DIGITALIZATION IN THE TEXTILE INDUSTRY: AN ANALYSIS COMPARING VALUE STREAM MAPPING 4.0 AND SHINGO 4.0 – MIF

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ABSTRACT

In the context of digitalization and the continuous quest for operational excellence in industry, it is crucial to examine tools that offer an in-depth insight into production and information flows from various viewpoints. This study investigates the relative use of the Shingo 4.0 - Material and Information Flow (MIF) model alongside Value Stream Mapping 4.0 (VSM 4.0) to highlight their shared features, distinctions, and supportive functions in examining production and information processes. The research took place in the textile sector. Employing a case study approach, the study presents quantitative data collection. The research analyzed how each instrument understands operational dynamics and information transfer. The Shingo 4.0 - MIF model facilitated a clear separation between process and operational activities, providing an in-depth illustration of both human and physical flows. In contrast, VSM 4.0 provided insights into digital maturity, especially regarding information access, system integration, and efficient data use. Results indicated that although both tools are based on lean thinking, they provide different analytical viewpoints. The Shingo 4.0 - MIF emphasizes improving insight into spatial and operational movements, while VSM 4.0 excels at revealing informational shortcomings and pointing out gaps in digitalization. The study illustrates that the combined use of the Shingo 4.0 - MIF and VSM 4.0 creates a strong foundation for assessing existing operational and informational methods. This dual-tool method enhances strategic decision-making and ongoing improvement in production settings experiencing digitalization, especially those marked by complexity and variability.

Keywords: Digitalization. Industry 4.0. Shingo 4.0 - Material and Information Flow (MIF). Value Stream Mapping 4.0. VSM 4.0. Digital VSM, Textile Industry.

RESUMO

No contexto da digitalização e da busca contínua pela excelência operacional na indústria, é crucial examinar ferramentas que ofereçam compreensão aprofundada dos fluxos de produção e de informação sob diferentes pontos de vista. Este estudo investiga o uso relativo do modelo Shingo 4.0 - *Material and Information Flow* (*MIF*) juntamente com o *Value Stream Mapping 4.0* (*VSM* 4.0), a fim de destacar suas características comuns, distinções e funções complementares na análise de processos produtivos e informacionais. A pesquisa foi realizada no setor têxtil. Utilizando uma abordagem de estudo de caso, o trabalho apresenta coleta quantitativa de dados. A análise examinou como cada instrumento interpreta a dinâmica operacional e a transferência de informações. A visão do Shingo 4.0 - *MIF* possibilitou uma separação clara entre atividades de processo e operacionais, oferecendo uma representação detalhada dos fluxos humanos e físicos. Em contraste, o *VSM* 4.0 forneceu percepções sobre a maturidade digital, especialmente no que se refere ao acesso à informação, à integração de sistemas e ao uso eficiente de dados. Os resultados indicaram que, embora ambas as ferramentas sejam fundamentadas no pensamento enxuto, oferecem perspectivas analíticas distintas. O Shingo 4.0 - *MIF* enfatiza a

compreensão dos movimentos espaciais e operacionais, enquanto o V*SM* 4.0 se destaca por identificar deficiências informacionais e lacunas na digitalização. O estudo demonstra que a aplicação combinada do modelo Shingo 4.0 - *MIF* e do *VSM* 4.0 constitui uma base sólida para avaliar métodos operacionais e informacionais, fortalecendo a tomada de decisão estratégica e a melhoria contínua em ambientes produtivos digitalizados, especialmente em contextos complexos e variáveis.
Palavras-chave: Digitalização. Indústria 4.0. Shingo 4.0 - *Material and Information Flow* (*MIF*). *Value Stream Mapping* 4.0. *VSM* 4.0. Digital *VSM*, Indústria Têxtil.

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1 INTRODUCTION

The pursuit of operational excellence has intensified the need for process optimization and digital integration in industrial environments. Globally, the textile industry is facing an uncertain economic climate and shrinking demand, made worse by inflation and global economic instability which reduce profit margins and operational productivity, according to Aghion et al, (2022). In this context, understanding how materials and information move across the production chain becomes essential for identifying inefficiencies and guiding digitalization strategies (Falani, Aguiar & Dal Forno, 2019).

In Brazil, these global challenges are intensified by a high tax burden (Sutter et al., 2016), low digital maturity (Petrillo, Rehman & Baffo, 2024), and elevated industrial energy costs (Melo, Silva & Campello, 2012). While VSM 4.0 permits the integration of digital technologies and the real-time data in process analysis (Meudt et al., 2017), Shingo 4.0 - MIF complements this approach by focusing on how information is generated, accessed and used throughout the value chain (Nunes, Chiká & Santos, 2024). Together, these methodologies support comprehensive analysis of both material and informational inefficiencies, supporting operational and managerial decision-makin**g** and the implementation of the Industry 4.0 practices. This study presents the application of VSM 4.0 and Shingo 4.0 in the analysis of a production flow within a medium-to-large-sized textile company. The study aimed to identify non-value-adding activities and informational gaps associated with the analyzed production process. Through this case study, the research seeks to demonstrate how mapping tools can foster greater integration between operational areas, support the identification of opportunities for process integration and operational improvement. In this context, the research question of this study is: how can integrating Value Stream Mapping 4.0 (VSM 4.0) and Shingo 4.0 - Material and Information Flow (MIF) help identify opportunities for digitalization in a medium sized textile company? The general objective of this study is to analyze how the combined application of VSM 4.0 and Shingo 4.0 - MIF supports the identification of operational inefficiencies and digitalization opportunities in a textile production process. To guide the achievement of this general objective, the following specific objectives were established: The specific objectives of this study are: (i) to map the operational and informational flow of a textile production process using VSM 4.0 and Shingo 4.0 - MIF; (ii) to identify value-added and non-value-added activities throughout the production flow; (iii) to evaluate the level of digital integration and information utilization within the analyzed environment and; (iv) to analyze operational and informational inefficiencies associated with the production process.

This manuscript is organized into five sections to ensure a comprehensive and systematic presentation of the study. The first section introduces the research context, relevance, objectives

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and this introduction. The second section presents the theoretical foundation of this study. The third section describes the company in which the case study was conducted and details the analysis of the current state of the information flow, supported by visual mapping and interpretation of results. Finally, the fourth section offers concluding reflections, highlighting the main contributions of the study and proposing directions for future research.

Although Value Stream Mapping 4.0 and Shingo 4.0 - Material and Information Flow (MIF) have been individually applied to analyze operational and informational processes, empirical studies combining both approaches within the same industrial environment remain scarce. This study contributes to the literature by providing an integrated application of these methodologies in a textile manufacturing context, enabling the simultaneous assessment of operational inefficiencies, informational fragmentation, and digitalization opportunities. By combining operational and informational perspectives, the study extends current lean and Industry 4.0 diagnostic approaches and offers a structured framework for supporting digital transformation initiatives.

2 THEORETICAL REVIEW

2.1 TOYOTA PRODUCTION SYSTEM

The Toyota Production System (TPS) focuses on improving operational efficiency rather than increasing efforts: it boosts productivity, reduces waste, and satisfies clients by encouraging contributions from everyone, from the shop floor to the boardroom, in ongoing small improvements termed kaizen (Ohno, 1988; Nunes, Vaccaro & Júnior, 2017). At its heart, TPS tackles three big headaches, unnecessary waste, overburdened people and machines, and uneven workflows, to create a smooth, reliable production rhythm (Shingo, 1989). Unlike old-school mass manufacturing, TPS can adapt rapidly to market demands, quickly adjusting to what customers really want (Ohno, 1988).A fundamental approach of TPS focuses on recognizing and removing seven key types of waste: overproduction, unnecessary transport of products, excessive processing steps, product flaws, waiting periods, inefficient movements, and excess inventory (Monden, 2012; Strassburguer et al., 2023). Addressing these inefficiencies is essential for increasing productivity and improving product quality. A key element in the Toyota Production System (TPS) is the Shingo Production Mechanism (SPM), which was presented by Shigeo Shingo. This framework emphasizes two related dimensions of production: the Process Function, which examines the movement

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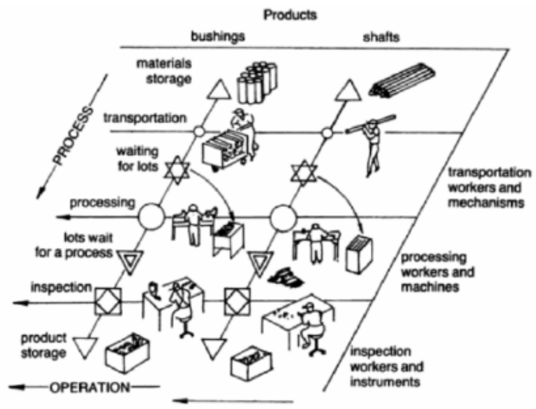
and transformation of materials, and the Operation Function, which concentrates on the execution of tasks by machines and personnel (Shingo, 1989).

SPM provides a structured approach that boosts ongoing improvement efforts and reduces waste by perceiving production as more than just a simple series of activities (Strassburguer et al., 2023). Figure 1 shows Shingo's Production network (operations and processes), clearly distinguishing processes from operations and illustrating the movement of materials and services across the system.

Figure 1 – Shingo´s Production network (processes and operations)



Source: Nunes, Chiká, and Santos (2024); Shingo (1988) and Strassburguer et al. (2023).

TPS and instruments like the SPM have been utilized and researched in different industrial sectors, offering insights for both discrete manufacturing and process industries (Agostinho et al., 2020; Müller et al, 2025). Additionally, they provide assistance for incorporating lean principles throughout the complete value chain (Stoffel, Nunes & Piran, 2018; Strassburguer et al., 2023).

2.3 VSM 4.0 (VALUE STREAM MAPPING)

The implementation of Value Stream Mapping 4.0 (VSM 4.0) has proven to be an effective tool for identifying informational inefficiencies in logistics environments, particularly in the context of digitalization. Chiká and Nunes (2024) applied this methodology in a Brazilian distribution center and found that 84% of the information was still manually processed, with no integration between data collection and its effective utilization. Key indicators such as Digitization Rate (DR), Data Availability (DA), and Data Utilization (DU) revealed critical gaps, DR was only 9%, and DU was 0%. These findings support the framework developed by Meudt et al. (2017), which advocates the inclusion of information flows in lean mapping practices as a central element of process diagnostics.

The proposal to implement these technologies illustrates how VSM 4.0 can support digitalization by identifying and quantifying critical gaps in current workflows (Chiká and Nunes, 2024). In their study, the lack of a WMS contributed significantly to prolonged order picking times, making it the most time-consuming activity in the process. According to Rother and Shook (2009), value stream mapping serves as a visual tool to detect inefficiencies within production and service processes. VSM 4.0 builds upon this by incorporating data quality and usage dimensions, as proposed by Meudt et al. (2017). As organizations move toward digitalization, VSM 4.0 emerges as a critical evolution of traditional lean tools.

Effective digitalization initiatives require to have precise, reliable data flowing effortlessly throughout all areas of the factory Classic lean tools weren't built for today's complex shop floors, where layers of sensors, software, and networks operate simultaneously. To address this limitation, Bega et al (2023) rolled out VSM 4.0 Plus, representing an expanded version of traditional Value Stream Mapping. Now you don't just chart the flow of materials; you capture how often data is recorded, how precise those measurements are, what interfaces tie systems together, and which protocols carry the information.

2.3.1 Steps of VSM 4.0

Value Stream Mapping 4.0 (VSM 4.0) emerged as an extension of traditional value stream mapping by incorporating informational and digital dimensions into process analysis. While conventional VSM primarily focuses on material flow and operational activities, VSM 4.0 expands this perspective by evaluating how information is generated, stored, accessed, and utilized throughout production systems (Meudt et al., 2017). This approach is particularly relevant in Industry 4.0 environments, where operational performance increasingly depends on data integration, digital accessibility, and information utilization.

The VSM 4.0 framework proposed by Meudt et al. (2017) is structured into six sequential stages. Initially, the current-state value stream is mapped to identify operational activities, material flows, and potential process inefficiencies. Subsequently, the informational layer is incorporated through the identification of storage media, including ERP systems, spreadsheets, manual records, and isolated digital resources. After this stage, informational elements and KPIs are associated with their respective storage sources and collection methods, enabling the visualization of informational dependencies and integration conditions.

The framework also evaluates how information is used across organizational activities, identifying whether collected data support operational monitoring, managerial analysis, or decision-making processes. Based on these informational interactions, specific indicators are calculated to assess the digital maturity of the analyzed environment. Figure 2 presents the analytical structure of the VSM 4.0

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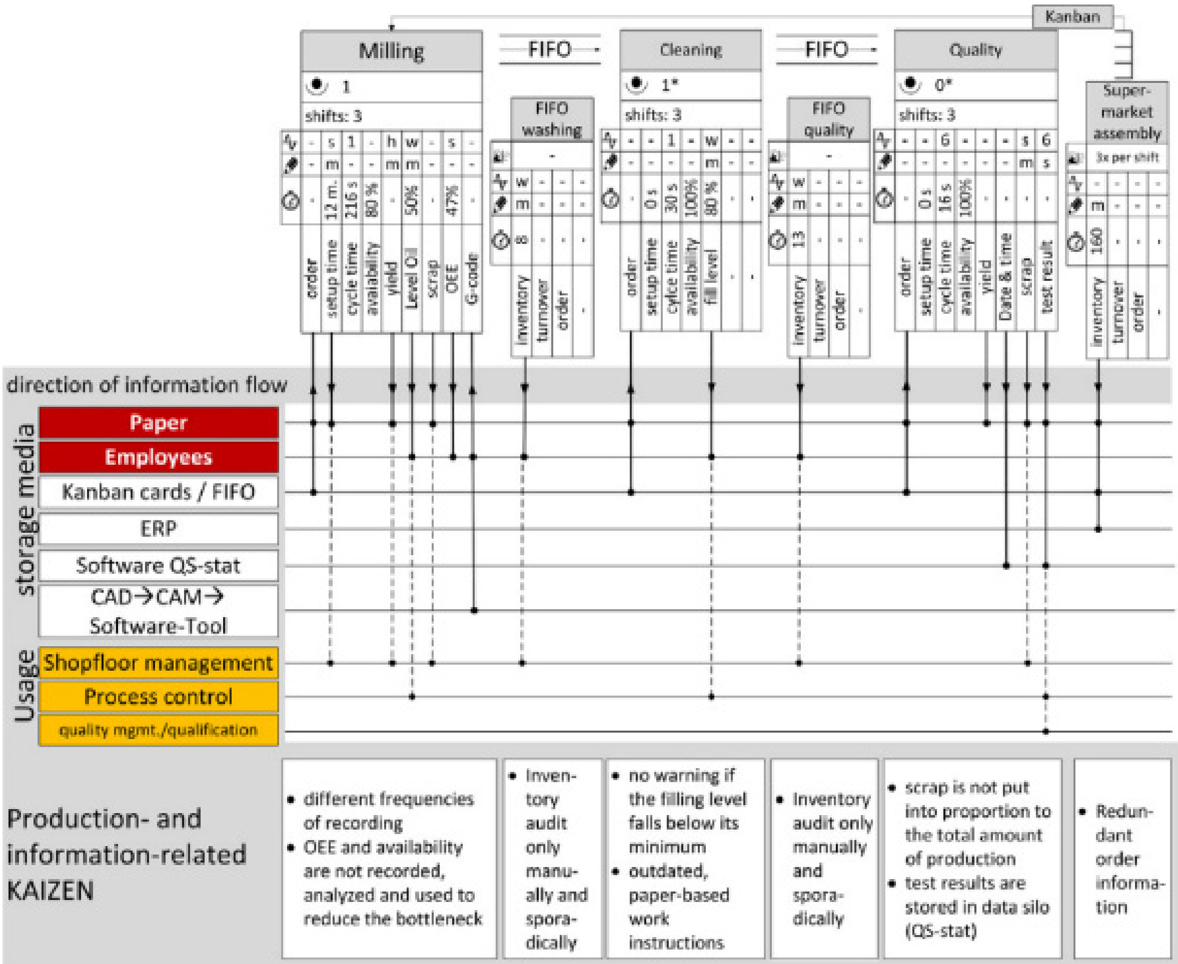
framework, including the integration between operational mapping, informational classification, KPI association, and digital maturity assessment.

Figure 2 - Value stream map 4.0 section of process learning factory CiP.



Source: Chiká and Nunes (2024); Meudt et al., (2017).

Among the principal indicators proposed by Meudt et al. (2017), the Digitization Rate (DR) measures the proportion of information automatically collected through digital systems. The Data Availability (DA) rate evaluates the accessibility of information across integrated platforms, while the Data Utilization (DU) rate measures the extent to which collected information is transformed into managerial indicators and operational support mechanisms. Low values associated with these indicators may reveal limitations related to digital integration, informational accessibility, and data-driven decision-making. The indicators proposed by Meudt et al. (2017) are calculated according to Equations 1, 2, and 3.

- Digitization Rate (DR): Its shows how much of the information is obtained automatically and digitally captured (Equation 1).
- $DR = \left(\frac{\Sigma \text{ Data obtained automatically and digitally captured}}{\Sigma Total\ data\ captured}\right) x\ 100 \quad (1)$
- Data Availability (DA) rate: It shows the part of information that is available compared to all information captured (Equation 2).

$$DA = \left(\frac{\Sigma\, Information\ captured}{\Sigma Desired\ information}\right) x\ 100 \quad (2)$$

- Data Utilization (DU) rate: It measures which collected data is effectively used for decision-making or improvement, with low values signaling weak or non-data-driven management (Equation 3).

$$DU = \left(\frac{\Sigma\, Information\ used}{\Sigma Information\ captured}\right) x\ 100 \quad (3)$$

The combined interpretation of these indicators enables the evaluation of informational maturity, system integration, and the extent to which operational data support managerial activities and continuous improvement initiatives. Finally, the results obtained through VSM 4.0 support the identification of improvement opportunities associated with process integration, informational standardization, and digitalization initiatives. In this context, the methodology strengthens the analysis of operational and informational inefficiencies, contributing to lean-oriented decision-making and Industry 4.0 implementation strategies.

2.4 SHINGO 4.0 - MIF (MATERIAL AND INFORMATION FLOW)

Managing the flow of materials and information is key to ensuring that logistics and production operations run smoothly and effectively. When these streams are aligned, it becomes much easier to meet customer needs, reduce inefficiencies, and enhance the system's ability to adapt to changes in demand (Ohno, 1988; Stoffel, Nunes & Piran, 2018).

In this context, the Shingo 4.0 - Material and Information Flow (MIF) method acts as an effective technique for examining and charting the physical transportation of products and the corresponding information flow. This approach divides information-processing tasks into three specific categories: activities conducted within ERP systems, those carried out with external digital tools, and those completed via manual or non-digital methods (Nunes, Chiká & Santos, 2024).

Among the indicators utilized in this method, the ERP Activity Rate is notable for assessing the extent to which the workflow is controlled by integrated ERP systems. This measure offers understanding of the extent of digitalization and the level of data integration among processes (Stoffel, Nunes & Piran, 2018). The metric is determined by contrasting the amount of data handled by ERP systems with the overall information flow across the operation (Equation 4) (Krauspenhar et al., 2024; Nunes et al., 2024).

$$Activity\ rate\ in\ ERP = \left(\frac{\Sigma\ Information\ generated\ via\ ERP\ or\ integrated}{Total\ flow\ information}\right) x\ 100 \quad (4)$$

The activity rate except ERP measures digital activities not performed through ERP, such as spreadsheets, text documents, or standalone systems. These elements, though digital, are often not integrated and may create informational silos (Equation 5).

$$Activity\ rate\ except\ ERP = \left(\frac{\Sigma\ Information\ is\ wich\ software\ not\ integrated\ witch\ ERP\ is\ used}{Total\ flow\ information}\right) x\ 100 \quad (5)$$

The rate of non-digital activities considers informal or analog information exchanges, such as verbal communication, handwritten notes, or actions relying on employee memory. These are often invisible to system-based tracking and reduce traceability (Equation 6).

$$Rate\ of\ other\ activities = \left(\frac{\Sigma\ Information\ that\ does\ not\ uses\ digital\ means}{Total\ flow\ information}\right) x\ 100 \quad (6)$$

The information access rate determines how much of the information is available through systematized, integrated platforms accessible to authorized users. This reflects transparency and ease of access for decision-making (Equation 7).

$$Information\ acess\ rate = \left(\frac{\Sigma\ System\ or\ Related\ information}{Total\ flow\ information}\right) x\ 100 \quad (7)$$

Lastly, the information use rate captures how much of the information collected is actually used to generate KPIs that support operational or strategic decisions. During mapping, each KPI should be identified and linked to its source (Equation 8).

$$Information\ rate = \left(\frac{\Sigma\ of\ the\ information\ collected\ that\ generate\ KPIs}{Total\ flow\ information}\right) x\ 100 \quad (8)$$

Employing these indicators allows organizations to evaluate the extent of digitalization and the integration of their data streams. This assessment is vital for pinpointing bottlenecks, unnecessary tasks, and chances for enhancement in both operational and management processes (Roh et al., 2019; Strassburguer et al., 2023).

Additionally, research conducted by Alles, Nunes and Sordi (2018), along with Stoffel, Nunes and Piran (2018) illustrates how the mapping and analysis of information flows enhance service levels and minimize waste during the order cycle. This leads to nimbler, data-informed, and customer-centered operations. Recent empirical studies have reinforced the applicability of the Shingo 4.0 MIF approach in industrial-logistics environments characterized by fragmented informational flows and low digital integration (Bauer et al., 2025).

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2.5 DYNAMIC VSM (DVSMS) AND DIGITAL VSM (DVSM)

With the rise of Industry 4.0 technologies, Value Stream Mapping (VSM) has evolved into more dynamic and digital approaches, such as Dynamic Value Stream Mapping (DVSMS) and Digital Value Stream Mapping (DVSM). DVSMS incorporates real-time data into process analysis, enabling companies to monitor operational changes and support faster decision-making (Thulasi et al., 2022). DVSM extends this perspective through the integration of sensors, real-time location systems, and management software, creating a digital representation of production environments that improves process visibility and operational responsiveness (Sullivan et al., 2022).

In addition, Noto and Cosenz (2021) emphasize that the integration of systems thinking principles into lean management approaches may strengthen the long-term effectiveness of digital mapping initiatives. According to the authors, the incorporation of systemic analysis supports managerial decision-making by improving the understanding of interactions between operational processes, informational flows, and organizational performance. Similarly, Horsthofer-Rauch et al. (2022) highlight that automated techniques such as process mining may significantly reduce manual mapping efforts and improve analytical precision, particularly in environments characterized by large volumes of operational data. However, the effectiveness of these technologies depends on the availability of reliable data, system integration, and organizational capabilities associated with data interpretation and operational management.

Therefore, the implementation of DVSMS and DVSM should be understood as a multidimensional organizational initiative involving technological, operational, and managerial factors. The successful adoption of these approaches requires not only digital infrastructure, but also process integration, employee adaptation, and the development of analytical capabilities that support the effective utilization of operational information within manufacturing environments.

Updating value stream mapping for the digital age goes beyond simply replacing paper with screens. It's about using new technologies that improve process visibility what's happening on the production floor in real time. The Figure 3 below illustrates a digital Value Stream Mapping (DVSM) model following the implementation of an automated Kanban system. Unlike traditional VSM diagrams, this digital representation integrates real-time data and visual indicators to monitor each step of the production process. Arrows and icons reflect both material and information flows, while embedded metrics provide immediate insights into cycle time, delays, and process efficiency. This visualization supports better decision-making and highlights opportunities for continuous improvement within Industry 4.0 environments (Horsthofer-Rauch et al., 2022; Trebuna, Pekarcíková & Edl, 2019).

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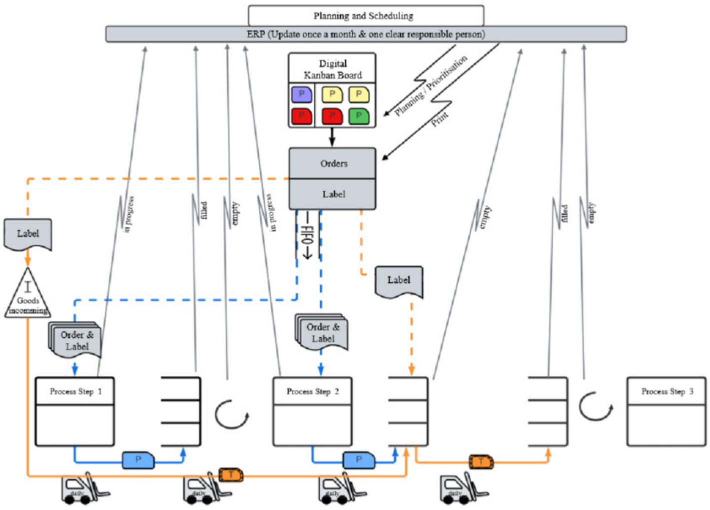
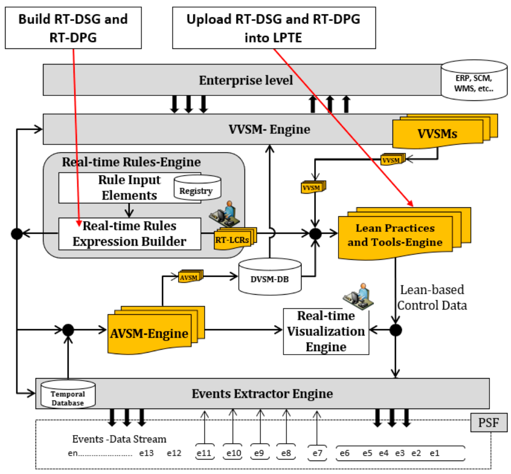
Figure 3 – Digital Value Stream Mapping of Processes after automated / digital Kanban Implementation



Source: Trebuňa, Pekarčíková and Edl (2019)

The structure of the Digital Value Stream Mapping (DVSM) system is depicted in Figure 4 and includes different real-time engines that bridge the physical and virtual worlds. The Actual Value Stream Mapping (AVSM) engine reflects the current status of the physical environment and serves as the DVSM interface with the Physical Stream Flow (PSF) (Ramadan et al., 2020).

Figure 4 - The IT system architecture of the Dynamic Value Stream Mapping (DVSM) for Lean 4.0



Source: Ramadan et al., (2020)

In the next section the classification of the research carried out will be presented.

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3 METHODOLOGY

This section presents the methodological procedures adopted in this study. From the perspective of its objectives, this research is classified as descriptive. It is a case study (Gil, 2019; Miguel, 2012) conducted in a medium-to-large-sized textile company, in which one of the productive flows was selected for process mapping. The chosen research approach involved a single case study and this enabled an in-depth look at the organizational setting, allowing us to pinpoint the processes specific features as they occur in real-world situations (Yin, 2015). This approach enabled an in-depth analysis of the organizational environment, evaluating current practices and finding improvement opportunities all based on solid proof.

The chosen process for examination involves converting yarns into fabric via looms, an essential phase in the textile manufacturing system. Data collection was conducted through non-participant direct observation and documental analysis, including production records, work orders, performance indicators, and data retrieved from the company's internal systems. These sources allowed for the mapping of activities, identification of resources used, execution times, and the associated information flows at each stage of the process.

For process modeling and analysis, the Value Stream Mapping 4.0 (VSM 4.0) methodology was applied. This is an evolution of the traditional Value Stream Mapping technique, adapted to Industry 4.0 standards, incorporating elements such as digital systems, automation, and real-time data integration (Meudt et al., 2017; Hartmann et al., 2016). The Shingo 4.0 (MIF) tool was also used to complement the diagnosis by offering a comprehensive view of material and information flows, with particular attention to digitalization levels, the use of key performance indicators (KPIs), and the identification of bottlenecks (Nunes, Chiká & Santos, 2024).

The data analysis was descriptive and interpretative in nature, The interpretation of activities followed lean manufacturing principles proposed by Shingo (1989) and Rother and Shook (2009), especially regarding the classification of value-added and non-value-added activities. Data triangulation between observation, documentary analysis, and interviews was adopted to increase analytical reliability. The collected data were first consolidated in a Microsoft Excel® spreadsheet, after which the textile production flow mapping was initiated. The following case study explores the application of VSM and Shingo 4.0 - MIF techniques to map the information flow within a textile production environment and identify opportunities for improvement.

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3.1 RESEARCH CONTEXT AND UNIT OF ANALYSIS

This study was conducted in a medium-to-large-sized textile company located in Rio Grande do Sul, Brazil. The organization operates in the textile components sector, supplying materials to the fashion and footwear industries. The company was selected due to its operational complexity, production variability, and the presence of partially digitalized processes, which provided an appropriate environment for the analysis of operational and informational flows under Industry 4.0 conditions. The production structure is organized into five operational pavilions. The present study focused on Pavilion 5, specifically the weaving and finishing sector, where yarns are transformed into textile fabrics through Jacquard looms and subsequent finishing activities. This production area was selected because it presented recurrent operational interruptions, fragmented information flows, and limited integration between production planning and shop-floor execution.

The sector analyzed contains sixteen Jacquard looms. However, six machines were selected for detailed mapping because they presented complete operational records, production traceability data, and accessibility for direct observation during the research period. The selection criterion considered process representativeness, data availability, and operational relevance within the production flow. The unit of analysis consisted of the complete production flow associated with weaving, finishing, inspection, packaging, and dispatch activities. The analysis incorporated both material and informational flows to identify operational bottlenecks, delays, non-value-added activities, and limitations associated with digital integration and information management.

3.2 Data Collection Procedures

Data collection was conducted through non-participant direct observation, documental analysis, and semi-structured interviews with production supervisors and machine operators. The combination of these procedures enabled a comprehensive understanding of the operational sequence, information exchanges, and execution logic associated with the production process. The documental analysis included production records, work orders, internal reports, operational indicators, and data extracted from the company's information systems. These documents supported the identification of process activities, execution times, operational resources, and informational interactions associated with each production stage.

Direct observations were carried out during regular production shifts in order to capture actual operational conditions, including material movement, manual activities, waiting periods, inspections, transportation activities, and information exchanges between operators and departments. During this stage, execution times were recorded using direct timing procedures, considering the start and end of each activity within the production flow.

Semi-structured interviews were conducted to validate operational sequences, confirm informational flows, identify informal communication practices, and clarify activities not fully documented in organizational systems. The interviews also contributed to identifying manual decision-making practices and operational limitations related to information accessibility and system integration. The data collected were consolidated into Microsoft Excel® spreadsheets to support the subsequent mapping and analytical stages of the research.

3.3 MAPPING AND ANALYTICAL PROCEDURES

The mapping and analytical procedures were based on the combined application of Value Stream Mapping 4.0 (VSM 4.0) and the Shingo 4.0 - Material and Information Flow (MIF) approach. The integration of these methodologies enabled the simultaneous analysis of material flows, operational activities, informational exchanges, and digital integration conditions throughout the production environment. Initially, the current-state production flow was mapped according to the principles of traditional Value Stream Mapping, identifying activities, waiting periods, transportation stages, inspections, operational delays, and production lead time. Subsequently, the Shingo Production Mechanism (SPM) logic was incorporated to distinguish process functions from operation functions, enabling a clearer visualization of material transformation activities and operator-related actions.

After the operational mapping stage, the informational layer was incorporated through the VSM 4.0 methodology proposed by Meudt et al. (2017). This stage included the identification of information sources, storage media, ERP interactions, manual records, isolated digital tools, and information accessibility conditions. Each informational activity was classified according to its level of digitalization and integration. Based on this classification, five indicators were calculated: ERP Activity Rate, Non-ERP Activity Rate, Non-Digital Activity Rate, Information Access Rate, and Information Use Rate. Additionally, the VSM 4.0 indicators proposed by Meudt et al. (2017), namely Digitization Rate (DR), Data Availability (DA), and Data Utilization (DU), were applied to evaluate the informational maturity of the analyzed process.

The mapping procedures also included the classification of activities into value-added and non-value-added categories according to lean manufacturing principles. The symbolic representation adopted in the study followed the Shingo-based production mapping logic proposed by Nunes et al. (2024).

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3.4 DATA ANALYSIS

The data analysis was descriptive and interpretative in nature, aiming to identify operational inefficiencies, informational bottlenecks, delays, and opportunities for process improvement and digital integration. The interpretation of activities followed lean manufacturing principles proposed by Shingo (1989) and Rother and Shook (2009), especially regarding the classification of value-added and non-value-added activities. The analysis considered both quantitative and qualitative dimensions of the production flow. Quantitative analysis involved the calculation of operational lead times, activity durations, process delays, transportation times, and informational indicators associated with digitalization and data utilization. Qualitative analysis focused on the interpretation of informational exchanges, communication practices, manual procedures, and limitations associated with fragmented systems and non-integrated information flows.

Data triangulation between direct observation, documental evidence, and interview information was adopted to increase analytical reliability and reduce interpretative bias. The combination of operational mapping and informational indicators enabled a systemic understanding of the production environment, supporting the identification of inefficiencies associated with both physical operations and information management practices. Finally, the results obtained through the integrated application of Shingo 4.0 - MIF and VSM 4.0 were interpreted considering the principles of lean manufacturing and Industry 4.0, emphasizing opportunities for operational improvement, process integration, and informational digitalization.

4 RESULTS AND DISCUSSIONS

The integrated application of Shingo 4.0 - Material and Information Flow (MIF) and Value Stream Mapping 4.0 enabled a comprehensive evaluation of the analyzed textile production flow. The mapping procedures identified operational inefficiencies, informational bottlenecks, delays, and limitations associated with digital integration throughout the weaving and finishing activities. The current-state mapping incorporated operational and informational dimensions, enabling the visualization of material movement, process interruptions, manual activities, and information exchanges between production stages. Based on the collected operational data, the production activities were classified according to their typology, execution time, and contribution to value generation within the process.

After organizing the collected data, the production flow was mapped using the Shingo production mechanism representation combined with the VSM 4.0 logic. This integrated approach enabled the simultaneous visualization of material and informational flows. In addition, five informational indicators were calculated: ERP Activity Rate, Non-ERP Activity Rate, Non-Digital Activity Rate, Information Access Rate, and Information Use Rate, supporting the evaluation of digital integration throughout the process (Nunes, Chiká & Santos, 2024). Table 1 presents the mapped activities associated with the analyzed textile production flow, including activity typology, execution time, informational source, KPI association, and operational resources involved in each stage of the process.

Table 1: Activities carried out in the textile production process

Sequence	Typology	Activity Description	Time (hh:mm:ss)	Information Flow	KPI Name	Resource Flow (excluding Human Resources)
0	Start of Flow	Sales representative enters the order	-	ERP	-	Computer
1	Process Delay	Analyzes production order	00:03:45	ERP	-	Computer
2	Process Delay	Collects production order data on machine	00:42:33	Memory	-	Manual
3	Process Delay	Prints production order	00:00:35	ERP	-	Printer
4	Process Delay	Programs production order	02:47:20	Order of Production	-	Paper
5	Process Delay	Move production order to machine	00:00:32	Memory	-	Manual
6	Process Delay	Places production order on production sequence	00:00:26	Order of Production	-	Paper
7	Lot Delay	Waits for the remaining production batches	29:45:32	Order of Production	-	Manual
8	Non-value-added work	Regulate the article	00:06:29	Order of Production	-	Manual
9	Non-value-added work	Produces 3 meters for inspection	01:06:17	Machine	meters for hour (m/h)	Loom
10	Inspection	Visual inspection of color	00:00:09	Product Standard	-	Visual
11	Process Delay	Removes the fabric of the roll	00:00:16	Memory	-	Manual
12	Inspection	Inspects size template	00:00:22	Product Template	-	Template/ Manual
13	Non-value-added work	Position the fabric onto the machine rol	00:00:48	Memory	-	Manual

14	Value-added work	Production of the fabric	14:26:55	Order of Production	meters/hour	Loom
15	Process Delay	End of production	00:01:36	Order of Production	-	Manual
16	Process Delay	Regulates the next article to lower the fabric	00:04:32	Order of Production	-	Manual
17	Process Delay	Produces next article to lower fabric	01:05:32	Machine	-	Manual
18	Process Delay	Ends 3 meters of inspection	00:01:24	Machine	-	Meter tape
19	Process Delay	Cuts fabric from the machine	00:00:14	Memory	-	Manual
20	Process Delay	Apply tape to the roll	00:00:13	Memory	-	Tape
21	Process Delay	Attach the production order to the fabric	00:00:08	Memory	-	Manual
22	Process Delay	Pick up the cart	00:01:15	Memory	-	Manual
23	Transport	Transport fabric to dubbing	00:01:03	Memory	-	Cart
24	Process Delay	Fills out production order	00:00:19	Order of Production	-	Computer
25	Lot Delay	Waiting for the remaining articles to be ready	01:45:33	Order of Production	-	Manual
26	Process Delay	Inspects production order	00:00:08	Order of Production	-	Visual
27	Non-value-added work	Dubbing setup	00:02:09	Memory	-	Manual
28	Value-added work	Starts dubbing	01:34:24	Memory	meters/hour	Calender
29	Inspection	Check the size of the product	00:00:34	Product Standard	-	Template/ Manual
30	Process Delay	Apply tape to the roll	00:00:10	Memory	-	Tape
31	Process Delay	Removes fabric from calender	00:00:12	Memory	-	Manual
32	Process Delay	Collect the production order	00:00:04	Order of Production	-	Manual
33	Process Delay	Move to the computer workstation	00:00:06	Memory	-	Manual
34	Process Delay	Fills out production order	00:00:05	Order of Production	-	Computer
35	Process Delay	Pick up the cart	00:00:07	Memory	-	Manual

36	Transport	Places fabric on cart	00:00:10	Memory	-	Manual
37	Process Delay	Attach the production order to the fabric	00:00:04	Order of Production	-	Manual
38	Transport	Moves cart to review	00:00:10	Memory	-	Cart
39	Transport	Removes fabric	00:00:06	Memory	-	Manual
40	Lot Delay	Waits for demand of other fabrics	01:36:35	Order of Production	-	Manual
41	Process Delay	Inspects production order	00:00:05	Order of Production	-	Visual
42	Process Delay	Curl the fabric in the roll	00:00:16	Memory	-	Manual
43	Process Delay	Separates roll of 40 meters	00:04:51	Memory	-	Meter tape
44	Process Delay	Removes the fabric	00:00:16	Memory	-	Manual
45	Process Delay	Picks up packaging	00:00:07	Memory	-	Manual
46	Process Delay	Pack the fabric	00:00:20	Memory	-	Manual
47	Process Delay	Collect the production order	00:00:07	Order of Production	-	Manual
48	Process Delay	Goes to computer	00:00:07	Memory	-	Manual
49	Process Delay	Fills out production order	00:00:03	Order of Production	-	Computer
50	Process Delay	Prints the label	00:00:07	Order of Production	-	Printer
51	Process Delay	Returns to review table	00:00:07	Memory	-	Manual
52	Process Delay	Closes product label	00:00:10	Memory	-	Tape
53	Process Delay	Labels the product	00:00:04	Purchase Order	-	Label
54	Transport	Transporting the fabric to shipping	00:02:33	Purchase Order	-	Cart
55	End the Flow	Dispatch takes off the product	-	Purchase Order	-	Cart

Source: authors (2025)

Based on the collected data and the sequencing of operational activities, the total lead time of the analyzed process was calculated at 55 hours, 28 minutes, and 5 seconds. The analysis considered value-added and non-value-added activities throughout the production flow. To standardize the representation of productive activities, the study adopted the symbolic structure proposed by the Shingo production mechanism. This representation facilitated the classification and visualization of operational activities within the mapped flow (Strassburguer et al., 2023).

Figure 5 – Symbology for application in the mapping of production activities

Productive activities	Symbol
Raw material storage	▲
Non-value-added work	●
Inspection	◇
Lot Delay	✡
Transportation	•
Process Delays	▽
Value-added work	●
Product storage	▼

Source: Strassburguer et al. (2023)

Based on the operational classification and activity sequencing presented in Table 1, the current-state production flow was mapped according to the Shingo production mechanism representation (Figure 6).

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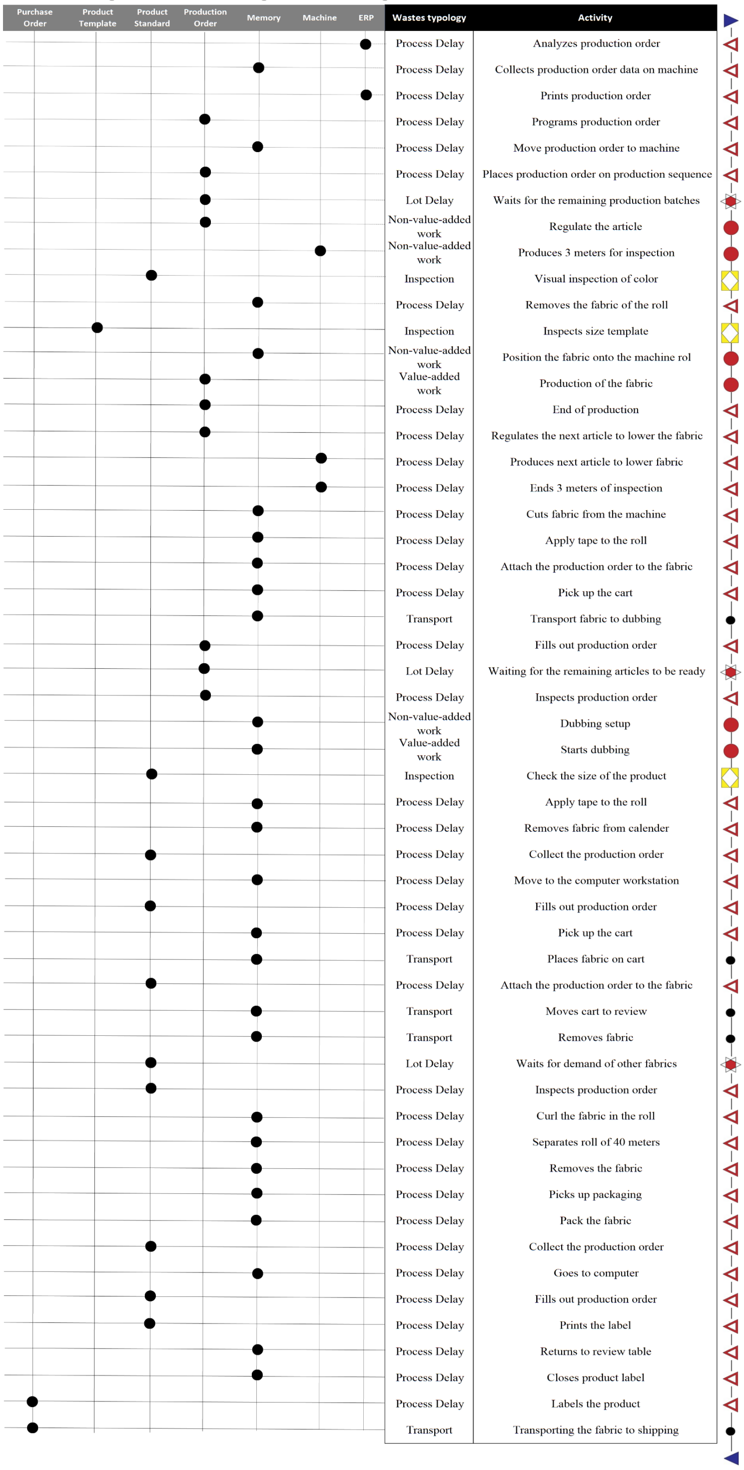
Figure 6 – Shingo mapping of the current state flow



Source: authors (2025)

The mapped activities were subsequently classified according to their contribution to value generation. Table 2 presents the distribution of activity typologies and their respective durations within the analyzed process.

Table 2: Typology and times

Typology	Time in (hh:mm:ss)	Total
Lot Delay	33:07:40	59,72%
Value-added activities	17:07:36	30,88%
Process Delay	4:58:16	8,96%
Non-value-added work	0:09:26	0,28%
Transport	0:04:02	0,12%
Inspection	0:01:05	0,03%
Total	55:28:05	100,00%

Source: authors (2025)

The results indicate that lot delays represented 59.72% of the total lead time, while value-added activities accounted for 30.88% of the process duration. Process delays, transportation activities, inspections, and non-value-added work represented the remaining portion of the operational flow. These findings demonstrate the predominance of waiting periods and operational interruptions within the analyzed production environment. To strengthen the analysis of value generation, the activities were consolidated into value-added and non-value-added categories. Table 3 presents the distribution between these two dimensions.

Table 3: Total of Value-Adding and Non-Value-Adding Activities

VA and NVA	Time in (hh:mm:ss)	Total
Non-value-added work	38:20:29	69,12%
Value-added work	17:07:36	30,88%
Total	55:28:05	100,00%

Source: Authors

The results demonstrated that non-value-added activities represented 69.12% of the total lead time, indicating substantial opportunities for operational improvement and process synchronization. In contrast, value-added activities accounted for only 30.88% of the production flow duration.

As part of the informational analysis, each activity was classified according to its information source, including ERP systems, isolated digital tools, and non-digital practices. Based on this classification, five informational indicators were calculated to evaluate the level of digital integration and information accessibility within the analyzed process (Nunes, Chiká & Santos, 2024). The ERP Activity Rate was calculated as the number of activities using ERP systems divided by the total number of information flows. From the collected data, 3 out of 56 activities were carried out through ERP, resulting in the Equation 9 (Nunes, Chiká & Santos, 2024).

$$Information\ rate\ in\ ERP = \left(\frac{\Sigma\ Information\ generated\ via\ ERP\ or\ integrated}{Total\ flow\ information}\right) x\ 100 = \left(\frac{3}{55}\right) = 5{,}45\% \quad (9)$$

For activities supported by digital tools that are not integrated with ERP, such as Excel, email, or production orders, the Non-ERP Activity Rate was calculated as shown in Equation 10 (Nunes, Chiká & Santos, 2024).

$$Information\ rate\ except\ ERP = \left(\frac{\Sigma\ Information\ via\ software\ not\ integrated\ with\ ERP}{Total\ flow\ information}\right) x\ 100 = \left(\frac{3}{55}\right) = 5{,}45\ \% \quad (10)$$

To assess the extent of manual practices, the Non-Digital Activity Rate measured the proportion of activities conducted using memory, telephone, or visual cues (Equation 11) (Nunes, Chiká & Santos, 2024).

$$Rate\ of\ other\ activities = \left(\frac{\Sigma\ Information\ that\ does\ not\ use\ digital\ means}{Total\ flow\ information}\right) x\ 100 = \left(\frac{50}{55}\right) = 90{,}09\% \quad (11)$$

The Information Access Rate demonstrated restricted accessibility to organized digital information across the mapped process. Similarly, the Information Use Rate revealed that only a limited portion of the collected information was effectively transformed into performance indicators or managerial support tools. These findings indicate a fragmented informational environment characterized by low digital integration and limited utilization of operational data (Equation 11) (Nunes, Chiká & Santos, 2024).

$$Information\ access\ rate = \left(\frac{\Sigma\ System\ or\ related\ information}{Total\ flow\ information}\right) x\ 100 = \left(\frac{27}{55}\right) = 49{,}09\% \quad (12)$$

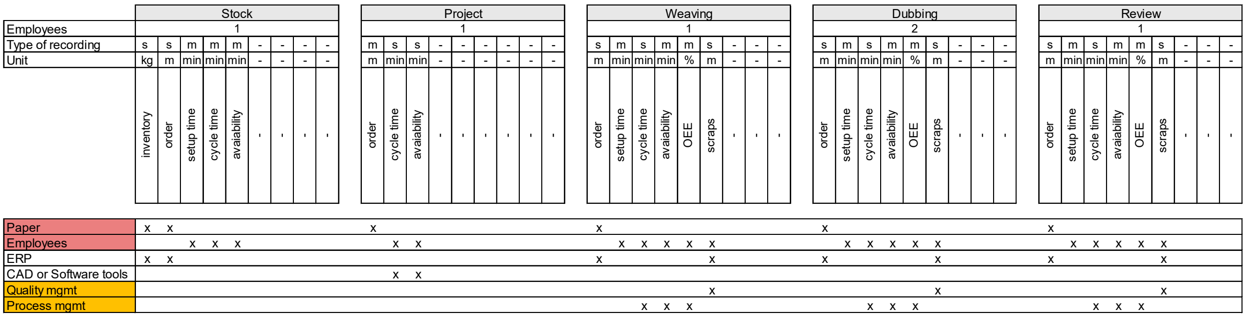
To complement the operational analysis, the VSM 4.0 framework was applied to incorporate the informational layer into the mapped production flow. Unlike the Shingo production mechanism, which emphasizes operational and spatial dimensions, VSM 4.0 enabled the evaluation of digital integration, information accessibility, and data utilization across the analyzed activities (Equation 13) (Nunes, Chiká & Santos, 2024).

$$Information\ rate = \left(\frac{\Sigma\ of\ the\ information\ collected\ that\ generates\ KPIs}{Total\ flow\ information}\right) x\ 100 = \left(\frac{3}{55}\right) = 5{,}45\% \quad (13)$$

These findings indicate limitations in data accessibility and system integration, reinforcing the need for improved informational coordination throughout the production process. Figure 7 presents the VSM

4.0 representation of the weaving process, integrating operational activities, informational resources, and data flows throughout the production environment.

Figure 7 – VSM 4.0 diagram of the weaving industry procedure



Source: authors (2025)

Based on the methodological structure proposed by Meudt et al. (2017), 55 information exchanges were identified and analyzed according to three dimensions: digital acquisition, data accessibility, and information utilization for decision-making and operational improvement. Each informational element was evaluated regarding automatic collection, digital availability, and managerial utilization.

The Digitalization Rate (DR) reached 10.9%, indicating limited automated data acquisition throughout the production flow. The Data Availability (DA) rate reached 49.09%, demonstrating restricted access to organized information across the mapped activities. In parallel, the Data Utilization (DU) rate reached only 5.4%, revealing low use of operational information for performance monitoring and managerial decision-making. These indicators demonstrate a predominantly manual and fragmented informational environment that constrains operational responsiveness and process integration. The findings are also aligned with recent evidence reported by Bauer et al. (2025), who identified that low informational integration and excessive dependence on manual activities substantially increase waiting times and operational variability in industrial-logistics environments. Similar to the present study, the authors demonstrated that limited ERP integration and fragmented informational flows contribute directly to process inefficiencies, reinforcing the importance of digital synchronization and standardized information management within Industry 4.0 operations.

The combined application of Shingo 4.0 and VSM 4.0 enabled the simultaneous analysis of operational and informational inefficiencies. While the Shingo approach strengthened the visualization of material flows, manual activities, and non-value-added operations, VSM 4.0 supported the evaluation of informational accessibility, digital maturity, and system integration throughout the production process

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(Hartmann et al., 2016; Roh et al., 2019). Table 4 presents a synthesis of the principal characteristics and analytical applications associated with both methodologies.

Table 4 – Synthesis Table Between Shingo 4.0 - MIF and VSM 4.0

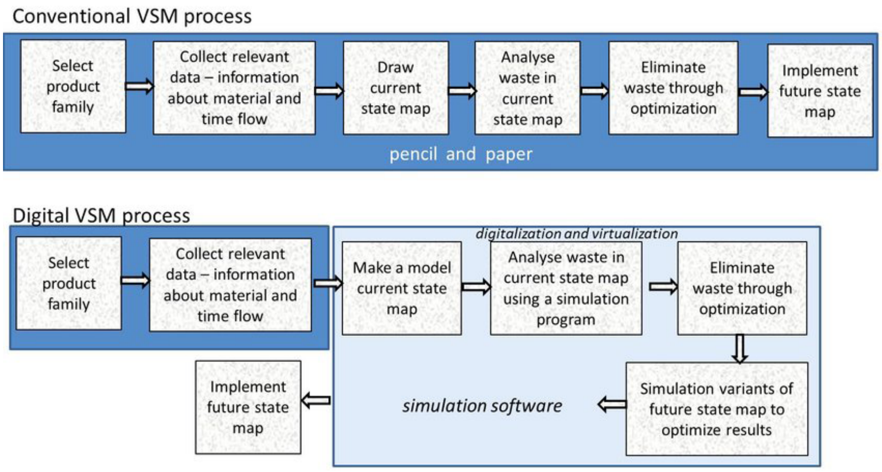
Topics	Shingo 4.0 MIF	VSM 4.0
Main Focus	Simultaneous mapping of process (material) and operation (agent) flows	Mapping of value stream with integrated informational and digital flow analysis
Dimension of Analysis	Physical and operational flows in time and space	Material, information, and system integration flows
Key Outputs	Identification of operational inefficiencies and hidden waste	Measurement of digitization, information usage, and system integration
Application Strength	High visibility of human-machine interactions and manual tasks	Strategic alignment with Industry 4.0 and digitalization
Limitations	Limited insight into digital systems and data governance	Less emphasis on operational details and manual flows
Best Use Context	Environments with frequent manual operations and task variability	Contexts requiring assessment of digital maturity and KPI generation

Source: Authors

The findings suggest that the combined use of Shingo 4.0 - MIF and VSM 4.0 provides analytical capabilities that are not fully captured when either approach is applied independently. While Shingo 4.0 enhances the visualization of operational waste, material movement, and human-machine interactions, VSM 4.0 strengthens the assessment of informational maturity, data accessibility, and digital integration. This complementary perspective represents an important contribution to the literature on lean digitalization and Industry 4.0 diagnostics.

In this research, Digital Value Stream Mapping (Digital VSM) was applied to analyze the logistics flow within Pavilion 5. The use of digital tools enabled a more precise evaluation of operational activities and informational flows when compared to conventional manual mapping approaches, as illustrated in Figure 8.

Figure 8 - Conventional VSM process (VSM) vs. digital VSM process (DVSM)



Source: Trebuňa, Pekarcíková and Edl (2019)

Digital VSM enables a more dynamic visualization of operational activities when compared to conventional mapping approaches. However, its analytical representation remains dependent on data collected during a specific operational period, which may limit the understanding of process variability in dynamic production environments. In contrast, Dynamic VSM incorporates real-time data integration through technologies such as IoT devices, sensors, and enterprise systems, enabling continuous monitoring of operational conditions and supporting faster managerial responses to production deviations. Although Dynamic VSM was not applied in the present study, its potential contribution to process monitoring and operational responsiveness represents an important opportunity for future investigations.

5 FINAL REMARKS

This study contributes to the literature on lean digitalization and Industry 4.0 by demonstrating the complementary application of Shingo 4.0 - Material and Information Flow (MIF) and Value Stream Mapping 4.0 within the same manufacturing environment. Unlike previous studies that typically employ these approaches separately, the present research shows how their integration enables a simultaneous assessment of operational inefficiencies, informational fragmentation, and digital maturity, providing a broader diagnostic perspective for industrial transformation initiatives.

The results indicated that Shingo 4.0 contributes primarily to the visualization of operational flows and non-value-added activities, while VSM 4.0 strengthens the analysis of informational maturity, data accessibility, and digital integration. The complementarities between both approaches expand the diagnostic capacity of lean-oriented mapping methodologies under Industry 4.0 conditions.

From a managerial perspective, the study highlights the importance of integrating operational analysis with informational diagnostics to support digital transformation initiatives. The identification of manual information exchanges and isolated digital practices demonstrated the necessity of improving ERP integration, data accessibility, and process standardization.

This research was limited to a single case conducted in a specific textile production environment, restricting the generalization of findings. Additionally, the analysis was based on a current-state mapping approach and did not incorporate real-time monitoring technologies associated with Dynamic VSM environments. Future studies may expand the application of the integrated Shingo 4.0 and VSM 4.0 framework to other industrial sectors characterized by high operational variability and fragmented information flows. Further investigations may also incorporate real-time monitoring technologies and advanced data analytics to strengthen the integration between operational performance and digital decision-making.

5.1 MANAGEMENT IMPLICATIONS

The findings of this study highlight the importance of integrating operational mapping and informational analysis to support industrial digitalization initiatives. The combined application of Shingo 4.0 - MIF and VSM 4.0 enabled the identification of operational delays, fragmented information flows, manual activities, and limitations associated with ERP integration and data accessibility within the analyzed textile environment.

From a managerial perspective, the results demonstrate that production environments with low informational integration tend to depend heavily on manual communication, isolated decision-making practices, and non-standardized operational routines. These conditions contribute to delays, reduced process visibility, and limitations in performance monitoring. In this context, the adoption of integrated mapping approaches may support managers in identifying operational bottlenecks and prioritizing digitalization initiatives based on process criticality and informational deficiencies.

The study also reinforces the role of engineers and operations managers in coordinating digital transformation initiatives within manufacturing systems. Operational mapping supported by informational indicators allows organizations to improve production planning, process synchronization, and data utilization in decision-making activities. Additionally, the analysis demonstrated that the integration

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between operational and informational perspectives may contribute to greater process standardization and improved communication between production sectors.

Another relevant implication involves the use of digital indicators associated with information accessibility, utilization, and ERP integration. The low values identified in the analyzed environment indicate that operational data were often collected but not systematically transformed into managerial information or performance indicators. This finding highlights the necessity of improving data governance practices and strengthening the connection between operational activities and digital management systems.

Finally, the study suggests that digital transformation initiatives should not focus exclusively on technological acquisition. The results indicate that improvements in operational visibility, information standardization, and process integration are equally necessary to support sustainable digitalization strategies in industrial environments characterized by operational variability and fragmented informational flows.

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