a screen. Each participant answered the questionnaire and all the questionnaires were collected at the end of the session. The obtained results are presented in the next section.

4. Results analysis and discussion

A total of 67 valid questionnaires was collected during the experiments following the methodology previously described (section 3). The participation was voluntary and anonymous. Data was processed using the SPSS statistical tool. The non-parametric Mann-Whitney *U* Test, alternative to the *t*-test for independent samples, was used to analyse the differences between the two groups (WID and VSM groups) using a significance level of 5%.

4.1. Participants characterization

Most of the participants were IE students (61,2%, corresponding to 41 students), 22 from Portugal and 19 from Brazil. The remaining 26 participants were IE professionals from Portugal. Some of the participants were asked to evaluate the WID tool (46,3%) and the remaining 53,7% were asked to evaluate the VSM tool. Note that some participants were already somewhat familiar with the VSM but none had any previous contact with WID.

4.2. Percentage of correct answers

In order to understand the performance of the participants in each question of Part A, from both VSM and WID groups, the total percentage of correct answers was computed (Figure 5). A correct answer means that, independently of the response time, the participant has accurately interpreted the concept represented in the diagram (e.g. worst process in terms of WIP – question A5).

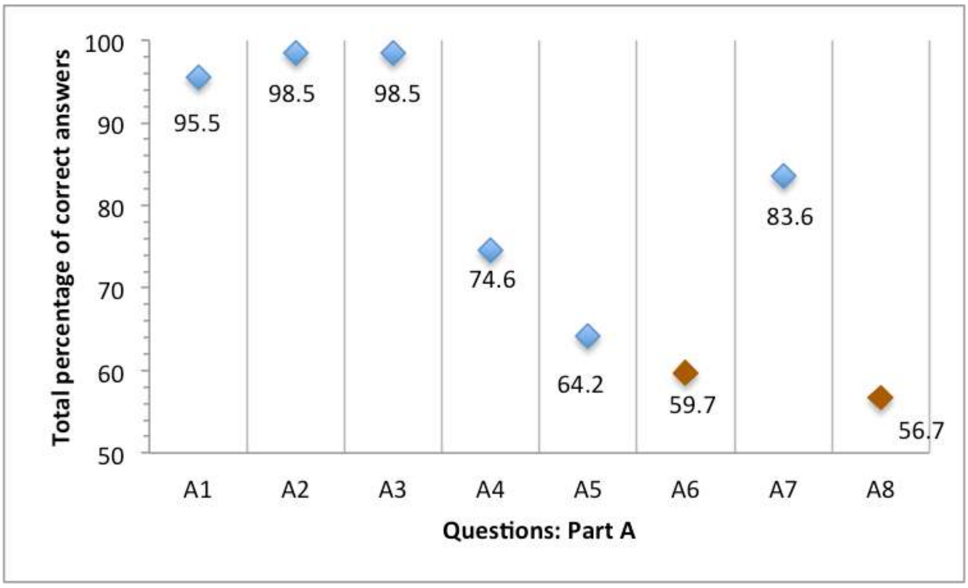


Figure 5. Total percentage of correct answers for Part A questions.

For any question, the total percentage of correct answers is always higher than 50%. The lower percentage of correct answers occurred with the A8 question (*Identify the process(es) with more planned stops*) with 56,7%, followed by A6 (*Identify the process(es) with the highest available capacity*) with 59,7%, and A5 (*Identify the process(es) with the highest inventory*) with 64,2%. For the remaining five questions, the values are higher or equal to 75%. For any question the percentage of correct answers is higher than the percentage of incorrect answers, although for questions A6 and A8 the percentage of correct answers is only slightly higher (p > 0,05).

Table 2 presents the distribution of the percentage of correct answers by category (IE students and IE professionals) according to the groups under analysis (WID and VSM).

Table 2. Percentage of correct answers by category (student/professional).

Question	**Group**						**Statistics**
	WID			**VSM**			
	Student (%)	**Professional** (%)	**Total** (%)	**Student** (%)	**Professional** (%)	**Total** (%)	
A1	100	92,3	96,8**	91,3	100	94,4**	*U*=545
A2	100	100	100**	95,7	100	97,2**	*U*=542,5
A3	100	100	100**	95,7	100	97,2**	*U*=543,5
A4	94,4	76,9	87,1*	60,9	69,2	63,9*	*U*=428,5

A5	94,4	92,3	93,5⁺	52,2	15,4	38,9⁺	*U*=253
A6	94,4	53,8	77,4*	39,1	53,8	44,4*	*U*=374
A7	55,6	84,6	**67,7***	95,7	100	97,2*	*U*=393,5
A8	72,2	76,9	74,2*	34,8	53,8	41,7*	*U*=376,5
Average	88,9	84,6	87,1	70,7	74,0	71,9	
* $p < 0{,}05$; $^{+}$ $p < 0{,}001$; ** $p > 0{,}05$							

Table 2 reveals that students and professionals performed better with the WID tool, except for question A7 (67,7% and 97,2% of correct answers for WID and VSM, respectively). To answer the A7 question (*Identify the process(es) with the highest setup time*) the participants exposed to the VSM example read the setup value indicated in the data boxes underneath the process boxes. On the other hand, for the WID case the participant may simply look at the block's depth (Figure 1) and decide based on the visual appearance. In fact, for the WID example (Figure 4) the depth (setup time) of the processes "CNC/CUTTING" and "RABETTING/EXP" seems to be similar and for that reason the participants may in some cases assume the wrong interpretation.

Table 2 also shows that for the VSM case, professionals have an overall performance slightly better (74,0%) than the students (70,7%). For the WID case, the situation reverses: students perform a little better (88,9%) when compared to professionals (84,6%).

Regarding the percentage of correct answers on the VSM case, the question with worse performance is question A5 (*Identify the process(es) with the highest inventory*) with 38,9% of correct answers in total. In opposition a very good performance was achieved (93,5%) when the same question was applied to the WID groups. The performance obtained by the WID groups is clearly better since a significance level of 1% (Table 2) was used for the statistical analysis. The lower performance of the VSM groups regarding question A5 eventually occurred because the relative position of the inventory icons is not always the same. In fact, in the VSM (Figure 3), the positioning of the inventory icon in the first process is different from the positioning on the other processes.

In terms of performance comparison for questions A4 (*Identify which process(es) is (are) the bottleneck*), A6 (*Identify the process(es) with the highest available capacity*) and A8 (*Identify the process(es) with more planned stops*), the results show a clear advantage of WID (using a significance level of 5% for the statistical analysis).

As for questions A1 (*How many processes are represented?*), A2 (*How many workers are involved?*), and A3 (*Identify the process(es) with more workers*), the results show no difference in performance when comparing the VSM and WID (using the same significance level of 5% for the statistical analysis).

Finally, the only situation where the percentage of incorrect answers (84,6%) was greater than the percentage of correct answers (15,4%) occurred with professionals, while responding to the A5 question in the context of the VSM.

4.3. Response time

The time spent by each of the participants to complete Part A of the questionnaire was recorded. It was assumed that this time is related to the tool's effectiveness to transmit information. The distribution of the response time (in minutes) for both VSM and WID groups is shown in Figure 6.

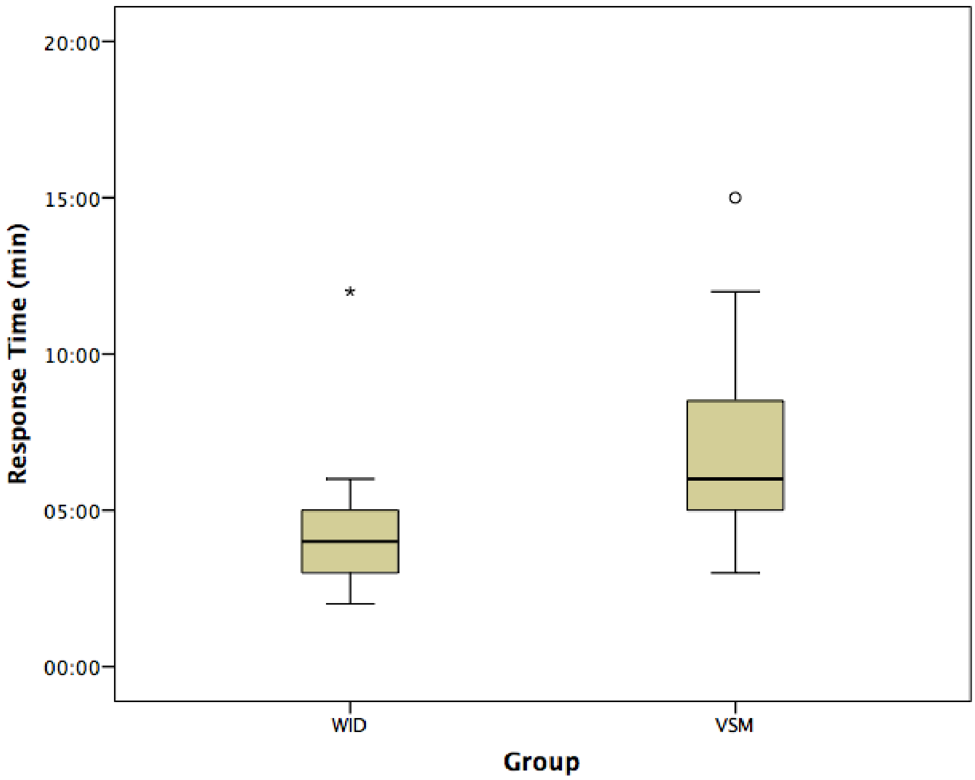


Figure 6. Response time for Part A questions (VSM and WID groups).

Overall, the WID groups need a shorter time to answer the Part A questions (4 minutes in average) and also present a lower variability (ranging from 2 to 12 minutes). The highest registered value (12 minutes) was obtained from a student. This value is considered as an outlier. The second highest value was 8 minutes. For the VSM groups, overall, the response time used was 8 minutes in average, varying from 3 to 15 minutes. As for the WID groups, the highest value measured was obtained from a student and also considered as outlier. The second highest value was 12 minutes. From the results obtained, it can be concluded that the response time for the WID group was statistically significantly lower than for the VSM group (U = 207, p < 0,001).

4.4. Overall effectiveness

An additional indicator is now proposed, based on the two previous indicators (percentage of correct answers and response time, both relative to the Part A of the questionnaire), and will be designated as overall effectiveness. The basis for this performance measure is that if a person needs less time to interpret a diagram X than to interpret a diagram Y, with the same level of accuracy in the interpretation, then the diagram X is more effective in representing the information required. Based on a similar reasoning, if a person requires less time to reach the same level of accuracy in interpreting a diagram *X* than in interpreting a diagram Y, then the diagram X is more effective. A possible way of quantifying this overall effectiveness is through the following equation:

$$Overall\ Effectiveness = \frac{Percentage\ of\ correct\ answers}{Time\ to\ complete\ the\ questionnaire} \quad (3)$$

Table 3 shows the results obtained for the VSM and WID tools, using the data represented on Table 2 and Figure 6.

Table 3. Overall effectiveness for VSM and WID.

	Correct answers (%)	**Time spent** (min)	**Overall effectiveness** (% / min)
WID	87,1	4	21,8
VSM	71,9	8	9

As can be observed, the participants spent less time (in average) in interpreting the WID than in interpreting the VSM and, even though, their interpretation is more accurate (in average). In average, when interpreting a VSM, participants reached only 9% of correct answers per minute, while in the WID case that value rose to 21,8% of correct answers per minute (i.e. an increase of 142%).

4.5. Perceptions about WID

The Part B of the questionnaire is applied only to the WID groups and the purpose is to gather the opinion of the participants about the WID tool (section 3). Figure 7 illustrates the distribution and the range of answers obtained from the participants.

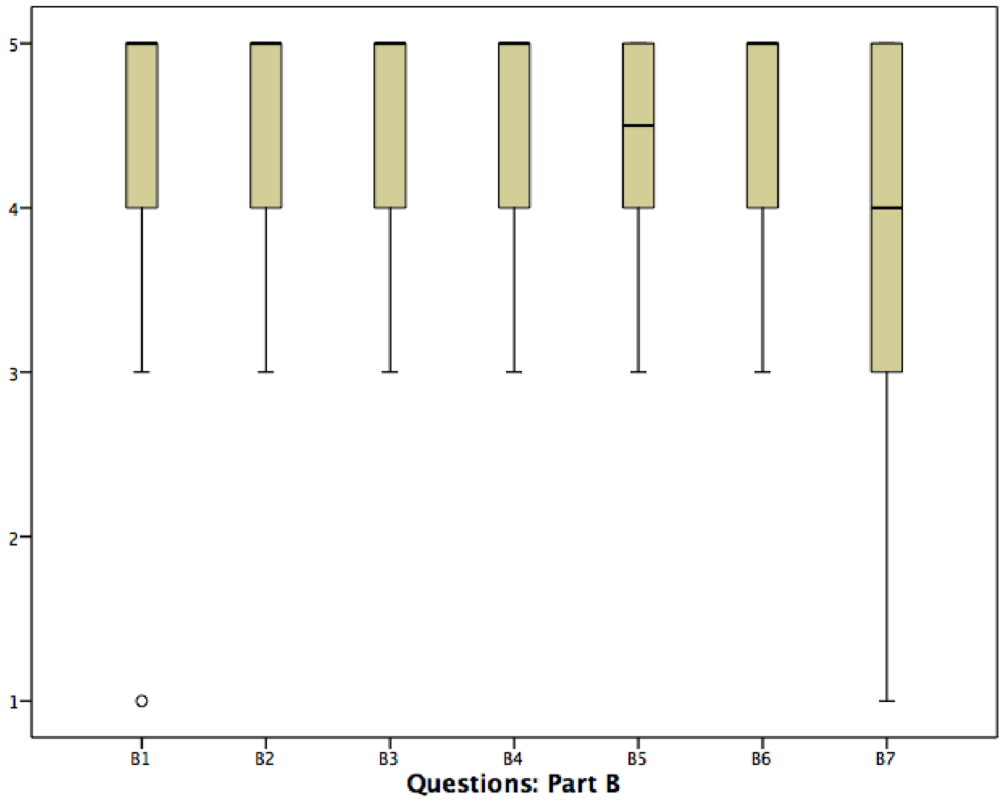


Figure 7. Distribution of answers to the Part B questions (WID groups only).

Except for question B7, all opinions were positive (≥ 3) being 75% with results ≥ 4 (*"Agree"*). Regarding the question B7 (*Do you see any advantage on including the workers icons?*), 50% recognized a very positive opinion (≥ 4), with 25% with lower opinion (≤ 3). More than 50% of the participants strongly agree that it is relevant to include layout information (question B1) and only one person strongly disagreed. All participants agreed and at least 50% strongly agreed that it is relevant to include information about transport waste (question B2) and the same results were obtained for the questions B3 (*Do you find relevant the inclusion of information about workers'* *related waste?*), B4 (*Do you find relevant the inclusion of information about waste's costs?*), B5 (*Do you find relevant the graphic information about cycle times, thickness of transportation arrows, etc.?*) and B6 (*Do you find relevant the inclusion of the table with performance indicators?*). As for question B7 (*Do you see any advantage on including workers icons?*) the participant opinions were not as convincing, as 12,5% of the participants disagreed.

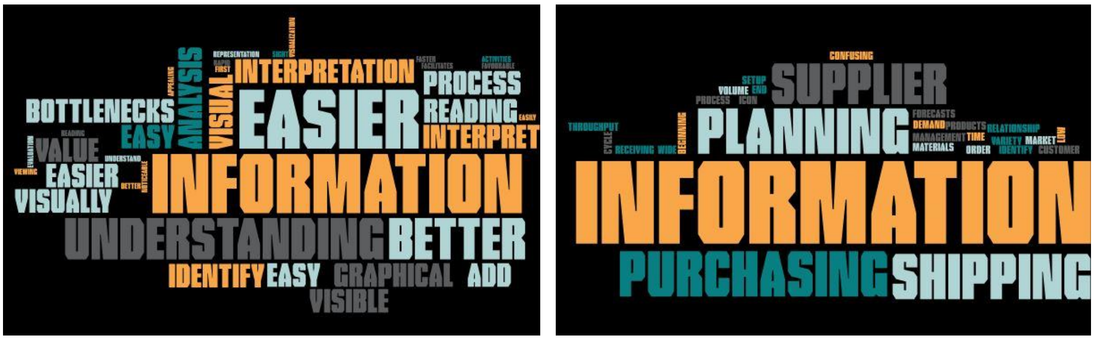
4.6. Other advantages/disadvantages of WID

The answers to the question B8 (*Identify other advantages/disadvantages of WID; Please include relevant comments*) were categorized into positive aspects and negative aspects.

Regarding the positive aspects, most of the answers are general comments referring the easier visualization and interpretation of the production unit's information. Some participants' citations are: "*More visual and easy to interpret*", "*Easier viewing, which facilitates the interpretation*", "*Reading more favourable, since it is graphical and noticeable at first sight*", "*Reading and analysis easier than VSM*", "*Easy to understand*", "*Better understanding of the process, faster*", "*Much more visible and better than the VSM*", "*A more visual representation allowing to retrieve information more easily than VSM*", "*It is graphical, making it easier reading*", "*More visually appealing and easy to interpret*", "*Easier visualization and analysis, allowing for a better understanding*", "*It is most visible when evaluating information*", "*Allows a rapid interpretation / understanding of the process*" and "*It is better represented visually, allowing an easier evaluation of the information*". A small number of answers was a bit more specific: "*Easy to identify the bottlenecks and the stops*", "*You can immediately see the process bottlenecks, etc.*", and "*It is much easier to identify the activities that add value and those that do not add value*".

As for negative aspects, a number of answers is related to the absence of representation of the information flow, e.g.: "*No information about planning, purchasing, supplier and customer*", "*No information on shipping and order management*", "*lack of information about shipping, receiving materials and planning*" and "*No information about the market (demand and forecasts)*". Finally, some other negative aspects were identified by the participants: "*Lack of an icon to identify the beginning and end of the process*", "*Difficult to apply in organizations with low-volume / wide variety of products*", "*The* *setup information is confusing*” and “*In this diagram the relationship between cycle time and throughput time is not as visible*”.

The provided answers, both for positive and negative aspects of WID, were fed into a word cloud tool resulting in the visual representation depicted in Figure 8.



(a) (b)

Figure 8. WID appreciation (a) positive aspects (b) negative aspects.

In both cases, the word information is emphasized. Regarding the advantages of WID, it means visual/graphical information easier to identify and understanding/interpret (e.g. bottleneck). As for disadvantages, information is also highlighted because WID does not represent the information flow involving suppliers, purchasing, shipping and production planning.

5. Conclusions

The objective defined for the work was accomplished. The comparison of the VSM and WID of a case study was performed, based on a questionnaire applied to industrial engineering (IE) students and professionals, and a set of quantitative and qualitative results was obtained and analysed.

In global terms, the quantitative results show that the interpretation of the WID was 87,1% correct, while for the VSM the figure was 71,9%. Furthermore, the average time necessary to interpret the supplied WID diagram was 4 minutes, against 8 minutes for the VSM. Thus, the so-called overall effectiveness indicates 21,8% of correct interpretations per minute in the case of WID and only 9% in the case of VSM.

In more specific terms, the IE students achieved an higher percentage of correct interpretations when interpreting WID in all aspects except for question A7 (*Identify the process(es) with the highest setup time*), as well as IE professionals, except for questions A1 (*How many processes are represented?*) and A7.

Specifically about WID (questions B1 to B7), IE students and professionals clearly acknowledge the relevance of most of the information elements (layout information, transportation waste, workers related waste, wastes' costs, etc.).

In the qualitative perspective (question B8), the IE students and professionals recognize that WID provides an easier visualization of the production unit's information and it is easier to interpret than VSM. The main disadvantage pointed to the WID is the absence of representation of the information flow, namely in terms of suppliers, purchasing, shipping and production planning.

It is important to recognize that the results obtained in this study are somehow limited since they are obtained from a single case study relating to a single process in only one context. In future research different industrial contexts should be considered, with special focus in more complex product routes since the production unit selected for this study was a single route in a sequential (line type) production flow. Another important recommendation involves the selection of practitioners with more experience in lean implementation - probably some lean consultants should be included as their opinions could be more effective while identifying the true potential of WID.

As final remark it can be stated that VSM can be built easier and faster, given to the analyst and decision makers enough representation about the current state of small linear type production units or a general overview of large production units. On the other hand, the WID is more adequate when: (i) more detailed data is necessary, (ii) the production unit is more complex in terms of production routes, and, (iii) it is necessary to know where the different wastes occur and how large they are and a deeper understanding of the current state of a particular production unit.

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References

Abdulmalek, F. A., and Rajgopal, J. 2007. "Analyzing the benefits of lean manufacturing and value stream mapping via simulation: A process sector case study." *International Journal of Production Economics*, 107(1), 223-236.

American Society of Mechanical Engineers. 1947. *ASME standard; operation and flow process charts*. New York. ASME.

Barnes, R. M. 1968. *Motion and Time Study: Design and Measurement of Work*. 6th edition, John Wiley & Sons, Inc.

Coimbra, E. A. (2009), *Total Flow Management*, Kaizen Institute, ISBN 978-0-473-14659-7

Dinis-Carvalho, J., Moreira, F., Bragança, S., Costa, E., Alves, A., and Sousa, R. 2014. "Waste Identification Diagrams." *Production Planning and Control: The Management of Operations*, 1-13. doi: 10.1080/09537287.2014.891059.

Dinis-Carvalho, J., Guimarães, L., Moreira, F., Rodrigues, J., and Lima. R. M. 2014. "Waste Identification Diagrams with OEE data," in *Proc of CIO-ICIEOM-IIIE 2014*, July 23-25, Malaga-Spain, ISBN-13978-84-616-9935-3, pp. 313-320.

Forrester, J. 1958. "Industrial dynamics: a major breakthrough for decision makers." *Harvard Business Review*, July-August, 37-66.

Gupta, S., Sharma, M., Sunder M, V., (2016) "Lean services: a systematic review", International Journal of Productivity and Performance Management, Vol. 65 Issue: 8, pp.1025-1056, doi: 10.1108/IJPPM-02-2015-0032 3.

Hicks, C., Heidrich, O., McGovern, T., and Donnelly, T. 2004. "A functional model of supply chains and waste." *International Journal of Production Economics*, 89(2), 165-174. doi:10.1016/S0925-5273(03)00045-8.

Hines, P., and Rich, N. 1997. "The seven value stream mapping tools." *International Journal of Operations & Production Management*, 17(1-2), 46-64. doi:10.1108/01443579710157989.

Hoekstra, S., Romme, J. 1992. *Towards Integral Logistics Structure – Developing Customer-Oriented Goods Flows*. McGraw-Hill, New York.

Hunt, V. D. 1996. *Process Mapping – how to reengineer your business processes*. John Wiley & Sons, Canada.

Kemper, B., de Mast, J., and Mandjes, M. 2010. “Modeling Process Flow Using Diagrams.” *Quality and Reliability Engineering International*, 26(4), 341-349. doi: 10.1002/qre.1061.

Lian, Y. H., and van Landeghem, H. 2007. “Analysing the effects of Lean manufacturing using a value stream mapping-based simulation generator.” *International Journal of Production Research*, 45(13), 3037-3058. doi: 10.1080/00207540600791590.

Little, J. 1961. “A proof for the queuing formula: L = λW.” *Operations Research*, 9, 383-9.

Miles, L. 1961. *Techniques of Value Analysis and Engineering*. McGraw-Hill, New York.

Neumann, W. P., and Medbo, L. 2010. “Ergonomic and technical aspects in the redesign of material supply systems: Big boxes vs. narrow bins.” *International Journal of Industrial Ergonomics*, 40(5), 541-548. doi:10.1016/j.ergon.2010.06.004.

New, C. 1974. "The production funnel: a new tool for operations analysis.” *Management Decision*, 12 (3), 167-78. doi:10.1108/eb001048.

New, C. 1993. “The use of throughput efficiency as a key performance measure for the new manufacturing era” *The International Journal of Logistics Management*, 4(2), 95-104. doi:10.1108/09574099310805028.

Nogueira, M. A. A. 2010. *Implementation of Lean Production Management: a Case Study* (in Portuguese). Master Thesis on Industrial Engineering and Management, Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa.

Ohno, T. 1988. *Toyota production system: beyond large-scale production*. Productivity press.

Rahani, A. R., and Muhammad, A. 2012. Production Flow Analysis through Value Stream Mapping: A Lean Manufacturing Process Case Study. *International Symposium on Robotics and Intelligent Sensors 2012*. Procedia Engineering 41 (2012) 1727 – 1734. doi:10.1016/j.proeng.2012.07.375.

Rother, M., and Shook, J. 1999. *Learning to see: value stream mapping to add value and eliminate muda*. Productivity Press.

Sá, J. C. Carvalho, J. D. and Sousa, R. M. 2011. "Waste Identification Diagrams," in *Proc. of the 6º Congresso Luso-Moçambicano de Engenharia*, Maputo, Mozambique.

Sá, J. C. 2010. *Model for Analysis and Diagnosis of Production Units* (in Portuguese). Master Thesis on Quality, Safety and Maintenance / Industrial Engineering, Escola de Engenharia, Universidade do Minho.

Serrano, I., Ochoa, C., and De Castro, R. 2008. "Evaluation of value stream mapping in manufacturing system redesign." *International Journal of Production Research*, 46(16), 4409-4430. doi:10.1080/00207540601182302.

Shingo, S., & Dillon, A. P. (1989). *A study of the Toyota production system: From an Industrial Engineering Viewpoint*; Productivity Press.

Singh, B., Garg, S. K., and Sharma, S. K. 2011. "Value stream mapping: literature review and implications for Indian industry." *International Journal of Advanced Manufacturing Technology*, 53(5-8), 799-809. doi:10.1007/s00170-010-2860-7.

Sugimori, Y., Kusunoki, K., Cho, F., Uchikawa, S. (1977) "Toyota production system and Kanban system Materialization of just-in-time and respect-for-human system", *International Journal of Production Research*, 15(6), pp. 553–564. doi: 10.1080/00207547708943149.

Sunder M, V., (2016) "Constructs of quality in higher education services", *International Journal of Productivity and Performance Management*, Vol. 65 Issue: 8, pp.1091-1111, doi: 10.1108/IJPPM-05-2015-0079

Tapping, D., Luyster, T. and Shuker, T., 2002. *Value Stream Management – Eight Steps to planning, mapping, and sustaining Lean Improvements*. New York: Productivity Press.

Teichgraber, U. K., and Bucourt, M. 2012. "Applying value stream mapping techniques to eliminate non-value-added waste for the procurement of endovascular stents." *European Journal of Radiology*, 81 (2012) e47– e52. doi:10.1016/j.ejrad.2010.12.045.

Womack, J. P., & Jones, D. T. (1996). *Lean Thinking*. *The Library Quarterly* (Vol. 5). https://doi.org/10.1086/601582

Xinyu, L., and Jian, L. 2009. "Research on the Integration of the Methods of Enterprise Value Stream and Material Flow," in *Proc. of the IEEE 16th International Conference on Industrial Engineering and Engineering Management*, Beijing, China.