PRODUCTION ENGINEERING ARCHIVES 2026, 32(1), 112-122

PRODUCTION ENGINEERING ARCHIVES

ISSN 2353-5156 (print)
ISSN 2353-7779 (online)

Exist since 4th quarter 2013
Available online at https://pea-journal.eu

Value Stream Mapping: some Pragmatic Aspects

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Article history
Received 21.10.2025
Accepted 10.01.2026
Available online 16.03.2026

Keywords
Value Stream Mapping,
Value Stream Mapping Misunderstandings,
Key Performance Indicators,
Lean Education,
Lean Thinking.

Abstract
Value Stream Mapping (VSM) is a widely used industrial tool to represent material and information flows, helping to identify improvement opportunities and define the desired future state. However, its construction often raises difficulties that can lead to mapping errors. This paper draws on the authors' experience of more than three decades, in academic and industrial contexts, to systematise recurrent misunderstandings observed in VSM construction. The study focuses on six problem areas: (1) distinctions between value-added time, processing time, and cycle time; (2) process lead time and inventory lead time; (3) inventory quantification; (4) representation of multiple material flows; (5) treatment of shared processes; and (6) system balancing and bottleneck identification. Several of these issues are absent from the literature, while others, although mentioned, continue to be misapplied. For each, the paper provides clarification and/or a corrective approach, thereby contributing to a more rigorous and consistent use of VSM.

DOI: 10.30657/pea.2026.32.10

1. Introduction

This paper addresses recurring misunderstandings and errors observed in the construction of Value Stream Mapping (VSM). Although VSM is widely used as a diagnostic tool in production systems, practical difficulties in its construction often lead to inaccuracies that compromise the interpretation of material and information flows.

Over the years, the authors have encountered several misunderstandings and errors in VSM construction in multiple academic and industrial contexts. These problems were identified during supervised master's and doctoral projects, student projects developed in industrial environments under Project-Based Learning (PBL) programs, research and consultancy projects, and the review of scientific articles. Despite the relevance of these issues, many of them are not explicitly addressed in reference books or scientific publications. For example, the cross-sectional scenario used in the reference work "*Learning to See*" by Rother & Shook (1999) for constructing a VSM is intentionally simple; it does not allow for the illustration of some of the problems identified in this article.

It is important to note that this article is not about the limitations of the VSM itself, e.g. difficulty in applying it in certain scenarios, but rather about how to construct a VSM correctly. It is also important to note that the work developed focuses only on the original VSM, as presented in the aforementioned book "*Learning to See*", although there are several VSM-inspired tools (as shown in section 3).

Value Stream Mapping (VSM) is one of the most widely used tools to visualize and analyse material and information flows in production systems. It enables the identification of improvement opportunities and the design of a desired future state. However, despite its popularity, literature still presents inconsistencies and incomplete guidance regarding how to correctly construct a VSM. This research addresses that gap by systematically identifying recurrent misunderstandings and proposing methodological clarifications supported by real examples from academic and industrial practice.

2. Methodology

The methodology supporting this study is represented in the structure shown in Fig. 1. The study was triggered by recurrent problems observed in the construction of VSM during multiple academic and industrial projects. These sources were basically the following:

- Master's and doctoral projects supervised by the authors,

- Student projects in industrial context under Project Based Learning (PBL) programs,
- Research projects in which the authors were directly involved as research coordinators,
- Consultancy projects supervised by the authors, and,
- Review of scientific articles.

In these projects and activities, the authors and their research teams have encountered several complex issues in the construction of VSM that were quite challenging to solve. For all the issues identified, a search was carried out in foundational books and scientific articles indexed in Scopus to determine if these problems had already been identified, analyzed, and solved.

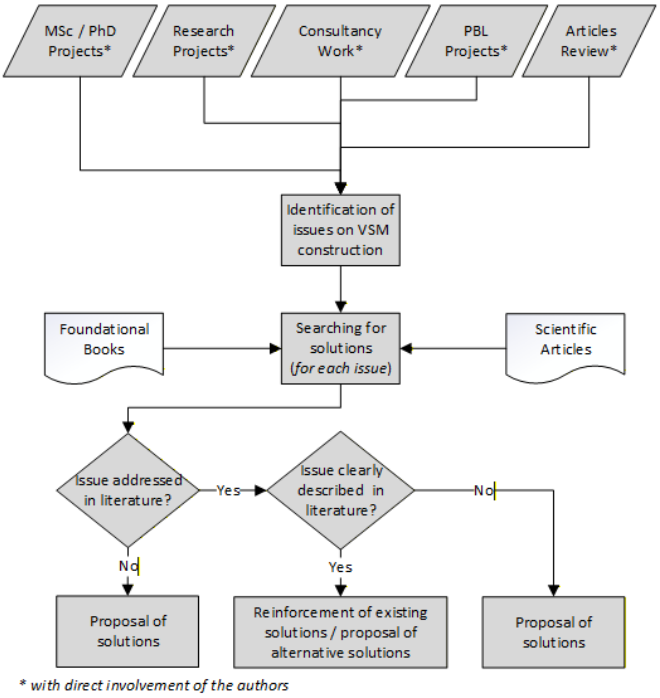


Fig. 1. Structure of the research methodology

As can be observed, a three-tied scheme was defined to categorize the literature coverage of the identified issues and act accordingly: (1) for issues not addressed in the literature, the authors will develop solutions, (2) for issues clearly addressed in literature, the existing solutions will be reinforced and/or alternative solutions will be proposed, and (3) issues not clearly addressed in literature will lead to the development of solutions.

3. Literature research

Apart from the famous books on VSM, "*Learning to See*" (Rother & Shook, 1999) and "*Seeing the Whole*" (Jones & Womack, 2002), the first scientific article on VSM, listed on Scopus or Web of Science, was published in 1997 (Hines & Rich, 1997). Since that publication to date (May 2024), a further 1635 articles have been listed in the Scopus database reporting studies on VSM in lean context, as revealed by a search carried out in the Scopus database, whose results can be seen in Table 1. The search string applied included the name of the tool and the term "lean" (e.g., "Kanban" AND Lean) to avoid different contexts. The search was performed considering article title, abstract, and keywords. As shown in Table 1, VSM is clearly the most popular lean tool being referred to in scientific publications.

Table 1. Number of publications referring to each lean tool

Lean tool	Nr. of publications
Value Stream Mapping	1635
5S	937
Kanban	730
Visual Management	342
SMED	336
Root Cause Analysis	224
Standard Work	181
Poka-Yoke	169
Jidoka OR Autonomation	105
Heijunka	67

VSM is frequently recognized as an effective lean tool for small and medium-sized enterprises (SME) (Narke & Jayadeva, 2020) and one of the most important lean tools applied in industrial sectors together with 5S and Kanban (Sumant & Patel, 2014). Similarly Gonzalez et al. (2019) highlight its widespread adoption across U.S. industry. It has also been identified as the most widely used tool in publications addressing the implementation of lean practices in healthcare environments (Lima et al., 2021).

VSM is not just a tool for visualizing current or future production flows—it is also a methodology deeply aligned with the principles of continuous improvement (Rother & Shook, 1999). It is a cycle that begins with selecting a product family, mapping its current value stream, defining and mapping the future (desirable) state, developing an improvement plan, and repeating these steps every 6 months or so.

The tool initially designed to depict material and information flows within industrial settings has sparked the development of similar tools across various sectors, all under the same name and/or its variations. What began as a set of rules for industrial environments has transcended its original scope, inspiring adaptations for diverse fields. Many studies presented as applications of VSM in different sectors, actually introduce VSM-inspired tools tailored for applications beyond the industrial realm for which it was originally intended. Some notable examples of articles published on the application of VSM or VSM-inspired tools in various other sectors are:

- Construction (Morato & Ferreira, 2024)
- Healthcare (Vidal-Carreras et al., 2022)
- Offices (Costa et al., 2013)
- Oil and Gas industry (Lobo et al., 2020)
- Education(Riezebos & Huisman, 2021)
- Supply Chain (De Steur et al., 2016)
- Product Development (Tyagi et al., 2015)
- Public Services (Arlbjørn et al., 2011)

Most publications report the use of VSM as a tool to describe the current state of a certain production context, design an ideal state and future state, identify problems and improvement opportunities and then lead to the design of solutions to deal with those problems. In most cases, the results are improvements in flow as presented by Azizi & Manoharan (2015) and consequently (or not) in other performance measures. On the other hand, other published studies, also about VSM inspired approaches, add information or changing representations such as "Overall Greenness Performance for Value Stream Mapping" (OGP-VSM) (Muñoz-Villamizar et al., 2019), Value Stream Mapping 4.0 (Meudt et al., 2017), Scrap Value Stream Mapping (S-VSM) (Carmignani, 2017), Ergonomics and other physical/mental health issues (ErgoVSM) (Jarebrant et al., 2015), or VSM+WID (Dinis-Carvalho et al., 2015), just to provide some examples. Table 2 presents a brief description of each of these approaches/tools.

Table 2. Examples of VSM-inspired approaches/tools

VSM-inspired approaches/tools	Characteristics/features
OGP-VSM (*Overall Greenness Performance for VSM*)	Complements the traditional VSM with the measurement of environmental performance, aiming to identify proposals that contribute to achieving so-called "green manufacturing".
VSM 4.0	Adapted to the Industry 4.0 context, specifically focused on the information flow, able to capture information logistical waste and to identify digitalization opportunities.
S-VSM (*Scrap VSM*)	Specifically designed to map and improve scrap management processes, using loss categories identified through the Cost Deployment method.
ErgoVSM (*Ergonomic VSM*)	Complements the traditional VSM with ergonomic assessments that consider risk factors for musculoskeletal disorders.
VSM+WID (*VSM with Waste Identification Diagram*)	Combination that allows better identification/quantification of waste and its distribution throughout the production process under analysis.

In terms of VSM limitations there are also several publications. An important article worth mentioning is one that presents a literature review on problems and challenges found in literature for 15 years (Forno et al., 2014). In this important study the authors identified eleven categories of problems, challenges, and limitations. These categories may be related to products, processes, and people.

Regarding the issues highlighted in this article pertaining to VSM construction, the authors' investigation only identified literature addressing the "multiple flows of materials" problem, namely the works by Braglia et al. (2006) and Sangwa & Sangwan (2023). Therefore, there is a research gap regarding the other identified issues (value-added time, processing time, and cycle time; process lead time, and inventory lead time; inventory quantity; shared processes; and balancing and bottleneck).

The search is difficult because the keywords used have a wide range of meanings. During the search the authors tried combinations between the keyword "Value Stream Mapping" and keywords close to problems, difficulties, errors, and misunderstanding; together with keywords close to construction, computation, and drawing. An example of a search string applied was: ("const* probl*" OR "const* difficul*" OR "const* error*" OR "const* misunderstand*") AND "value stream map*". The result was no publications. Other similar or equivalent strings were used with the same outcome, i.e., no results. The only search with results was with the string: ("comp* probl*" OR "comp* difficul*" OR "comp* error*" OR "comp* misunderstand*") AND "value stream map*", where "comp*" covered words such as "computational", "computation", or "computing". The result was 6 publications, but none was related to the objective of the search.

4. Some pragmatic aspects of VSM

The following subsections describe the most common issues (misunderstandings/errors) identified by the authors in several works involving the construction of VSM.

4.1. Value-added time, processing time and cycle time

According to Rother & Shook (1999), in the simplest case (see Fig. 6 for the general case), the timeline associated with a process should include: (1) lead time associated to inventory $T_{L,Inv}$ and (2) value-added time T_{VA} or processing time T_P (Fig. 2).

The processing time T_P is the quantity of time required to process one unit of the product. If it includes no-value-added work elements (most common case), i.e. wastes (e.g. movements and transports), then T_P is higher than the value-added time T_{VA}, otherwise it is equal. The choice of the value to place in the VSM timeline depends mainly on the availability of the data. It can be argued that ideally it should be T_{VA}, especially if one wants to calculate the value-added ratio (Dinis-Carvalho et al., 2023) referred by Jones & Womack (2002) as Ratio of Value-Created Time. However, T_{VA} is often not available and obtaining it may require too much effort (time and/or difficulty). In these cases, T_P can be used (it is easier to measure), although it will introduce an error if one intends to account for the value-added time T_{VA} of the entire value stream. For the sake of simplicity, from now on, the processing time T_P will be used, unless otherwise stated (in fact, the processing time can always be used, assuming that $T_P = T_{VA} + T_{NVA}$ and that the no-value-added time T_{NVA} may not exist).

The designated cycle time T_C of a given process is in fact a period (inverse of frequency) that indicates the time interval between the delivery of two consecutive units of the product[1]. Like in the case of processing time, cycle time may include wastes (most common case) or not, depending on the nature of the involved work elements.

[1] It is accepted that cycle time is expressed in units of time, although, rigorously, it should be in units of time/product (but then the term "cycle time" would not be correct either).

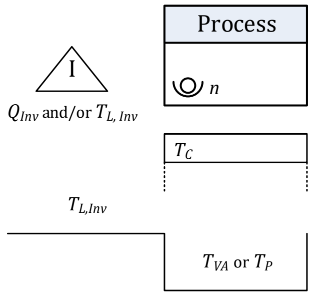
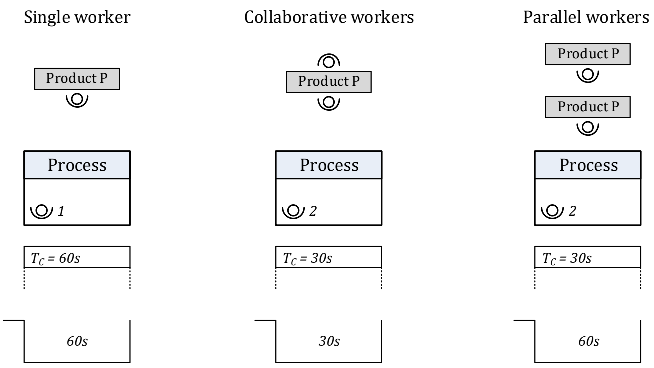


Fig. 2. Timeline associated to a process (simplest case)

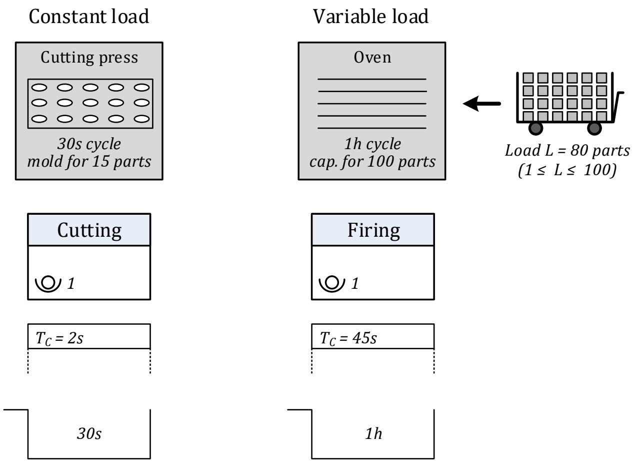
It is precisely in the calculation/indication of cycle time T_C, as well as its relationship with processing time T_P, that a significant number of the problems observed in the construction of VSM was found. For instance, with some frequency, authors observed cases of VSM with processes in which T_P was always, mistakenly, considered as equal to T_C. Although this happens in the main example used in the seminal book by Rother & Shook (1999), this only occurs under certain circumstances, as is mentioned in the book itself but without much detail. The T_P is equal to T_C if only one unit of the product is processed at a time (Fig. 3(a)), regardless the number of workers involved in the processing. Fig. 3(b)) depicts a scenario in which two workers process one unit of the product (the same of Fig. 3(a)), resulting in a cycle time T_C of 30s (assuming that two workers need half the time of one, which may not be true) and, consequently, the processing time T_P is also 30s (because, in this context, the VSM's perspective is on the flow of the product). However, if more than one unit of the product is processed at a time, then the cycle time and the processing time differ. For example, in Fig. 3(c) a second worker (or cobot) was added to produce, in parallel, its own unit of the product (the same of Fig. 3(a)) and, consequently, the cycle time T_C reduces by half but the processing time T_P remains equal (because it is per unit of the product).



(a) (b) (c)

Fig. 3. Examples of relationship between cycle time T_C and processing time T_P in different scenarios; (a) single worker, (b) collaborative workers, and (c) parallel workers

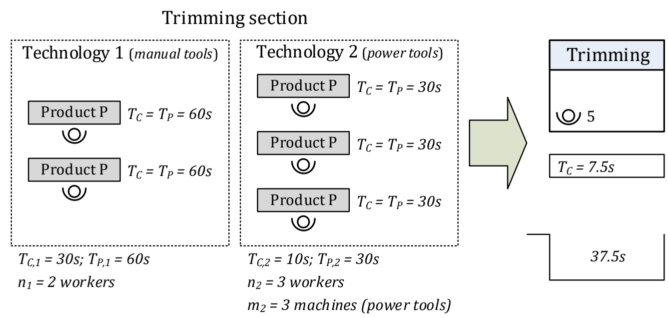
Other scenarios deserve to be analysed, namely one observed in the cutting section of a metal-mechanical company (Fig. 4(a)) and other in the firing section of a ceramics company (Fig. 4(b)), both involving machines that produce several units of a product at a time. Regarding the cutting press, as in every machine cycle (30s) a constant number of parts is produced (determined by the mold/die; 15 parts in this case), the cycle time is $T_C = 30/15 = 2s$ and the processing time is $T_P = 30s$. Regarding the firing section, as the load that is placed in the oven can vary, the cycle time also varies; in the example shown (Fig. 4(b)), $T_C = 3600/80 = 45s$. If, hypothetically, the oven is loaded with a single part, then the cycle time and processing time will be equal (1h), but in practice this would be a strange event.



(a) (b)

Fig. 4. Examples of relationship between cycle time T_C and processing time T_P in different scenarios; (a) constant load, and (b) variable load

To wrap up this subsection, a last scenario is presented, which the authors experienced in a consultancy project in a clothing company, more specifically in the trimming section (where excess threads are removed from garments). The section has five workers ($n = 5$), and two types of technology are available to execute the trimming operation: manual tools and power tools (Fig. 5 (a)), leading to different processing times for the same product. The corresponding VSM excerpt is depicted in Fig. 5(b).



(a) (b)

Fig. 5. Trimming section (a) description diagram (b) excerpt of VSM

The cycle time of the subsection using technology 1 (manual tools), $T_{C,1}$, is 30s as the two workers work in parallel (Fig. 5(a), Fig. 3(c)). Similar situation occurs in the subsection using technology 2 (power tools), leading to a cycle time $T_{C,2}$ of

10s. The processing times are different because the power tools allow for a faster processing. To map the entire trimming section with a single VSM process (Fig. 5(b)), the corresponding cycle time T_C and processing time T_P, can be obtained using:

$$T_C = \frac{T_{C,1}T_{C,2}}{T_{C,1}+T_{C,2}} \quad (1)$$

$$T_P = (n_1 + n_2)T_C \quad (2)$$

Equation 1 was obtained by inverting the sum of the production rates for subsections 1 and 2. To obtain Equation 2, the weighted average of the processing times of each subsection was used. The weight for each subsection was determined by dividing its production rate by the overall production rate of the entire section. It can be easily verified that the parallel scenario described in Fig. 3(c)), complies with equations (1) and (2). A common mistake in scenarios like this is to assume a weighted average value of the cycle times for the cycle time of the aggregate.

4.2. Process lead time and inventory lead time

According to Rother & Shook (1999), in the general case (see Fig. 2 for the simplest case), the timeline associated with a process can include the process lead time T_L and/or, the value-added time T_{VA} or processing time T_P (Fig. 6).

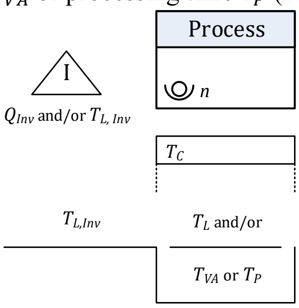


Fig. 6. Timeline associated to a process (general case)

Nonetheless, it is rare to find VSM that include T_L. This also happens in the main example in the book by Rother & Shook (1999), where it is considered that $T_L = T_C = T_P$. Rigorously, the process lead time T_L should be included, even if it is equal to the cycle time, especially, once again (section 4.1), if one wants to accurately compute the value-added ratio. A concrete scenario in which the process lead time T_L must be included occurs when the process is subcontracted, as indicated in the secondary example of Rother & Shook (1999); for an outsourced process, the processing time or the value-added time is not known, nor is it important to know it (Fig. 7 (a)). The authors' proposal is a bit different since that value is necessary to calculate the total value-added time (or total processing time). Therefore, the value-added time or processing time of outsourced processes should be known or estimated. This is natural since it is important in the pricing reference for negotiation with the outsourced company. The authors' proposal is presented in Fig. 7 (b). Instead of having two days assigned to inventory lead time and one day assigned to process lead time (Fig. 7(a)), the authors propose three days of inventory lead time, and the inclusion of the value-added time (or processing time; 600s is just as an example. This is justified by assuming that the lead time associated with inventory ($T_{L,Inv}$), shown below the inventory triangle symbol in VSM, includes both products waiting to be processed and those currently being processed. With that in mind, this proposal simplifies the representation, and it is coherent with the other internal processes representation. In those processes, the lead time associated to inventory $T_{L,Inv}$, normally includes also the products being processed. The authors do not see the need to separate the concepts of inventory lead time and process lead time as the only value needed is the lead time of each process at the takt time pace.

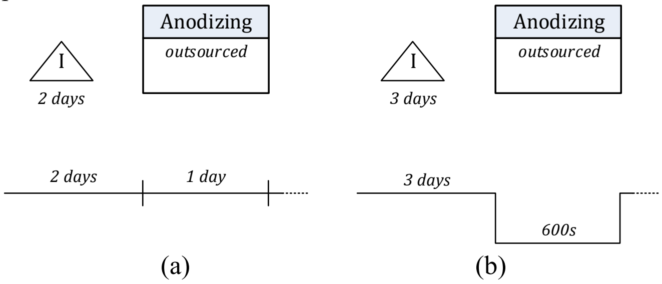


Fig. 7. Process lead time of (a) standard way and (b) proposed way

Note that both inventory lead time $T_{L,Inv}$ and process lead time T_L are expressed in days; this is important as the available time per day may differ from process to process, thus influencing the takt time (see section 4.6).

Another case, again in the authors' point of view, occurs when the process does not add value to the product, e.g. quality inspection. The authors' proposal is depicted in Fig. 8, with the cycle time in the data box of the *Inspecting* process and a value (zero or not) in the value-added time in the corresponding timeline.

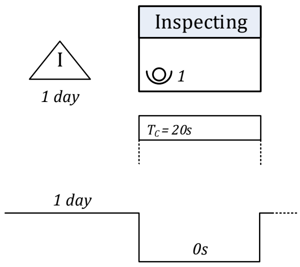


Fig. 8. Inspection process issue

The value-added time assigned to an inspecting process could be zero, assuming that inspection does not adds value to the product. However, some companies consider inspection as a value-adding process if its cost is paid by the customer. Thus, in a VSM it could be acceptable to assume value adding time to an inspection process.

To finalize this subsection, the inventory lead time $T_{L,Inv}$ (Fig. 2, Fig. 6) will be addressed as it is often incorrectly calculated/represented in VSM. Indeed, the authors have observed many VSM in which the inventory lead time is calculated based on the cycle time of the process. This is a strange mistake because Rother & Shook (1999) clearly explain that the inventory lead time must be calculated based on the takt time. Indeed, what really matters is the customer demand and not the production rate of the process, i.e., the purpose of VSM (in this regard) is to show how many days a given inventory quantity lasts, not at the rate that the process consumes it (production rate), but at the rate that the customer wants it (demand). As a simple example, consider a customer characterized by a demand D of 350 parts/day, and a process with a cycle time T_C of 45s and an inventory Q_{Inv} of 1900 parts. Therefore, the inventory lead time is $T_{L,Inv} = Q_{Inv}/D = 5.4$ days (Fig. 9).

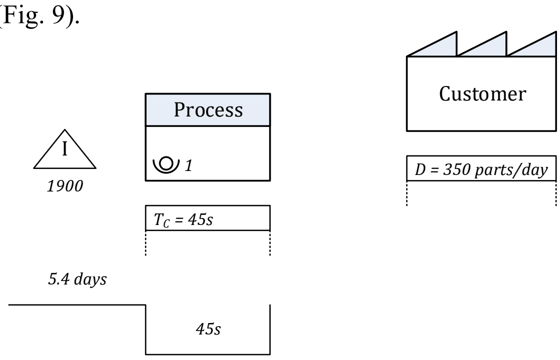


Fig. 9. Inventory lead time

If, incorrectly, the calculation was carried out using the cycle time, the inventory lead time would only be 3,1 days (considering a working day of 460min).

4.3. Inventory quantity

The inventory quantity Q_{Inv} associated with a given process, which includes the quantity waiting to be processed and the quantity being processed, often raises some doubts/difficulties, particularly in terms of: (1) unit used, and (2) quantification. Regarding (1), the unit of inventory quantity should always be the same throughout the different processes within each VSM, for example, product units. Only in this way is there consistency in the construction of the timeline and, consequently, in the calculation of the value chain's throughput time. However, the quantification of this inventory depends on the product's bill of materials (BOM). For example, if one unit of product P, that is processed in process X, consumes two subassemblies S from the inventory at the entrance to that process, then, if there are 100 subassemblies in that inventory, the representation in the VSM should be $Q_{Inv} = 100/2 = 50$ products (Fig. 10).

Still about quantifying the inventory associated with a given process, a very common scenario occurs when several product families, that share raw materials/components/subassemblies, pass through that process. As the VSM maps one product family at a time, it is necessary to determine how much inventory should be allocated to each family.

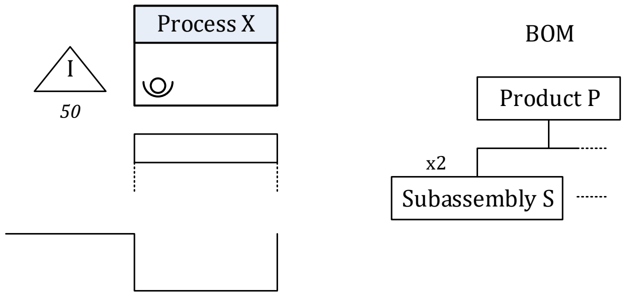


Fig. 10. Inventory quantity depending on the product's BOM

One can consider the entire inventory (and this is quite common in practice), but in this case an error is being made that will impact the lead time of the value chain, inflating it. A simple way of quantifying this is to combine the percentage that the quantity produced of the product family being analysed represents in the total quantity produced by the process, with the consumption expressed in the BOM. To illustrate this scenario, consider a process X at the input of which there is an inventory of 250 subassemblies. Three product families (A, B and C) go through this process at percentages of 20%, 50% and 30%, respectively. Furthermore, each product from each of these families consumes, respectively, 1, 2 and 1 subassemblies of the inventory at the input of process X. Combining the production percentages with the subassemblies consumption, leads to a combined consumption of subassemblies of 13.3%, 66.7% and 20%, respectively for families A, B and C (Table 3).

Table 3. Inventory quantity depending on the product's percentage of production and BOM

Types of barriers	Family A	Family B	Family C
Production quantity [%]	**20%**	**50%**	**30%**
Subassemblies consumption [subassemblies]	**1**	**2**	**1**
Subassemblies consumption [%]	**25%**	**50%**	**25%**
Combined subassemblies consumption [%]	**13.3%**	**66.7%**	**20%**
Subassemblies inventory [subassemblies]	**33**	**166**	**50**
Inventory quantity for VSM [products]	**33**	**83**	**50**

Note that, as in VSM the inventory must be expressed in product units, for each family it is necessary to divide the inventory of subassemblies by the respective consumption indicated in the BOM, as can be seen in the last line of Table 3. Please note that rounding to the nearest integer may be necessary as the number of subassemblies in inventory may not be a multiple of the consumption required by the different products (this is the case in this example). Thus, for the described scenario, the VSM excerpts of each family of products are represented in Fig. 11. The examples presented demonstrate that inventory quantification must consider both the production mix and the bill of materials (BOM) structure.

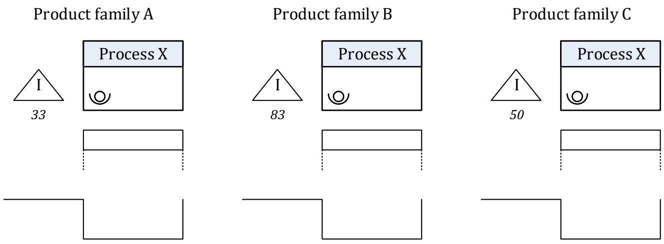


Fig. 11. Inventory quantity depending on the product's percentage of production and BOM

This approach ensures coherence throughout the value stream and prevents the overestimation of lead times when several product families share common inventories. Maintaining a consistent unit of measure across all processes is also essential to ensure comparability and accuracy in the analysis.

4.4. Multiple flows of materials

When there are several material flows associated with a product/family of products, trying to map them all will probably consume a lot of time and lead to a VSM that is too dense and complex (particularly when constructing the timeline), which ends up be counterproductive (Jones & Womack, 2002). Rother & Shook (1999) also state that the most important flows can be mapped, but not all. The question that arises is: what criteria can be used to choose the most important material flow? One can choose the flow of a structural component that always accompanies the product, e.g. the chassis of a car or a printed circuit board of an electronic device; one can choose the material flow that involves more workers or the material flow in which there are more quality problems; etc. From the authors' perspective, another criterion can be the material flow with the longest lead time. The justification comes from the concept of critical path, associated with the critical path method used in project management. In fact, to reduce the duration of a project (lead time of the value stream) one must start by reducing the duration (lead time) of the critical path (material flow with the longest lead time). Of course, reducing lead time may not even be one of the objectives, but it can also be, and, in this case, this approach makes sense. As an example, consider the case of a product/family of products whose assembly requires three subassemblies, built by the company itself using components from external suppliers (Fig. 12).

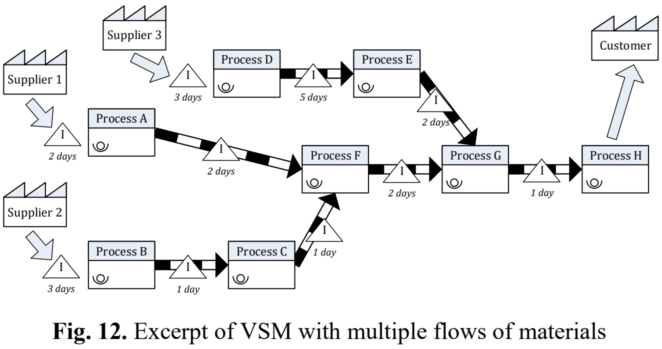


Fig. 12. Excerpt of VSM with multiple flows of materials

As can be observed (Fig. 12), the representation of all material flows could make the VSM dense and poses difficulties in constructing the timeline. One problem is the difficulty in presenting an interpreting all the information in the map. Another problem is the difficulty in presenting and interpreting the timelines. One solution could be representing the various material flow as long as it is understandable and only one timeline of the most representative, or chosen, material flow. Thus, if the objective is to map only the material flow with the longest lead time, a quick analysis of Fig. 12 or Table 4 identifies that this flow is: *Supplier3-D-E-G-H-Customer*, with a lead time of 11 days.

Table 4. Lead time of material flows in the VSM excerpt in Fig. 12

Material flow	Lead time [days]
Supplier1 - A - F - G - H - Customer	2+2+2+1=7
Supplier2 - B - C - F - G - H - Customer	3+1+1+2+1=8
Supplier3 - D - E - G - H - Customer	3+5+2+1=11

Therefore, with this approach, the VSM excerpt represented in Fig. 11 is obtained.

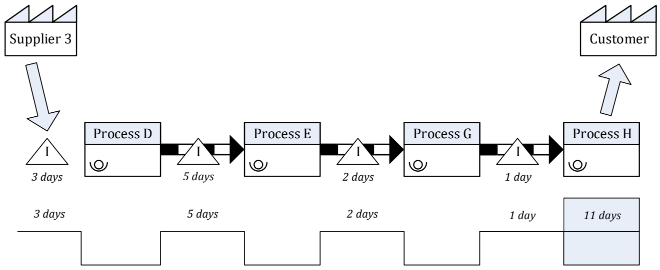


Fig. 13. Excerpt of VSM of the material flow with the longest lead time

If intended, it is possible to reduce the lead time of this material flow to eight days, making this the lead time of the entire value stream (Fig. 12). However, to further reduce the latter it is necessary to simultaneously reduce the lead time of the flow *Supplier2-B-C-F-G-H-Customer* flow, since it also has a lead time of 8 days (Table 4).

4.5. Shared processes

In many cases, one process (or more) is shared by several families of products (i.e. several material flows), besides the one represented in the VSM. This poses an additional challenge, which is how to make the capacity of that process visible. As the process is not exclusively dedicated to the material flow represented in the VSM, there can be misinterpretations regarding the available capacity. Even if the cycle time is significantly lower than the takt time of the family represented in the VSM, this does not mean that there is too much capacity available (in fact, there may not even be enough capacity). To exemplify, consider the excerpt of VSM represented in Fig. **14**, where the *Drilling* process is shared by other families of products, in addition to the one represented that corresponds to 20% of the process capacity (in terms of time); note that nothing in the VSM indicates that the process is shared.

Consider a demand D = 150 parts/day and an available time for production T_A = 27 600 s/shift. The corresponding takt time is calculated as:

$$T_t = \frac{T_A}{D} = \frac{27600}{150} = 184s \quad (3)$$

As the process is shared with other product families and only 20 % of its capacity is available for the family under analysis, the effective takt time becomes:

$$T_t = \frac{0.2 \times 27600}{150} = 36.8s \quad (4)$$

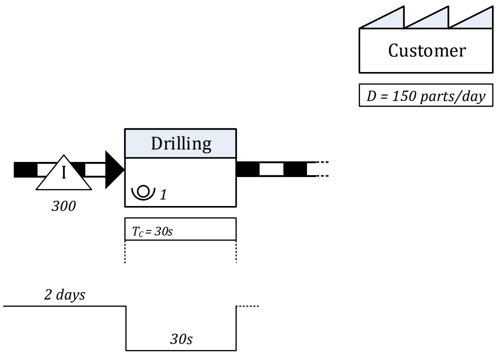
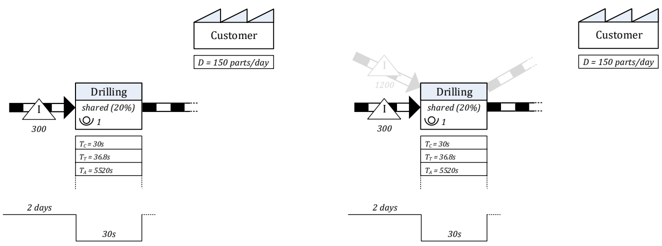


Fig. 14. Excerpt of VSM involving a shared process

It is therefore clear that the process does not have that much spare capacity after all, something that is not visible at all in Fig. 14.

As this case was not addressed in the foundation books nor in scientific articles, the authors propose an explicitly indication that the process is shared by other families of products, including the respective sharing percentage in the process box and the real takt time in the process data box (Fig. 15 (a)). Alternatively, to enhance clarity, a faded arrow to represent of the remaining material flows can also be included (Fig. 15(b)).



(a) (b)

Fig. 15. Proposals for shared process representation (a) without remaining material flow (b) with remaining material flow

To conclude, representing shared processes explicitly, as proposed, avoids misleading interpretations regarding the available capacity of each process. Including the percentage of capacity shared with other product families directly inside the process box provides clarity about real utilisation levels. Optionally, adding faded arrows to represent the remaining material flows further enhances transparency and facilitates understanding of the system's overall dynamics.

4.6. Balancing and bottleneck

A last situation, observed by the authors, involving misunderstandings, is related to the analysis of the cycle time T_C of the processes in a VSM, aiming to diagnose the balancing of the system and/or to identify its bottleneck.

To exemplify, consider the excerpt of VSM represented in Fig. 16, where the customer poses a demand D of 960 parts/day and the available time for production T_A is 27600s/shift (8h minus 20min for breaks).

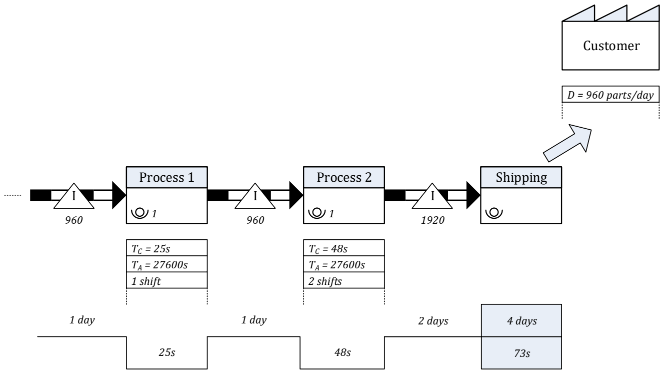


Fig. 16. Excerpt of VSM involving processes with different number of shifts

The examples provided illustrate that the correct interpretation of system balancing and bottlenecks in a VSM requires considering not only the cycle times but also the number of shifts or available working time of each process. Ignoring this factor may lead to inaccurate conclusions regarding capacity or flow constraints. Therefore, the inclusion of this analysis ensures a more realistic assessment of the production system's behaviour.

It can be seen (Fig. 16) that there is a large imbalance in the cycle times of processes 1 and 2 (25s and 48s, respectively). However, as *Process 2* works in two shifts, the immediate negative effect of this imbalance (i.e., excessive WIP accumulation) is mitigated (without however resolving the discrepancy of cycle times). Thus, directly comparing the cycle times of processes without considering the number of shifts/time available for working in each process can lead to incorrect conclusions regarding the balance of the system.

The same problem can occur when identifying the system bottleneck. It is often found that, incorrectly, this identification immediately falls on the process with the longest cycle time. In the case of Fig. 16, this approach would identify *Process 2* as being the bottleneck, when it is not. In fact, *Process 2* has a production rate of 1150 parts/day ($1/48\ \text{parts/s} \times 2\ \text{shifts/day} \times 27600\ \text{s/shift}$), while in *Process 1* this rate is only 1104 parts per day. In other words, although in VSM (Fig. 16) *Process 2* has the longest cycle time (48s), due to the different number of shifts, the bottleneck is the *Process 1*, with a cycle time of just 25s.

It should be noted that, for this analysis, the authors interpreted that the bottleneck is the process that limits the system's production rate, despite it being capable of responding to customer demand. In this case, as each process has a different available time, the same will happen to their takt time $T_T = T_A/D$. For *Process 1*, $T_{T,1} = 27600/960 = 28{,}75$ s and for *Process 2*, $T_{T,2} = 2 \times 27600/960 = 57{,}5$ s. Thus, as the takt time of each process is greater than the respective cycle time, the system can respond to customer demand. This also shows that, as mentioned in section 4.2, the inventory lead time must be expressed in days, as a day may have more than one shifts/available time that varies depending on the process, but it is still a day.

5. Discussion

The issues (misunderstandings/errors) in VSM construction, reported in this article, can be organized into three categories: (1) issues clearly described in the "*Learning to See*" (LTS) book, but which are often misunderstood or ignored, (2) issues insufficiently described in LTS book and not referred in scientific articles, and (3) issues neither described in the LTS book nor scientific articles.

5.1. Issues clearly described in the literature

In this category, the authors include the issues referred to in the section 4.2 as process lead time and inventory lead time in outsourced processes. Although they are clearly described in the LTS book, a new (different) proposal is presented (section 4.2) as well as a specific example (Fig. 7). In the authors' opinion, it is reasonably more realistic to assume that the processing time is not, by far, equal to the outsourced lead time. The value-added time (or processing time) should be known or at least estimated for the outsourced processes. That information is important to determine the total value-added time as well as its weight on the total lead time, which is an important indication of the level of fluidity of the whole process (value-added ratio).

Another issue in this category is related to the inventory lead time calculation (section 0). Although this issue is clearly described in the LTS book, many people misinterpret or ignore it. The inventory lead time associated with a process is obtained by multiplying the inventory quantity by the takt time (Fig. 9) and not, as many people think, multiplying by the process cycle time. This may not be intuitive at first glance, but that is how it should be calculated.

The last issue in this category occurs when multiple flows of materials are represented in the VSM (Fig. 12), which may become very confusing and present difficulties in terms of timeline. In such cases, the LTS book proposes the representation of only one flow of materials, that of the key components. The authors propose alternatives; one is to represent only the flow with the highest lead time (inspired by the concept of critical path) as shown in (Fig. 13), or the flow that, for some other reason, the analysts are focused on. Another option is to represent more than one flow of material, as long as they are readable, and represent only the timeline that is targeted in the study.

5.2. Issues insufficiently described in the literature

The issues reported here are not described in sufficient detail in the LTS book and no scientific articles about them were found in the search presented in section 3.

The first issue is related to the difference between the concepts of cycle time and processing time (section 4.2). Most of the time these values are the same (e.g. Fig. 3(a)) but, in other cases, they are not (e.g. Fig. 3(c)). Specific scenarios (involving more than one worker/machine working in parallel, or a machine processing several products at the same time) are provided by the authors, along with the respective solutions.

The second issue of this category is related to the inventory quantity calculation. A detailed description and a new proposal can be found in section 4.3. One problem is when the quantity of a component, or raw material, necessary to make one product is not unitary. If, for instance, four wheels are needed to build one car, in the wheels flow the inventory would be the number of wheels divided by 4 in order to keep good calculations of lead time in the entire VSM flow.

A final issue in calculating inventory quantity arises when multiple product families use the same inventory at the start of a process. This is complicated by the fact that the families may consume the inventory at different rates, and VSM only maps one family of products at a time. An example is provided in Table 3 and Fig. 12, along with the corresponding solution, involving three product families passing in the same process, with different production quantities and inventory consumptions.

5.3. Issues not covered in the literature

The issues reported in this section are not described in the LTS book and no scientific articles about them were found in the conducted literature search (section 3). One of those issues is the cycle time calculation depending on the number of workers and work organization. Detailed description can be found in section 4.1 and specific examples in Fig. 3, Fig. 4, and Fig. 5. The cycle time calculation may not be straightforward in all these cases. The trickiest one is when parallel machines, with different technologies, are processing products at different rates (Fig. 5). In these cases, although the overall processing time is the weighted average processing time, the cycle time of the overall process is a bit more complicated to obtain, as explained at the end of section 4.1.

A second issue is related to the representation of non-value-added processes. A proposal is presented in section 4.2 with a specific example of inspection (Fig. 8). In this example, although there is a cycle time associated with the inspection process, zero is assigned to the value-added time in the timeline. Nevertheless, the inspection time can be considered in the timeline if it is assumed that the client formally recognizes this cost and is willing to pay for it.

A third problem occurs when, in addition to the product family whose value stream is being mapped, other product families exist (not represented in the VSM) sharing a common process (or more). In these cases, the cycle time presented may lead to analysis errors in terms of the available capacity of that process. The authors' proposal is presented in Fig. 15 and brings more transparency by explicitly indicating the shared nature of the process (including the sharing percentage).

The last issue of this category is related to bottleneck interpretation, which can be confusing if different processes work with different numbers of shifts. As can be seen in Fig. 16, at first glance, the bottleneck appears to be *Process 2*. Nevertheless, when looking a bit closer, *Process 2* works in two shifts while *Process 1* works only in one shift. That changes everything. In fact, *Process 1* has less capacity than *Process 2* being thus the system bottleneck.

5.4. Synthesis

To summarize the work developed in terms of performed analysis and proposed solutions, Table 5 was created.

Table 5. Synthesis of analysis structure and proposed solutions

	Literature coverage			
Issue	**Clearly described**	**Insufficiently described**	**Not covered**	**Outcomes**
Cycle time and processing time (*distinction*)		X		Concepts were clarified (*Fig. 2 section 4.1; section 5.2*)
Cycle time and the number of workers and work organization (*calculation*)			X	Representative real cases are presented, and respective solutions are proposed (*Figs. 3-5, section 4.1; section 5.3*)
Process lead time and inventory lead time in outsourced processes (*calculation*)	X			Yet, a new solution was proposed (*Fig. 7, section 4.2; section 5.1*)
Non-value-added processes (*representation*)			X	A solution was proposed (*Fig. 8, section 4.2; section 5.3*)
Inventory lead time (*calculation*)	X			Existing solution was reinforced (*Fig. 9, section 4.2; section 5.1*)
Inventory quantity (*calculation*)		X		Calculation procedures were defined for representative scenarios (*Figs. 10-11, section 4.3; section 5.2*)
Multiple flows of materials (*representation*)	X			Yet, two new solutions were proposed (*Fig. 13, section 4.4; section 5.1*)
Cycle time of shared processes (*calculation*)			X	A solution was proposed (*Fig. 15, section 4.5; section 5.3*)
Balancing and bottleneck, and number of shifts (*interpretation*)			X	A representative scenario was presented and the solution for the correct interpretation was proposed (*Fig. 16, section 4.6; section 5.3*)

It becomes evident that a significant number of issues (4 out of 9) is not covered by the literature, justifying thus the pertinence of the developed solutions). Even for two of the three issues clearly described in the literature, alternative solutions were proposed.

6. Conclusion

The primary objective of this paper was to identify the main existing misunderstandings/errors in the construction of VSM (based on the authors experience of more than three decades), verify if these issues are addressed in the scientific literature, and propose ways to solve them or clarify existing solutions, always providing concrete examples. Naturally, the global aim is to develop the ability to construct VSM correctly and rigorously, given the importance that this diagnostic tool has, or can have, in the development of projects to improve production systems performance.

The findings revealed the existence of three classes of issues. The first encompasses a set of issues which, although they are well explained and resolved in the literature, strangely give rise to frequent errors in the construction of VSM, possibly motivated by some misinterpretation which then spreads (e.g. the calculation of inventory lead time). For this first category, the authors reinforce and complement existing explanations/solutions in the literature and even propose alternative solutions in some cases (e.g. process lead time of outsourced processes).

The second category of issues is addressed in the literature, but in a clearly insufficient way (lack of details and examples). For this reason, this category gives rise to frequent errors, and thus the authors have developed detailed explanations and present concrete solutions, duly exemplified (e.g. calculation of the quantity of inventory in processes shared by more than one product family).

Finally, the third category includes issues that are not mentioned in the literature. In these cases, detailed descriptions, concrete solutions and application examples are once again developed (e.g. calculating cycle time and processing time on machines with a fixed load and on machines with a variable load).

From the authors' perspective, all the problems identified are relevant due to their impact on VSM construction and, in this sense, the solutions presented (reinforced or completely new) are an important contribution to the general body of knowledge of Industrial Engineering and Management, not only in the academic context, but also in the professional environment.

Beyond these contributions, future research should explore the integration of VSM with digital technologies and Industry 4.0 tools, as well as the development of data-driven or simulation-supported approaches for dynamic VSM construction. These perspectives could further strengthen the tool's relevance in modern lean system analysis.

Acknowledgments

This work has been supported by FCT – Fundação para a Ciência e Tecnologia within the R&D Unit Project Scope UID/00319/2025 - Centro ALGORITMI (ALGORITMI/UM) https://doi.org/10.54499/UID/00319/2025"

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