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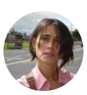

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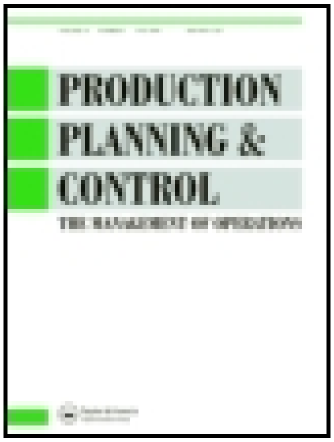

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Value Stream Mapping (VSM) is a very popular tool in lean environments to represent production flows, mapping value stream of a product or family of products, and helps to identify some types of waste. Although very popular, this tool has some limitations as already described in many publications, especially in terms of restrictions in showing most types of waste as well as in its inability to represent various production routes. The purpose of this study is to introduce the waste identification diagram (WID), a new tool to represent production units with its different forms of waste, which overcomes some VSM limitations. The originality of WID comes from the use of its symbols' dimensions to convey, in a visual and immediate way, relevant information about a production unit. In this paper, WID is applied on a production unit of a lift manufacturer, for testing its performance and comparing it to VSM. The main findings are that WID is in general more effective than VSM in terms of representation of complex production units and in terms of identification of more forms of waste. WID must however overcome some of its limitations such as the lack of information-flow representation and the links to suppliers and clients.

Keywords: lean production; value stream mapping; waste identification

1. Introduction

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

Lean production is targeted at progressively aligning shop-floor operations with clients' requirements specifics. These might include reliable deliveries, product-quality aspects, shorter lead-times and 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, it is very unlikely that the customer has to pay for it (Ohno 1988; Shingo and Dillon 1989; Womack and Jones 1996). All forms of waste intrinsically relate to the concept of value; therefore, in order to recognise 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 and Dillon (1989) identified seven major forms of waste:

- Overproduction – producing more than required downstream or before the required time.
- Inventory – material waiting to be processed, to be transported, to be inspected, etc.
- Waiting – people waiting for information, for machines to finish their automatic cycles, for other people, for materials, etc.
- Defects – producing products with defects, leading to many associated costs such as cost of materials, labour cost, machine cost, etc.
- Over-processing – more work is performed in the product than required by the customer.

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- Motion – people walking or making movements with no value added to products.
- Transportation – moving materials from one place to another.

A technique that has received considerable recognition among Lean practitioners for doing hectic shop-floor diagnoses is that of Value Stream Mapping (VSM) technique (Jones and Womack 2002). VSM as well as other visual techniques pursue communication effectiveness, which is referred by Parry and Turner (2006) as more important than information availability. Two interesting examples of other visual techniques with good-communication effectiveness are spaghetti diagrams (Neumann and Medbo 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

VSM 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 and Shook 1999). Hines and 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; and
- 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 VSM presented by Rother and Shook (1999).

Rother and Shook (1999) defined VSM 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 and Shook 1999). VSM is considered to be a very useful tool for analysing the production process as a whole, allowing the identification of various types of wastes that spur along the way. The works of Pavnaskar, Gershenson, and Jambekar (2003) highlighted that VSM offers a great potential to improve production systems. Serrano, Ochoa, and Castro (2008) also emphasise that other tools in the field do not match VSM comprehensiveness and framework conditions when applied to production systems design. Hodge et al. (2011) present a survey about implementation of lean principles in the textile industry, where 9 out of 11 companies indicate VSM as a primary representation/diagnostic tool, able to be used in all levels of lean implementation (from visual management to just-in-time – JIT). Despite all the advantages that VSM can potentially bring to shop floor, some limitations were also spotted and thoroughly described by multiple report studies, starting from 1998. A list of such limitations is presented in Table 1.

The proposed WID will address many of the VSM limitations mentioned in Table 1 (marked with * or **). The limitations marked with (*) are fully resolved by WID. Those marked with (**) are covered by WID, if the analyst decides to address them. In fact, the WID may or may not represent the layout, depending on the analyst intention. Similarly, costs and economic indicators can be included in WID by transforming existing data into economic figures (e.g. motion and waiting wastes can be easily quantified in economic terms).

The WID is then able to deal with:

- Products with different routes.
- Transport waste quantification.
- Parallel production processes.
- Low-volume and high-variety industries.
- Percentage of flow in different routes.
- Visual communication.

The WID is also easily adapted to include the following features:

- Layout visualisation – achieved by placing the blocks in the corresponding layout positions.
- Representation of economic indicators – when cost information is available, the analyst may transform, in economic indicators, information such as inventory, transport effort or labour utilisation on each waste type.

Several authors have acknowledged VSM limitations and developed alternatives and/or adaptations to the traditional VSM tool. Irani and Zhou (1999) created the Value Network Mapping (VNM) and Braglia, Carmignani, and Zammori (2006) developed the Improved Value Stream Mapping Procedure (IVSM). In 2012, Villarreal (2012) adapted VSM to the transportation systems, and coined it as Transportation Value Stream Mapping. A clear link

Table 1. VSM limitations.

Publication	Limitations
Hines et al. (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 organisation.
Irani and Zhou (1999)	Cannot be applied when there are multiple items with different manufacturing routes (*). Does not provide layout visualisation (**). 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, Van Aken, and Rentes (2002)	It is difficult to apply on parallel production processes (*).
Nazareno, Silva, and Rentes (2003)	It is focused on the representation of material and information flows and does not represent the flow of people.
Huang and Liu (2005)	The costs associated with work-in-process are not analysed (**) Waste of waiting is not represented (*) Distances between the processes are not represented (**) Fail to show batch production characteristics.
Seth and Gupta (2005)	Only effective to represent identical or similar product routings. Does not provide any rule to achieve improvements (only provides hints).
Braglia, Carmignani, and Zammori (2006)	Limited degree of accuracy and the number of versions that can be manipulated at the same time is small. Difficult to apply on low-volume, high-variety industries (*).
Mehta and Rampura (2006)	It is not as good for mapping the flow of information as it is for mapping material flows.
Abdulmalek and Rajgopal (2007)	It is not possible to have evidence that the changes will work after the implementation of the future state map.
Hale and Kubiak (2007)	Shows the actual cycle time but not the potential cycle time, characteristic of each operation (*).
Chitturi, Glew, and Paulls (2007)	Difficult to represent production systems with large diversity of products and production routes (*).
Lian and Van Landeghem (2007)	Limited modelling capability. It is a static tool that cannot describe the dynamic behaviour and cannot deal with any complexity or uncertainty.
Serrano, Ochoa, and Castro (2008)	There is a large gap between the theory proposed by the literature and its application in a real context.
Lasa, Castro, and Laburu (2009)	Does not integrate guidelines to construct future maps. Heijunka systems are not graphically detailed fully.
Xinyu and Jian (2009)	Does not consider energy expenditure, unnecessary use of resources and pollution as a waste.
Kemper, de Mast, and Mandjes (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, Feng, and Jiang (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, Garg, and Sharma (2011)	Does not include cost–benefit analysis of proposed improvements (future-state map). Effect of changes to current state map ignores the human factor.
Teichgräber and de Bucourt (2012)	Has been drawn from a manufacturing environment, so it is difficult to adapt to other environments (such as hospitals and health care).

has been also made between VSM tool and simulation tool, such as in the works of Lian and Van Landeghem (2007) with Simulation-based Value Stream Mapping and that of Shararah, El-Kilany, and El-Sayed (2010) with Value Stream Mapping Simulator using ExtendSim. Parthanadee and Buddhakulsomsiri (2012) also refer that VSM does not include some relevant performance indicators and describes the so-called simulation-based VSM (SBVSM) which not only avoids that limitation but, mainly, tries to overcome the static nature of VSM. As previous-referred works using simulation, SBVSM allows the test of alternative improvement proposals (different future state maps).

3. Waste identification diagrams

In order to overcome some of the VSM limitations, an innovative tool called waste identification diagram (WID) is being developed by the Department of Production and Systems, School of Engineering, University of Minho. The department is continuously involved in projects in industry, focused on improving production performance and competitiveness. These projects include materials flow analysis, performance evaluation, layout changes, waste reduction, production systems redesign, pull systems design, set-up time reduction and so on. A common need in majority of these projects is the description of a production unit before and after the project, in order to show the differences and gains. Effectively describing production units, in order to communicate the important bits of information in the various dimensions, is not an easy task to do as no standard language is available. The development of a standard graphic model which is able to describe production units and contains the most relevant data, from the industrial engineering perspective, became an important goal to be achieved. Since neither the VSM nor any other published tool could cover all the identified requirements, it was necessary to develop a new tool which was coined as "waste identification diagram" and will be presented in this paper.

The initial proposed challenge was to develop a diagram tool which is able to:

- Represent entire production units, not only a particular product family flow.
- Represent all production flows in the production unit.
- Cope with low-volume and high-variety industries.
- Allow layout visualisation.
- 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.

This research started with the generation of ideas; and after some debate sessions, it was possible to converge it to a first version. A prototype version was developed and deployed for tests in real production units. Based on feedback from practitioners, the tool was improved and this cycle was repeated a few times until the version here presented was reached. WID is presented as an advantageous alternative to VSM, particularly in terms of representational power and wastes identification.

The proposed diagrams are basically composed of 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.

The total height of the block assigned to Station X (see Figure 1) represents the takt time value for that

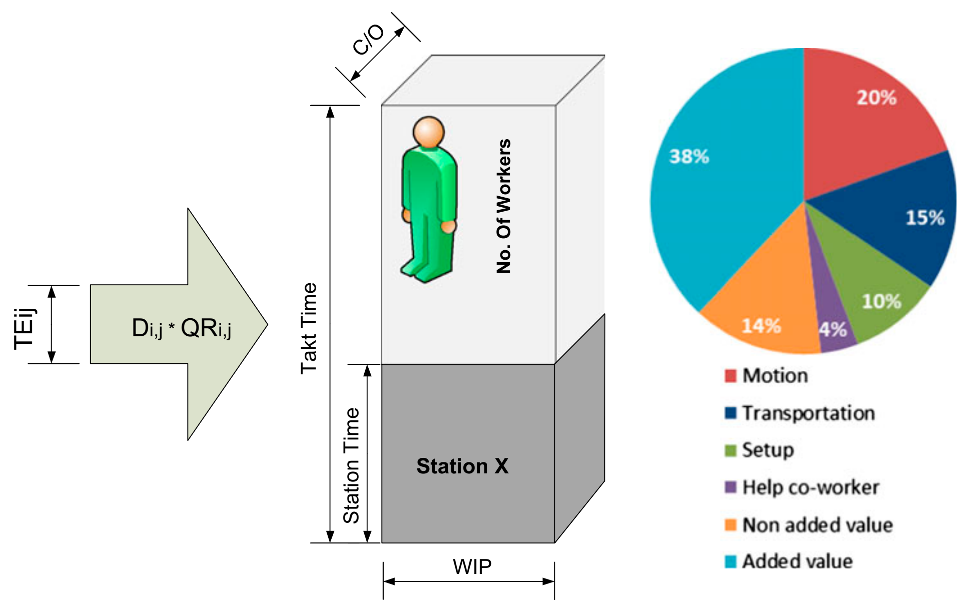

Figure 1. WID main icons.

station. The takt time as defined by Chen and Christy (1998) is given by the following equation:

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

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 min. The customer demand per day represents 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 operation times of the 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 work in process (WIP) 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 station after being processed. The throughput time is obtained, according to Little's law (Little 1961) by:

$$\text{Throughput Time} = \text{Takt Time} \times \text{WIP} \quad (2)$$

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 visual 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 travelled distance. It is obtained in the following way:

$$\mathrm{TE}_{i,j} = \mathrm{QR}_{i,j} \times D_{i,j} \quad (3)$$

where $\mathrm{TE}_{i,j}$ – Daily transport effort from supplier station i to customer station j; $\mathrm{QR}_{i,j}$ – Daily quantity to be transported from supplier station i to customer station j; $D_{i,j}$ – 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 therefore can be the same for all arrows in the diagram.

The third main icon is related to the workers' time spent 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) provides 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.

A possible approach to be followed in order to build a WID diagram includes three main phases. The first phase is related to production flows, the second phase is related to people activities and the final phase is related to performance evaluation. The first phase includes the following steps:

- Clearly identify the production unit – physically where it starts and where it finishes; which resources are included; the people involved; the storage areas; etc.
- Identify product information – families of products and its routes; processing times; demand; BOM; supplying mechanism.
- Draw a block for each workstation on its layout relative position – it is advisable to start from downstream processes; the size of the block must be scaled with corresponding values; the value assigned to WIP should result from the average of various observations in different occasions.
- Assign workers to workstations.
- Draw the arrows according to the production routes.

The second phase, regarding the use of people, is based on work sampling and includes the following steps:

- Create a template to register observations – this record sheet identifies the set of alternative activities expected as the ones presented in Figure 1.
- Make the observations according to work sampling techniques.
- Build the pie chart for workers utilisation using percentages or cost.

In the final phase, the analyst will determine overall performance indicators and include their values in the diagram. These indicators are computed using the information available from previous phases.

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 WID 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.

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 on product's bill of materials – the door supplied by St_5, plus the door frame supplied by St_2 plus the brackets supplied by St_6 are packed together at St_1 resulting in one product unit. The St_2 receives parts supplied by St_3, St_4, St_7 and St_8.
- A general idea about the production routes – the arrows indicate material routes, e.g. the longest route is assigned to top-track accessories that are first assembled at St_8, then assembled at St_7, becoming part of a door frame at St_2 which finally is packed with other parts at St_1.
- The number of workers and to which stations they are assigned to – St_5, St_7 and St_8 require two workers each while all other stations only require one worker each.
- How WIP is distributed on the shop floor – in this particular case, the WIP is computed in tonnes as well as in the corresponding number of doors. The stations with more WIP are St_1, St_2, St_3 and St_4 (blocks with larger width). Any effort to reduce WIP should be focused on those stations.
- Where the transport effort is more relevant or less relevant – the most relevant case (widest arrow) corresponds to the highest transports waste existing from St_5 to St_1. The less relevant cases are the transport from St_8 to St_7 as well as from St_8 to St_2.
- An idea about the throughput times on each stations (frontal area of each block) – quantifying WIP in number of doors simplifies the visualisation and evaluation of throughput times since the takt times are expressed in terms of number of doors. The diagram clearly shows that the station with longest throughput time is St_3.

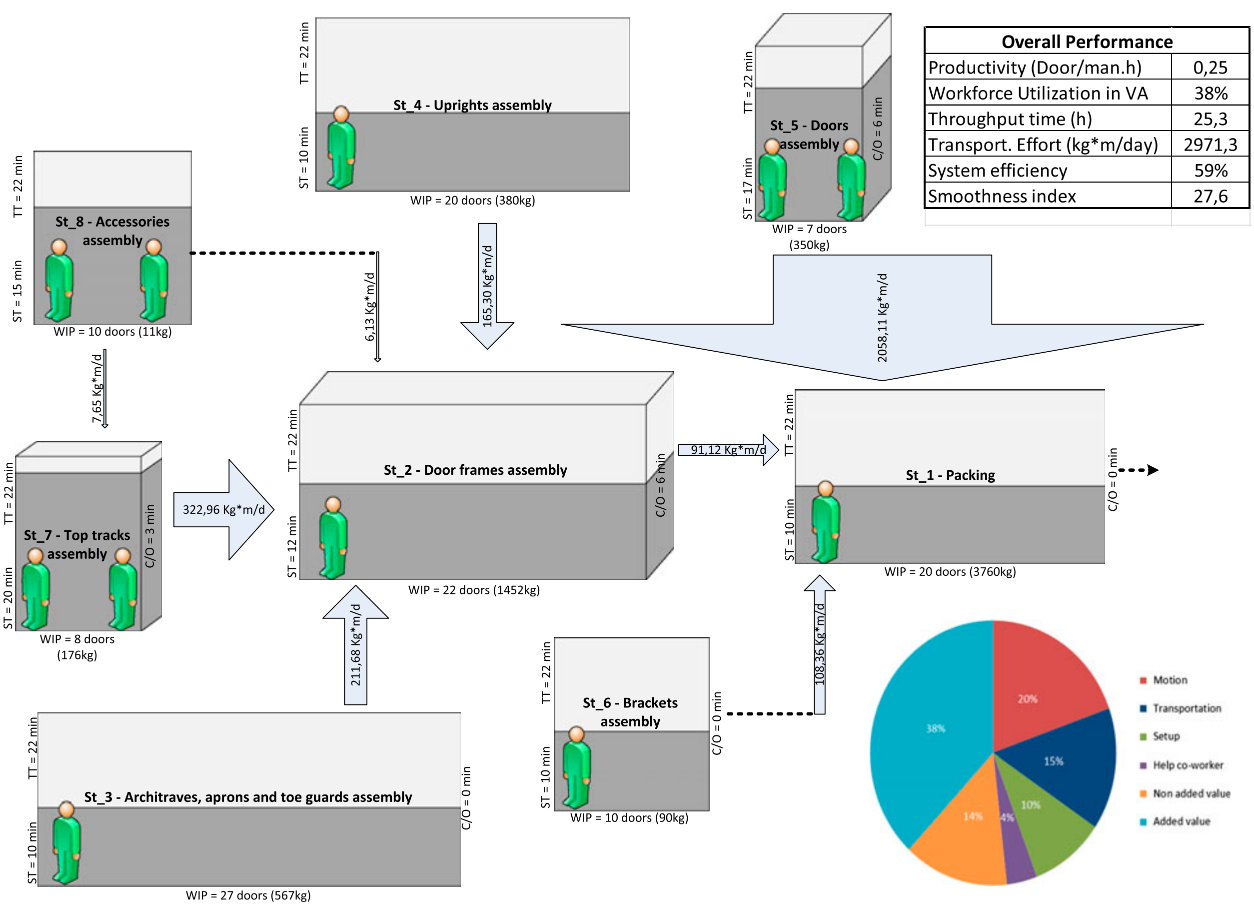

Figure 2. WID of a lift's doors production unit.

- An idea on how workers spend their time (see pie chart) – the first evidence is that most of workers' time is spent on non–value-added activities and the second evidence is that both motion and transport wastes are very frequent.
- The relative importance of changeover times – by looking at the diagram is not easy to see any relationship between changeover times and WIP. It can be assumed that WIP exists only because of the inexistence of an effective pull system.

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, expressed in the depth dimension of the blocks, is zero for most workstation (the blocks with no depth) meaning that no changeover is needed. Only stations St_7, St_2 and St_5 show need for changeover.

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 travelled 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 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 × 22 min/door + 22 doors × 22 min/door + 20 doors × 22 min/door. The result is 1518 min (25.3 h).
- 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 travelled 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 of 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 travelled 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 are 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.h) is the expected value that will be achieved for the given takt-time value of 22 min per door when using 11 workers.
- The workforce utilisation 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. In other words, the throughput time for each station is in fact 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, SE is given by the following equation:

$$\mathrm{SE} = \frac{\sum_{i=1}^{m} \mathrm{St}_i}{TT \times m} \tag{4}$$

(m being the number of stations, TT the takt time and St_i the station i time)

The smoothness index (SX) as presented by Scholl (1995), measures the equality of the distribution of the work among the stations:

$$\mathrm{SX} = \sqrt{\sum_{i=1}^{m} (\mathrm{TT} - \mathrm{St}_i)^2} \tag{5}$$

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

By comparing WID and VSM, it is possible to verify several differences between them. 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 indicators such as takt time, cycle time and changeover time. In the VSM case (see Figure 3), to visualise this type of information, more time is needed and it is necessary to analyse 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 indicated is also visually represented (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 a narrower and cleaner set of 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 types of waste.

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

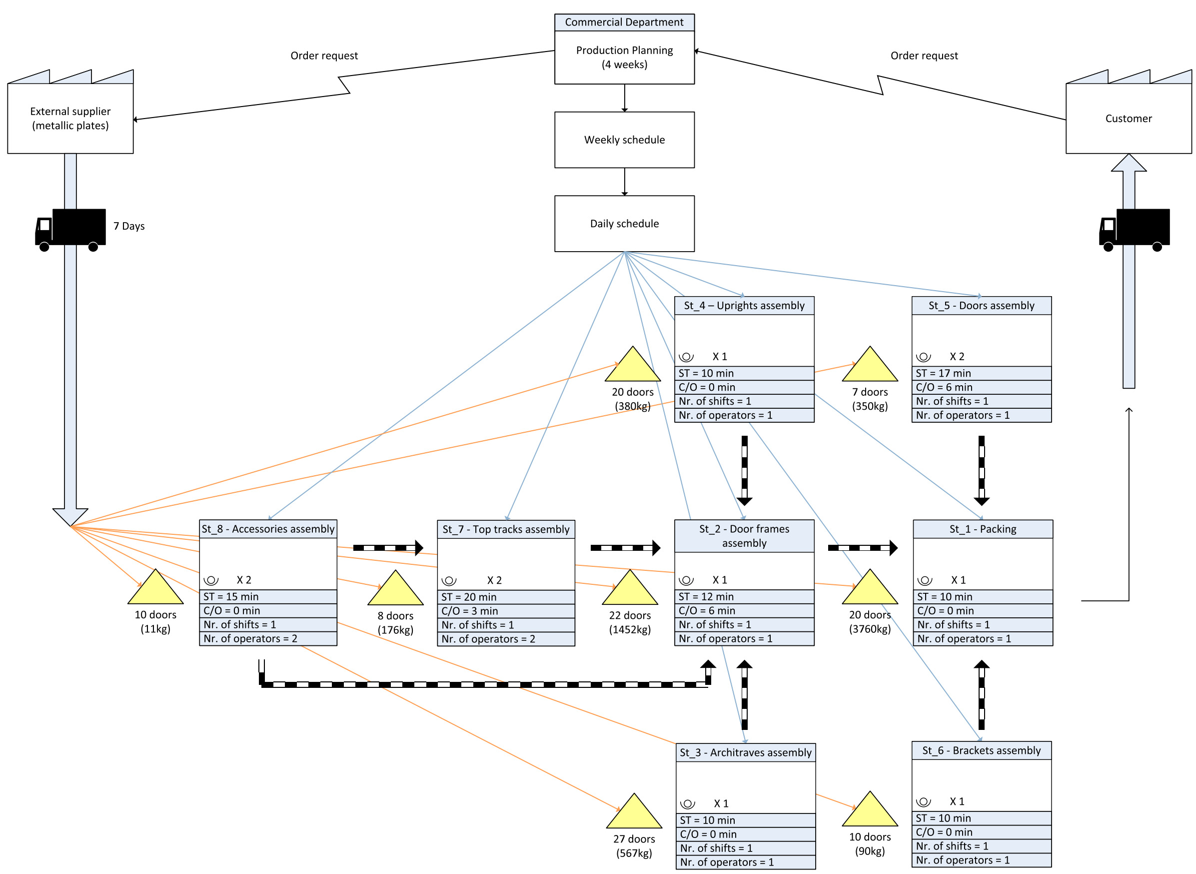

Figure 3. Value Stream Map of a lift's doors production unit.

Table 2. Effectiveness in identifying types of waste.

Waste type	VSM	WID
Inventory	Inventory is graphically represented by a triangle. Its level is given by a number	Inventory level is numerically indicated and graphically represented by the length of the block
Overproduction	Difficult to be interpreted	Difficult to be interpreted
Transportation	It is represented but not evaluated	Clearly evaluated by the arrow width
Defects	Non-existing	Non-existing
Over-processing	Inspection and testing operations only	Inspection and testing operations as well as other presented in the pie chart
Motion	Non-existing	Presented in the pie chart
Waiting	Non-existing	Presented in the pie chart

As far as the overproduction waste is concerned, it is believed 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 companies' management. Another important advantage of WID is the visual information, as 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 utilisation expressed in the pie chart icon. Therefore, this type of waste is in fact identified from two different viewpoints.

Some sorts of over-processing operations are very difficult to identity unless a very close look is performed in every existing operation. Nevertheless, some are easy to identify such as rework, testing and inspection. Operations such as inspection and testing can be presented in VSM although not evaluated. In WID diagrams, this type of waste is presented and evaluated both in the material flows and in the pie chart. In the latter, the rework as well as other identified over-processing operations can be evaluated.

Motion is a type of waste that is only associated to people and it is clearly considered in the workforce utilisation 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 are already a type of waste called "Inventory". Waiting is assigned to people or other resources. Monden (1983) describes waiting waste as a worker's waiting for the machine to complete an automatic operation cycle. A more complete description is presented by Liker and Kaisha (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 get delivered on time is referred by Ohno (1988) and a very similar description is given by Womack and Jones (1996). In the WID, the waiting waste is represented 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 3, even though they are depicted in various routes, only the main flow is accounted for the analysis of lead time and value-added time. To analyse 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 in 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 presents a list of criteria used to compare VSM to WID. That list was built to include the following three types of criteria: (1) the most popular negative VSM aspects referred in the literature; (2) some criteria that the authors believed to emphasise other interesting features of WID and (3) disadvantages of WID when compared to VSM.

The WID ability to represent the whole production unit overcomes the VSM inability to represent multiple production routes, expressed by many authors (Irani and Zhou 1999; Chitturi, Glew, and Paulls 2007) or the difficulty to apply VSM on parallel processes (McDonald, Van Aken, and Rentes 2002). This ability to represent multiple routes is also approached by Braglia, Carmignani, and Zammori (2006) with their IVSM although limited to few production routes.

In terms of measuring waste (Table 3) while VSM only gives the inventory values, the WID also includes transportation values as well as many other labour-related wastes such as movements and waiting. The

Table 3. Comparing VSM and WID.

Comparison Criteria	VSM	WID
Capacity to represent multiple production routes	Only one or two	Only limited by the size of the diagram
Capacity to provide Layout visualisation	Non-existing	Full capacity
Capacity to reflect a products' Bill of Materials	Non-existing	Only limited by the size of the diagram
Capacity to associate costs to waste	Non-existing	Most types of waste are easily evaluated by cost
Easy to visualise the excess of capacity in each station/process	Only by reading values	Very clearly shown visually
Effectiveness as a continuous improvement tool	Some aspects are effective	The effects of improvements are easily spotted
Capacity to measure waste	Only inventory	Most types of waste are evaluated
Evaluation of workforce-related types of waste	Non-existing	Most of them
Visual representation of the throughput time/lead time	The time line and associated values	Complete visualisation
Showing overall performance indicators	Only few indicators	Many indicators can be shown
Production Planning and Control (PPC) Information flow	Important information is shown	Non-existing
Link to suppliers and clients	Material and information link	Non-existing
Push/Pull symbolic information	Clearly shown	Non-existing

transportation arrows presented on WID and its transportation effort evaluation totally solve the VSM limitation presented by Lovelle (2001). 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 and 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 most forms of waste as stated in table 3. The pie chart, where labour-related wastes are represented in terms of percentage of labour utilisation, can easily be translated in terms of cost by simply multiplying the total labour cost by the percentage associated to each type of waste.

When there are conditional routes, VSM does not indicate the percentage of flow which follows each route (Kemper, de Mast, and Mandjes 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 products follow the same route.

Another two VSM limitations presented by Irani and Zhou (1999) are its inability to provide layout visualisation and the inability to reflect a products' Bill Of Materials. The same authors proposed the VNM to reflect products' Bill Of Materials, although, at the cost of losing some other VSM capabilities. WID allows layout visualisation 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.

As presented in Table 3, the proposed WID diagrams have some limitations and disadvantages when compared to VSM. A first example is the Production Planning and Control (PPC) information flow present in VSM that does not appear at all on the WID diagrams. In the same line of disadvantages is also the link to suppliers and clients present in VSM both in terms of material and information flow that does not exist in WID diagrams. Finally, another disadvantage of WID representation is the lack of information regarding pull mechanisms, when existing. To overcome these drawbacks some solutions are being tested and some will be included in next versions of these WID diagrams.

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), utilisation of workers in value adding and non-value adding activities, key performance indicators of the system such as productivity, resources utilisation 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 providing important visual information that can be rapidly perceived by production personnel.

The contribution of this work to theoretical knowledge is mainly focused on modelling production units in its most important dimensions as well as allowing global mathematical reasoning based on existing variables. In terms of practical implications of this research, it is expected the adoption of WID by many companies to represent their production units, wastes and performance. The most relevant limitations reported by practitioners of this proposed tool are the quantity of data that must be collected as well as the difficulty in building the diagram.

WIDs still have however some noteworthy limitations such as the lack of PPC Information flow, the absence of links to suppliers and clients and the lack of identification regarding push or pull mechanism. Further research is required to solve these and other drawbacks of WID diagrams. Other improvements are also planned in order to include Overall Equipment Effectiveness information and some way of identifying over-processing waste. Finally, in terms of future work, the need for the development of a software tool to help or to assist WID construction becomes more and more evident to the authors as the number of projects including WID diagrams is increasing. Such software tool would automate some of the graphical constructions and assure data processing and computing of performance indicators.

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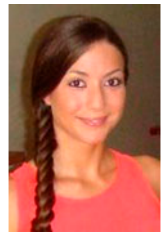

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