Cycle Time Analyses of Plants by Automated Modeling Techniques and DEVS

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Abstract

Planning, implementation and operation of plants are very costly and time-consuming processes. Due to parallel material movements, various possible combinations of the plant building blocks and because each plant is designed as a complete, customized system, the complexity of the plants can be enormous. For these reasons, a tool based on discrete event simulation has been developed, which allows the producer of the plants to model, emulate, simulate and animate the plant processes. This allows the system experts to make exact forecasts of the attainable cycle time. In this paper we describe the development of this automated modeling and simulation tool, regarding system architecture, processing of control system orders and task handling in the simulation environment. Finally, based on the findings of the realization and validation of the tool, this paper discusses the opportunities arising from this approach as well as its future potential.

1 Introduction

Cut-to-size plants with sorting and stacking solutions are very complex systems. Some of the characteristic problems are parallel material movement, buffer-areas and a large number of simultaneous activities. On cut-to-size plants several kinds of panels can be processed. The main cut-to-size processes are cutting, sorting and stacking. These processes are executed on machines like cut-to-size saws, sorting carriages, stacking devices, roller tracks, etc. In combination with their control unit, these machines are specified as self-contained plant units.

The acquisition, planning, implementation and operation of cut-to-size plants impose special challenges. Some of these can be traced back to the fact that a sales process usually takes place before the initiation of planning and implementation, since cut-to-size plants are built according to customer specifications (make-to-order strategy). Plant businesses show a high level of specialization of its product range and services [16]. In case of cut-to-size plants, performance is usually measured by cycle times. Besides that, there exist substantial information and knowledge asymmetries between suppliers and customers [16]. As the latter is not capable of evaluating the whole complexity of a plant, he needs to put a lot of confidence into the provider's projections concerning the performance and benefits of the plant.

An essential sales instrument of cut-to-size plants is the reputation of the provider company. Apart from this, reference plants are used to prove the technical feasibility and efficiency of the plants to the customers [18]. This is one of the reasons why the marketing of plants is a very complex organizational process which contains a considerable amount of risk for both parties. The supplier usually faces substantial sunk costs if the customer decides not to purchase the plant upon a rather extensive projection process. In order to reduce supplier-side risks, this paper describes a simulation-based approach to support the process from retail to operation and to make the distribution of cut-to-size plants more efficient. This planning instrument makes it possible for system experts to model, animate, simulate and emulate the cut-to-size processes without a need for any deeper simulation or emulation knowledge.

2 Theoretical Principles and Literature Review

Before providing details about the simulation approach for sales and projection processes, the following section will introduce some basic theoretical principles of simulation and emulation techniques. Based on that we will provide a review of the relevant literature within the field of discrete event simulation for decision support in industrial processes.

As it will be discussed below, simulation techniques are likely to provide a wide range of analytical possibilities for planning and evaluating industrial processes. In the context of this paper, a future manufacturing process as designed in the sales phase can be considered as one specific industrial process.

In the literature, a variety of concepts and applications exist which are concerned with the application of discrete event simulation in Supply Chain Management (SCM). The application scenarios for this decision-supporting method are widespread in this case. They include to a large extent the general optimization tasks which are to be performed by SCM [2]. The target variables of simulation studies concentrate mainly on a reduction of cost, the optimization of material and information flows, the reduction of processing and lead times, or a consequent process-related orientation of the company [4]. A recent study analyzes over 80 articles which describe an application of Supply Chain Simulation either in an industrial pilot project, commercially available software, or a simulation test within a logistics chain [20]. This study shows that only 11 papers are concerned with manufacturing processes of which the vast majority aims at integrating the manufacturing process into the overall supply chain or scheduling of production lots. Only four papers describe scenarios for applying simulation for planning manufacturing layouts: Olhager and Persson describe the successful application of simulation for redesigning manufacturing plants in the electronics industry [15]. The other three articles are related to the simulation software package Supply Chain Builder (SCB) of Simulation Dynamics Inc. (SDI). The first approaches of SDI concentrated primarily on the intra-organizational optimization of value chains. The Plant Builder, for example, is focused on the simulation of internal value chain activities [19]. As an extension, the in-plant distribution as well as the supply chain on the distribution side is included in the simulation.

Besides that, a number of articles report simulation studies in order to find optimal layouts for flexible manufacturing facilities [1, 3, 7, 33] or cellular manufacturing layouts [9, 14]. These approaches mostly aim at the (near) optimal solution of a specific problem rather than evaluating a multidimensional scenario like the assessment of feasibility for a future manufacturing plant projection.

By contrast, the starting point for optimizing the sales process is the definition of critical performance indicators (e.g. certain lead or cycle times) which have to be realizable by a projected facility or plant. Subsequently, the main issue is to identify admissible and feasible plant configurations which optimize these performance variables. As this paper will show, discrete event simulation can very efficiently support this task.

Emulation is the virtual reproduction of certain aspects of hardware or software systems (external system) on another system (host system) [13]. Therefore emulation can be seen as a special case of simulation, supplemented with the coupling of real functional components. For emulation of cut-to-size plants, job data is generated within a "virtual plant" and processed by the simulation tool.

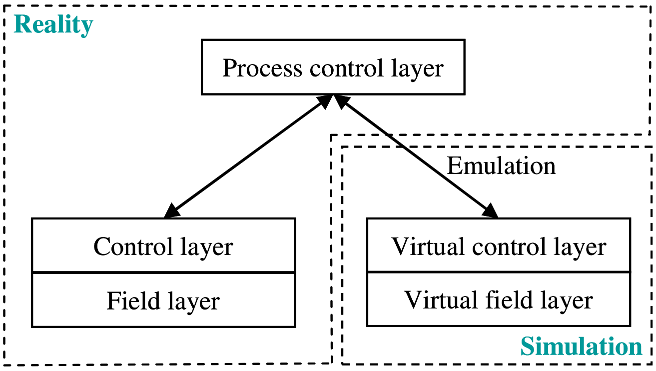


Figure 1: Central, hierarchical control systems

Classical plants are centrally and hierarchically controlled real time systems (see figure 1) [8]. On a real system the *field layer*, which constitutes the lowest level, represents all mechanical components with their actuators and sensors and controls the material handling. The *control layer* resides above the process level. On this layer, sensor data is processed and control signals for the actuators are generated. This level represents the basis for an automated, unit based plant. Moreover, it coordinates the handover of load data and controls the material flow of the plant units. The *process control layer* is the highest layer in the control pyramid and is usually called *plant server*. The *control layer* and the *process control layer* are connected by means of a communication channel, which passes on the scheduled orders to the *control layer* and receives confirmation when all actions have been processed.

The plant logic of the real time system as described above is mapped to a model within the virtual plant: The *virtual field layer* of the emulated system visualizes all mechanical components and displays the kinematic movement of the material handling in a virtual view. The *virtual control layer* prepares all orders from the *process control layer* and controls each virtual plant unit. Since there is a tight coupling between real time and simulation systems this system can be viewed as an emulation system [12].

3 General Design Principles

The following chapter provides a general overview of the system architecture for our simulation-based decision support approach. Also, the modeling process and the clear separation of virtual control layer and virtual field layer are discussed. Furthermore, our task handling method for event lists will be described.

The application platform of our simulation based decision support system provides simulation libraries with generic modeling functions, which can be used to implement domain-specific modeling environments. A number of domain-specific modeling methods and applications, such as planning of transportation networks or warehousing structures, have already been implemented upon this platform [5]. As one part of the described platform, specific methods for cut-to-size plants were implemented. The main intention has been to enable domain experts (i.e. technical sales personnel) to define alternative projected plant configurations within the virtual system and to evaluate them according to the predefined critical performance indicators in order to identify an optimal solution. By using a domain-specific modeling environment with an underlying simulation model built-in, the domain expert can take advantage of emulation techniques without need of simulation expertise. Therefore, the software architecture of the decision support system for cut-to-size-plants is arranged in two levels (see figure 2).

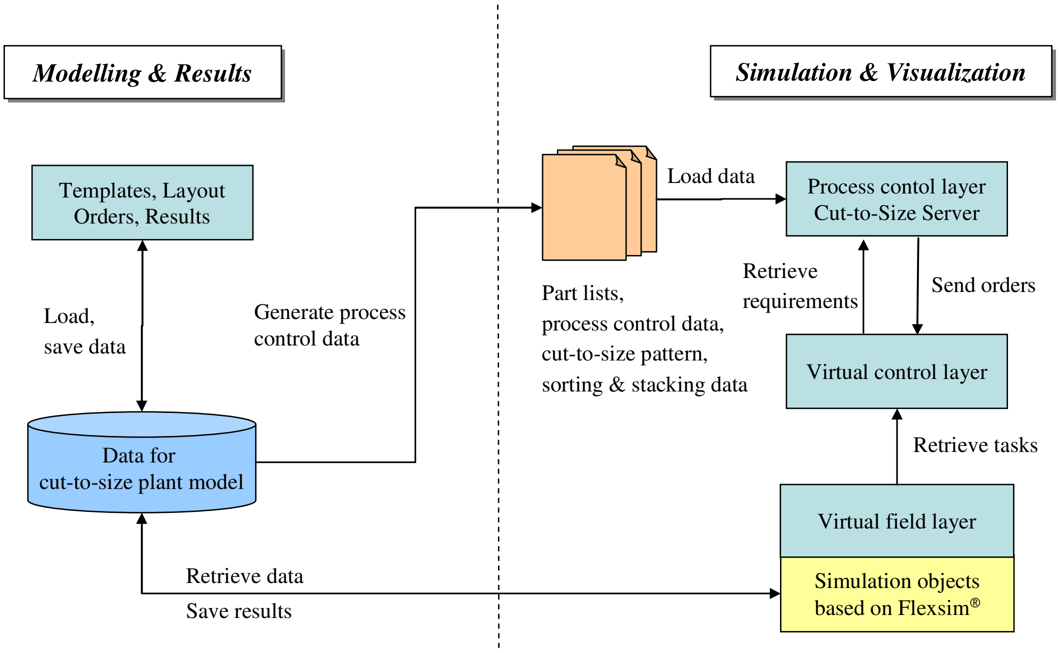


Figure 2: Software architecture for decision support system

The *Modeling and Results Level* is used for the development of unit-based models [21] in which a plant is designed as a collection of plant units. The modeled plant is persisted and process control data for the cut-to-size server is generated automatically. Depending on this process control data, bills of materials, batch sizes, optimized cut-to-size patterns, sorting and stacking patterns for panels are then computed. The computation results represent the planning data used as a basis to generate the orders for the virtual plant. Furthermore, the simulation run and the visualization of the material flow are triggered at this level. Out of the orders, which are broadcasted by the cut-to-size server, *task sequences* are created (see figure 3). A single task describes an activity that imitates the physical mechanism which is executed on the simulation object.

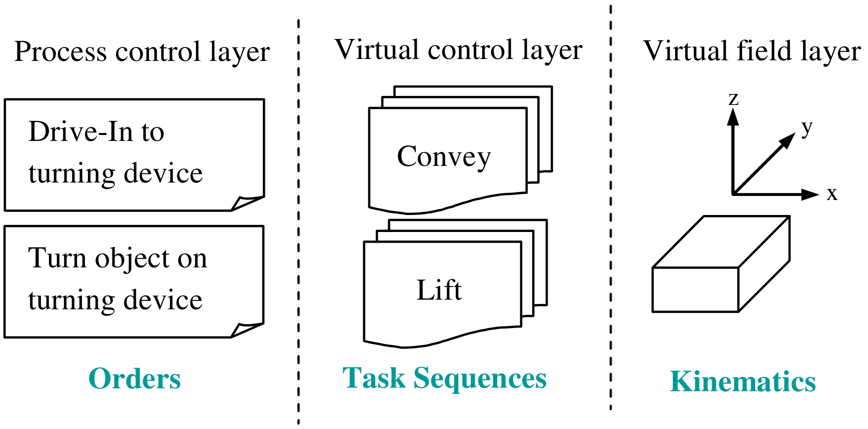


Figure 3: Order handling

The *Simulation and Visualization Level* represents the virtual system, which is controlled. It is based on the simulation engine Flexsim$^{©}$. Depending on the model data and associated meta-information, the simulation model is created automatically. After the initialization and start of the emulation model, the *virtual field layer* receives the *task sequences*, which are created on the *virtual control layer* and transforms them into discrete events. According to these tasks, kinematic flows are created (see figure 3) and run time information is logged simultaneously.

Our approach to model large-scale plant systems is based on three complementary services (see figure 4).

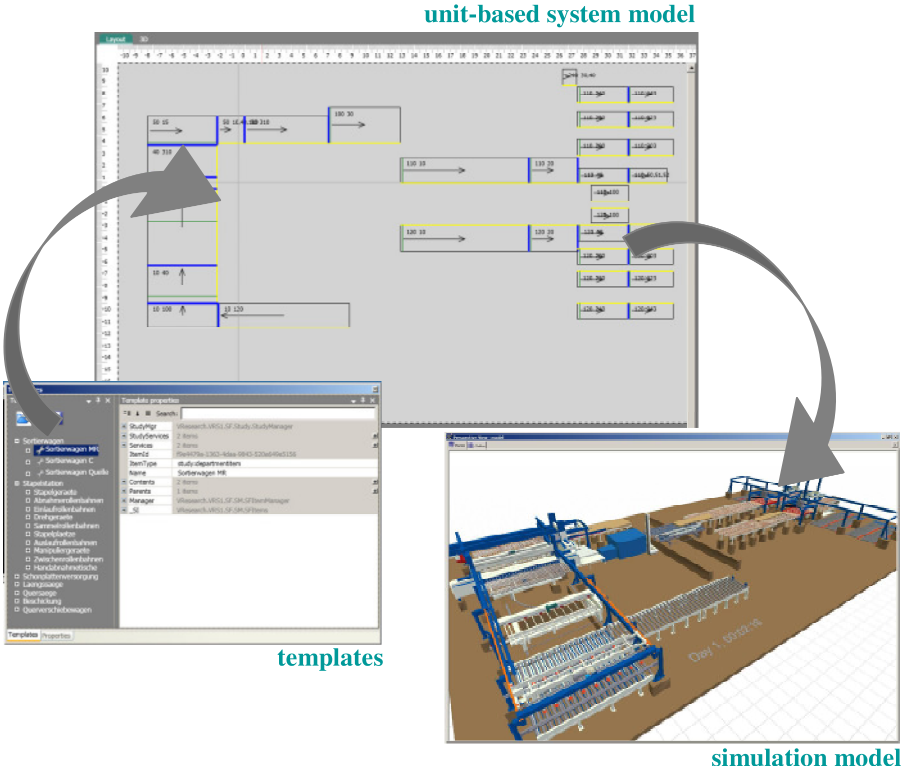


Figure 4: Simulation services

A *plant unit template* represents a self-contained plant unit, which consists of a set of devices. The collection of devices can be viewed with *the template designer*. A device is specified by attributes which describe process- and mechanical information, velocities and meta-information for the instantiation of each class type used in the *virtual field layer* and the *virtual control layer*. They cannot be broken down further.

The *graphical editor* uses the previously described *plant unit templates* and allows the user to instantiate the plant units using drag-and-drop and to couple the material flows using a snap function. Once the model is specified as a *unit-based system model* it needs to be transformed into a simulation model. Therefore, the *unit-based system model* is persisted as a well-formed XML document. The transformation process to build a *simulation model* is automated and consists of three parts: The instantiation of the *virtual control layer* the creation of all simulation objects and the assignment of values to all public properties.

The object-oriented hierarchical simulation model of the plant is based on the functional decomposition approach. The simulation includes the modeled units of the real plant and each unit of a production set is uniquely identifiable and traced during its lifecycle. The model is created according to the modeling process described in the previous section.

After starting the emulation the event list will be served through plant units of the *virtual control layer*. When the *process control layer* sends orders to designated plant units of the *virtual control layer*, all activities are registered as tasks and are stored in the event list in the correct order. The instruction set consists of 22 commands of three types: basic commands, motion commands and item operations.

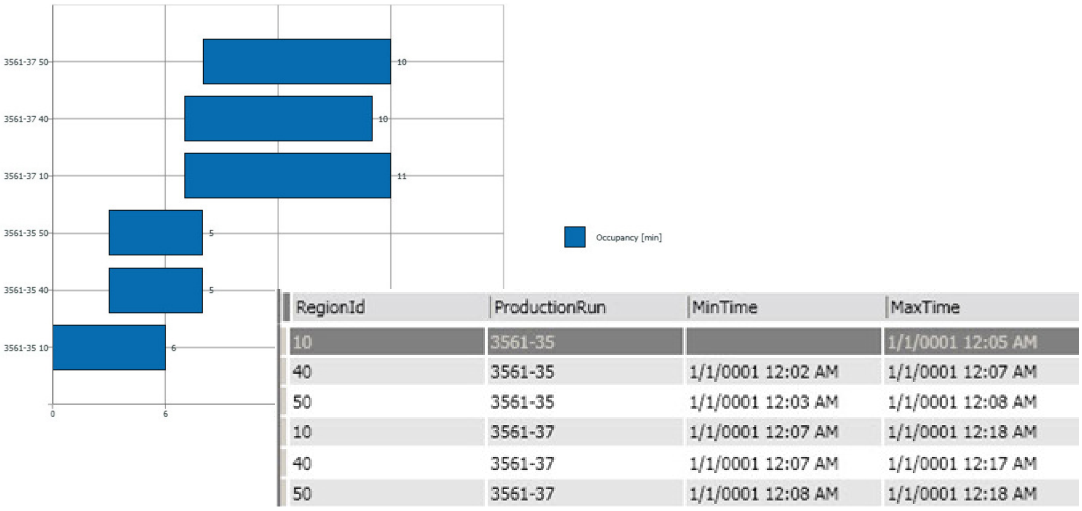
Basic commands are generally used by the model to handle items. Motion commands describe the kinematic behavior of a plant unit or device. Item operations relate to a panel, respectively parts of a panel.

The implementation of a *blocking rendezvous* pattern [6] for handling the event list makes it possible to have a simulation model in which the behavior is independent of simulation speed. If the *virtual field layer* confirms the execution of a task sequence, the confirmation call is blocked until the *process control layer* has sent new orders to the destination *plant units*. The elapsed time up to the confirmation call is skipped and will not be counted towards simulation time. This is because in real-time, the system which is controlled, has no time delay between order confirmation and receipt of orders. Consequently, the connection between the simulation model and the *process control layer* allows logging of system states and measurement of the performance of the emulated system's cycle time.

While running the simulation or emulation model, results are written to an Oracle© database which afterwards can be viewed and analyzed by the user through the application platform. On the *virtual field layer* of the simulation system, two kinds of information are logged:

- The information whether a device is *busy*: The status of a device is *busy* if it is moving in some direction (turning, opening, closing, etc.).
- The information whether a plant unit is *occupied*: The status of a plant unit is *occupied* if a flow object is located on it.

With these recorded information several sorts of result analysis can be carried out. These results are shown in tables and charts. The user has the possibility to group the displayed information by devices, plant units or regions of the plant units. Additionally it is possible to compare several simulation or emulation runs. With these options the user is able to analyze throughput rates and cycle times (see figure 5) as well as utilization of plant units and devices of the cut-to-size plants.



RegionId	ProductionRun	MinTime	MaxTime
10	3561-35		1/1/0001 12:05 AM
40	3561-35	1/1/0001 12:02 AM	1/1/0001 12:07 AM
50	3561-35	1/1/0001 12:03 AM	1/1/0001 12:08 AM
10	3561-37	1/1/0001 12:07 AM	1/1/0001 12:18 AM
40	3561-37	1/1/0001 12:07 AM	1/1/0001 12:17 AM
50	3561-37	1/1/0001 12:08 AM	1/1/0001 12:18 AM

Figure 5: Analysis of cycle time of simulation runs

4 Model Validation

For the verification and validation of emulation models, special aspects have to be taken into account [17]:

- an enormous exchange of data based on orders has to be established in an adequate way between the real process control layer and the simulation model,
- if the simulation model is particularly developed for the emulation, the model cannot be tested autonomously,
- there are interactions with the development of the real control system.

For these reasons the verification and validation of the described emulation model is realized on two different levels: the validation of the plant server communication and the validation of the model execution. The applied techniques are described in the following chapter.

The main challenge with the implementation of an emulation model lies in the establishment of an adequate communication between the process control layer and the virtual control layer. In the realized system, the broadcasted orders from this layer are transformed into task sequences, containing several single tasks that can be executed on the virtual control layer (see figure 3).

The most important requirements are the correct order sequence and the order confirmation at the right time. Depending on the order confirmation, new orders are triggered for processing next task sequences. The implementation of a blocking rendezvous pattern ensures that these rules are adhered to.

To be able to validate the correct order sequence, a Fixed Value Test will be applied to verify the deterministic model properties [17]. The emulated system's cycle time, for example, will be measured independent of simulation speed.

The emulation model cannot be executed autonomously which makes the validation process even more complex and time-consuming. In the verification and validation process of the model execution several validation techniques [17] were applied like described below.

First of all, *animation* of material flows and cut-to-size processes in 3D was used to verify the behavior of the plant. In the current application the visualization of the plant processes plays an important role, due to the fact that the decision support system will be applied as acquisition tool to demonstrate virtual cut-to-size plants to future customer. For this reason, extensive effort was taken to visualize plant units and the contained devices with graphical data files (.vrml) which were generated directly out of the CAD-System of the manufacturer. Nonetheless, when using animation for model validation, it has to be considered, that it cannot guarantee a valid or debugged model [11]. Still it can be used to demonstrate non valid situations [10] and especially helps system experts to more easily understand the simulated processes and associate them with the processes of real cut-to-size plants. Based on the animation of the processes, *structured walkthroughs* were carried out with participation of the simulation experts who implemented the model and system experts who have detailed knowledge of cut-to-size processes. The purpose of this procedure was to go through the execution of tasks of each single plant unit and identify mistakes, irregularities and problems within these processes. During these walkthroughts the experts were supported with *operational graphics* in form of displayed transportation speeds and cycle times (e.g. saw cycle, feed cycle, etc.). Related to the presentation of these performance indicators at a certain point of time, is the observation of values in the course of time which can be done within the result analysis of the simulation runs (see figure 5).

Currently, effort is put in the validation of emulated cut-to-size plants in direct comparison to real plants. The foundations for such *historical data validation* can be fulfilled as cut-to-size runs on real system can be logged. Also the modeling of these real cut-to-size plants into a corresponding emulation model can be realized in an easy way. Still there are some requirements in the preparation of the logged data, which allows a direct comparision of real and virtual plants.

5 Results and Findings

The implemented simulation and emulation tool provides the experts with relevant information, models and methods for the acquisition, the planning as well as the operation of cut-to-size plants. The tool facilitates the anticipation of the behavior of real plants on a virtual system and allows plant experts to model, simulate, emulate and animate sequences of cut-to-size plants without being experts in simulation or emulation.

When building up an emulation model, plant units like sawing, sorting or stacking machines are put into a model and linked together according to the modeling process described in the previous chapters. By running the emulation job, data of the virtual machines are generated on the host system, processed in the emulation model and results are written to the database. Subsequently the analysis of cycle times, throughput and utilization of the plant units can be realized by the means of tables and charts. The application of the decision support instrument brings various advantages in several phases of the selling and realization of cut-to-size plants.

First of all, by using the decision support tool in the acquisition process vendors of cut-to-size plants can more easily demonstrate the plant concepts, which will help the customer to understand the facts. Especially the animation of material flow helps the user to get a clearer idea of the processes on cut-to-size plants. The possibility of calculating exact cycle times, throughput rates and utilizations of machines improves the accuracy of prediction of performance specifications. Therefore technical expertise, steadiness and reliability can be demonstrated through virtual plants. With this approach costs and time can be saved in the acquisition process. Apart from this, the tool supports the system experts in the plant planning process, in validation of control strategies and in the analysis of bottlenecks in the material flow. The comparison of several simulation scenarios is also possible and allows the system experts to constantly optimize the hardware and software. During implementation of the plant the tool can serve as training instrument to get familiar with the control system and plant processes. While operating the plant it is possible to perform impact analysis of modifications of the virtual as well as the real system. This allows an efficient analysis and resolution of errors without disrupting the normal course of business. With the realization of the described decision support tool a planning instrument could be developed which makes it possible to reduce acquisition and startup times for cut-to-size plants and continuously test and optimize the processes.

Currently the operational use of the implemented simulation-based decision support instrument is being initiated in one company. The concerned specialist for cut-to-size plants was directly involved in the realization process of the simulation and emulation systems.

Additional activities in the further development and extension of the emulation tool are planned in course of this year. Currently the machine units can only be tested separately and not as a combined plant system. The idea is to create a complex system where a combination of reality and simulation (see figure 1) can be achieved. This would mean that real units of the plant could be tested within the whole virtual system. This approach will help the plant experts to be able to find failures on machines or in the material flow much earlier as without the decision support tool.

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