Article

Agent-Based Simulation of Value Flow in an Industrial Production Process

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Abstract: The current competitive environment demands companies to be more and more efficient. In order to increase manufacturing efficiency, two apparently independent approaches have emerged: lean strategies, focusing on identifying and minimizing non-added value activities, identifying wastes in the system and their elimination, and information tools for planning and controlling activities. In this paper, a manufacturing system was considered for which it was necessary to increase the production capacity in order to respond to the customer's increased demand. A practical case study in the automotive industry for a medium-sized enterprise was considered. In order to investigate the production process parameters and to implement lean principles, Value Stream Mapping (current analysis and optimized solution) and Anylogic agent-based simulations were carried out. Based on this, the lean performances, specific for the target VSM, were evaluated in terms of key performance indicators. The benefits of integrating agent-based simulation in the design and analysis of the value flow in the production chain are the capitalization of the information offered by Value Stream Mapping and the possibility to choose the best one from the possible scenarios. It generates important time and cost reductions without further resource waste.

Keywords: value stream analysis; value stream design; agent-based simulation; sustainable production process; SME's

1. Introduction

The manufacturing of products has lately evolved from mass production to customized production [1]. In this context, optimizing the use of resources remains a challenge for organization. In [2], Lieder at al. defines the industrial businesses as "a complex adaptive system between customers (actors) and manufacturing systems (technical artefacts) producing products".

The lean philosophy, applied in the permanent improvement of processes, is based on the concept of product value. The value of the product, from a business perspective, is defined as what the customer pays. Wherever a product is made, there is a flow of value [3]. Depending on the scale, strategy, and level of development of the organization and of the culture where it is applied, lean is a management system, a philosophy or a tool set [4–6].

Starting from the identification and elimination of non-value-added activities, Womack and Jones [7] define five lean principles: value, value stream, flow, pull, and perfection. The first step is represented by setting the value from the client's perspective. Once the value has been established, the next step is mapping the processes by identifying value flows. After the losses have been identified and removed from the process, the next step presupposes ensuring process fluidity, without throttling, smoothly, uninterrupted flows to the customer. By following the steps outlined above, if implementation is correctly done, lean

remarkable results can be achieved in terms of efficiency, time cycle reduction, productivity, material costs, scrap reduction, resulting in lower overall costs and high competitiveness [7].

The main types of waste that are addressed within lean are defects, unnecessary transport, unnecessary motion, setup time, finished goods inventory, inappropriate processing, failure time, work-in-process (WIP), raw material inventory, and lack of integrated approach [8,9]. Starting from the lean classic, the methodology evolves towards lean digital and lean 4.0 [10].

The intersection between lean and simulation was investigated in several studies. From small businesses to multinational companies, organizations apply simulation models to analyze logistics networks, reduce costs and improve customer service [11]. That is why, mapping this flow, modelling and optimizing it by using specific tools represent necessary actions within the company [12,13].

During a production process, many dysfunctions can occur because of various influencing factors. An appropriate method to analyze, prevent, optimize, or look for solutions those production dysfunctions is using a process modeling and simulation technique, by digital plant environment implementation [14–16]. The advantage of using process simulations is that it helps maintain or even increase the value of the manufactured products to serve for negative influencing factors identification and eliminate the unnecessary waste.

However, according to the authors' best knowledge, some of simulation models are necessary to acquire additional datasets with respect to the data provided by Value Stream Mapping (VSM). A model simulation which allows to use only VSM information is what this research wishes to address.

In this respect, the paper presents a methodology to improve VSM by adding the agent-based simulation to it. The work is structured in the following sections. Section 2 describes the lean concepts, VSM, and simulation in the light of recent research. As a result of the bibliographic, theoretical and applicative research on the integration of VSM with other modeling/simulation tools, Section 3 presents the simulated model of the VSM. After the presentation of the current VSM, making the decision is assisted, by using specific tools, so that VSM target can respond to the company's objectives for a given time. A case study at a medium-sized enterprise, presented in Section 4, contributes to the easy understanding of the proposed model. Section 5 includes a summary and the analysis of results further research directions, and Section 6 contains the conclusion.

2. Value Stream—Mapping and Simulation

2.1. Mapping a Value Stream

VSM, as a visual tool, proves to be effective in the continuous improvement of processes. Beginning from the classic approach, in four steps, many authors have proposed its integration within other tools that might increase VSM's effectiveness [17].

Goti et al. [17] and Yin et al. [18], in a comparative study of various modeling methods, highlight VSM's superiority, its degree of formalization, completeness, modeling skills, and model extension, in relation to Flowchart, Role behavior, IDEF0 (Integrated DEFinition) diagram, and Petri net.

Researchers as well as practitioners, after critical analyses, have looked for ways to improve VSM by integrating other tools at various stages of building a value chain. Braglia et al. [19] and Gunduz et al. [20] present VSM as a tool for linear systems. In the case of complex systems, it is necessary to improve the approach by connecting it to other tools [3,10,12,14,15].

A model for the improvement of the value-mapping process by the integration of stakeholders' requirements for the development of sustainable business is proposed by Geissdoerfer et al. [21].

VSM is a lean management method for the analysis of the current state of being and for the design of a future situation for the series of events that a product or service undergoes from the raw material to the customer [19], VSM was developed in 1995 [22].

Seth and Gupta [13] define VSM as the process of mapping material and information flows in the form of value stream afferent to components and subassemblies, taking into account manufacturing,

suppliers and distribution to the customer. According to Meudt [10] and Heravi et al. [23], VSM is one of the most efficient methodologies for mapping and analyzing process chain.

Andreadis, Garza-Reyes, and Kumar [24], analyzing with a view to increasing the competitiveness of the organization, describe the VSM methodology, underlining the importance of value chain implementation and management.

VSM presents graphically all the activities necessary for the achievement of the product or service requested by the client for which the flow of materials and information is viewed in the analyzed area [25]. In this way, losses in the value flow can be identified, and solutions are looked for in order to have them reduced or eliminated.

Designing the value flow map means the graphical representation of material, human, and information flows that are involved in the achievement of the product. The analysis of the values flow and the design of the diagram lead to an overall image of processes at all levels, from raw material to delivery to the customer. The objective is to describe all steps that are taken and to identify those that do not add any value in order to have them eliminated. Last but not least, VSM results in a better understanding of the process as a whole.

Although the design of the value flow is often associated with production, the methodology is also used in logistics, in the supply chain, in the related industries, in the health services, in software development, in the administrative and office processes as an effective tool for the improvement of processes by the identification of waste. This approach, based on four steps, was proposed by Rother et al. [26] and Tapping et al. [27].

The VSM stages, described in the papers presented in the previous paragraphs, are:

- choice of the product family;
- representation of the current VSM status;
- VSM achievement–target;
- establishment of the action plan.

2.2. Production Process Simulation

In the context of increased demand for a higher degree of product customization and personalization, simulation leads to resource economy [28–30]. Manufacturing processes simulation, as an intermediate stage in implementing digital manufacturing asks for the use of specific technologies and methods [31–39].

While System Dynamics and discrete-event simulation modeling are traditional, agent-based simulation modeling is relatively new and can be used across all abstraction levels [40]. Agents may model objects of very diverse nature and scale and allow defining the agents' behavior which will prove useful for more complex research. The agent-based approach is more general and powerful [31,32,40,41]; it is also easier to implement and maintain [40].

In a defined environment, Borshchev and Filippov [40] as well as Schonemann et al. [28] propose to use agent-based modeling simulation. This approach involves modeling of individual object behavior [41]. According to Norton [42], Chamoso [43], Cocco [44], and Thang [45], agent-based modeling focuses on the individual active components of a system. This is in contrast to both the more abstract system dynamics approach, and the process-focused discrete event method.

With agent-based modeling, active entities, known as agents, must be identified and their behavior defined. They may be people, households, vehicles, equipment, products, or companies, whatever is relevant to the system [42–44]. Connections between them are established, environmental variables set, and simulations run. The global dynamics of the system then emerge from the interactions of the many individual behaviors [46].

Ruiz et al. [47] present an evaluation of the most used software simulation tools for manufacturing systems, as Arena, Extend, Microsaint, Quest, Witness, FlexSim, and Promodel. The results of [45] include the advantages of using the agent paradigm. Heydaryan et al. [48], Kokareva et al. [49], Fil'o et al. [50]

and Siderska et al. [51] propose as solutions for simulating production processes, Siemens Tecnomatix software which includes, for making digital models of production lines, Process Simulate package [41], or Promodel [52]. Simulink, Anylogic, Witness are described by Goodal in [53].

Anylogic is a software system developed by the AnyLogic Company for modeling, simulation, analysis, visualization, and optimization of production systems and processes, material flow and logistics operations [40]. Anylogic provides a single platform for dynamic simulation [53].

Goodall et al. [53], Schwab et al. [54], Zhang et al. [55], and Ohab et al. [56] describe different applications using agent-based model in Anylogic software. The AnyLogic simulation environment allows working with agent-based, discrete-event, and system dynamics simulation models to customize material and information resources in a production system. Simulation modeling uses objects and rules that describe the dynamic behaviors of systems [56,57].

The simulation shown in this paper uses agent-based modelling using Anylogic.

3. Material and Methods of Simulated VSM

Starting from the conclusions presented at the end of the previous section, the authors suggest introducing some additional steps for the study of the dynamic behavior of the systems, and respectively VSM simulation.

3.1.VSM Achievement

a) Current VSM is made starting from the requirements of the customer and is developed following the steps of the product process flow. The main flows in a VSM are information flow and material flow. A process flow diagram identifies the parameters that represent process characteristics.

In order to analyze the current state of VSM, the entry data is:

- choice of the product with the highest production volume;
- calculation of client's takt time;
- identification of the operations required to achieve the product;
- cycle time measurement;
- identification of the positioning for operators;
- inter-operations inventory;
- calculation of the duration of the assembly process;
- calculation of the Lead time process;
- calculation of operator load and of the number of operators required;
- general plan of the production line.

b) VSM target
It represents the ideal manufacturing line and the predicted process. The VSM target contains:

- proposal to position operators to reach the target;
- reducing inventory between operations;
- calculating the duration of the assembly process;
- calculating lead time process;
- establishing the operator's load capacity and the number of operators required to reach the target;
- general plan of the manufacturing line;
- mapping the value flow.

3.1. VSM Simulation Model

The completion of this stage involves building an agent model using the Anylogic simulation environment [53,58]. The process-centric model of real-world systems is used, and it contains the following elements [53]:

- primary elements: agents and resources;
- derivatives;
- processes detailed to operations and sequences, characterized by queues, delays, and resource utilization.

The model of the process defined by flowcharts allows graphic representation; the graphic process representations were obtained from the Process Modeling Library's blocks (Figure 1a). In the next steps, the process flowchart is created.
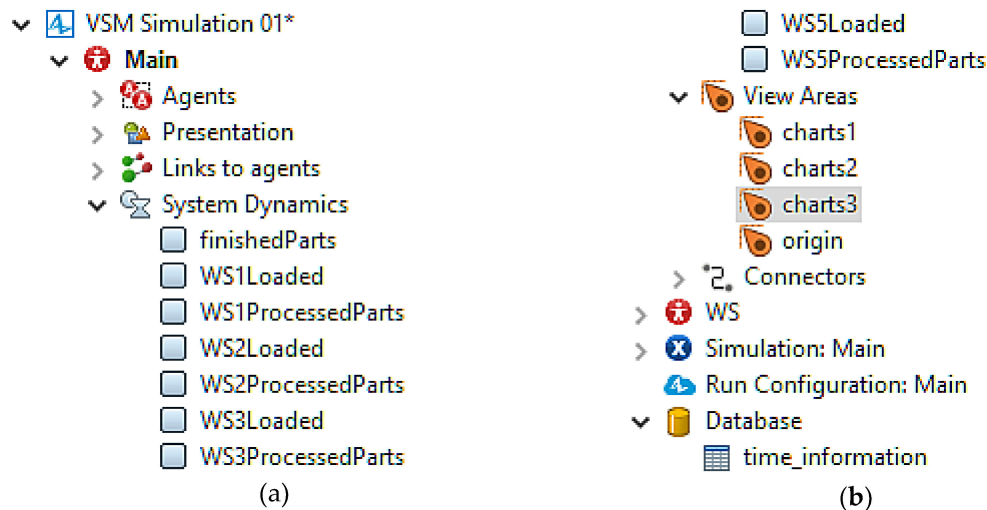

(a)　　　　　　　　　　　　　　　　　　　　　　　　(b)

Figure 1. AnyLogic project (**a**) Design of agent; (**b**) Design of view areas.

AnyLogic was used to simulate the process with the initial cycle times and the process with the final cycle times given by the VSM target.

The variables and the view areas of the final project structure are depicted in Figure 1b. Multiple view areas are needed as AnyLogic time plots. These plots are necessary for machine load tracking, for the tracking of the machine load evolution in time, for a comparative view of machine loads, and for tracking the number of processed and finished parts. Since the input data already consists of full cycle times, measured as the difference of time between the product's time of leaving the current workstation and the time leaving the previous workstation, it is sufficient to use the main agent and the WS (workstation) agent (used only to graphically represent the workstations).

Simple graphics (Figure 2) were also used to graphically simulate the flow of products through the workstations (WS). Resource pools containing only one object were used to enable the seizing and releasing of each of the workstations for processing, with the added benefit that the total load of a workstation can be seen directly next to it. As the loads are restricted from the beginning to 75% of the total working time by taking into account only six hours out of eight, the process uses maximum loads.
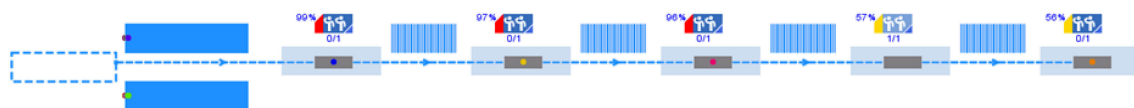

Figure 2. Model graphics

To keep things simple and flexible, a logic which employs delays was used for each workstation (Figure 3). It consists of putting the product in the rack, delaying it there if needed, seizing the workstation, taking the product from the rack and moving it (delay block to specify moving time), processing it, and releasing the workstation when done.

Figure 3. Logic model for work in process part storage (storeWIP), moving and processing (repeated for each workstation).

The external input data for the simulation consists of the cycle times for each operation. Since the project needed to be prepared to handle frequent data changes, this data was saved in Excel sheets and then imported into the project's data base. This enabled easy data changes for simulating new scenarios. A database table with the two sets of the cycle times is depicted in Figure 4b.
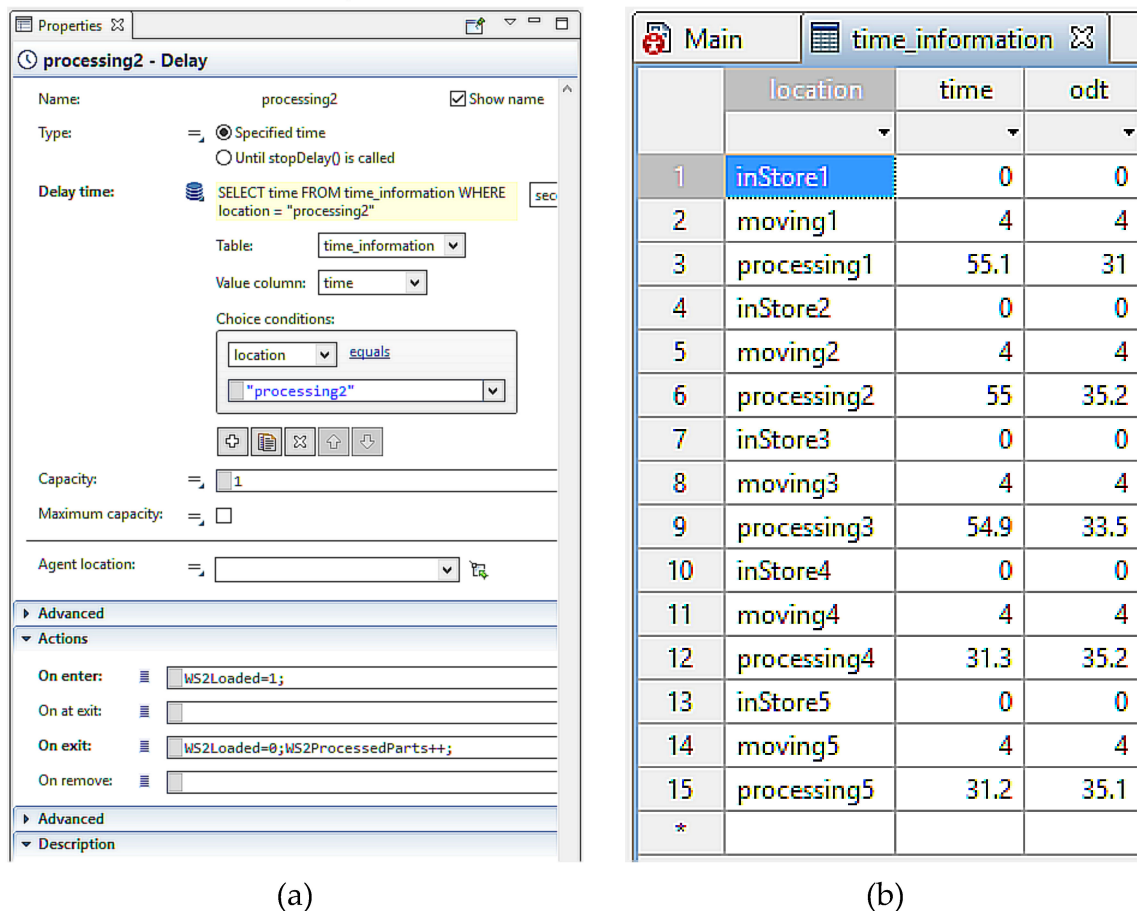

(a)   (b)

Figure 4. AnyLogic project (**a**) Object design; (**b**) Time information in the database.

It is noticeable that the actual cycle times were split in two (an interval of 4 s for moving the product and the rest of the cycle times for processing the product at the workstations). This was found to be necessary in order to make the processing of individual products at a workstation show up in the charts. Figure 4a shows how a delayed object is connected to data from the project's database and how actions are used to modify the values of variables to obtain new results.

3.2. Evaluation of Lean Performance for the VSM Target Simulation Model

In order to evaluate the results of the production process improvement using simulation, the references [59–62] recommend the evaluation of lean performance by using seven key performance indicators (KPI) presented in Table 1, from which three indicators specific to the problem to be solved will be used.

Table 1. Evaluation of Lean performance using KPI, KPI: key performance indicators.

KPI	Symbol	Short description
Overall Equipment Effectiveness	OEE	general effectiveness of equipment uses
People Productivity	PP	ratio between the number of good units made and the number of direct operator hours it takes to make those units
Value Added Per Person	VAPP	number of direct people involved in the conversion process to add value to the product
Not Right First Time	NRFT	number de defective units per million
Delivery Schedule Achievement	DSA	it measures the quantitatively and timely correct delivery of goods ordered by the customer and promised to be delivered
Floor Space Utilisation	FSU	sales revenue generated per square meter of factory floor space
Stock Turns	ST	speed of inventory rotation

Of the seven indicators referring to Table 1, VSM allows to deal with three of them: people productivity (PP), value added per person (VAPP), and percent of use of production space (FSU) [30].

4. Application in an Industrial Process Case Study

The development of the proposed model will be done on a medium complexity product of a medium-sized enterprise, a twin-tube damper. The various stakeholders (practitioners, researchers, an external observer) were involved in consensus building steps, emphasis on flow and the use of the proposed simulation.

The dampers can be manufactured in eight constructive variants. The components of the damper are the following: two concentrically positioned tubes, a piston rod, a sealing and guiding piston rod pack, a piston pack, a lower valve, and a valve pin for the adjustment function. The connection elements are: an upper ring connection screwed in the piston rod and a ring attached in the aluminum tube by a spherical nut on the bottom (Figure 5). The necessary adjustment elements are: an adjustment lever, a sliding guide slider, two stringback springs, and an adjusting cable adapter.

(**a**)   (**b**)
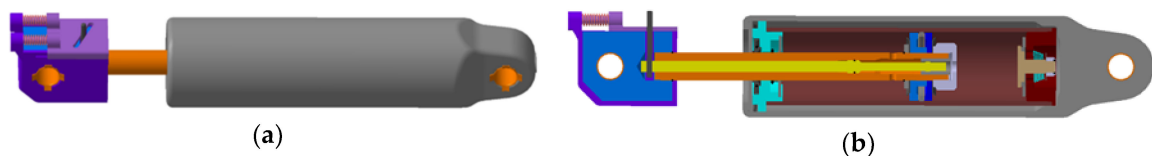
Figure 5. Final product (**a**) General view; (**b**) A constructive variant.

The current situation is characterized by a demand of 367 dampers per day; the known problems are inventory management, the execution of parallel operations, and an inefficient use of the workforce. The foreseen demand is 550 dampers per day.

In order to establish current VSM, the flow value analysis on the production line is necessary. It is noticeable that the production line is a manual assembly one. Table 2 shows the data taken from the production line applied to scenario 1, measured for 20 days.

Table 2. Parts and client target takt time for 367 parts/day, measured for 20 days.

Damper type	Percent	No. of good parts	Scrap	Total	UM
Adjustable damper	98.92%	7246	7	7253	(parts)
Locking damper	1.08%	76	3	79	(parts)
Non-adjustable damper	0.00%	0	0	0	(parts)
	100.00%	7322	10	7332	(parts)
Loading degree		100%		75%	
Client Takt target		78.6 (s/parts)		58.9 (s/parts)	

Two scenarios will be evaluated, one for 367 dampers (as a current situation, represented by Value Stream Analysis), and the other for 550 dampers (as a target situation, represented by Value Stream Design).

The assembly line of the twin-tube damper is a manual one (In Table 3 there is a Workcenter description). In order to meet customer requirements, taking into account the type of line, cycle time must be 75% of customer's takt (58.9 s/parts).

Table 3. Workcenter description.

Work center	Work center description	Work center	Work center description
1	O1. Checking piston rod	4	O4. Rod assembly–piston
2	O2.1. Component preassembly–A1	5	O5. Basic components assembly
2	O2.2. Component preassembly–A2	6	O6. Flaring
2	O2.3. Component preassembly–A3	7	O7. Adjustment lever assembly–serious checking
3	O3. Piston rod assembly–connecting ring	8	O8. Final assembly–packing

The cycle time was measured with a timer for each operation, with one operator for a batch of 40 pieces.

The data existing in Table 4, which support the actual VSM, are introduced in the agent-based simulation model.

Table 4. Degree of loading per operator.

Work Center	Cycle time (s)	No. of parts (products/day)	Degree of loading per operator (%)	Current no. of operators/shift	Forecast (parts/week)	Forecast (parts/day)
1	19.7	367	25.1	1.00	2750	550
2	6.8	367	8.7	0.33	2750	550
2	8.9	367	11.3	0.33	2750	550
2	25.5	367	32.5	0.33	2750	550
3	42.6	367	54.3	1.00	2750	550
4	70	367	89.2	1.33	2750	550
5	25.5	367	32.5	0.33	2750	550
6	22.5	367	28.7	0.33	2750	550
7	25.5	367	32.5	1.00	2750	550
8	45	367	57.3	1.00	2750	550
	292			7.00		

The first set of charts is used to analyze the existing production process (Value Stream Analysis).

Figure 6a shows the real-time load of the first workstation during the last ten minutes of the first hour. An important difference of cycle times is noticeable between the first three workstations and the last two. Figure 6b shows the evolution of the load for all the workstations, during the first hour. The evolution of the number of processed part (Figure 6c) and of the finished part (Figure 6d) are also simulated, during the first hour.
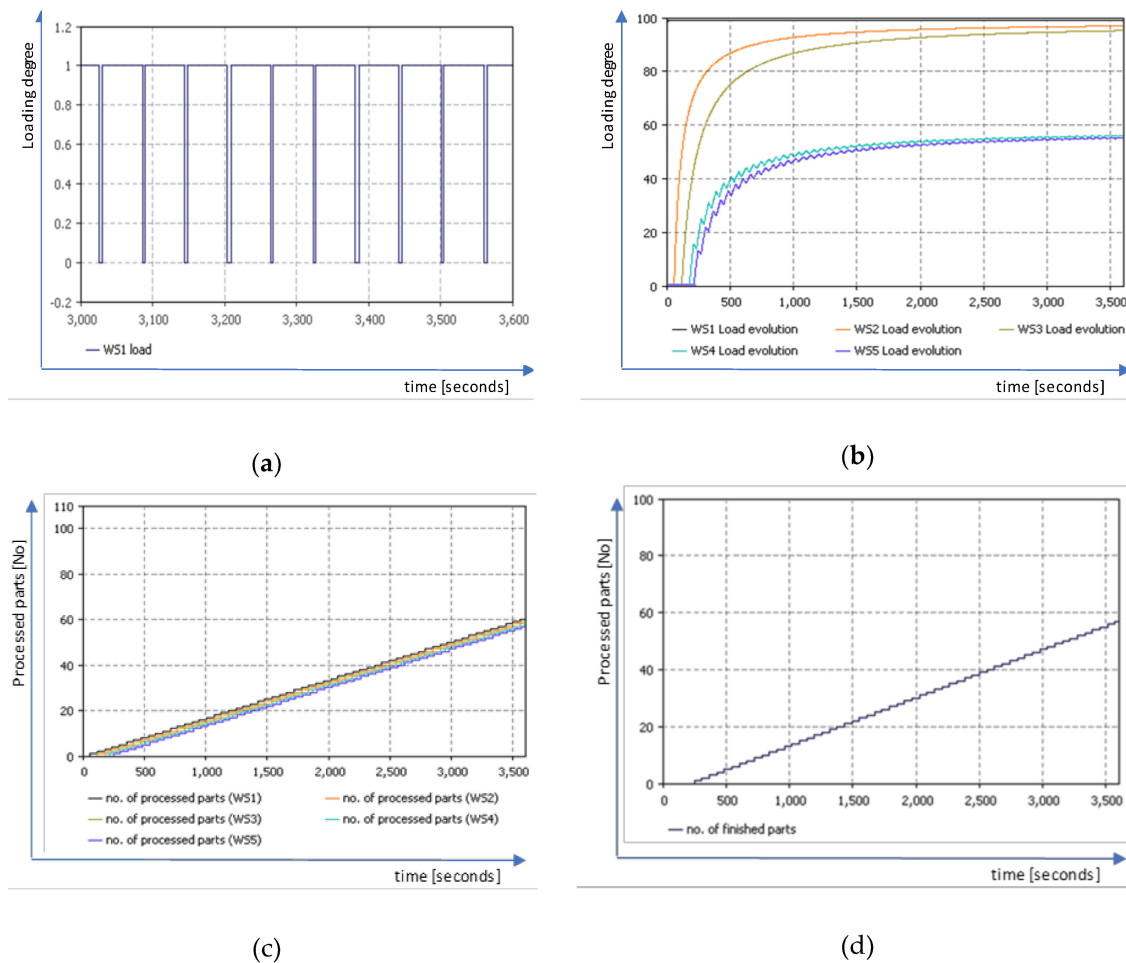
(**a**)

(**b**)

(c)

(d)

Figure 6. Simulation results of current situation: (**a**) Loading degree (per a workstation); (**b**) Loading degree per all the workstations; (**c**) Evolution of the number of processed part; (**d**) Evolution of the finished part.

The second set of charts was used to analyze the final production process with cycle times given by VSM target (presented as Value Stream Design).

Figure 7a shows the real-time load of the first workstation during the last ten minutes of the first hour. Closer values for all cycle times are noticeable. Figure 7b shows the evolution of the load for all the workstations, during the first hour, as well as the evolution of the processed and finished par (Figure 7c,d).
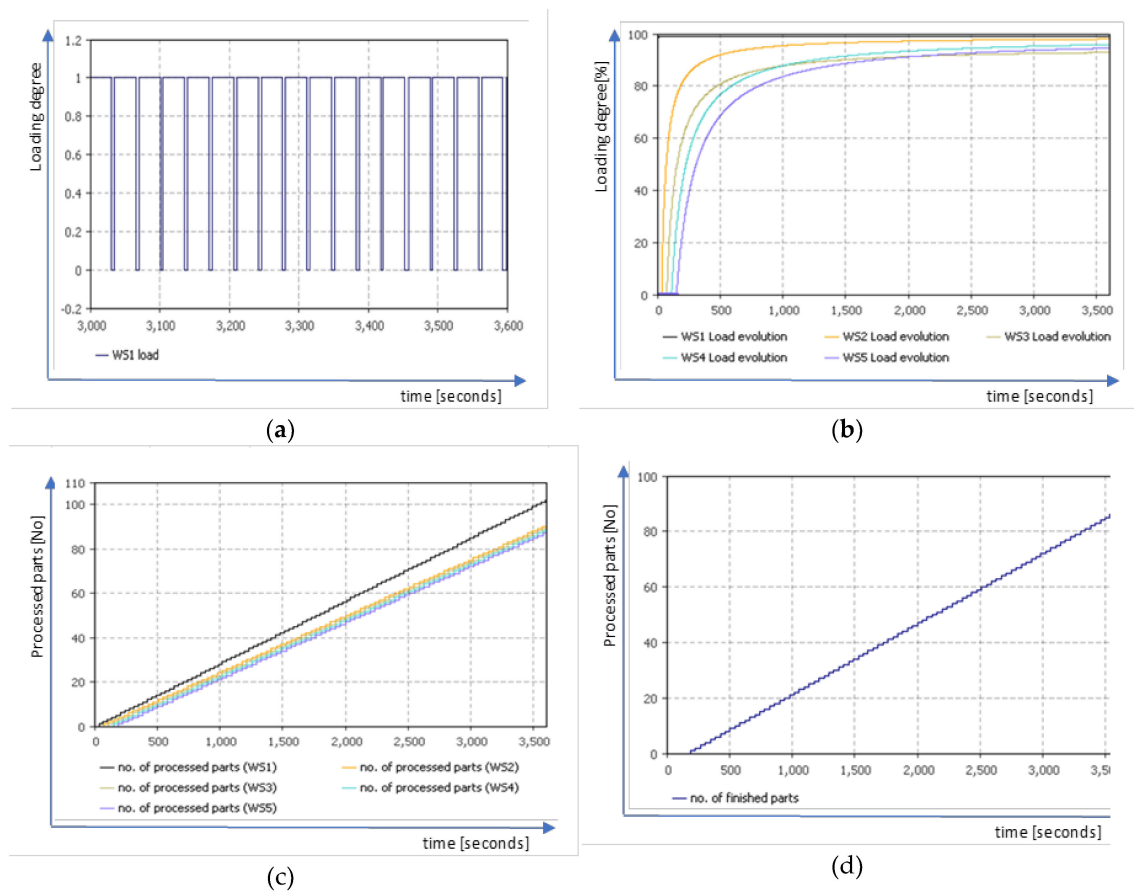
(a)

(b)

(c)

(d)

Figure 7. Simulation results of target situation: (**a**) Loading degree (per workstation); (**b**) Loading degree per all the workstations; (**c**) Evolution of the number of processed parts; (**d**) Evolution of the finished part.

For the VSM target simulation, the following requirements were considered:

- the processing has to consider client's maximal production time, otherwise the results will lead to overproduction or non-compliance according to the customer's requirements;
- production in line with the customer's maximal production time involves balancing workload at all stages of the process;
- the replacement of production in isolated islands with a continuous production flow, or, if not possible, production will be coordinated by pull supermarket systems;
- production planning will only be involved at very few moments in the added value flow;
- different types of products are programmed in equal batches per day for equalizing distribution during basic processes.

5. Discussion

The results obtained using simulated scenarios were depicted in Table 5. Taking into account the specifics of the case study and manual assembly production line, three KPIs were used:

- growth of the PP value indicates the fact that most of direct employees' work is adding value to the process, non-value-added work is reduced to minimum, waste is eliminated;
- VAPP emphasizes the difference between the input value and the output value during production. The output and input values reflect the difference between the final value of the end product and the value of raw materials and services used;
- FSU stands for the increasing of the space efficiency taken up by the production process.

Table 5. Key performance indicators (KPI) for simulated scenario.

KPI	Value before VSM	Value after VSM
PP (%)	61.16	91.66
VAPP (Euro/employees)	203.9	275
FSU (Euro/m^2)	30.6	45.8

The evaluation of the results of simulated scenario, according to the problem presented in the case study, were depicted in Table 5 (according to [61]).

Adopting the chosen solution (validated by the results of simulation) generate an action plan. In the application described above, the actions will be: the presentation of customer demand and modification plan, hiring an operator or displacing an operator from another manufacturing line, training the new operator, settling the operators after the new layout, and beginning production according to the target takt.

From the point of view of the evaluation of agent-based simulation model, the assessment was made after a brainstorming by practitioners, researchers, and external evaluators. The proposed solution led to realistic improvements.

6. Conclusions

A research on adding simulation to VSM reveals the following conclusions:

- putting VSM into practice is studied by manufacturing and other domains such services [62,63], health care, logistics, and transport [64–66]
- a VSM approach in the Industry 4.0 context [3,10,12] implies, besides the development of specific software tools, a "refinement of the necessary data";
- flows represented in a VSM are: the material and the informational flow from a static point of view;
- VSM can be a tool taken from the classic lean approach to the digital lean approach and the lean 4.0 approach. It consists of mapping and analyzing where the process is improved;
- simulation is a complementary tool, allowing both the visualization of the evolution of processes represented by the help of VSM, as well as the workstation position optimization;
- the use of dynamic simulation in process analysis helps to increase the system's response rate to customer demand;
- the exploitation of the benefits of Lean and simulation approaches will be pillars for Industry 4.0 paradigm.

The theoretical model (VSM and agent-based simulation) developed within the present research was applied to a damper product assembly line. The simulation project modules in the AnyLogic environment allow for an easy deployment in any situation in which it is used as a VSM optimization methodology.

The proposed solution is a flexible one, adapted to a small and medium-sized enterprise. The input data is represented by the time frames associated to each modeled agent (current situation and target situation) by filling an Excel table and importing it into AnyLogic.

The other elements that characterize the process are already defined in the design phase of the application. The temporal response of the system (using the AnyLogic multiplier system) focused both on the load rate analysis of each workstation as well as on the comparison between workstations. Following this indicator, along with the tracking of the number of manufactured parts resulted in the development of balancing solutions.

The simulation of the target variant, aimed at increasing the production according to the client's future requirements, allowed the analysis of the systems' reaction and the validation of the proposed solution.

Future research directions will refer to the development of new algorithms that will represent the base for the simulation of the production systems, by including as an input parameter to track

the energy consumed by the workstations (in the automatic workstations case) and people behaviors (in the manual assembly workstation), according to agent-based model facilities. This approach will help even more in taking an efficient decision regarding the optimization of processes [67–70].

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Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

VSM	Value Stream Mapping
KPI	Key performance indicator
PP	People Productivity
VAPP	Value Added Per Person
FSU	Floor Space Utilisation
WS	Workstation
WIP	Work in process

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