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VALUE STREAM MAPPING 4.0: A STRUCTURAL MODELING APPROACH

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ABSTRACT: *This article presents a new methodology VSM 4.0 (Value Stream Mapping 4.0) which is a digital and collaborative working environment for lean management teams in the era of Industry 4.0. The VSM 4.0 supports business leaders in the optimization of the production process by digitizing the value stream. It is based on a systems engineering approach adopted for their modeling, this tool will enable the optimization of the production process by digitizing the value stream. The idea focuses on higher levels of digitization, integration, and automation of information and material flows for a plant and beyond.*

Systems engineering methods have also been called upon in this paper to address the complexity of system modeling and increasing system dynamics.

KEYWORDS: *Industry 4.0; Value Stream Mapping 4.0; Systems engineering; Systems modelling; AutomationML.*

1 INTRODUCTION

For more than thirty years, companies have widely adopted the Lean manufacturing spirit to continuously improve their operations. Moving towards the fusion of digital and physical systems as part of the transition to Industry 4.0 or the fourth industrial revolution that is taking shape following the three major devolution phases described as revolutions: mechanization, industrialization, automation (Alasdair Gilchrist, 2016). This fourth revolution, Industry 4.0 refers to a new generation of connected, and intelligent factories. It is a digital transformation that is shaking up the manufacturing company, fundamentally characterized by intelligent automation and by the integration of new technologies into the company's value chain. With this digital revolution, the boundaries between the physical and digital worlds are blurring, giving life to an interconnected 4.0 factory in which people, machines, and products interact. Classic Value Stream Mapping (VSM) has found application in various processes in different sectors over the last few decades, allowing the process to be analyzed to identify the bottlenecks to its performance. But using classic VSM there is no power to take advantage of the promising new opportunities of digitization and Industry 4.0 to integrate information flows, reduce lead times and improve flexibility.

However, the current trend towards digitization of processes requires greater depth and level of detail in the description of information flows, which converges with the idea of digital VSM 4.0, which allows for more transparent decisions and suggestions for improvements

that are more relevant to production systems. In addition to its clarity and relative simplicity, its strength lies in its ability to capture the main material and information flow in production processes.

Using the VSM 4.0 application, it is now possible to perform value flow analysis, create a value flow design digitally, and access it from anywhere, horizontally, and transparently. This makes information silos a thing of the past.

The System Engineering approach adopted for their modeling must make it possible to manage all the tasks necessary for the development of the system, from the determination of the functional architecture to be carried out, to the validation of the choices made. As a result, we consider in this research the model-based System Engineering methods as the best engineering alternative for the development of complex systems. This is why we focus on the SysML (Systems Modeling Language Language) and the AutomationML (AML) profile.

We have used the SysML language for various reasons, initially, in a complex system such as Smart VSM, the material and information flows exchanged between components and blocks do not permit to describe a system only in the text format, therefore the use of a graphic medium becomes crucial. Also, the presence of hierarchical layers often requires an assembly of graphical representations, while a SysML model offers more operable information than other types, with information about structures and dynamics, so there are more possibilities to achieve exploitation of VSM 4.0.

Using AutomationML as a solution for data exchange, all engineering information will be stored according to an object-oriented paradigm and provides for the materi-

al and logical modeling of components, such as data objects encapsulating different aspects. Objects can form a hierarchy, which means that an object can be composed of a set of sub-objects and can itself be part of a larger composition or aggregation. Besides, each object can contain information about the object by describing the properties that cover it (Nicole Schmidt, Arndt Lüder, 2015).

In our research work we aim to propose a conceptual model for the implementation of Smart VSM .

The rest of the paper is organized as follows: Section II presents the VSM4.0 methodology as a digital tool to the intelligent factory, specifying its properties and benefits. A SysML model of the system that allows for understandable exploitation for all participants is provided in Section III. Section IV deals with the data exchange language: AutomationML (AML) which is designed as data exchange between the automation tools in our chain. Section V concludes the paper.

2 LITERATURE REVIEW

Value Stream Mapping is a visual analysis tool that enables a visual and group inventory to identify all the activities produced, those with added value (VA) and those with non added value (NVA), necessary for production. The final objective of this tool is the elimination of wastage with ensuring a continuous flow of products. (Mike Rother and John Shook, 1999).

However, despite the incontestable contribution of the use of classical VSM in the implementation of a Lean Manufacturing approach, several research studies have demonstrated the limited application in different business processes in different sectors over the last decades (Herron and Braiden, 2006), there are various gaps and challenges in the development, analysis and application of vsm.

VSM is a representation of the system with all flows in the current state, it is a static paper-based mapping with data retrievable by field observation and manual integration in order to trace the value chain, to record all stocks and processes(Grewal, 2008), this makes it incompatible with the dynamic processes when new production orders arrive and therefore a change of data which requires manual recalculation of VSM. Consequently, it should be equipped with a high degree of responsiveness and flexibility that will allow the system to manage more data variance in order to increase its efficiency.

As a result, classical VSM does not permit the mapping and identification of the non-value-added activities of a dynamic system which is characterised by its constant evolution, it's uncertainty principle which does not correspond to the Lean Manufacturing methodology based on consistent standardisation, and its structural volatility. As well as the detection, validation and prioritisation of problematic or poor value-added tasks are time-consuming activities (Stadnicka and Litwin, 2019) .

It can be concluded that classical VSM is a manual, tedious and time-consuming method, with a lack of flexibil-

ity and reactivity and unable to support dynamic aspect systems.

However, with the Digital Manufacturing revolution, new technologies are an opportunity to be seized to meet the challenges of the times with industrial constraints that force manufacturing companies to be more flexible and quicker and to innovate through new digital tools that allow the creation of added value. LM's basic tools necessary for the successful implementation of Industry 4.0 are value chain mapping, Kanban and SMED standardisation. They mainly concern ERP implementation, modularity and interoperability, plug&play solutions, batch size reduction and data management(Ghobakhloo and Fathi, 2019) .

In order to overcome the above-mentioned challenges, this article focuses on the combination of digital technologies such as Virtual simulation, Automation, Internet of things (IoT), Big Data (BD) with VSM, which has led to the birth of Value Stream Mapping based on the Industry 4.0 approach (VSM 4.0).

This subject has not yet been the object of much research, only a few publications have been published recently (Hartmann et al., 2018) (Meudt et al., 2017). This gap in terms of scientific research is linked to the fact that the methodology is still recent. However, it seems interesting to us to examine this new type of research which could open up new avenues with interesting results.

The new VSM 4.0 method, also known as Smart Value Stream Mapping, is a digital and collaborative work environment for lean management teams in the era of Industry 4.0 and offers manufacturing companies an enormous added value for plant planning and optimisation of the production process by digitising value, so it can enable improvements and more transparent decisions.

According to(Meudt et al., 2017), the process of implementing VSM 4.0 follows six steps, which are represented below:

Step 1: Conducting conventional value chain mapping.

Step 2: the listing of all types of data storage and indicators.

Step 3: the collection of data and indicators by the process according to frequency, type of collection and current value.

Step 4: The classification of the collected data and indicators.

Step 5: After the subjective description of wastage, a detailed view of the connection and linkage between processes.

Step 6: The listing of possible improvements in each process that can eventually be implemented.

With Value Stream Mapping 4.0, all product and information flow in a value chain are analysed and signed. It comprises Value Stream Analysis 4.0 (VSA 4.0) and Value Stream Design 4.0 (VSD 4.0).

The application of VSA 4.0 allows detailed observation of the information flow, it targets the waste generated during the processing and application of the data.

VSD 4.0 is used to determine the future state of the process, which focuses on the integration of the necessary

material and information flows and the development of consistent implementation in IT systems.

The objective of the method is that the type of data collected, the processing of the information, the storage medium, the key performance indicators (KPIs) and the use of the collected information can be visually represented. In addition to material flow, the information flow of a value chain can also be collected, visualised and analysed with VSM 4.0. It can therefore be concluded that the integration of digital technologies with VSM makes VSM easy, fast and more flexible. In the context of Industry 4.0, VSM will be able to manage dynamic aspect systems and quickly detect problematic tasks and NVA activities in production processes.

The research work is in the area of systems engineering so that the realisation of innovative systems requires the use of a process capable of piloting the project, from the expression of needs to the deployment of the system. This type of process is called a systems engineering (SE) process. It indicates a sequence of functions to be carried out, requiring the usage of methods often supported by tools.

3 SYSTEM ARCHITECTURE MODELING USING SYSML

The realization of an innovative system requires the adoption of a process capable of piloting the project, from the expression of needs to the deployment of the system.

This type of process is referred to as a System Engineering (SI) process, which allows the analysis of the different facets of a system: its functions, structure, and compartment (Gero and Kannengiesser, 2004). It indicates a sequence of tasks to be realized, requiring the employment of methods supported by tools.

3.1 Use cases Diagram

To express the scope of the VSM 4.0 project, it is natural to start by defining the boundaries of the study. To do this, we define the use cases of the developed system (figure 1). A use case (UC) represents a number of sequences of actions that are carried out by the system and that produce an observable result for a particular actor. Each use case specifies a behaviour expected from the system considered as a whole, without imposing the mode of realisation of this behaviour. It allows describing what the future system will have to do, without specifying how it will do it (Hartmann et al., 2018).

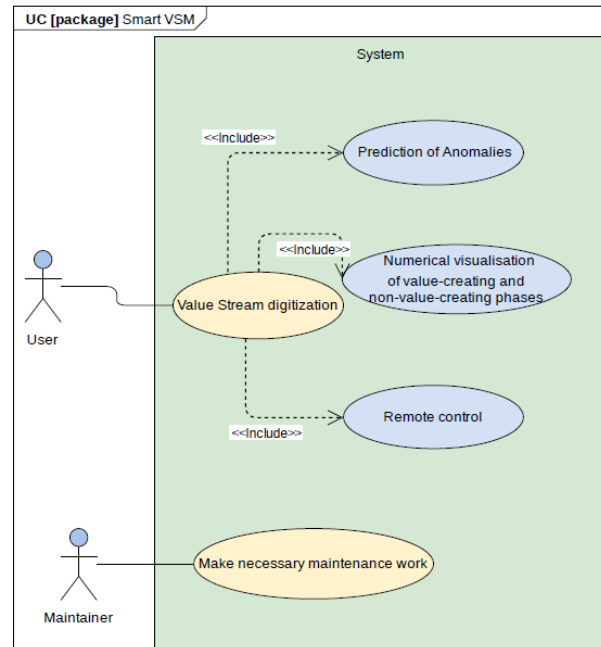


Figure 1: Use Case Diagram of the Smart VSM

3.2 Requirement Diagram

The requirement diagram is used to structure the needs expressed by all the partners during the various successive specifications. The Requirements Diagram (RD) gives the possibility to organize the requirements in a precise way and allow them to decompose each one of them, to obtain simple requests, which can be assigned and linked to targeted elements of the diagram.

A pole of requirements for the quantitative data analysis process was identified. The RD was organized into three requirements representing each of these themes (figure 2).

These are decomposed into more specific requirements expressing for most quantified requirements. The transparency of material and information flows can be created by identifying all non-value added processes and their causes, thus eliminating sources of waste. The representation also indicates the principal components which allow specifying the different types of data storage that will provide, in real-time, the right information to the right person at the right time.

A second requirement groups the requirements that relate to the analysis of data with a view to quality. The Smart VSM must include the complete and accurate analysis of the spectrum of existing material and information flows, the identification of improvements to be made, and the subsequent optimization in terms of lean production. with regular use, a continuous improvement loop will appear.

The third phase of the requirements diagram of the new VSM methodology based on industry 4.0 is the description of the solutions and enhancements offered by the latter. The Smart VSM should enable us to capture and model value chains, and access them from anywhere,

horizontally and transparently to ensure that the present state of value streams will be recorded quickly and easily through the implementation of touch screens and mobile touch devices on the shop floor that will bring responsiveness, which will take us towards visual management. The navigation within the SysML requirements diagram can also be oriented to focus attention on the total flexibility of the mapping through the use of paperless modeling (easy and fast data exchange).

same level by an association, or of different levels by a composition. It can also show the main characteristics of each block by showing its operations and properties. In this sub-section, we present a hierarchical structure constituting a standard called "Computer Integrated Manufacturing" (CIM) (Sanjay B. Joshi and Jeffrey S. Smith, 2013), implementing the BDD diagram. In such a structure, our works are located in the real-time levels of the CIM, and thus in particular in the data exchange between the different layers of the CIM pyramid. In order to de-

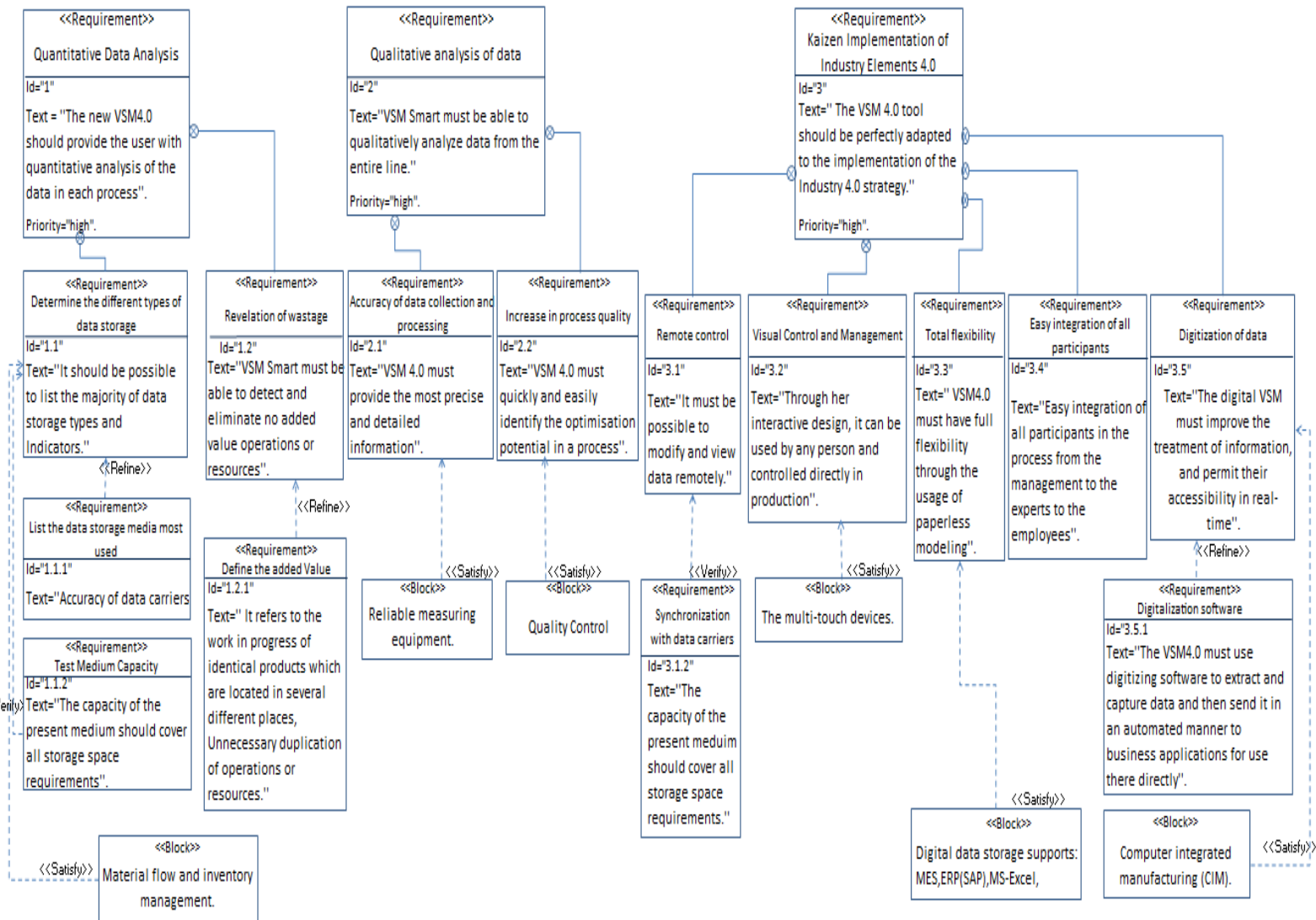


Figure 2: SysML Requirements Diagram of the Smart VSM

3.3 Block Definition Diagram

To define the logical architecture of the system and to have a hierarchical view of the components grouped within the functional entities (the subsystems), it is necessary to use the Block Definition Diagram (BDD). It describes all the structures of the modeled system: logical, material, functional.

It allows to visualize the structure of the system at a glance by representing the links between blocks of the

fine our block definition diagram (figure 3), we propose to go into the details of the processing and exchange of process data, focusing on the source, format, and granularity of the information, with which our VSM 4.0 methodology will interface.

- **block: Management of material flows and inventories**

- Reception of raw materials or components:

The reception of raw materials is the first stage of production, which is taken into account by the ERP or by the production follow-up (MES) or jointly.

- Inventory of stocks and work in process :

All companies that have stocks and work in progress must make an inventory of them. Inventory management is a key factor for many manufacturers. With the ERP software, it is possible to control multi-deposit stock levels, by location, by index, by packaging or by logistics unit in modes: FIFO, LIFO.

- Batch tracking:

Batch tracking in an ERP system is useful or even mandatory, it allows to identify each component of a product and to follow its trajectory.

- **Block: Planning and Scheduling**

The planning and scheduling of tasks and activities are part of the basis for good business performance. In our case, we are talking about the planning of production orders that are to be transmitted by the ERP system, which is equipped with an operating interface for the task planning, allowing to follow all the production orders in production or planned, or CAM (Computer-Aided Manufacturing) to the MES software.

- **Block: Production order management**

A production order (PO) defines the products to be produced and the resources required for production. They are usually objects of exchange between the ERP and the MES production monitoring. The POs are generally prepared in the ERP (or CAM) from the orders and transferred to the MES production monitoring, but some manufacturers prefer the direct creation of POs in the MES. In fact, the direct creation of the POs in the MES provides a backup mode in case of ERP maintenance.

- **Block: Quality control**

Quality, an essential component of production monitoring, is a transversal function that operates from the reception of raw materials to the delivery of products.

- Quality controls in reception:

At reception, one or more checks are carried out at the end of which the batch of raw materials or components will be accepted or rejected. These controls can be manual or automatic (the data are then acquired directly from the equipment). The parameters of these controls are traced on ERP.

- Quality rate and performance:

In terms of performance, production losses due to non-quality obviously play a crucial role. The quality rate is one of the three components of the OEE (Overall Equipment Effectiveness) which measures the productivity of a production line. It is calculated automatically

based on the measurement (automatically and/or by input) of rejected products at the different stages of manufacturing.

Through the execution system, managing and monitoring the production in progress in the workshop, the operator is immediately alerted of a malfunction and is able to put in place the necessary rectifications. Finally, a number of activities will lead ERP and MES to cooperate, such as scheduling, quality and maintenance.

- **Block: Industrial Processes**

- Production performance:

In order to optimize industrial processes, it is necessary to collect the information, either manually or automatically, to process and consolidate it in a structured database form.

Whether by calculating and monitoring the OEE (Overall Equipment Effectiveness), the MTBF (Mean Time Between Failures), the MTTR (Mean Time To Repair), the results of these processes are translated into production performance indicators (Key Performance Indicators) or reports. The indicators, states and balances obtained are disseminated to all operators and managers in an appropriate form.

- Display of graphs in real time :

The dissemination and analysis of production information, also called EMI (Enterprise Manufacturing Intelligence) is an essential link in the monitoring of your manufacturing. The module's EMI functions benefit from all the ease of use and power of Microsoft Excel to create your real-time graphs and reports. Longer reports are edited in PDF format with chapters and sections.

- **Block: Measurement, recording and data transmission**

The recorders support the automatic recording of measurements or data in event mode, thus saving storage space. Periodic forcing is still possible.

Periodic archiving, setting the data retention time 'online', is also managed, all this with the industrial supervision (SCADA system) and the control command of the installations which are an essential component of the control of your production, and to ensure the communication with the automatons and equipment, which offers to the operators an optimal driving ergonomics.

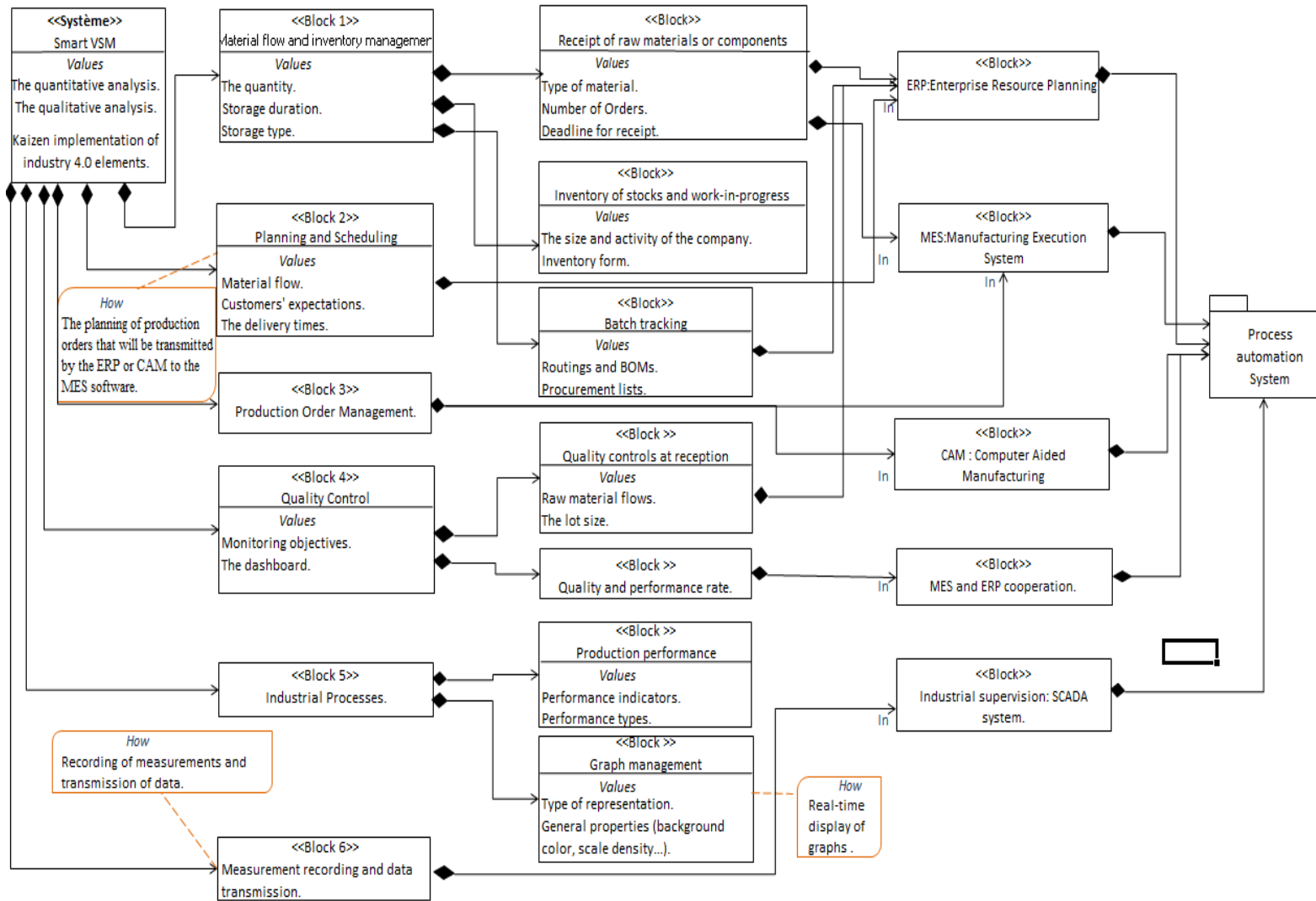


Figure 3: SysML Block Definition Diagram (BDD) of the Smart VSM

4 AUTOMATIONML MODELING

Production system engineering is generally characterized by strong phase separation and a variety of specialized engineering tools for each phase. This poses the problem of a wide range of heterogeneous tools, with individual and often proprietary data formats and insufficient data exchange support. Hence, data exchange between engineering tools has been identified as a major bottleneck in the engineering workflow. Therefore, AutomationML (AML) (Estefan, 2008) aims to fill this gap by facilitating the exchange of various aspects of automation engineering and its ability to handle multiple semantics in a heterogeneous engineering tool landscape. This section provides an overview of the correspondence between AML and SysML, as well as the modelling in AML.

4.1 AML profile design for SysML (AML4 SysML)

An AML profile can extend an existing modeling language (SysML) by adding new concepts or by specializing concepts defined by it. We present an interdisciplinary integration chain for AML and SysML based on interoperability techniques driven by AML/SysML profiling and model transformation models (Berardinelli et al., 2016).

4.2 Between AML and SysML

The proposed correspondence between AML and SysML is intended to promote cross-fertilization between these two standards and their communities. As a result of the resulting mapping, the AML community can, on the one hand, benefit from the graphical representation provided by SysML diagrams, based on model-based techniques and tools for SysML and UML. On the other hand, the SysML community can use many AML libraries to model production systems, such as those defined by the AML standard, to mention only a few cross-fertilization possibilities.

4.3 AML modeling of VSM 4.0

An AutomationML (AML) modeling of the new VSM methodology in the industry 4.0 eras, which was discussed earlier in our manuscript, is presented in figure 4. Note that AML does not provide a standard concrete notation as does the SysML language. Therefore, we provide holistic modeling following the architecture of AutomationML in the form of a graphically oriented diagram. The legend under the schematic representation of the Smart VSM explains this notation with AML concepts.

information as Internal Elements (IE). We will now focus on the other three windows of the main hierarchy, Interface ClassLib which contains a number of abstract interface classes such as Data transfer Interface ClassLib and control Interface ClassLib, which are used in the VSM 4.0 project, then Role ClassLib contains a Role Class, and then System Unit ClassLib, which deals with process automation system components.

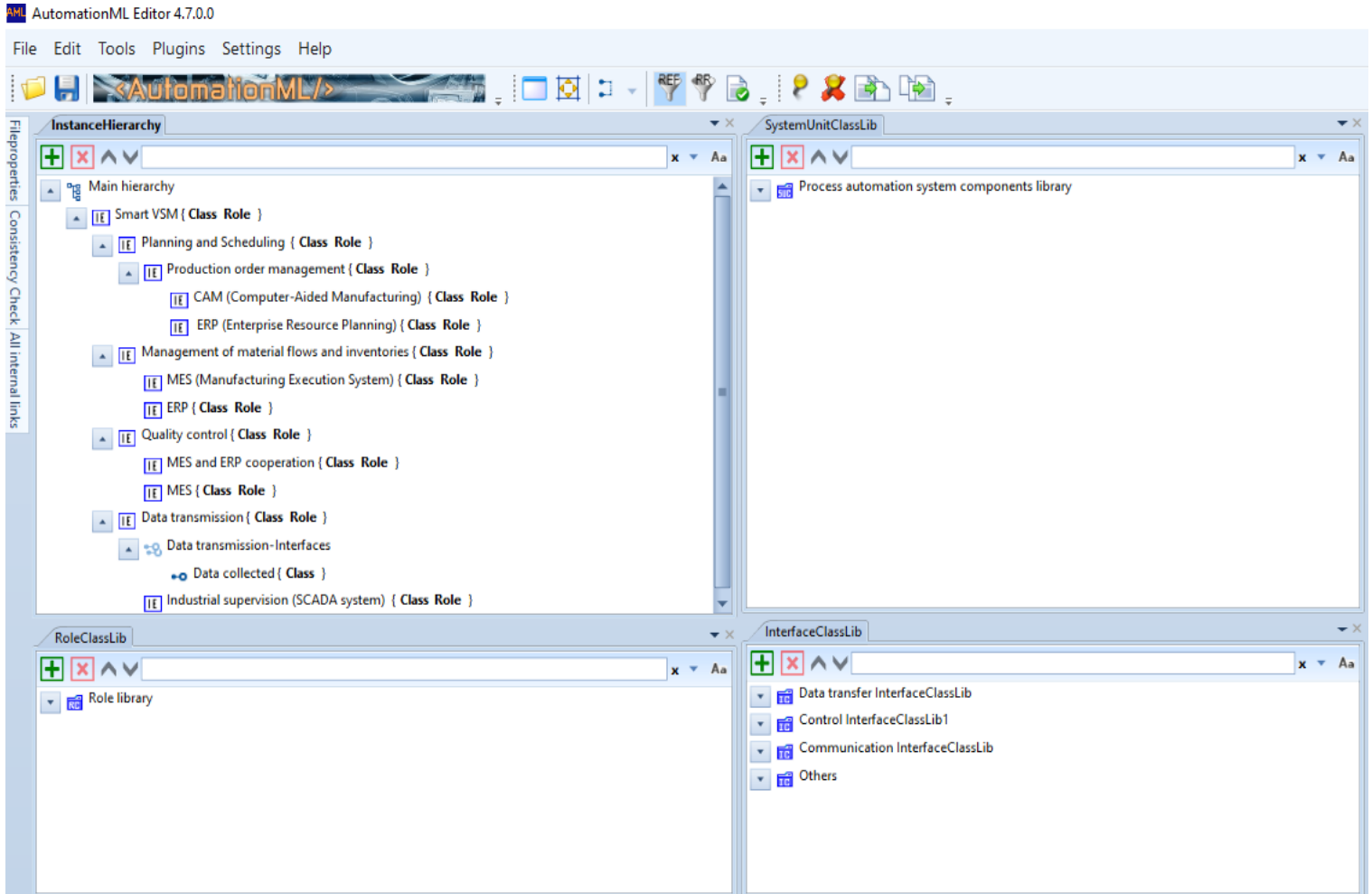


Figure 4: The mapping of the Smart VSM with the AutomationML model

SysML blocks can be modeled in the form of the instance hierarchy and 3 library hierarchies, which allows modeling the diagram of the SysML block definition and the internal block diagrams in the form of modular component trees representing the element specification (Berardinelli and al., 2017). Its content can now be edited and displayed on AML-specific diagrams. In particular, Fig.4 shows the Smart VSM instance hierarchy on an Instance Hierarchy Diagram (IHD) corresponding to the SysML BDD shown in figure 3.

4.4 Smart VSM with AutomationML Editor

AutomationML supports four types of hierarchy, as illustrated in figure 4 with Automation Editor, the box on the upper left allows us to model individual objects hierarchically, both as physical elements and as virtual infor-

5 CONCLUSION

When we began our work, our ambition was to help business leaders, mainly SMEs, to become aware of the importance of the on-going industrial revolution. We wanted to guide them in managing the digital value chain with the aim of improving industrial performance. Today, companies in all sectors of activity are facing increased competition. The willingness to transform digitally is today decisive for the success and failure of a company. To achieve its objectives, the company must adapt or develop solutions with high added value. The management of the digital value chain of manufacturing companies in the context of industry 4.0, in particular, is

increasingly becoming a distinguishing factor within the competition.

Value Stream Mapping 4.0 (VSM 4.0) is a digital and collaborative work environment for lean management teams in the Industry 4.0 era that helps us optimize the production process by digitizing the value stream. The idea focuses on higher levels of digitization, integration, and automation of information and material flows for a plant and beyond, which can enable more transparent decisions and improvements to production systems.

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