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A model-based approach for digitizing human decisions in a production line

Mohamad KAOUK, Lilia GZARA, Jean-Marie FLAUS
Univ. Grenoble Alpes, CNRS, Grenoble INP*, G-SCOP, 38000 Grenoble, France
* Institute of Engineering Univ. Grenoble Alpes

ABSTRACT

In this paper, an approach based on models is presented to help manufacturers in digitizing their production lines. Our solution aims at digitizing human's decision activities as it has several benefits for the productivity and reducing production time inside the factory. The proposed approach starts by constructing a physical model to represent all the components included in the production line. Secondly, an information model that describes the different activities in the production line and the data flow between them is constructed. In the next step, the human activities to be digitized are selected from the information model based on defined criteria. Then each one of this activities is presented with a decision model. The decision model is used to describe the sequence of steps performed by the human to make a decision. Finally, a data model is built from the previous models using UML class diagram. The data model defines the data structure of the system and its relationships. It can be used for the generation of the source code required to replace the human activities on the production line also as an effective tool for the simulation of the production line process. Finally, the applicability of the proposed approach is demonstrated through a case study in order to show how it can be applied to a real production line for the assembly of printed circuit boards.

Keywords: Digitalization, Smart Manufacturing, Industry 4.0, Modelling, UML

INTRODUCTION

Global market competition has placed manufacturing companies under pressure to improve their production systems. Companies should transform their production lines to a highly adaptive and resource efficient system to address the always increasing needs of customers and retain their leading position in the economy. The adoption of digital technologies in the industrial sector has played a key role in helping to develop solutions to cope with these challenges [1]. Recently, the introduction of emerging digital technologies such as the Internet of Thing (IoT) and Cyber-physical Systems (CPS) in the industrial sector has resulted in the fourth industrial revolution known as 'Industry 4.0'. The fourth revolution represents the path taken by industrial companies to transform and optimize their entire value chain through the digitization of their ecosystem [2].

The benefits of digitization are significant. In the manufacturing sector, the technological advances have driven dramatic increases in productivity with lower costs and higher quality. With digital technologies machines are able to predict their failure, configure themselves, and optimize their performance [3]. Furthermore, by enabling the automation of decisions and tasks, production systems can now adapt to changes and conditions dynamically to achieve high efficiency and flexibility in production [4].

However, the digital transformation presents many challenges. The first challenge for many businesses is to know where to start. In fact, the digitalization affects many aspects of organizations, including information technology, strategy and business models, operators, production systems, products and services, and processes. Therefore, it is essential to identify what it should be digitized in the first place. On the other hand, there is a lack of research regarding the way to realize the digitalization. In fact, the literature has explained widely the benefits of introducing the digital world in the industrial sector and its related technologies, however, it doesn't provide methods or solutions to achieve this digitalization.

The key toward a successful digitalization process should begin at the line and plant level. Manufacturers need to rely on more digitized processes and less manual interaction to effectively managing their operations and optimizing their production. Therefore, the first step through the digitalization should begin with the human factor. The reason behind this is that the machine is considered better than human in achieving certain tasks. As an example, machines surpass humans in the ability to [5]:

- respond quickly to control signals
- perform repetitive and routine tasks
- store and manage huge amount of information
- reason deductively, including computational ability

- handle highly complex operations, i.e., to do many different things at once.

In this work, we focus on human activities that require mental effort such as the data proceeding, the decision-making, and the control tasks, and we propose a method for digitizing them. We define the digitalization of human activities as the process of replacing human with computers or software computers that can operate in a better way. However, it should be clear that in this work we are not aiming at fully digitizing the human activities: human remains the most flexible and powerful element to solve and accomplish planned and unplanned problems during the production cycle [6]. On the other hand, there are human tasks are too difficult to be technologically digitized, especially those that depend on the intelligence and cognitive reasoning of the human. Therefore, we have defined several criteria according to which we will choose from the activities to digitize.

In order to understand and design industrial systems, modeling techniques have caught much attention in both the academia and industry. Different models have been used to describe the different aspects of a given system. In the digitalization process, models can play an important role: as the digitalization seems to concentrate on data and its uses, data models can be used to facilitate the process of digitalization. In this context, we present in this paper a methodology based on models to enable the digitalization of some human activities in a production line. Our approach is based on four types of models used to identify the data at the production line level and how it is processed between the different components of the systems.

The advantage of our solution is that it is simple to implement and do not demand a high level of skills or knowledge. It can serve as the first step for different companies that seek to digitize their production line to improve their productivity and reduce production time. The models proposed in our solution helps to understand how the data is managed and processed in the production system which is essential to the digitization process that aims at the first place to explore the benefits of collecting and analyzing data from all machines. The remainder of the paper is organized as follows. The second section enumerates previous work related to the modeling solution in manufacturing. The third section provides a detailed description of the proposed solution and illustrates it with a case study that shows how it can be applied to a real production line. The last section concludes the paper.

BACKGROUND

A detailed inspection in the literature shows that there is no method or solution on how to digitize human actions in production systems that have been proposed by the research community. However, many efforts have been made by researchers and industrialists to develop models that describe the structure and the behavior of production systems.

Petri net models have been used in manufacturing systems for the logical control validation, planning and scheduling activities, and performance analysis [7]. They have been considered as a suitable tool to tackle deadlock problems in automated manufacturing systems. By modelling resources and the control function in the systems, researchers have been able to propose any solution to prevent deadlock problems [8]. Petri Net models are considered sufficient to specify the systems' control view. However, there are not suitable for modelling other aspects of the system like the data and system functions [16].

In another work, researchers have focused on using automata-based methods to model the states of industrial systems [9] [10]. From a planning and control perspective, an industrial production line can be seen as a dynamic system whose states evolve according to the occurrence of abrupt physical events. Therefore, an automata approach is used to model those states and transitions between them. This approach has gained much attention in the field of supervisory and control in the industrial sector and has been used widely in the design and implementation of PLC software. Despite this, automata approaches did not meet wide acceptance, mainly because they are considered as application depended.

Other researchers have attempted to apply agent technology in the design and conception of complex manufacturing systems [11]. In the agent-based modelling approach, an agent represents manufacturing activities or physical resources that have defined tasks and can negotiate with other agents [12] [13]. Each agent can be described in detail from several aspects: goals, attributes, some important behaviours and interaction mechanisms [14]. The agent-based modelling approach has been essentially used in simulating the actions and interactions of autonomous agents to study their behaviour and their effects on the system as a whole [15].

In other approaches, researchers have developed solutions to model industrial systems using the UML languages. For example, the authors in [16] have presented an extension of the UML activity diagram to model the activities involved in production systems using workflow concepts. In another work [17], the authors have used different UML diagrams to represent the different aspects of embedded industrial systems such as the functional aspects of the system, the relations among the objects that constitute the system and their interactions, and the dynamic behaviour of the system components.

Recently, the SysML modelling language has caught important attention by researchers and industrialists. SysML is an extension of the UML language. It is a graphical language for building models of large-scale, complex, and multi-disciplinary systems. The advantage of using SysML is that it shows a great promise for creating object-oriented models of systems that incorporate not only software, but also people, material, and other physical resources, expressing both structure and behaviour for such systems

[18]. Thus, it is considered more suitable for the industrial sector and has been used widely to model production and cyber-physical systems in the manufacturing sector [19].

Finally, other researchers have worked on modelling the human behaviour in the manufacturing field. As an example, the authors in [20] have proposed a novel software agent model to replace the partial decision-making function of a human. The developed model is able to provide the human reasoning capabilities to generate decisions related to the production. They demonstrated the applicability of their solution in the context of the error detection and recovery in an automated manufacturing environment.

Modelling techniques can provide greater possibilities and use cases. In our work, we rely on modelling solutions to propose a method for the digitalization of human decisions in a production line. In the next section, we describe our choices of models and their usage in order to digitize the human decisions at the production line level.

PROPOSED WORK

Our solution differs from previously proposed solutions is that it focuses on representing the data in a production line from different perspectives (data flow, data processing by human, storage...) using different types of models. For this purpose, our solution consists of four steps as shown in Figure 1. It starts by constructing a physical model to represent all the components in the production line. From the physical model, we can identify all activities in the production line. Then, we present these activities and the data flow between them using an information model. In the third step, the human activities to be digitized are selected from the information model based on certain criteria. Each of the selected activities is represented then by a decision model that describes the sequence of steps performed by the human to elaborate a decision using data as input. Finally, a UML class diagram describing the data structure in the system is built from previous models. In this section, we explain every model, and we show how they can be constructed through a case study.

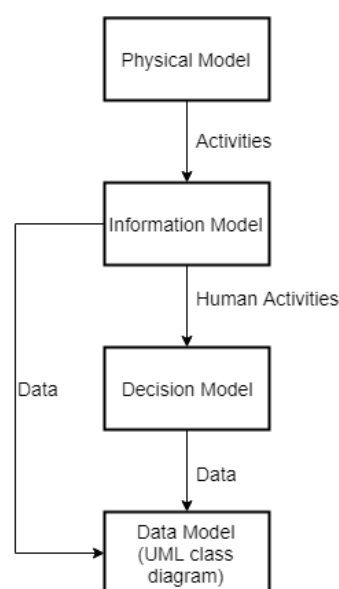


Figure 1: Proposed solution steps

Study case: Printed circuit board assembly line

Surface-mount technology (SMT) is a method for producing electronic circuits in which the components are mounted or placed directly onto the surface of printed circuit boards (PCBs). The SMT process starts with the screen printing process which applies solder paste using a stencil and squeegees to the appropriate pads on the PCB. Then the PCB pass through the solder paste inspection machine to check the

solder paste deposit. Once the printed PCB has been confirmed to have the correct amount of solder paste, it moves into the next part of the manufacturing process which is the component placement. Each component is picked from its packaging using either a vacuum or gripper nozzle and placed in the programmed location on the PCB at high speed. Once all component placements have been placed on the PCB, it will move to the reflow oven machine where all the electrical solder connections are formed between the components and PCB by heating the assembly to a sufficient temperature. Finally, the PCB passes through the Automated Optical Inspection (AOI) machine to check the placement of components.

Physical Model

The first step in our proposed solution is to construct the physical. The physical model describes the machines involved in the manufacturing process, the role of different actors in the production process and their interaction with machines, and finally the physical flow between the different steps of the manufacturing process. We can identify four types of components in the physical model:

- The actor: An actor is anything that interacts with the production line. The actor can be either an operator or an information system.
- The machine: A machine represents a process that production activities.
- The Informational flow: the path taken by the data or the functional flow.
- The physical flow: the path taken by materials and products between the production machines.

Figure 2 shows the physical model of the PCB assembly line.

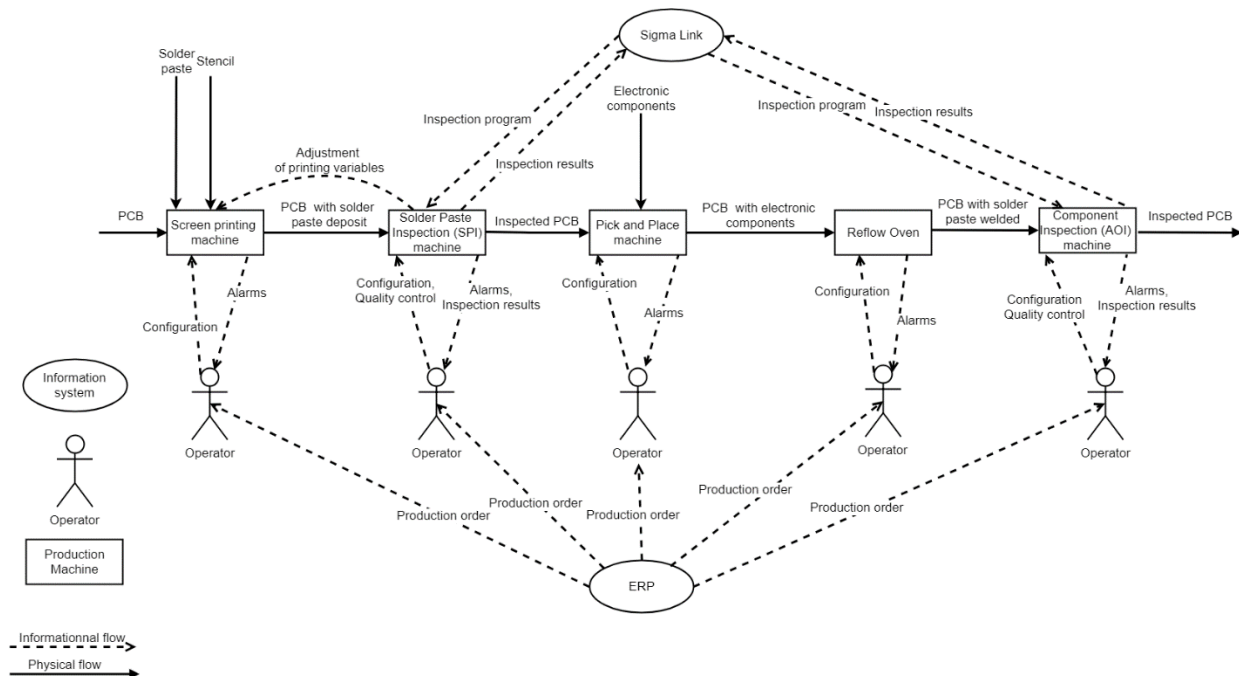


Figure 2: The Physical model

Information flow model

The information flow model indicates how data flows between the different entities in the production line using visual symbols. The physical constructed at the first place is used to identify all activities in the production line and the flow of information between them to build the information flow model. An activity represents a resource that processes data to accomplish a well-defined task related to the process of production. It uses data that they can be received or requested. Figure 3 shows the generic information flow model. In this model, we represent all the activities in the production line that take specific data as input, process them to perform a production-related activity, and output other data. The data generated by one activity is sent to another activity or is stored locally. We can find three types of activities in the information flow model:

- The human activity => H
- The activity of a machine => M
- The activity of a software/Information system => S

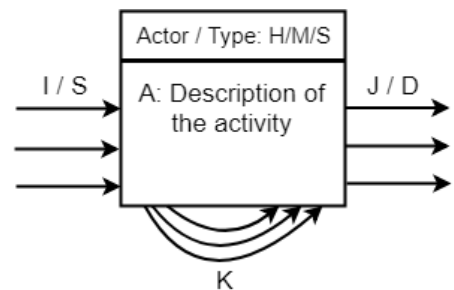


Figure 3: Generic information flow model

An activity is represented by a rectangle divided into two parts.

The first indicates the resource who performs the activity and its type (human: H, machine: M or software: S) while the second indicates the description of the activity. On the other hand, the information exchanged or generated by the activities are represented as labels on the arrows. In our diagram, we can find 3 types of information: I, J and K:

- I/S: Input of an activity. I : represents the information coming from the source S
- J/D: Output of an activity. J: represents the information generated by an activity and sent to the destination D
- K: represents the information generated during the activity and stored locally in the resource.

Figure 4 shows the information flow model for three activities from the production line. The first activity represents the process of configuration of the SPI machine executed by an operator. The operator generates the correspondent parameters from the information he receives from the EPR system and sends it to the SPI machine. He also generates the values of tolerance and send them to the SPI machine and the other operator. The second activity is carried out by the SPI machine to measure the deposit of solder paste and outputs the correspondent results. While the third activity is the quality control of solder deposit done by an operator who has to decide whether a board is acceptable or not when a default is detected by

the SPI based on the inspection results and the tolerance values that he receives from the SPI machine and the first operator respectively.

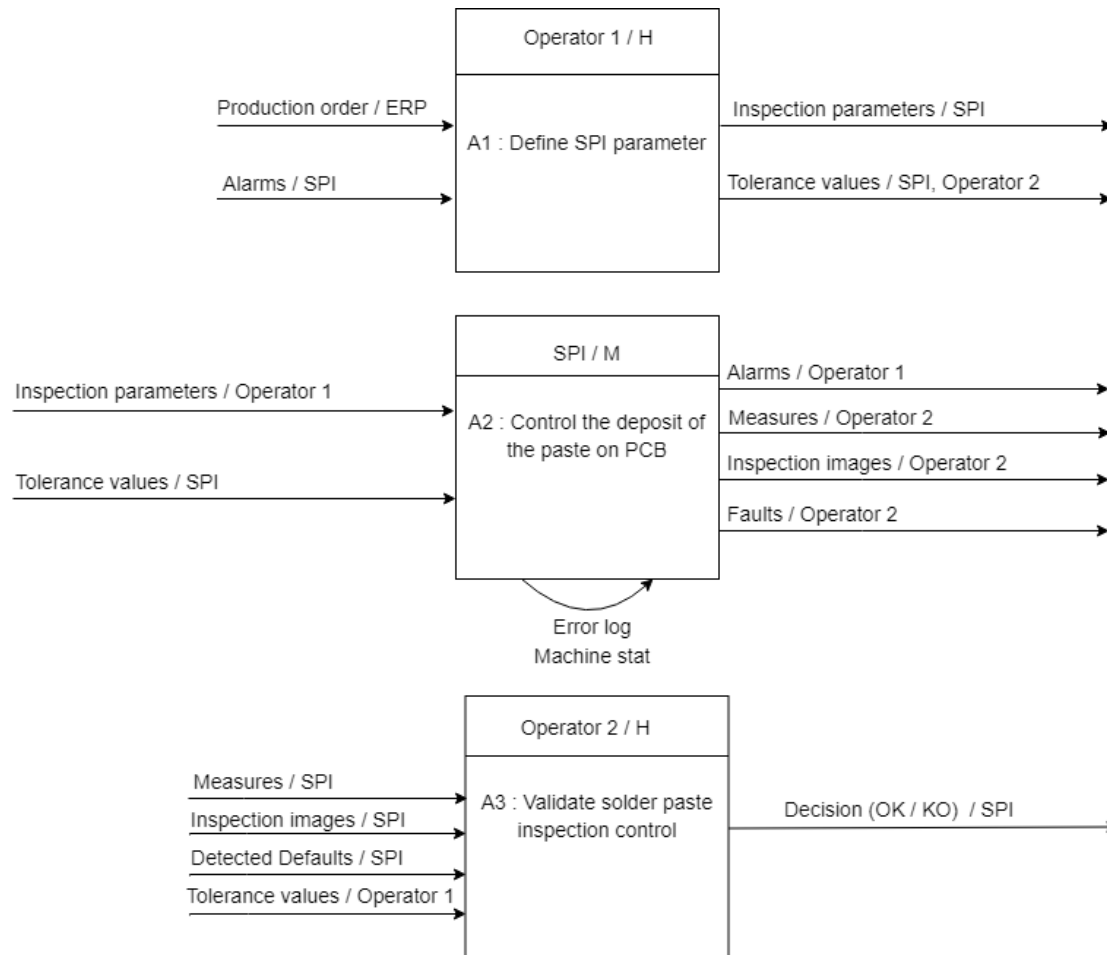


Figure 4: The information model

Decision model

After identifying all activities in the information flow model, the next step consists of selecting the human activities to be digitized. In our approach we consider digitizing the following human activities:

- The repetitive and routine tasks
- The tasks that are considered expensive in term of resources consuming (time, workers...) and can be digitized

The selected activity is then represented by a decision model used to represent the reasoning followed by a human to make a decision related to the production. It represents the logic of an algorithm that takes a number of variables as input and generates one or more decisions as output. The Decision model proposed in our solution is represented by the UML Activity diagram where we supposed that the decision node in the diagram can have multiple paths branching.

Figure 5 shows the decision model for the activity “validate solder paste inspection control” executed by the operator 2. The decision model illustrated describes the activities executed by the operator to decide whether a circuit is acceptable or not when a default with the solder paste deposit is detected. First, the operator reads the input data, then he identifies the default from the input variable ‘defaults’. Then he searches in the input attributes the measured value corresponding to the default and the theoretical value. In the next step, he compares the difference value to the value of the tolerance. Based on the comparison, he decides whether the board passes to the next step of production or not.

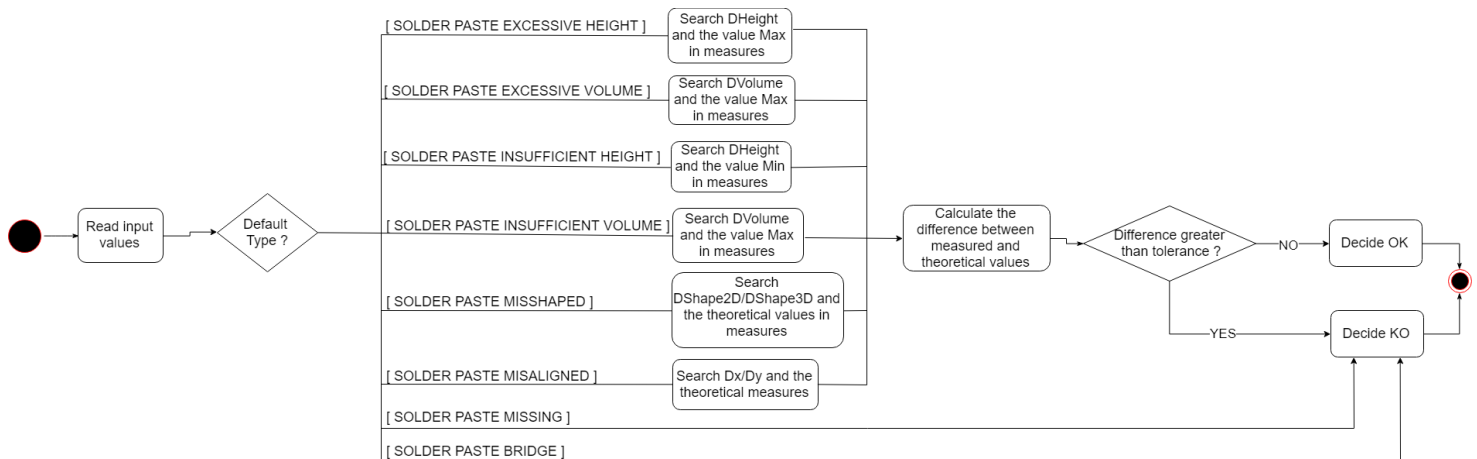


Figure 5: The decision model

Data Model (UML class diagram)

The last step of our solution consists of building a data model using a UML diagram class. The information needed to construct this model is extracted from the previously developed models. The class diagram represents all the data identified in the previous models and describes the relationships between them. As it is based on UML modeling language. The class diagram allows the system to be simulated and has automatic code generation capabilities. This will simplify the generation of required source code to replace human actions with digitized actions in the production line. Figure 6 shows the class model generated from the previously developed models.

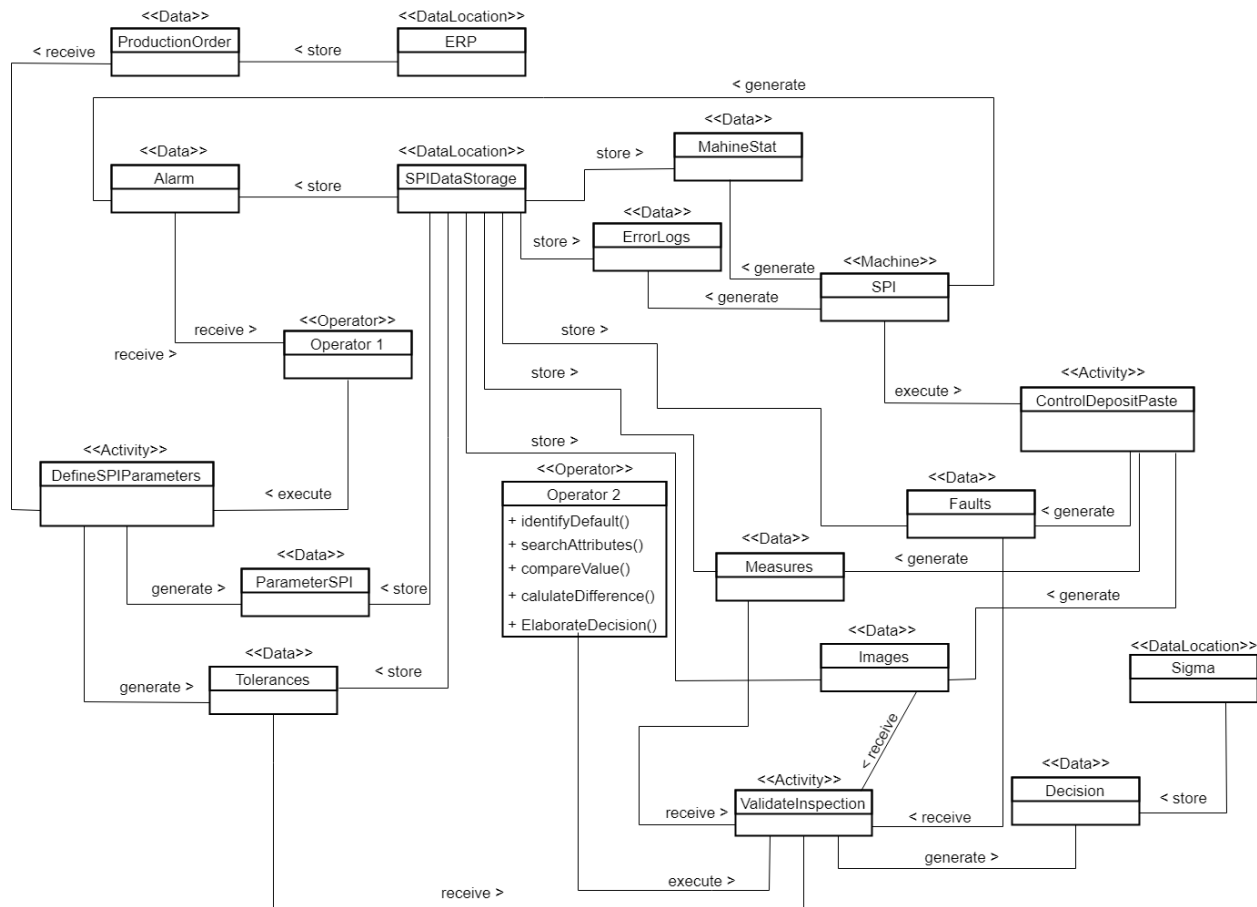


Figure 6: The data model

CONCLUSION

Today manufacturers have the ability to enhance their system's capabilities by digitizing their industrial assets. This will result in greater insight into their operations and increased agility at a lower cost to stay competitive in the market and ensure their success in the future. This paper explains a starting point for a systematic approach to tackle digital transformation at the production line level. The method aims at digitizing the human decision activities in a production line. The choice for the activities to be digitized was based on two criteria: the repetitive activities and those that are considered expensive in terms of resources consuming (time, workers...) and can be technologically digitized. Our solution describes four main models. The first one is the physical model used to identify the physical process and its components. Based on the physical model, the information flow model that represents all the activities in the production line and the data flow between can be constructed. Then the human activities are represented by a decision model that describes the human reasoning to make a decision. Based on these models, the data model is generated and represented as a UML class diagram. The data model represents the structure

of the data in the system and will be used in the generation of the source code that is required to replace the human factor in the production line. Finally, we have demonstrated the applicability of our solution by showing how our modeling methodology can be applied to a printed circuit board assembly line.

FUTURE WORK

Although this paper covers just the analysis phase, in the future, we intend to implement the class diagram (data model) by generating its corresponding source code in Java. Then using simulation, we can demonstrate the effectiveness of our solution by comparing the production time before and after digitalization. In addition, we would like to extend our solution for the digitalization of a production line with a complete architecture for an information system that will be developed to carry out the integration of digitalization inside the whole factory.

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