Waste Identification Diagrams

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ABSTRACT

Value Stream Mapping (VSM) is a very popular tool in lean environments to represent production flows, mapping value stream of product or family of products and helping to identifying some types of wastes. Although being very popular, this tool has some limitation already described in many publications especially in terms of its restrictions in showing most types of waste as well as not being able to represent various production routes. The objectives of this paper are: introduce a new type of diagram called Waste Identification Diagram (WID) able to represent multiple routes and most types of waste in a very visual approach; apply the WID to a real production unit; and compare VSM with WID in terms of their effectiveness in identifying and showing waste and performance. WID is being developed at the Department of Production and Systems at the University of Minho and has been tested in many different types of production units with very good results.

1. Introduction

More than ever, industrial organizations need effective and efficient production systems so they can deal with the current markets' characteristics, namely turbulence and demand variability. Modern industrial organizations should increasingly rely on an enlightened taskforce, appropriate processes and effective technology, along with a suitable organizational framework and a lively production dynamics. Altogether, these aspects may qualify the production system for the effective delivery of economic and high quality products able to fulfill the market demand and to generate revenue. By doing so organizations are capable of sustaining their activity over the long run and remain and thrive on the global market place.

Lean Production is targeted at progressively align shop floor operations with clients' requirements specifics. These might include reliable deliveries, product quality aspects, shorter lead-times, competitive pricing, among others. But, overall, Lean production sights far beyond - it deeply seeks to master effectiveness on doing all that by implementing a culture of deep involvement of the workforce on waste elimination activities, right down to the most basic features of the shop floor, and on the continuous improvement of the processes.

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 (Carvalho, 2008). Ohno (1988) and Shingo (1989) identified seven major forms of waste:

- Overproduction;
- Inventory;
- Waiting;
- Defects;
- Over-processing;
- Motion;
- Transportation.

In order to put Lean Production into practice, companies need to select and effectively implement various tools and techniques (Gadre et al., 2011), such as: Single-Minute Exchange of Die, 5S, Pull System, Kanban, Standard Work, etc. A common requirement to prior application of such tools and techniques is the need to diagnose production effectiveness. This might be focused on exploring unbalanced processes, existence of high levels of WIP and stocks, on high rates of rejection, excessive levels of movement of parts or people, simply understanding how orders get triggered down to production. A technique that has received considerable recognition among Lean practitioners for doing hectic shop-floor diagnoses is that of Value Stream Mapping (VSM) technique. Many other techniques are available to represent and identify forms of wastes. Two interesting examples are spaghetti diagrams (Neumann, 2010) and treasure maps (Kobayashi, 1995). Spaghetti diagrams are very effective in identifying waste of motion and transportation while the treasure maps are effective in representing visually the size and location of waste. Nevertheless VSM is the most used technique for unscrambling waste at the shop floor level, and for that reason it will be used as a benchmark for the new visual technique under proposal.

2. Value Stream Mapping

Value Stream Mapping visually represents the entire value creation chain of a product or a family of products, revealing material and information flows as well as the potential wastes that affect the shop-floor (Rother & Shook, 1999). Hines & Rich (1997) presented what they considered to be seven value stream mapping tools and compared them in terms of their effectiveness in identifying types of waste. These tools borrowed techniques from various fields, namely engineering, logistics and operations research:

- Process activity mapping;
- Supply chain response matrix;
- Production variety funnel;
- Quality filter mapping;
- Demand amplification mapping;
- Decision point analysis;
- Physical structure mapping.

More recently Ramesh and Kodali (2012) proposed a decision framework to select value stream mapping tools for the process of identifying and removing waste. These authors included one more tool called “Lean Value Stream Mapping” which is the commonly known and commonly used Value Stream Mapping presented by Rother and Shook (1999).

Rother and Shook (1999) defined Value Stream Mapping as a Lean tool that is targeted at the analysis of production systems, by visually outlining the flows of materials and information, while providing key performance data on prime processes. The objective of VSM is to represent the entire value chain, from delivery of the raw materials to the shipping of final products to the customers (Rother & Shook, 1999). VSM is considered to be a very useful tool for analyzing the production process as a whole, allowing the identification of various types of wastes that spur along the way.

The works of Pavnaskar et al. (2003) highlighted that VSM offers a great potential to improve production systems. Serrano et al. (2008) also emphasize that other tools in the field do not match VSM comprehensiveness and framework conditions when applied to production systems design. Despite all the advantages that VSM can potentially bring to shop-floor, some limitations were also spotted and thorough described by multiple report studies, starting in 1998. A list of such limitations is presented in Table 1.

Table 1: VSM limitations

Publication	Limitations
(Hines, 1998)	Does not consider wastes such as wasted energy or wasted human potential. Lack of understanding of a particular firm's position in a supply chain and the implications of their actions. Lack of understanding about human resource issues such as the appropriate internal or external culture, language and relationships required by the organization.
(Irani & Zhou, 1999)	Cannot be applied when there are multiple items with different manufacturing routes. Does not provide layout visualization. Does not have an associated economic indicator. Does not reflect a products' Bill Of Materials.
(Lovelle, 2001)	The transport is depicted with arrows between processes, but it is not quantified or measured in terms of impact. Waiting, over-processing and motion wastes are difficult to observe, virtually remaining "hidden" on the map.
(McDonald et al., 2002)	It is difficult to apply on parallel production processes.
(Nazareno et al., 2003)	It is focused on the representation of material and information flows and does not represent the flow of people.
(Huang & Liu, 2005)	The cost of wastes associated with inventory, waiting, work-in-process and distances between the processes, associated with batch production, are not evaluated.
(Braglia et al., 2006)	Limited degree of accuracy and the number of versions that can be manipulated at the same time is small. Difficult to apply on high-volume, low-variety industries.
(Mehta & Rampura, 2006)	It is not as good for mapping the flow of information as it is for mapping material flows.
(Abdulmalek & Rajgopal, 2007)	It is not possible to have evidence that the changes will work after the implementation of the future state map.
(Hale & Kubiak, 2007)	Shows the actual cycle time but not the potential cycle time, characteristic of each operation.
(Chitturi et al., 2007)	Difficult to represent production systems with large diversity of products and production routes.
(Lian & Van Landeghem, 2007)	Limited modeling capability. It is a static tool that cannot describe the dynamic behavior and cannot deal with any complexity or uncertainty.
(Serrano et al., 2008)	There is a large gap between the theory proposed by the literature and its application in a real context.
(Xinyu & Jian, 2009)	Does not consider energy expenditure, unnecessary use of resources and pollution as a waste.
(Kemper et al., 2010)	Does not indicate who does what and in what sequence, which decreases the possibility of optimal resource allotment. Does not distinguish a single job flow from an aggregated flow. When there are conditional routes it does not indicate the percentage of flow which follows each route. Relies mainly on FIFO queues, thereby ignoring other priority rules.
(Pan et al., 2010)	The mapping of the current state is hampered by: lack of records or incomplete records, disordered or excessive WIP movement,

	introduction of rush orders and high rates of non-conforming products.
(Gahagan, 2010)	Are not very effective communication tools, especially to decision makers unfamiliar with VSM and accustomed to slick visual presentations.
Singh et al. 2011	Does not include cost-benefit analysis of proposed improvements (future-state map). Effect of changes to current-state map ignores the human factor.
(Teichgraeber & Bucourt, 2012)	Has been drawn from a manufacturing environment, so it is difficult to adapt to other environments (such as hospitals and health care).

Several authors have acknowledged such limitations and developed alternatives and/or adaptations to the traditional VSM tool. Irani & Zhou (1999) created the Value Network Mapping (VNM) and Braglia et al. (2006) developed the Improved Value Stream Mapping Procedure (IVSM). In 2012, Villarreal (2012) adapted VSM to the transportation systems, and coined it Transportation Value Stream Mapping (TVSM). A clear link has been also made between VSM tool and simulation tool, such as in the works of Lian & Van Landeghem (2007) with Simulation-based Value Stream Mapping (SimVSM) and that of Shararah et al. (2010) with Value Stream Mapping Simulator using ExtendSim (VSMSx).

3. Waste Identification Diagrams

In order to overcome some of the VSM limitations it is being developed, by the Department of Production and Systems, School of Engineering, University of Minho, an innovative tool called Waste Identification Diagram (WID). The initial challenge proposed was to develop a diagram tool able to:

- Represent the entire production units, not only a particular product family flow.
- Represent all production flows in the production unit.
- Show and evaluate all types of wastes in a visual and intuitive way
- Provide effective visual information
- Provide performance information
- Be a reference tool to continuous improvement

After a few years of experimentation in real production units as well as several master theses on the subject, and after collecting feedback from industry, a proposal for a Waste Identification Diagram was developed. The proposed diagrams are basically composed by three main types of icons: blocks, arrows and pie charts. Blocks represent stations such as a machine, a workstation or a group of machines/workstations, arrows represent transportation effort, and the pie chart show the way the workforce time is used. Figure 1 shows examples of such icons as well as their parameters. The dimensions of the icons are scaled with their parameter values giving precious visual information to managers.

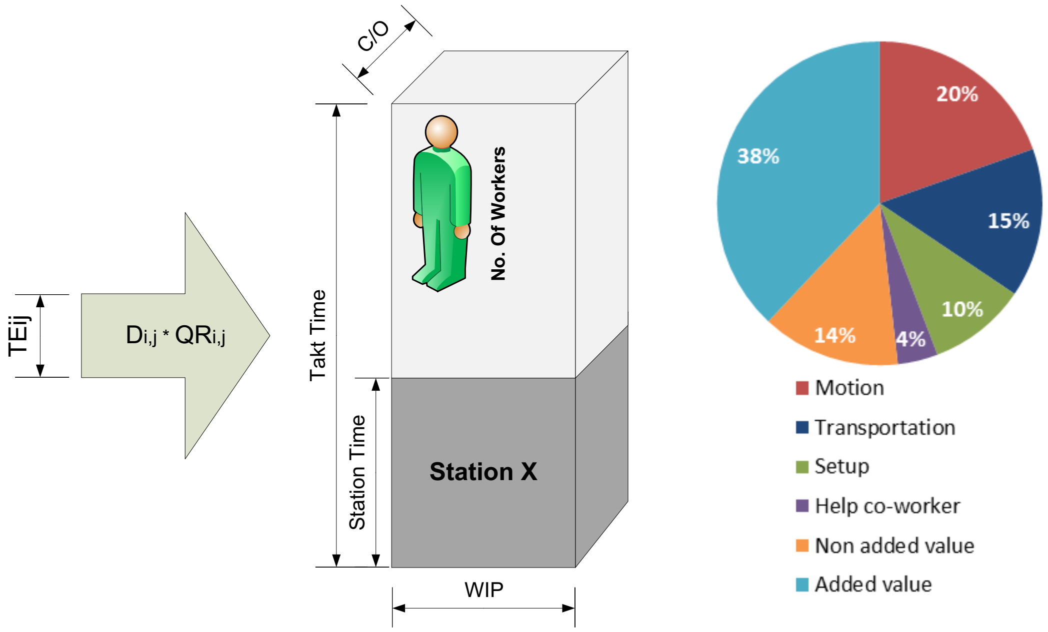

Figure 1: WID main icons.

The total height of the block assigned to Station X (see figure 1), represents the takt time value for that station. The takt time as defined by Chen & Christy (1998) is given by the following equation:

$$Takt\ time = \frac{Operation\ time\ per\ day\ (min)}{Customer\ demand\ per\ day\ (units)} \quad (1)$$

The operation time per day is the time that the referred station is available to operate in a day. The typical values for one working day are between 450 and 480 minutes. The customer demand per day represents here the quantity of products required by next station (which may be another production unit, another company or the end user).

The height of the bottom darker area of the block represents the station time value. The station time is the sum of all operations performed in Station X on one product. If different products with different operation times are performed in the same station then a weighted average time must be assigned to that station.

The width of the block represents the amount of WIP (Work In Process) waiting to be processed in the referred station. An interesting result of such representation is that the frontal area of the block represents the Throughput time on that station, i.e., the time that products spend since the moment they arrive to the Station X waiting queue until they leave the same station after being processed. The throughput time is obtained, according to Little's law (Little, 1961) by:

$$Throughput\ Time = Takt\ Time * WIP \quad (2)$$

In this way, the larger is the frontal area of a block, the longer is the corresponding station throughput time.

The depth of the block represents the changeover time (C/O) for the station. In many cases large changeover times influence the amount of WIP waiting to be processed on that station. The three dimensions of the block give visually information about how lean is the station. Blocks with large volumes mean problems and waste. In other words, the larger the volumes the less lean is the station.

The arrow type icon represents another important waste related parameter, the transport effort. The transport effort measures the quantity of products transported from one station to another multiplied by the distance to be traveled. It is obtained in the following way:

$$\mathrm{TE}_{\mathrm{i,j}} = \mathrm{QR}_{\mathrm{i,j}} * \mathrm{D}_{\mathrm{i,j}} \qquad (3)$$

where:

$TE_{i,j}$ – Daily transport effort from supplier station *i* to customer station *j*
$\mathrm{QR}_{\mathrm{i,j}}$ – Daily quantity to be transported from supplier station *i* to customer station *j*
$\mathrm{D}_{\mathrm{i,j}}$ – Distance to be travelled from supplier station *i* to customer station *j*

The arrow width represents the transportation effort associated to the product flow from the station supplier to the station client. The arrow length does not have any meaning and therefor can be the same for all arrows in the diagram.

The third main icon is related to the workers time spend in different types of operations. The values are obtained using work sampling techniques (Barnes, 1968) and then represented in a graph such as the one shown on the right side of figure 1. This icon (graph) gives very important information to managers about the way workers spend their working time. The values may be presented in percentage or in cost. The cost per month or per year by the workforce in non-value added activities such as transportation or motion work very well in drawing the attention of managers to the production waste issue.

4. WID Application Example

The production unit selected to apply the WID in this article is part of a lift manufacturer dedicated to produce and assemble the lift’s doors. The resulting Waste Identification Diagram is presented in figure 2. This diagram gives very important information about the production unit, from raw data such as station time and number of workers, to diagnosing data such as waste identification and evaluation as well as performance measures.

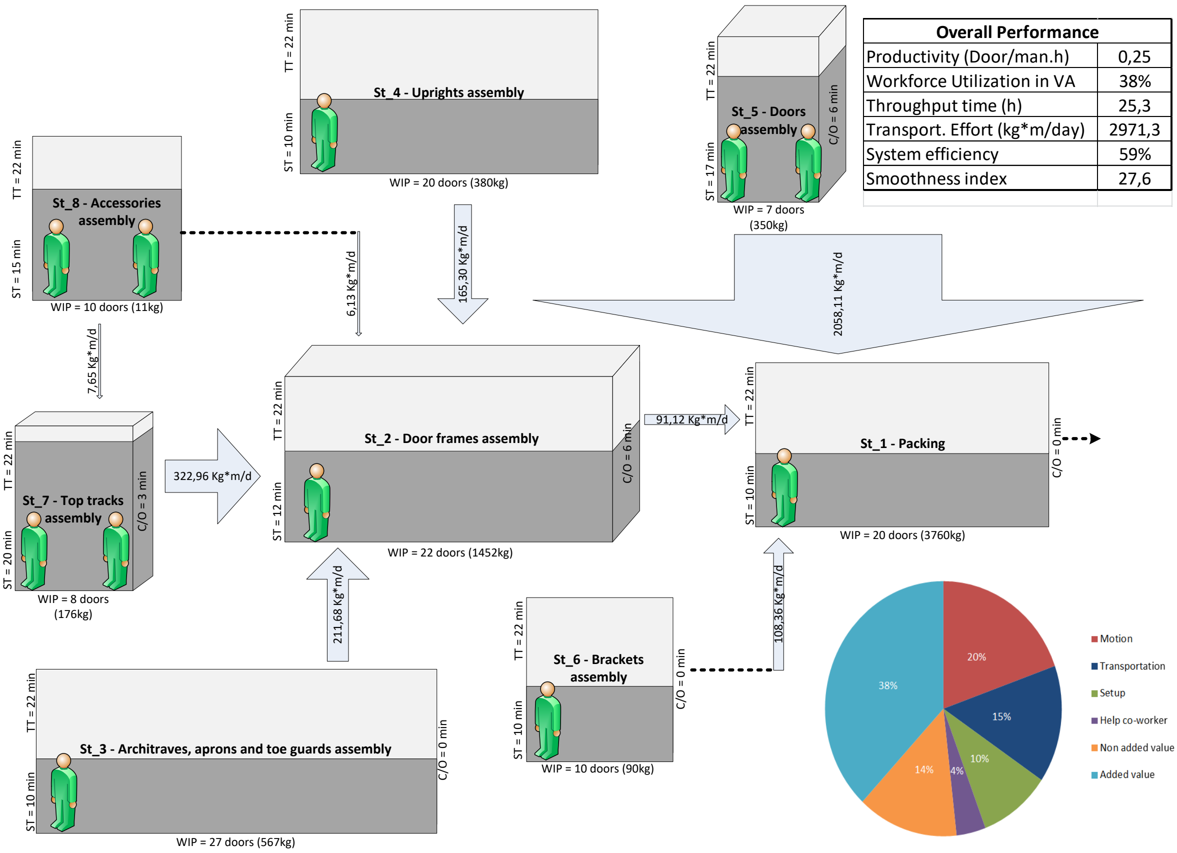

Figure 2: Waste Identification Diagram of a lift's doors production unit.

By just looking at the diagram presented in figure 2, the observer rapidly grasps a variety of visual information with great relevance related to the represented production unit. Some examples of such information are:

- A general idea about the production routes.
- A general idea about the product's bill of materials.
- The number of workers and to which stations they are assigned to.
- The location of big wastes (the bigger is the icon the bigger is the corresponding waste).
- How WIP is distributed on the shop floor.
- Where the transport effort is more relevant or less relevant.
- An idea about the throughput times on each stations (frontal area of each block).
- An idea on how workers spend their time (see pie chart).
- The relative importance of changeover times.

It is possible to verify that most workstations do not operate at full capacity, i.e. station time is well below takt time. There are also differences between these idle capacities in the various workstations. The workstation with the biggest occupation is the St_7 - Top tracks' assembly, with an idle capacity of only two minutes that corresponds to an occupation rate of 91%.

The changeover time values also present significant differences, due to the complexity of the setup operations to be performed. However, there are still many cases where there are only manual operations, so the changeover time is zero.

In addition, it can be seen that there is a significant difference in the transportation effort (seen by the thickness of the arrows). This difference may arise from two situations: (i) when the distance to be traveled is long, or (ii) when the loads are too heavy to carry.

In terms of materials flow related waste, it is possible to come to the following interpretations:

- The Stations with higher levels of inventory are: St_1 – Packing, St_2 - Door frames assembly, St_3 - Architraves, aprons and toe guards, and St_4 – Uprights assembly. Efforts must be made in order to reduce these levels of inventory and aiming the reducing of operation costs as well as throughput time.
- The throughput time for this production unit should be considered as the throughput associated to the longest path (St_3; St_2; St_1). The throughput time obtained, is the sum of the throughput time for each one of those stations, i.e., 27 doors x 22 min + 22 doors x 22 minutes + 20 doors x 22 minutes. The result is 1518 min (25,3 hours).
- Major transportation effort occurs between the doors assembly station and Packing Station.
- The transportation effort between Top tracks assembly station and Door frames assembly station must result from long distances to be traveled because the components are relatively small compared with other parts in the production unit. Efforts must be made in order to find solutions to reduce this distance.

From the point of view of the personnel related waste, expressed in the pie chart that represents the use of the workforce, it is possible to come to the following interpretations:

- Despite being a low value, from the various activities, 38% of the workforce is engaged in value added activities while the remaining is divided by several types of waste. The largest proportion of time occupied by wastes is concerned with motion (that represents 20% of the total time), followed by transport, with 15% of the time. It is possible to conclude that Motion and transportation wastes represent 35% of workers time and that probably results from inadequate layout with long distances to be traveled between stations.
- Workers spend in average 10% of their time doing changeovers. This is particularly relevant since only three stations are actually in need of changeover. Having that in mind, a closer look at these stations must be performed.
- Other non-value adding activities represent 14% of the available workers time. Another analysis should be performed in order to clarify what type of waste should be assigned to.

Finally, the general performance indicator for the production unit is presented on the top right corner of figure 2. The analyst decides the set of performance indicators to be displayed on the diagram, even if the relevant data is not presented on the diagram. In this case however all the presented indicators are obtained from the information available on the corresponding WID. The chosen performance indicators for this production unit are:

- Productivity (expressed on doors/man.hour) is the expected value that will be achieved for the given Takt time value of 22 minutes per door when using 11 workers.
- The workforce utilization in value adding activities is directly given by the pie chart.
- The overall throughput time discussed earlier is given by the longest path. It is important to note that the throughput time value for each station is given by multiplying the quantity of doors waiting to be produced on the station by the station takt time. On other words the throughput time for each station is no more and no less than the frontal area of the station block.
- The global transportation effort is the sum of all individual transportation efforts expressed on the diagram.
- The System Efficiency indicator (*SE*) follows more or less the same logic as the line efficiency (Bedworth and Bailey, 1987; Waldemar, 2011) used in the line balancing problem, measuring how much the stations capacity are used in average. In this way System Efficiency (SE) is given by the following equation:

$$SE = \frac{\sum_{i=1}^{m} St_i}{TT * m}$$

(*m* being the number of station, *TT* the Takt Time and *St* the station time)

- The Smoothness Index (SX) as presented by Scholl (1995), measures the equality of the distribution of the work among the stations:

$$SX = \sqrt{\sum_{i=1}^{m} (TT - St_i)^2}$$

Many other indicators could be used according to what is more important to measure in each case. In many cases, performance indicators related to quality, to safety or to customer satisfaction are also very important to appear.

5. Comparative Analysis

Comparing the two tools it is possible to verify several differences. The first impact caused by WID is its visual capabilities, since it allows an easy and intuitive identification of the major sources of waste. Production flows are well defined and the information of each workstation is clear and concise, allowing a quick perception of the number of operators and other important performance measures such as takt time, cycle time and changeover time. In the VSM case, to visualize this type of information more time is needed and it is necessary to analyze in detail each workstation's data box. For example, in VSM, to identify the amount of WIP in each workstation is necessary to check the written information in the triangle before it, while in WID this information, besides being numerically represented is also visually characterized (by the width of the block). The set of information in VSM is more confusing and the use of various symbols can lead to a lack of understanding for people unfamiliar with the tool. In contrast, WID uses narrower and cleaner symbols, easing the process of understanding and identifying waste.

The type of information that is given on the various wastes has different impacts whether the VSM or WID is concerned. Table 2 demonstrates the differences in the usability of the information provided by VSM and WID regarding the seven type of wastes.

Table 2: Effectiveness in identifying types of waste

Waste type	VSM	WID
Inventory	Medium	High
Overproduction	Low	Low
Transportation	Non-existing	High
Defects	Non-existing	Low
Over-processing	Non-existing	Non-existing
Motion	Non-existing	High
Waiting	Non-existing	High

In terms of Inventory waste both alternatives are able to show them as previously explained but the WID show it in a much more effective way because of the visual capability.

As far as the overproduction waste is concerned, we believe that neither VSM nor WID clearly identify this type of waste since may be difficult to judge if the existing inventory between workstations is more than the minimum necessary to satisfy the customer demand.

In VSM, the waste associated with the transportation is only represented by an arrow and is not quantified. However, in WID, the transportation effort not only is represented by an arrow but has also a value associated (in the diagram shown in the previous section it was expressed in kg*m*day). This difference in the usability of information takes a leading role in the decision making process by a company's management. Another important advantage of WID is the visual information since the larger is the transport effort the bigger is the corresponding arrow. Since a part of the transportation is frequently performed by people, this type of waste is also considered in the workforce utilization expressed in the pie chart icon. Therefore, this type of waste is identified from two different viewpoints.

As for defects waste the WID is able to show it in the pie chart associated as long as rework operations where considered in the work sampling observations.

Over-processing is very difficult to identity unless a very close look is performed in every existing operation. This type of waste is not considered in any of the alternative charts.

Motion is a type of waste that is only associated to people and it clearly considered in the workforce utilization expressed in the pie chart icon.

Finally, some considerations must be addressed concerning the interpretation of the waiting type of waste. Many authors assign the waiting type waste to products or parts waiting to be processed. In fact products or parts waiting is already a type of waste called “Inventory”. Waiting is assigned to people or other resources. Monden (1983) describes waiting waste when a worker is waiting for the machine completes an automatic operation cycle. A more complete description is presented by Liker (2004) which also considers waiting when workers wait for next processing step, tool, supply, part, etc. Periods of inactivity in a downstream process because an upstream process did not delivered on time is referred by Ohno (1988) and a very similar description is given by Womack & Jones (2003). In the WID the waiting waste appear in the pie chart icon.

With WID, contrary to what happens in VSM, it is possible to represent several production families and production routes. In the VSM shown in Figure 2 even though they are depicted various routes, only the main flow is accounted for the analysis of lead time and value-added time. To analyze everything in detail it would be necessary to create a VSM for each production route. This question does not arise in WID, since it is possible to represent the main and secondary routes, the difference is the representation (the main routes enter the block from the side and the secondary routes enter the blocks from the top/bottom).

In addition to the advantages already mentioned related to waste identification there are other aspects to consider. Table 3 shows these other aspects.

Table 3: Comparing VSM and WID

Comparison Criteria	VSM	WID
Capacity to represent multiple production routes	Non-existing	High
Capacity to evaluate waste	Non-existing	High
Capacity to provide Layout visualization	Non-existing	Medium
Capacity to reflect a products’ Bill Of Materials	Non-existing	Medium
Effectiveness in interpreting waste forms	Medium	High
Quantity of types of waste identified and evaluated	Low	High
Evaluation of workforce related types of waste	Non-existing	High
Visual representation of the throughput time/lead time	Low	High
Effectiveness as a continuous improvement tool	Medium	High
Easy to visualize the excess of capacity in each station/process	Low	High
Capacity to associate economic indicators	Non-existing	Medium
Showing overall performance indicators	Low	High

The WID ability to represent the whole production unit overcomes the VSM inability to represent multiple production routes (Irani & Zhou, 1999 and Chitturi et al., 2007) or the difficulty to apply VSM on parallel processes (McDonald et al., 2002).

The transportation arrows presented on WID and its transportation effort evaluation totally solves the VSM limitation presented by Lovelle (2011). The author states that in the VSM the transport is depicted with arrows between processes, but it is not quantified or measured in terms of impact.

The pie chart, presented on WID covers in a great deal the fact that waiting, over-processing and motion wastes are difficult to observe, virtually remaining "hidden" on VSM (Lovelle, 2001).

According to Huang & Liu (2005) the cost of wastes associated with inventory, waiting, work-in-process and distances between the processes, associated with batch production, are not evaluated. WID allows the possibility of associating cost to WIP, waiting and transport.

When there are conditional routes VSM does not indicate the percentage of flow which follows each route (Kemper et al., 2010). Although the case presented in figure 2 does not have conditional routes, the percentage of flow associated with each route is presented in WID. As presented in figure 2, the takt time is the same for all stations which shows that all (100% of the) products follow the same route.

Another two VSM limitations presented by Irani & Zhou (1999) are its inability to provide layout visualization and the inability to reflect a products' Bill Of Materials. WID allows layout visualization since the icons representing the stations can be positioned on the diagram as wanted. On the other hand WID is able to reflect products´ Bill Of Materials as shown in figure 2.

6. CONCLUSION

This paper presented an innovative tool as an alternative to the VSM representation of production systems. It is a visual and intuitive tool that represent the current situation or a future state of a production system, mainly its material flows, quantitative measures for each station (takt time, changeover time cycle time and WIP), utilization of workers in value adding and non-value adding activities, key performance indicators (KPI) of the system such as productivity, resources utilization and throughput time. An industrial case application was presented in order to show WID capabilities in exposing different types of waste. VSM and WID were compared and their advantages and disadvantages were also discussed according to a variety of criteria. In general it can be said that WID overcomes some of the limitations of VSM and represents many aspects of a production system that could not be represented by VSM. Besides many of the WID advantages in terms of quantitative information, another important advantage of WID is the effectiveness in given important visual information that can be rapidly perceived by production personnel.

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