The Value Stream Hierarchical Model: a practical tool to apply the Lean Thinking concepts at all the firms' levels

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Abstract. The increasing competition in the global markets is pushing many manufacturers to start the lean transformation with the final goal of being a Lean Enterprise, which applies the Lean thinking concepts at all its levels, from production to management. The biggest problem in this transition is to have a tool that consistently measures the undergoing evolution in the value stream selected, regardless of its extent, in order to take the subsequent actions needed. The main objective of this paper is to provide such a tool, the Value Stream Hierarchical Model (VSH Model), which could fit with every kind of manufacturing enterprise taking into account also the recent shift to industry 4.0 and the related new technologies available. In addition, another purpose of the model is to provide a scalable point of view that allows to "zoom in" on the company entity, based on the desired level of detail and the related information required. The VSH Model has born as a mix of the architectures existent in literature (ARIS, CIMOSA, PERA), which describe the enterprise from different point of views and levels, and the Lean Thinking concepts, starting from the Lean production tools and variables, passing through the Lean Accounting variables and ending with the Lean Management KPIs. The VSH model has already been applied to practical cases, consisting of a group of companies, as part of the industrial research carried out in Italy by the Politecnico di Torino.

Keywords: Lean Accounting, Lean Production, Lean Thinking, Value Stream Mapping, Industry 4.0.

1 Introduction

Krafcik introduced the term Lean in a paper derived from his thesis and published at Sloan School of Management in 1988 [1]. Womack, Jones and Roos extensively used the term Lean in their well-known book "The Machine that Changed the World" to describe the production system that allowed the company Toyota, since the 50s, to overcome the competition among automobile manufacturers around the world [2]. According to MIT researchers, the concept of "Lean Production" would therefore express the sum of the positive characteristics that an entrepreneurial organization had to possess in the 1990s in order to compete on the market. Some of these characteristics are expressed by a greater involvement of company employees with the natural overcoming of a rigidly hierarchical organization and by the importance of corporate value systems that contribute to increasing the quality of the finished product.

Over time, the term Lean Production has evolved in a broader concept known as Lean Thinking [3], which represents a philosophy or a way to approach to the functional areas of the firm such as organization, manufacturing, service, office. Once each area, from product design and development to logistic, adopts the way of acting derived from the Lean Thinking the model is applied to the entire company that becomes a Lean Enterprise.

Since Toyota and other Japanese companies have begun to increase their market share in the main automotive markets thanks to Lean Production many other organizations, in the manufacturing industry as well as in services, have started the transition from a Mass Production system to a Lean one. Some of these transition attempts have been successful, even if they have been slow and expensive; others have miserably failed returning to the initial situation. Many of the failures are firstly due to a wrong understanding of Lean Thinking but at the same time to the lack of tools that allow for assessing whether the changes made are really directed towards the final goal, that is the Lean Enterprise. Moreover, the organizations who have been able to complete the transformation are now dealing with a new challenge: operate the new technologies introduced by the industry 4.0 with the Lean principles.

This paper presents a common framework named “Value Stream Hierarchical Model” (VSHM) that exploits some of the I4.0 technologies such as IoT, simulation and data analytics, in order to assess which level of adoption a firm has reached in the transition towards the Lean Enterprise. Once defined how to report the information needed to identify the value stream, particular attention has been paid to the interaction between Lean manufacturing and Lean Accounting variables. In the end, the application of the VSHM for a prolonged time will help to create a common database, with information related to products and processes belonging to the different value streams monitored, to be used in order to improve the new product development phase and the product lifecycle management.

1.1 Literature review

To create an effective organizational model it is important to define the right context and reuse the knowledge and functionalities provided by existing models that are currently used for describing company information structures. Such models, with the support of international standards, allows for monitoring and controlling the production processes through the integrated information system. In the technical and scientific literature, the most relevant models are surely ARIS, CIMOSA and PERA.

ARIS stands for "Architecture of Integrated Information Systems”. According to Figure 1, ARIS describes the firm structure with a virtual model that reports how to develop and optimize the information system selected. Sheer [4] introduced such architecture for mapping and optimizing business processes according to different views. Each view has three levels of description: concept for the requirement definition, data processing concept for the design specification and, finally, the description for the implementation.

Another well-known model, developed by AMICE Consortium and illustrated in Figure 2, is "Computer Integrated Manufacturing Open System Architecture - CIMOSA" [5]. CIMOSA provides an open reference architecture oriented to the life cycle of the CIM system (the enterprise integration of machines, computers and people). The framework of the CIMOSA model is a parallelepiped that allows information to be broken down into three dimensions. The Generic dimensions explain the gradual evolution of the business model from the general to the particular; Life Cycle dimensions indicate the evolution of the modelling process and View dimensions provide a vision of the company from different points of view.

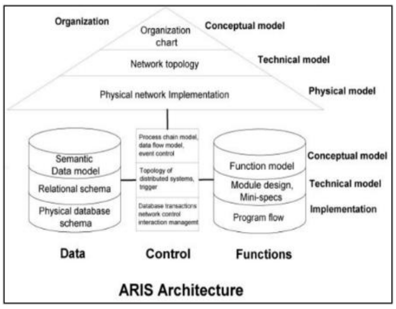

Fig. 1.ARIS Framework (pera.net)

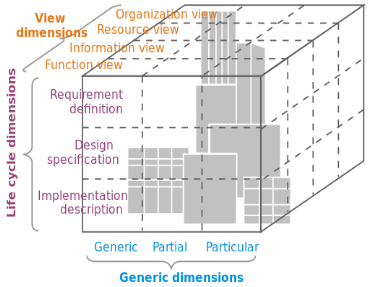

Fig. 2. CIMOSA Framework (wikipedia.org)

The third architecture largely used in the enterprise modelling, is the Purdue Enterprise Reference Architecture (PERA) [6], which is recognized in the standard ANSI/ISA 95 [7] and reported in many other standards such as ISO 15704 [8]. As shown in the figure 3, the PERA architecture divides the corporate structure into five levels assigned to three macro areas: production control that includes the physical process, the different devices and the control systems; management of production operations generally carried out by MOM and MES and finally Planning and logistics.

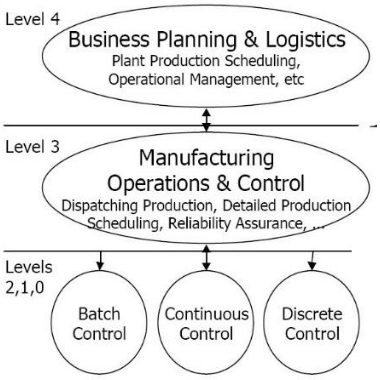

Fig. 3. PERA Reference model (wikipedia.org)

The main standards that have allowed the development of the Value Stream Hierarchical Model are the following:

- ANSI/ISA 95 Enterprise-Control System Integration, defines operations models and information exchange models within the manufacturing systems. It also provides interfaces between control functions and other enterprise functions in the business logistic system.
- IEC 60050 International Electrotechnical Vocabulary, is a set of publications that contains all the terms and definitions used to interpret the consulted standards [9].
- EN 62264 Enterprise-control system integration, adopts the model proposed by ANSI/ISA 95, and provides models of manufacturing operation management with related objects, attributes and activities [10].
- ISO 22400 Automation systems and integration — Key performance indicators (KPIs) for manufacturing operations management for Automation systems and integration, defines how to obtain the KPI for manufacturing operation management starting from the corresponding variables [11].

2 The Proposed Model

The "Value Stream Hierachical Model" (VSHM) is an evolution of existing models that aims to reconcile the needs of Industry 4.0 and the Lean Thinking approach.

The proposed model allows for stratifying the information related to a given value stream, regardless of its extent. Therefore, this model can describe a single production line, as well as a set of companies and factories, passing through a single company.

The difference between VSHM and other existing models lies in the point of observation on the company itself. In fact, the ARIS and CIMOSA architectures have an abstract approach that prevents a precisely defined vision, while the PERA architecture specifically delves into production without providing a link with the financial and economic results.

The Value Stream Hierarchical Model provides a scalable point of view that allows you to "zoom in" the company entity based on the desired level of detail and the related information required. The modelling starts from the description of a value stream and then connects it to all the related variables available in the enterprise. Therefore, based on the flow extension chosen, the VSH model can be associated to a single production cell, a plant, a set of connected companies / plants or an entire supply chain. Once the production flow and its extension have been chosen, the information of interest can be associated with the corresponding layer of the VSH model. This peculiarity allows for reading and creating the model in "Bottom-UP" mode starting from layer 1. However, it is also possible to associate the information to the different layers in parallel, adding more and more details to each layer.

The VSHM is composed of seven layers associated to the same value stream, as illustrated in figure 4.

Each layer provides a detailed description of variables, processes, functions and activities as well as their links with elements belonging to different layers.

1. 2D & 3D model Layer
2. Simulation model Layer
3. Material Flow model Layer
4. Variables model Layer
5. Financial model Layer
6. Social model Layer
7. Management model Layer

Fig. 4. WSHM architecture

2.1 General scheme

The general scheme for the layer description is illustrated in figure 5. It is graphically represented with a table that collects different information: Title, Description, Input, I/O transformation, Format, Output.

Title
Description
Input
I/O transformation
Format
Output

Fig. 5. General scheme structure

Each part of the table addresses a specific information about the enterprise operating processes:

- **Title** is the unique name of the layer.
- **Description** allows for understanding the function of the layer under examination. The description extensively and qualitatively reports the layer functions as well as the information required to populate it and the transformations it applies to the input information to produce the output information.
- **Input** is the input information from other layers or external sources, which describe the information requested in quantitative form.
- **I/O transformation** explains, for each layer, how to use the input information. Are the steps needed, or the software suggested, to obtain the output from given input information.
- **File format** indicates the format of the files or data, therefore of the output information, generated into the I/O transformation.

- **Output** represents the information produced by the current layer and used as input information in another layer.

2.2 The VSHM

The following sub paragraphs describe each layer extensively and finally provide an example of application in an industrial research project carried out at the Politecnico of Turin.

2D & 3D Model

Description. This layer represents the starting point of the Value Stream Hierarchical Model as it describes the value stream / cell / production plant from the point of view of layout and occupied space. In particular, the 2D model provides a two-dimensional description of the production devices and the workshop layout to give an overall picture of the situation. The layout refers, based on the extent of the value stream chosen, to the general arrangement of the basic positions of the workshop, auxiliary sections, production service departments, facilities, equipment, warehouses, passages, etc. Starting from the 2D layout and adding information about the height of the objects in the value stream is possible to get an idea of the spatial layout. The 3D model, which therefore indicates the space occupancy of the system, helps to understand the height limits related to the entire workshop and to the different devices included in it. In addition, the specification of the heights of the interfaces can be useful to examine the ergonomic efficiency of the systems.

The objectives that can be achieved by using the 2D and 3D model are:

- Reduce or eliminate waste related to the space occupancy by ensuring a "lean" environment
- Design and establish an efficient “Total Productive Maintenance” (TPM) program
- Apply “Workplace Organization”, providing safety, ergonomics and comfort to employees
- Minimize inventories and control operations
- Avoid non adding value investments

Input Information. Customer interviews or direct inspections provide the XY dimensions of the elements in the plant, their relative positions with respect to delivered reference system and the position of any interface of the devices with the external environment. Adding the Z dimension of devices, the model allow for representing the exact position of the human interfaces on devices, the flows of material involved in the value stream, the movements of human operators and the general visibility within the plant.

Input/output Transformation. The information gathered with interviews and inspections is transformed in structured data fostering other layers of the VSHM. 2D information is reported by drawings or 2D CAD models, while the 3D information is normally represented by 3D CAD models. Other results from this layer is the Spa-

ghetti Chart, a typical Lean tool that tracks the physical flows of materials and people involved in the value flow.
Format. Drawing and/or CAD file, in a specific format: .dwg, .3Ds, .dfx …
Output Information. The 2D and 3D plant layout, space occupation, operator interfaces and the Spaghetti Chart.

Simulation Model

Description. This model indicates the way the system works. Using the 2D, 3D and Spaghetti Chart models obtained as output from the previous layer, the simulation model adds information regarding the functioning of the value stream by simulating as much as possible what happens in reality. The simulation will have different purposes:

- Illustrate the analysed value stream (work unit, production line, plant) to all the involved actors such as managers and analysts. This will give the possibility to understand the functioning even to those who have never seen the flow live and to carry out their duties remotely.
- Design a line that does not yet exist by analysing all possible solutions in advance and obtaining savings on development by identifying potential inefficiencies resulting from incorrect design. In addition, the simulation also allows for designing the monitoring system.
- Simulate the operation of possible changes and improvements including the installation of new technologies such as sensors for data acquisition without having to interrupt work in reality.
- Check the correctness of the monitoring system having the possibility to set the target values and to simulate the data collection, which must be consistent with the parameters set.

Input Information. The input information are derived the 2D and 3D plant layout, the physical flow of materials and people involved. These data are mandatory but they are not sufficient to create a significant simulation because a larger amount of information is required. The development of the simulation usually requires an intensive data collection: re-inspect the location of the value stream selected, re-interrogate the involved actors to understand in detail the activities carried out and re-observe the real functioning of the machinery involved in the process. This last point is fundamental, because standard machinery are often customized according to special needs.
Input/output Transformation. Many simulation software allow the insertion of 2D or 3D CAD file as reliable basis in terms of size and position of the simulated objects. Subsequently, by adding the information obtained from the new inspections, crossed with the spaghetti chart data, it will be possible to model the simulation. In this operation, it is advisable to prepare a file that exactly describes the reality and how it was reported in the simulation, this will be useful if different individuals will work on it over time.
Format. The file format file will depend on the simulation software chosen, related to the process selected. For example, dealing with a discrete event process, a valid op-

tion could be FlexSim, which generates files in .fsm format. FlexSim has been used for the first application of this model in reality.
Output Information. The simulation, obtained from the selected software, including occupied spaces, human interfaces, movements of the materials involved and people. In addition, a file explaining reality and in parallel how it was decided to simulate it.

Material Flow Model

Description. Using the information from the simulation as a starting point, this layer shows all the possible flows of material within the value stream in question (in a plant, in a workshop, among the different workstations and between or inside devices).. It is the total material flow chart of the production system with the aim of displaying the materials used both inside and outside the devices and determining the cost of a single product. In the case of a production process, the materials are made up of all the levels indicated in the bill of materials (raw Materials, WIP, Finished Goods), therefore the parts actually transformed with an adding value function. In addition to these, there are the consumables, all those materials not listed in the bill of materials but necessary for the completion of the finished products, the energy sources that power the entire process and all the machines tools.
Input Information. The simulation of the entire value stream provided with an exact representation of the way in which all the material used interacts and flows in the plant and between the elements.
Input/output Transformation. Using the simulation produced by the upper level as a starting point, the flow of materials is identified by indicating the exact parking positions and the paths taken between them. One way to simplify the description can be to create a logic diagram of the material flow of the BOM with detailed indications of the amount of energy source, consumables and tools involved in the process. Later, also thanks to further inspections, the correct movements are reported in the simulation. All these information will allow to perform the analysis of the material flow in order to create both empirical data to compare with actual measured data and different possible scenarios with which to identify the path and the optimal use of physical resources.
Format. The same file format used for the simulation created in the previous layer.
Output Information. Quantification and identification of the materials involved in the value stream (plant / workshop / line / device). Useful starting point for identifying multiple variables and KPIs defined in subsequent layers.

Variables Model

Description. The performance and the operational status of the production devices in the value stream selected directly affect the level of production and cost of the single finished product. Therefore, it is necessary to monitor the value stream in order to promptly address problems, to ensure the reliability and efficiency of the process itself and take corrective actions, as predictive maintenance, to reduce all the wastes and the unnecessary operations. Based on the extent of the value stream, variables related to a single device or to the entire production system can be tracked to evaluate its performance. This layer is particularly important as it indicates the manufacturing variables on which some variables of the subsequent layers and the lean indicators also depend. In fact, at this level, data from different sources connected to the value stream in question are used to assign the value to the variables of interest. The sources used are:

- The sensors already present or to be installed on the line.
- The plc (programmable logic controller) or supervisor of the entire flow
- ERP software
- Any other source containing information on production

The data obtained are then interpreted, transformed into information and crossed with some information from the previous layer to determine the value to assign at each variable. In future applications could be realized a processor which allows to monitor the system efficiency real time.

Following various analyses carried out in the existing literature, concerning mass production and lean production, it was decided to refer to the ISO 22400 standard for the definition of classical variables [9]. The aforementioned standard was chosen for several reasons: to have a common language with anyone who would interface with the model, because it determines the main performance indicators of MOM (Manufacturing Operation Management) and finally because it concerns automation systems and their integration into the productive system. In order to correctly interpret the ISO 22400 variables, as said before were used support standards including: ISA 95, IEC, ISO 62264.

The identification of the variables obtained from the analysis of ISO 22400 is not directly applicable to a Lean management of processes, which aims to optimize the growth of the product value by measuring the contribution provided by each production activity. According to this vision, all the variables of the production system should be directly or indirectly related to the product, so that the increase in costs can be measured by comparing them with the increase in value. Precisely for this reason, the lean production variables were subsequently selected from the list of manufacturing variables of the standard in order to determine the Lean performance indicators to be shown in a real time dashboard (Output of the management model layer).

The output info is then referred to all the variables defined in the standard 22400, which are not described in detail in this paper.

Input Information. The data used in this layer comes from various sources. In fact, as said before, the data may come from the sensors installed on the line, from the logic control programmer or from the ERP software used. In addition, some data may come from the material flow model layer and from the plate values of the machines used.

Input/output Transformation. Once all the data from the machines have been obtained, these will be translated into information in order to create the relative correspondences with the defined variables.

Format. The data are those collected by the machines and by the ERP, so they could be values assigned to codes.

Output Information. APWT, AUPT, AUBT, AOET, APAT, APT, AQT, ADOT, ADET, AUST, ATT, TBF, TTR, TTF, FE, CMT, PMT, POQ , SQ, PSQ , GQ, RQ , PQ, RM, RMI, FGI, CI, CM , IGQ, PL, STL, OL, EPC, GP, PI, USL, LSL, $\bar{x}$, $\bar{\bar{x}}$, $\hat{\sigma}$, σ, σ^2, ADEC, PDEI, TP

Financial Model

Description. This layer defines the actual cost to be charged to the value stream and consequently to the products it generates. The purpose is to give continuity to the hierarchical model but also to make it easier to integrate the manufacturing variables with those of costing and finance. For this reason, a list of variables has been defined as reported in the output information.

The costing variables have been defined following the scheme shown in the figure 6.

The finance variables instead are those reported in the balance sheet.

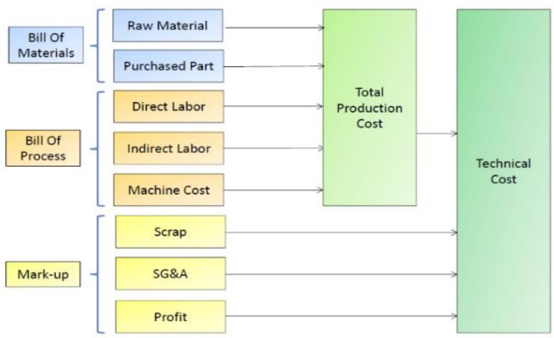

Fig. 6. Costing Variables Scheme

Input Information. The input information for the determination of costs can be obtained from various sources, some relating to manufacturing from the previous level, others from the nameplate values of the machines and finally from the company departments that deal with administration and finance.

Input/output Transformation. More than a transformation, in this layer a collection of data of interest will be carried out.

Format. The information of this layer are collected in an Excel file.

Output Information. As anticipated, the output of this layer consists in determining the cost of production of a given product of the value stream. The variables of interest are:

- Costing variables: bill of materials costs, bill of process and mark-up costs.
- Financial variables from financial statements.

In addition to these variables, the following information divided into three types may be useful:

- Operational parameters dependent on the production scenario: hours per shift, shifts per day, working days per year, gross hours per year, net hours per year, operational efficiency.
- Technical / economic characteristics of the machine: purchase and installation cost, useful life, residual value, line space requests, maintenance required, consumables required, utilities used (energy, water, etc.).
- Cost factors depending on the country in which it is produced: capital interest rate, space cost on line, cost of electricity, water, natural and artificial gas, insurance cost, property tax cost.

Social Model

Description. This layer serves to pay attention to the social effect of the adoption of the entire production system on employees and its possible evolutions in terms of externalities.

An example to reduce externalities can be the correct use and disposal of the resources involved: water, compressed air, energy, machines and tools usage. A possible way to improve the situation could be the introduction of renewable source of energy and a recycle system.

Moreover, in order to guarantee a better environment for the employees must be considered the percentage levels of light intensity, temperature, air pollution, humidity.

Input Information. Data obtained from sensors and standards adopted for recycle materials.

Input/output Transformation. All information could be fed into an econometric formula to determine a social effect index

Output Information. Energy consumption, contaminant emission, externality of the production, light intensity, temperature, air pollution, humidity, percentage of recycled materials involved in the production process.

Management Model

Description. Nowadays, competition in the market and the diversity of market demand are increasing, which is why it is necessary for a company to carefully manage the stream of value creation to eliminate waste, to be flexible and to satisfy the market demand.

This layer refers to the complete management of the value stream, collecting the information from the lower levels, which includes some activities carried out by the ERP system such as order management, production planning, inventory management, etc.

Once collected all the variables and information related to the value stream, it is necessary to create Key Performance Indicators that allow evaluating the performance to understand and explain how a company moves towards its business and efficiency goals.

In applying this scheme to a research project of the Polytechnic of Turin, the indicators obtained made it possible to create statistics that feed in real time a dashboard with sections dedicated to the various actors to monitor the efficiency of the system or a part of it.

Firstly, the list of KPIs of the ISO 22400 standard, obtained from the variables listed in the variables model, was analysed. Subsequently, with the variables of the standard 22400, formulas were created to obtain the performance metrics for a Lean production cell listed in the book "Lean Accounting" (2011) by Maskell, Baggaley, and Grasso [12].

The defined lean metrics, different from the traditional metrics used by mass producers, will thus allow to evaluate the current and starting state of the line to understand what changes are necessary to become a lean production cell.

The performance indicators of the lean cell are:

- DAY - HOUR - PER - HOUR D(hxh): this KPI indicates the ability of the cell to meet customer demand (internal or external to the company) in time. To create this indicator it is necessary the intervention of the operator, or of a sensor that performs the same operations, which at the end of each hour reports the quantity actually produced in that hour (GQh) and the good quantity accumulated up to that moment of the day (Σ GQ). Subsequently, in addition to the information relating to the hourly Takt-time (Tth) and to that accumulated up to that moment (Σ Tth), it is possible to determine the difference between the ideal and the actual production step (Σ Tth - Σ GQ).
- WIP - SWIP ratio (RWSWIP): this KPI represents the ratio between the semi-finished products present and those planned and is calculated at the beginning of the line and before each machine present in the line. Its objective is to determine the number of stocks present on the line to avoid unjustified interruptions or unused machines, therefore indirectly it has the objective of minimizing the actual unit downtime (ADOT). The SWIP value, which represents the Standard work in progress, should be a plate value of the entire line updated based on the data collected over time. While the WIP is measured in real time by the sensors.
- FIRST - TIME - THRU (FTT): it is the complementary of the (FOFFR) and indicates the percentage of pieces without defects produced with the same hourly frequency of the day-hour-by-hour. It is calculated as the ratio between the quantity produced (PQ) net of waste (SQ) and rework (RQ) and the quantity produced itself. [FTT = (PQ-RQ-SQ) / PQ]
- Operational effectiveness of equipment (OEE): Calculated as the KPI indicated in the ISO 22400 list.

With the KPIs from the last scheme and according to the production order inventory level, we can modify the production schedule and provide a production scheduling adjustment solution.

Input Information. The KPIs formulas, production order, inventory level and all the other information obtained from the lower levels.

Input/output Transformation. Once all the information has been collected and analysed, the calculations will be carried out to determine the performance indicators.

Format. A dashboard viewable on-line or offline

Output Information. WE, AR, THR, AE, UE, OEE, NEE, A, E, QR, SR, TE, PPT, APSCRR, FPY, SCRR, REWR, FOFFR, Cm, Cmk, Cp, Cpk, CEC, InvT, FGR, IGR, PLR, STLR, OLR, ELR, MTBF, MTTF, MTTR, CMR, DECE, DNECE, DEE, DNEE, D(hxh), RWSWIP, FTT, OEE

2.3 Application of the model in reality

The VSHM supports the modelling of several production processes in a project of industrial research where the Polytechnic of Turin was involved. The main objective of the project was to introduce the technologies belonging to I4.0, according to the Lean Thinking philosophy, in some manufacturing companies located in Piedmont. In Figure 7 is depicted the simulation created for one of the analysed processes belonging to the automotive industry. The VSHM supported the creation of a real-time cost analysis system that takes into account the lean process variables (time, material, working hours, waste, etc.) and the environmental data in the logic of cost engineering evaluation of the plant. The VSHM comprehended the already existing 2D and 3D CAD file of the plant. An accurate inspection of the manufacturing line provided data for the simulation and flow variable identification illustrated in Figure 7.

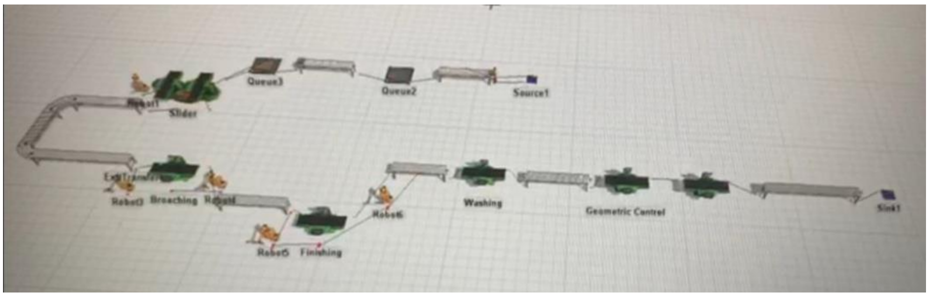

Fig. 7. Simulation model layer on a real production line

The modelling of the other four layers and the identification of the corresponding information allowed for developing the cost analysis system and a dashboard, roughly illustrated in Figure 8, to assess the performances of the production line from a Lean prospective.

In another production process, belonging to the agriculture industry, the Value Stream Hierarchical model focused on the evaluation of product sustainability according to the Lean thinking. The spray dryer distillation process illustrated in Figure 9, is highly conditioned by the environmental parameters and the application of VSHM allowed for the identification of variables and relationships with data collected from energy sensors, weather stations, IoT sensor and PLC devices.

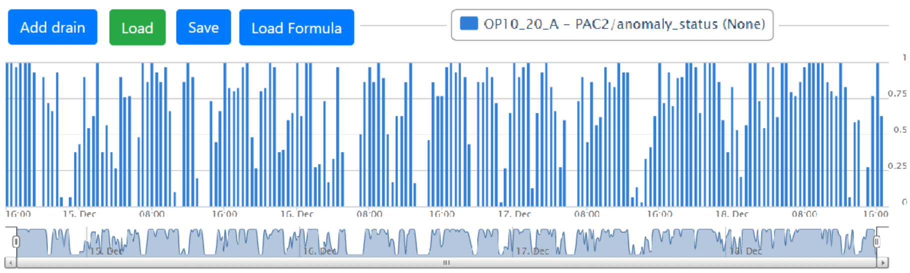

Fig. 8. Dashboard output for process monitoring

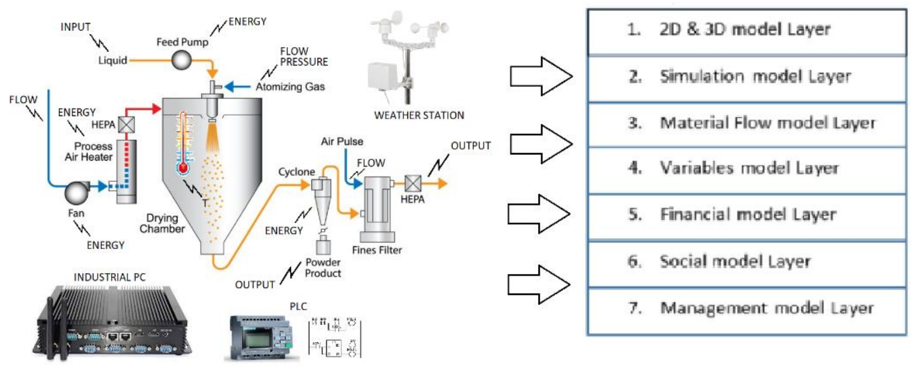

Fig. 9. Description of the Spray Dryer distillation process

According to the Lean thinking approach the result of such modelling activity is the evaluation of the four Lean KPIs, illustrated in the management model layer. Both the processes described were then used as a Lean pilot cell in view of the transition to Lean Enterprise.**Table 1.** Lean KPIs for Spray Dryer process

D(hxh)	Tth	GQh	ΣTth	ΣGQ	ΣTth- ΣGQ
RWSWIP	WIP /(PRI x Planned # Item per time)				
BPC	GQ / [GQ + validation rejects (SQ1) + sieve quantity (SQ2) + + reworked quantity (RQ)])				
OEE	PRI*# item/ PBT				

3 Conclusions

The studies carried out and the selected indicators have created the conditions for the definition of a new hierarchical model for the representation of corporate operational information called the “Value Stream Hierachical Model” (VSHM). The VSHM, born as an evolution of existing models with the aim of reconciling the needs of industry

4.0 and Lean Thinking, represent a guideline for the collection of the relevant information in a value stream in order to obtain variables and indicators of Lean Manufacturing. At the same time, the VSHM could be used as a tool that consistently measures the undergoing evolution in the value stream selected, regardless of its extent, to take the subsequent actions needed. Consequently, the collection of this information during the time will help to create a common database to be used in order to improve the new product development phase and the product lifecycle management.

Certainly the connection between the variables of the ISO 22400 standard and the Lean Accounting performance metrics are the most important result obtained, however there are many aspects in the model that need to be explored. In particular, for what concern the Variables Model Layer it is necessary to create a software infrastructure to correctly link all the data collected from the different sources. Secondly, the Social Model layer should be enriched of a formula to understand the real impact inside and outside the production plant. These finishes and others will be developed in future projects with the aim of supply the users of a real practical tool.

References

1. Krafcik. John F.Triumph of the Lean Production System. MIT International Motor Vehicle Program, Sloan Management Review, pp.41–52 (1988)
2. Womack, J. P., Jones, D. T., & Roos, D. T.: The machine that changed the world. Harper-Perennial, New York (1991).
3. Womack, J. P., & Jones, D. T. Lean thinking - banish waste and create wealth in your corporation. Journal of the Operational Research Society (1997).
4. Sheer, A.-W, T.: Architecture of Integrated Information Systems: Principles of Enterprise Modeling. Berlin et al. (1992).
5. ESPRIT Consortium, T.: AMICE CIMOSA: Open System Architecture for CIM Springer, Berlin, Heidelberg (1993). https://doi.org/10.1007/978-3-642-58064-2
6. Theodore J. Williams. The Purdue enterprise reference architecture. Computers in Industry, Volume 24, pp. 141-158 (1994). https://doi.org/10.1016/0166-3615(94)90017-5
7. ISA Homepage, http://www.isa.org. last accessed 2021/02/21
8. International Electrotechnical Commission Homepage, https://electropedia.org/
9. ISO 15704:2000. Industrial automation systems - Requirements for enterprise-reference architectures and methodologies, ISO Standards.
10. EN 62264-1-2-3:2017 Enterprise-control system integration
11. IEC/ISO 22400:2014 Automation systems and integration - Key performance indicators (KPIs) for manufacturing operations management, ISO Standards.
12. Maskell, B. H., Baggaley, B., & Grasso, T.: L. Practical lean accounting: a proven system for measuring and managing the lean enterprise. CRC Press (2011).