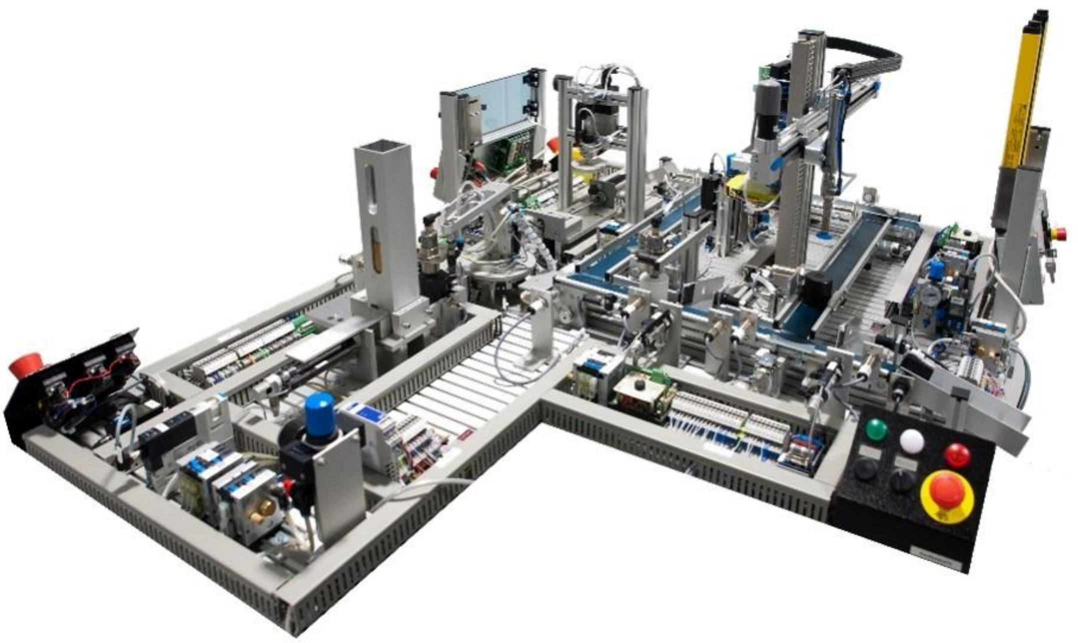
Technical Report

Researching Evolution in Industrial Plant Automation

Scenarios and Documentation of the extended Pick and Place Unit

Birgit Vogel-Heuser, Safa Bougouffa, Michael Sollfrank



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1 Introduction

The extended Pick and Place Unit (xPPU) has been established for a case study to investigate research on the evolution in plant and machine automation. The previous version of the PPU is limited in size and complexity [1]. However, its functionality has been extended together with additional structure. Different evolution scenarios are provided to demonstrate various change reasons, e.g. changing requirements, fixing of failures, and unanticipated situations on site.
The models included in this technical report are based on the ANSI/ISA S-88[1] standard of batch process control, published by the International Society of Automation, and the OMAC State Machine, part of the Packaging Modelling Language (Pack ML) standard [2]. The ANSI/ISA S-88 standard (abbreviated as "S-88" hereafter) processes a recipe of hierarchical management of batch control and frameworks to segment batch manufacturing processes. The separation of product and process by the hierarchical structure enables flexibility and reuse of equipment as well as easier integration of new equipment or alteration of the production flow. S-88 divides the batch management into a Procedural Control Model and a Physical Model. The Procedural Control Model describes the production flow of the current batch as it is linked to the physical equipment. This model consists of a Recipe Procedure, a Unit Procedure, Operations and Phases (see Fig. 1). The production flow of a single unit is controlled by the Unit Procedure. Each Unit has an exclusive operating Unit Procedure, which is bound to it. However, a single Unit is allowed to contain more than one Operation, but only one Operation can be active at a time. An Operation consist of a set of Phases (tasks), which are allowed to run simultaneously.

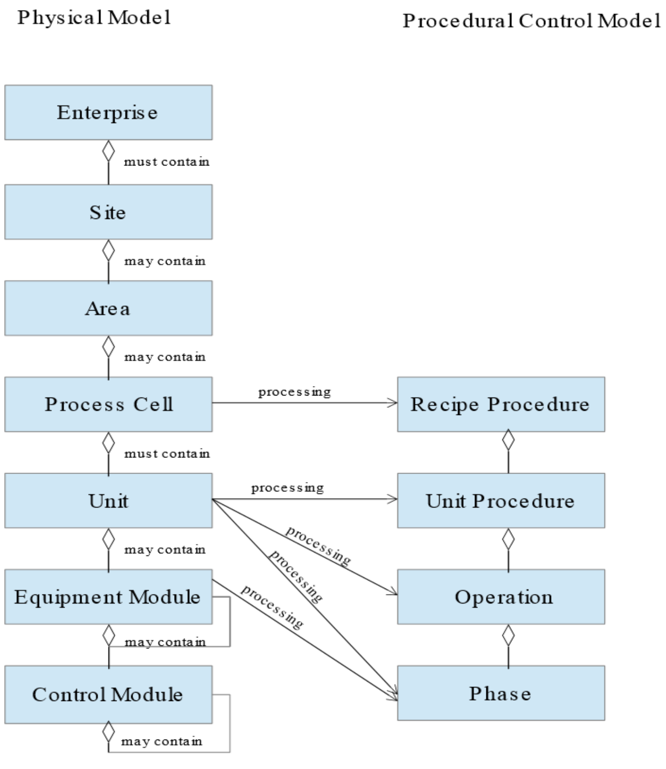

Fig. 1. Overview of the S-88 models [2]

The extended pick and place unit (xPPU) as a unit is part of a Process Cell. A Unit is an independent set of equipment, running a recipe and operating on a batch simultaneously. Units may contain Equipment Modules, which could contain Equipment Modules themselves. As a functional group of equipment, they fulfill a finite number of tasks, only one activity at a time. Equipment Modules are for instance the crane, the conveyor, the stack or the stamp (see Fig. 2). An Equipment Module contains Control

[1] National standard: ANSI/ISA S-88. International standard: IEC/EN 61512-1

Modules, which are the most basic elements of the equipment, such as motors, cylinders or valves, see Fig. 2.

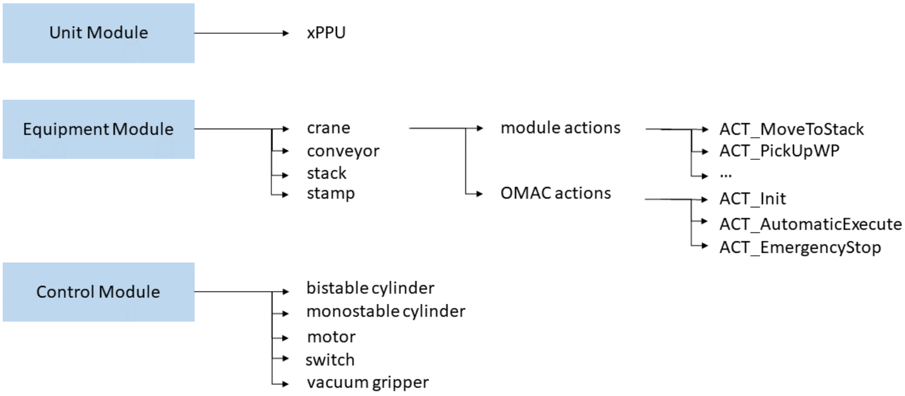

Fig. 2. Overview of the module structure of the xPPU

The PackML standard, which corresponds to the S-88 is used for modelling the xPPU together with the OMAC State Machine, which is a specialization of a finite state machine (see Fig.3). Using these standards, the source code gets more straightforward and offers high granularity through the different levels of the S-88 models, by connecting every component with specific functions. By means of PackML, every basic action is described by an operation state, consisting of basic operations with pre- and post-conditions. Every operation state can include other operation sub-state machines. An operation state machine is a set of operation states. If an OMAC State Machine with operation of sub state machines is connected to different levels of the S-88 physical model, it builds up the Hierarchical Connected Operation Strategy (HCOS) of an OMAC-state.

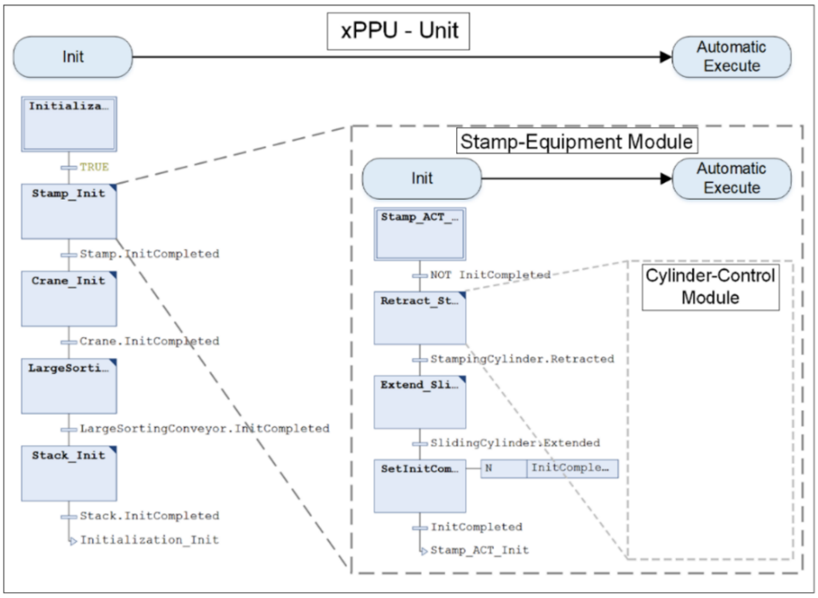

Fig. 3. Overview of a HCOS of the xPPU (excerpt)

The models shared in this technical report have been created in the open source tool Papyrus [3],which needs to be installed for opening and modifying the models. The models as well as the IEC61131-3 software implementation are publicly accessible from the GitHub repository [4].
In the remainder of this technical report, the enlargements in the xPPU evolution scenarios are presented in section 2. Subsequently, an overview of the xPPU is given. Detailed description of the xPPU's scenarios are provided in section 3. Finally, fault handling scenarios are provided in section 4.

2 Evolution steps of the extended Pick and Place Unit (xPPU)

This section introduces the enlargement of the Pick and Place Unit. The original PPU consists of four modules: a stack as a loader for work pieces, a stamp as a manipulation demonstrator, a conveyor as a sorting unit and a crane as a transporter to transfer work pieces between the other modules. The extension adds more modules and features, e.g., a reordering module for logistic flexibility named PicAlpha, reinforced security and safety, product recognition and more. An overview of the evolution steps of the extended Pick and Place Unit is shown in Fig. 4. The graph illustrated in the figure consists of Scenarios of the xPPU represented as nodes. The edges between these nodes represent the migration from one Scenario to another, i.e. the ***evolution steps***.

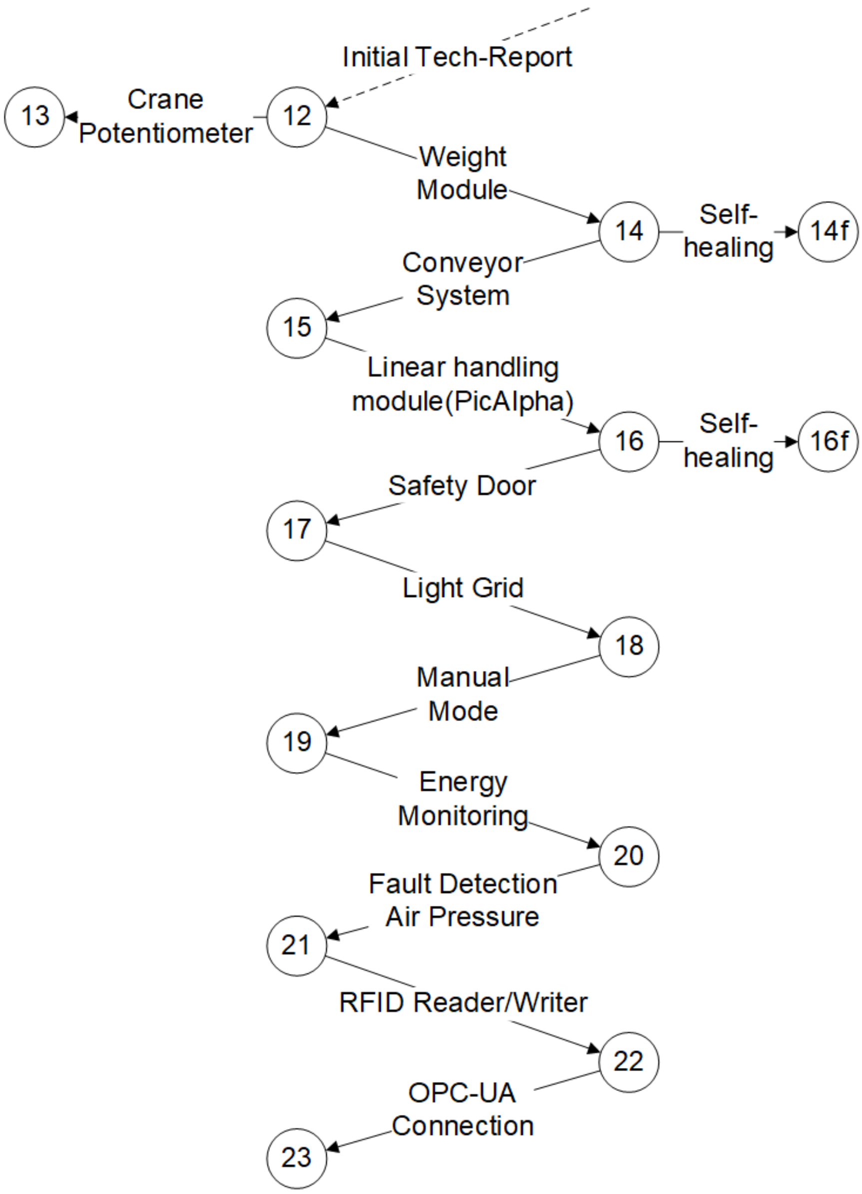

Fig. 4. Evolution steps of the xPPU

2.1 Evolution Step Ev14: Weight Module

Previous to the retrofit of the PPU, the implemented sensors only allowed for a distinction between metallic, black and white plastic work pieces. In order to further distinguish the work pieces that are processed inside the PPU by their weight, the Stack was extended by a weighing module (see Fig. 5) which is able to measure the mass of incoming work pieces. This enables further distinction between metal and plastic work pieces, whose material is indicated by their mass.

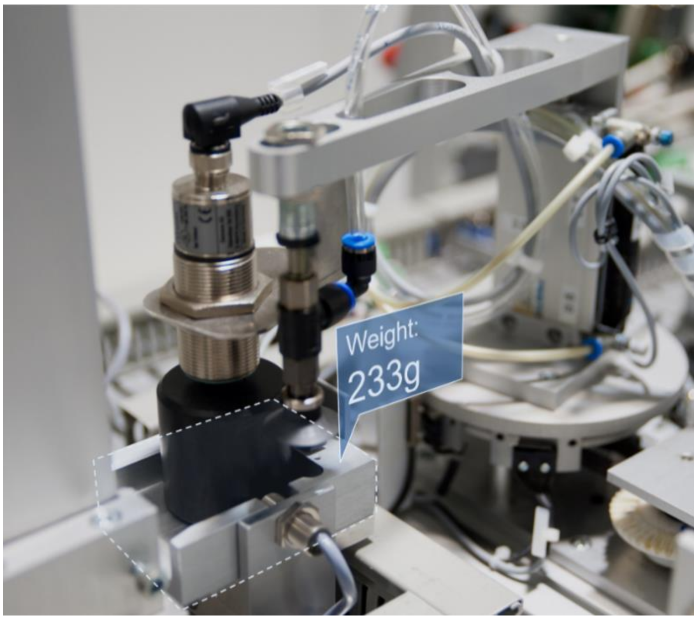

Fig. 5. Weighing module of the xPPU

2.2 Evolution Step Ev15: Conveyor System

More flexibility to the manufacturing process inside the xPPU is enabled by an extended conveyor system (see Fig. 6) that enables re-feeding work pieces from the large sorting conveyor back into the manufacturing process. This allows for the implementation of more complex processes as well as the re-feeding of work pieces, that are detected as being faulty or not fulfilling the quality requirements, into the process for a post processing.

Fig. 6. Conveyor System of the xPPU

2.3 Evolution Step Ev16: Linear Handling Module (PicAlpha)

To further increase the flexibility of the possible manufacturing processes as well as the performance of the logistic system, i.e. the conveyors of the xPPU, a linear handling module, so called PicAlpha has been mounted inside the xPPU. The device is mounted over one of the new conveyors and is aligned with it (see Fig. 7). This for one thing increases the performance of the logistic system and for another thing enables the manipulation of the work piece sequence, i.e. the resorting of work pieces to process.

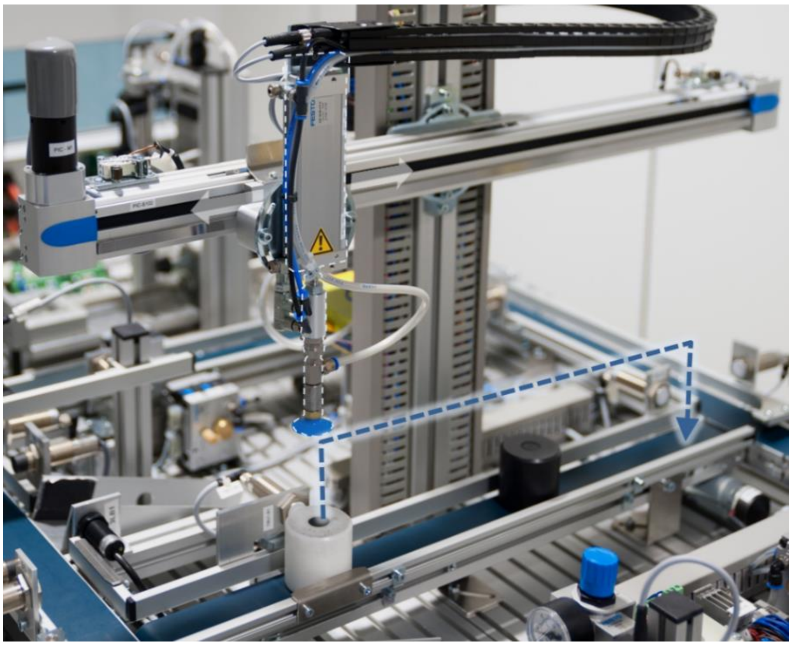

Fig. 7. PicAlpha Module of the xPPU

2.4 Evolution Step Ev17 and Ev18: Safety Door and Light Grid

Accidents which may cause harm to human personnel may occur on different parts of the plant. In order to prevent dangerous situations, safety cells have been implemented around the Stamp Module and the Linear Handling Module. The access to the Stamp Module is blocked by a Safety Door and human personnel that accesses the Linear Handling Module is detected by a Light Grid (see Fig. 7). The mounted hardware incorporates emergency-stop buttons as well as additional control elements.

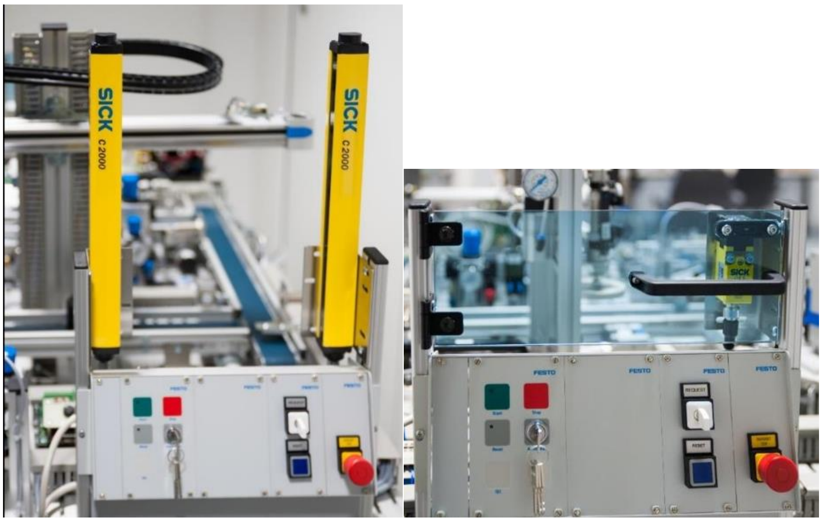

Fig. 8. Safety Door (right) and Light grid (left)

2.5 Evolution Step Ev19: Manual Mode

The PPU operates automatically after the start button on the operation panel has been pushed. Now, with the enlargement of the PPU an additional manual operating mode is enabled. The crane speed can be adjusted manually and the crane movement can be controlled by rotating the crane clockwise or counter clockwise. Additionally, all the conveyors can be controlled regarding their speed as well as their movement. Finally, the PicAlpha can be manually controlled regarding speed as well as movement.

2.6 Evolution Step Ev20: Energy Monitoring

For the manufacturing process inside the xPPU a large amount of energy is needed. For one thing, the automation hardware including sensors and actuators must be provided with electrical energy, for another thing most modules of the plant need to be provided with compressed air. As an extension to former versions of the PPU, inside the xPPU the consumption of these two forms of energy are measured by enhanced energy monitoring hardware (see Fig. 9) which enables diagnosis and optimizations to be implemented inside the automation software.

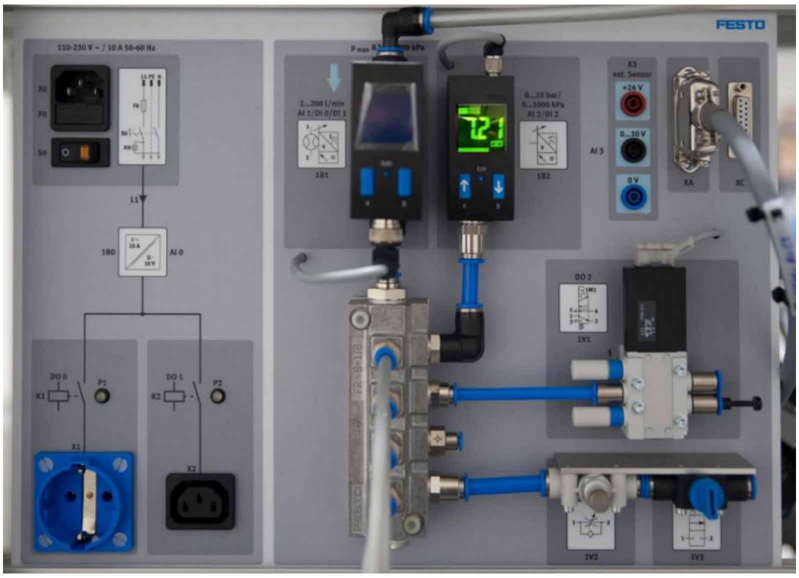

Fig. 9. Energy monitoring hardware of the xPPU

2.7 Evolution Step Ev21: Air Pressure detection

The increasing availability of cost-effective embedded devices enables an enhanced asset management that incorporates distributed smart devices. Inside the xPPU this is demonstrated by an enhanced pneumatic valve which is capable of implementing functions for monitoring the pressure of the compressed air and executing diagnosis functions for the connected handling device.

2.8 Evolution Step Ev22: RFID reader/writer

In order to enable more flexible production management, (re-)writable RFID-Tags (see Fig. 10) have been mounted to the work pieces. Hence, process related information (e.g. customer data, necessary manufacturing steps) can be stored directly on the work pieces. To write/read the tags, RFID-Reader have been mounted on the crane and on the sorting belt. This enables reading and writing work piece data throughout the whole manufacturing process of the xPPU.

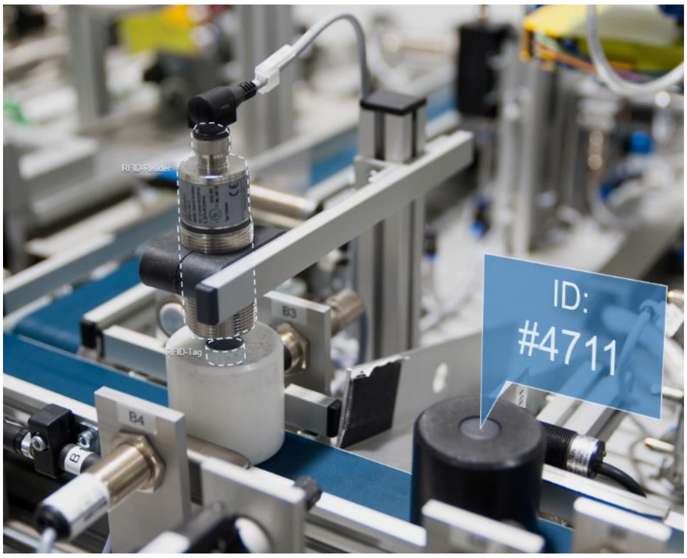

Fig. 10. RFID-reader/writer of the xPPU

2.9 Evolution Step Ev23: OPC UA connection

With the design aim of facilitating flexible process planning, an Open Platform Communications Unified Architecture (OPC UA) server together with web services have been implemented. The OPC UA client that is implemented in middleware and can access the xPPU through the network has the possibility to obtain information about the system via the OPC UA interface and to perform general operations on the xPPU.

3 Overview of the Extended Pick and Place Unit (xPPU)

An overview of the xPPU's structure is provided in Fig. 11. The respective changes made from one evolution step to another are illustrated in Table 1. Therein, a cross denotes a change. Both changes in structure and behavior of the xPPU are illustrated in the table. Moreover, it is distinguished in changes of the xPPU's components' structures, i.e. Stack, Crane, Stamp, Ramp, Large Sorting Conveyor (LSC), PicAlpha Conveyor (PAC), Small Sorting Conveyor (SSC), Refill Conveyor (RC), PicAlpha, Safety door and Light grid, as well as their respective behavior, i.e. Initialization, Automatic mode and Emergency behavior. As changes in automation systems can involve all disciplines of the engineering process, i.e. mechanical engineering, electrical/electronic engineering and software engineering, they can be classified as context changes (involving the mechanical parts of the system), platform changes (involving the electrical/electronic part of the system) and software changes.

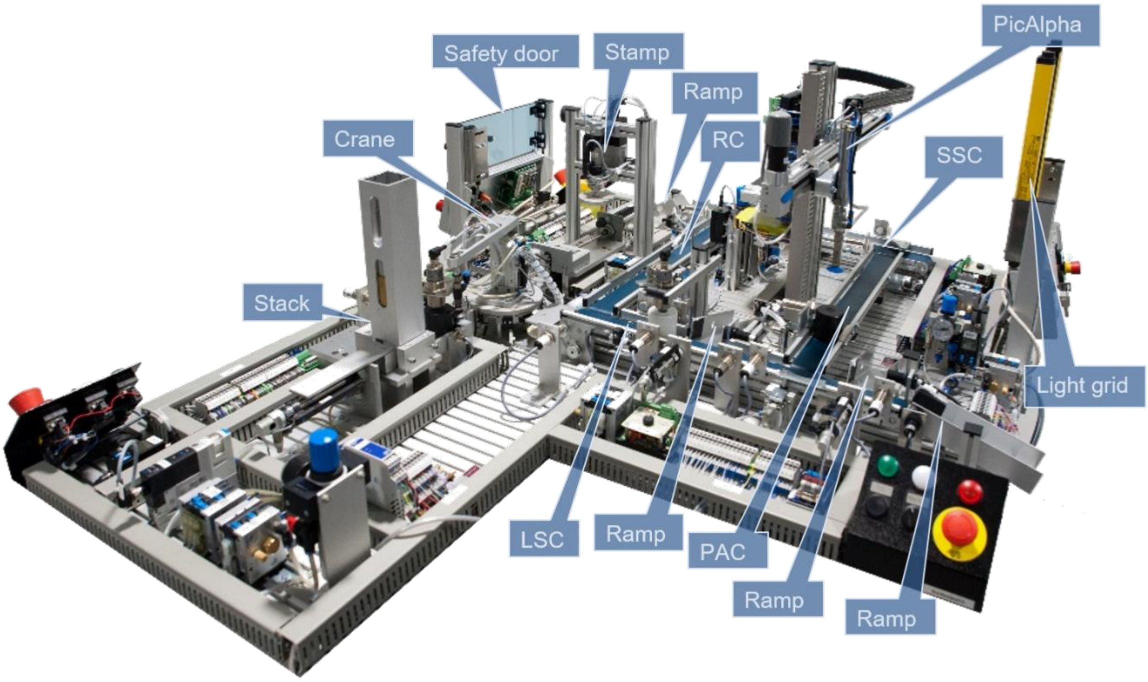

Fig. 11. Overview of the xPPU

Table 1. Overview on Evolution Steps

No.	Structure										Behavior		
	Stack	Crane	Stamp	LSC	PAC	SSC	RC	Pic-Alpha	Safety door	Light grid	Initiali-zation	Auto-matic	Emer-gency
Sc14	x										x	x	
Sc14f												x	
Sc15				x	x	x	x				x	x	x
Sc16								x			x	x	x
Sc16f												x	
Sc17									x		x		x
Sc18										x	x		x
Sc19	x		x	x					x	x			
Sc20													
Sc21											x	x	
Sc22		x		x									
Sc23													

4 Scenarios Description of the Extended Pick and Place Unit (xPPU)

In this section, different manifestations of the extended Pick and Place Unit (xPPU) within Scenarios are described separately. Each Scenario is described as a standalone section, i.e. independently from respective preceding or succeeding Scenarios. The components the xPPU is composed of within a Scenario are described in detail.

4.1 Scenario Sc14

Within Scenario Sc14, the xPPU consists of a stack, working as a work piece input storage, a large sorting conveyor, working as a transportation component of work piece to output storage, a stamp for stamping work pieces and a crane for transporting work pieces by picking and placing them between these three working positions. Moreover, the crane may use the stamp component for buffering purposes. For human interaction, an operation panel provides a start button as well as an emergency stop button.

The xPPU processes six types of work pieces: black plastic work pieces, white plastic work pieces as well as different types of metallic work pieces in this Scenario. One metallic work piece is completely made of brass, one completely made of alloy and two more alloy work pieces have a different lead filling and thus have an increased weight. Black work pieces are separated at the stack and subsequently transported directly to the conveyor. In contrast, white plastic work pieces and metallic work pieces are transported from the stack to the stamp, processed there and then transported to the conveyor. In this scenario, the xPPU is able to measure the mass of incoming work pieces. Therefore, a weighing module has been integrated into the Stack of the xPPU. This is necessary to handle the dynamic effects of different weighing work pieces during transportation. While heavy work pieces need more time to stop commuting after the crane's rotation, light work pieces are ready for further treatment after a shorter period of time. Hence, to optimize the material flow through the xPPU, a weight-dependent transportation process has been established. Furthermore, it is not sufficient to stamp light, medium and heavy weighing work pieces with the same pressure due to different mechanical properties; hence, being able to carry out different processes for each weight category is necessary. For this reason, light, medium and heavy weighing work pieces are stamped using three different pressure profiles. Within the large sorting conveyor, three ramps are used as output storages. Two of the ramps are filled using respective pushing cylinders. A third ramp mounted to the end of the conveyor is filled by translationally moving the work piece using the conveyor. Each of the ramps shall have the same sorting order of work pieces – mixed work pieces shall henceforth be stored within the ramps. In Fig. 12, an overview of the xPPU's structure in this scenario is given.

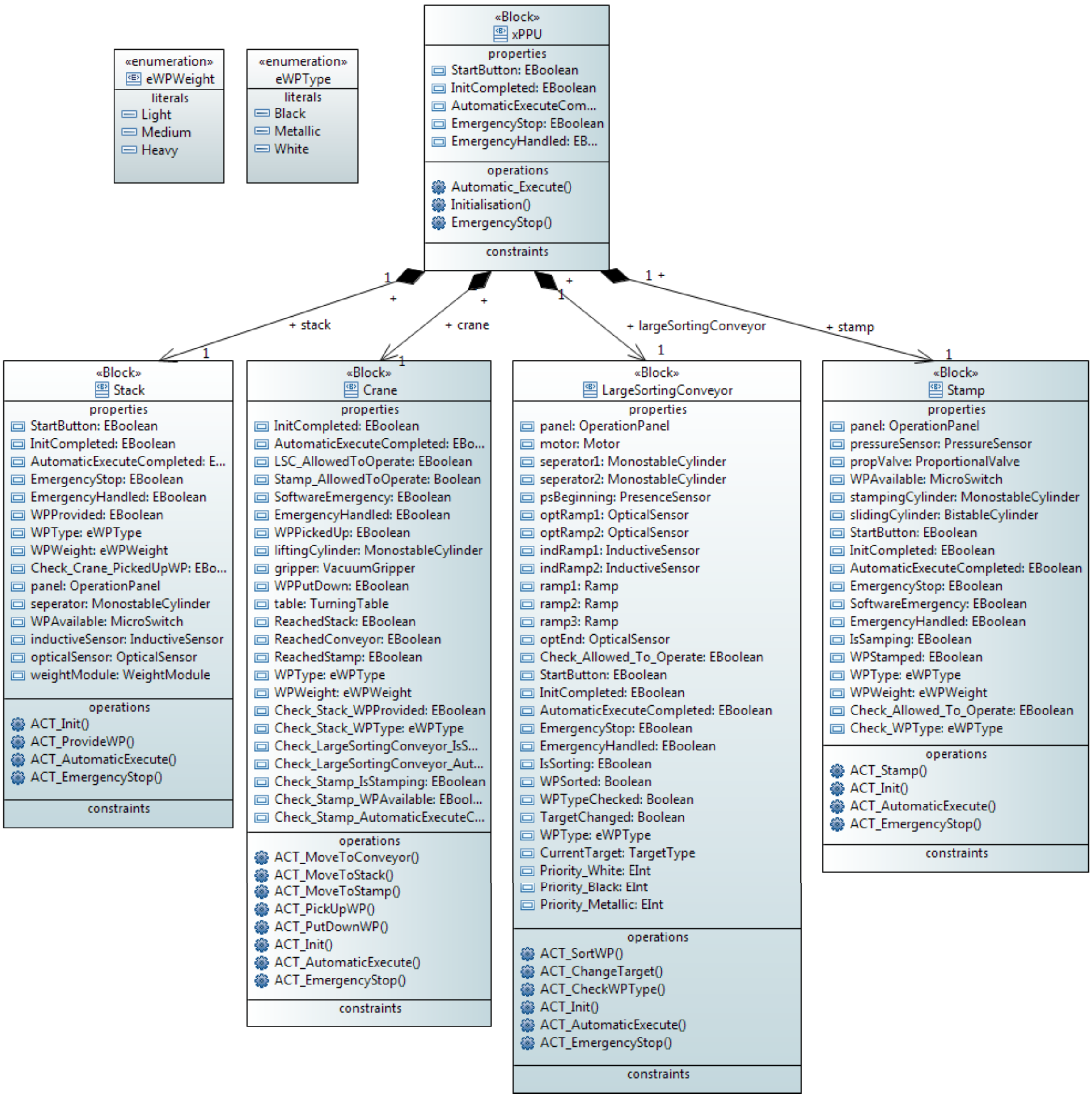

Fig. 12. Overview of the xPPU's structure in Scenario Sc14

4.1.1 xPPU's structure in Scenario Sc14

In the following subsections, the xPPU's structure, i.e. the composition of the xPPU from its components, is described.

4.1.1.1 Stack's structure in Scenario Sc14

The stack serves as an input storage for the work pieces. It consists of a solely mechanical magazine where the work pieces are stacked. In Fig. 13 and Fig. 14, an overview of the stack's structure is provided. For separating the lowermost work piece, the stack consists of a pneumatic cylinder (no.1), which is equipped with two binary sensors indicating the positions of the cylinder, i.e. whether it is extended or retracted. The cylinder is a mono-stable cylinder and hence further consists of a single valve for actuating. A digital micro switch (no. 2) intended to detect work pieces is installed at the so-called pickup position. The micro switch is activated if a work piece is pressed against it. However, due to the internal resistance of the micro switch, work pieces may be pressed back by the micro switch if not clamped properly by the cylinder. Therefore, it is essential to maintain the pressure at the micro switch in order to properly detect a work piece. Moreover, at the pickup position, an inductive sensor (no. 3) is installed for detecting, whether a work piece is a metallic one or not. An optical sensor (no. 4) detects, whether a work piece has a light or a dark surface and, hence, is used for distinguishing between black and white plastic work pieces. A weight module (no. 5) is installed for further distinguishing between work pieces of different masses.

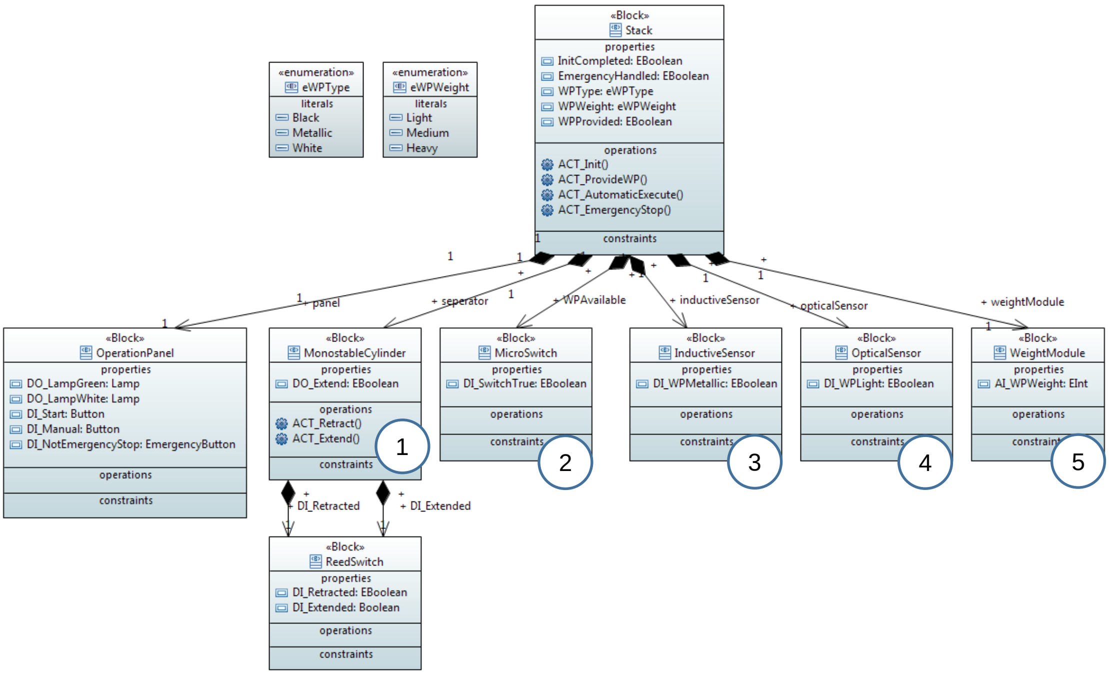

Fig. 13. Overview of the stack's structure in Scenario Sc14

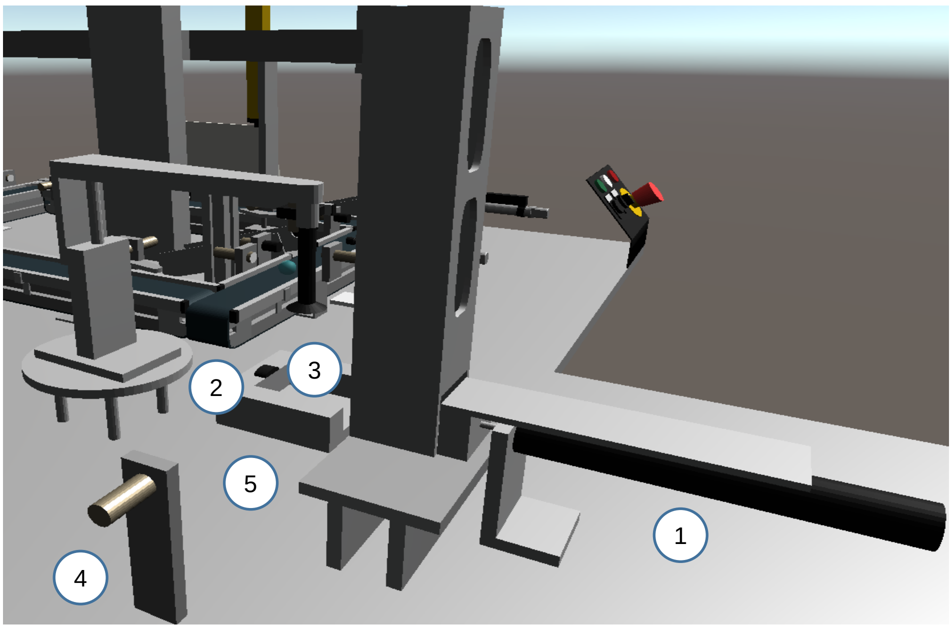

Fig. 14. 3D representation of the stack in Scenario Sc14

A detailed overview on the stack's components as well as their respective terminal connections is shown in *Table* 1.

Table 2. Component list of the stack in Scenario Sc14

Posi-tion	Resource	Clamp	Description	Component	Type
1	100	X1	Stack		
100	100A1	X1.1	Extend separator (Valve)	Stack	DO
100	100B9	X1.2	Separator is extended (Reed Switch)	Stack	DI
100	100B8	X1.3	Separator is retracted (Reed Switch)	Stack	DI
100	100S11	X1.4	WP is available (Micro Switch)	Stack	DI
100	100B10	X1.5	WP is metallic (Inductive Sensor)	Stack	DI
100	100B11	X1.6	WP is light (Optical Sensor)	Stack	DI
100	100B12	X1.7	Weight of the WP (Weight module)	Stack	AI

4.1.1.2 Crane’s structure in Scenario Sc14

The crane of the xPPU in Scenario Sc14 is the same as in Scenario Sc13 [1].

4.1.1.3 Stamp’s structure in Scenario Sc14

The stamp of the xPPU in Scenario Sc14 is the same as in Scenario Sc13 [1].

4.1.1.4 Large Sorting Conveyor’s structure in Scenario Sc14

The conveyer of the xPPU in Scenario Sc14 is the same as in Scenario Sc13 [1].

4.1.2 xPPU’s behavior in Scenario Sc14

In the following subsections, the xPPU’s behavior, i.e. the initialization behavior, the automatic operation mode behavior and the emergency stop behavior of the xPPU, is described.

4.1.2.1 Initialization behavior in Scenario Sc14

The xPPU’s initialization behavior in Scenario Sc14 is the same as in Scenario Sc13 [1].

4.1.2.2 Automatic operation mode behavior in Sc14

Six types of work pieces are used in this scenario and handled differently by the xPPU. Black work pieces are directly transported to the large sorting conveyor, whereas all types of metallic and white plastic work pieces are first stamped and afterwards transported to the large sorting conveyor. After startup, one of the work pieces stored in the stack is separated and pushed to the pickup position of the crane. In order to ensure the correct position for the work piece, the separating cylinder of the stack remains extended. For a description of the stack’s functionality see [1]. For an optimized process regarding dynamic handling of the material, the work piece’s weight is measured and classified as light, medium or heavy, see Fig. 15.

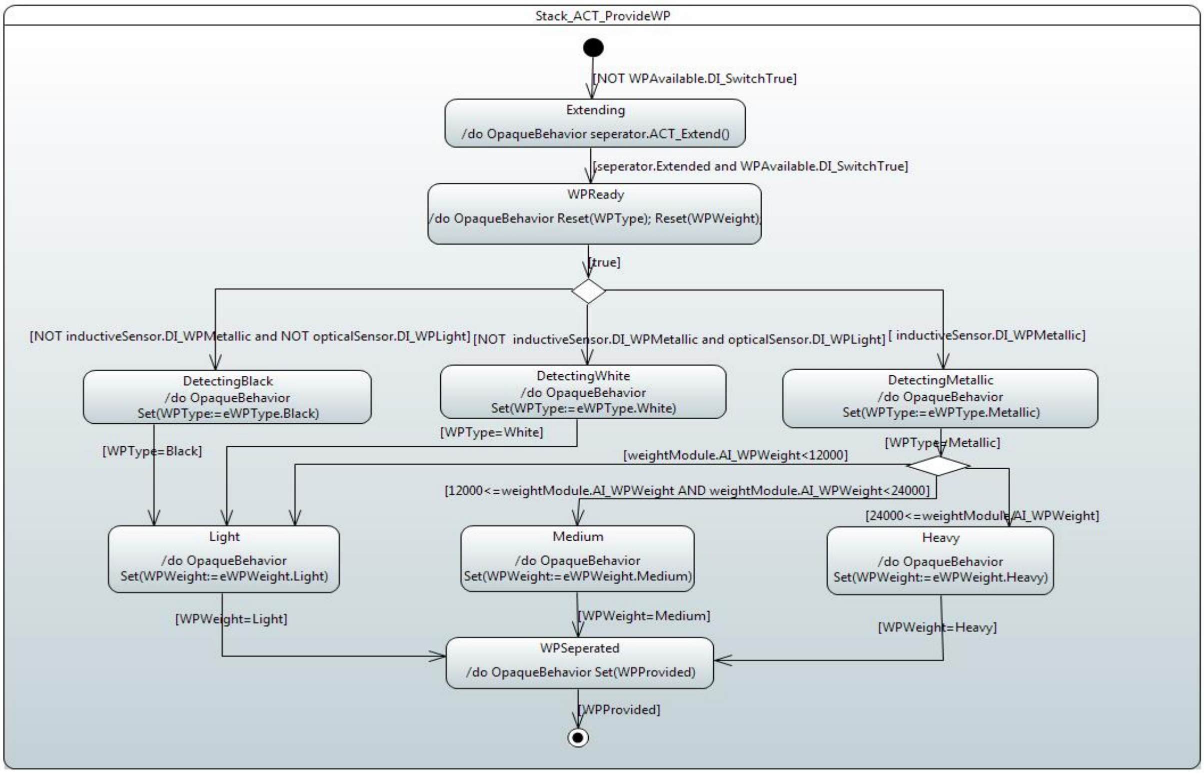

Fig. 15. Stack's behavior in Scenario Sc14

As soon as a work piece is detected by the digital micro switch at the stack's pickup position, the crane starts turning clockwise and stops at the stack's position. At that time, the weight of the work piece is measured and classified as one of three types: light, medium or heavy. The crane has to turn 90°-counterclockwise to transport black work pieces from the stack directly to the large sorting conveyor. For white plastic and all metallic work pieces, the crane has to turn 180°-counterclockwise to place them at the stamp. An inductive sensor, whose value is true for metallic work pieces, is used to check the specific kind of the extended work piece at the extension position of the stack. An optical sensor, whose value is true for white work pieces, is used to check the specific color of the extended work piece at the pickup position. A weight sensor is used to measure the different weight of the metallic work pieces. An overview of the detection of the work piece type is shown in Fig. 15.

The crane then picks up the work piece by using the vacuum gripper, lifts, turns to the desired position, waits the right amount of time till the pendulum of the work piece has stopped, lowers and deposits the work piece at the respective place. Heavy work pieces are put down after 2 seconds and medium work pieces are put down after one second, whereas light work pieces are handled immediately, see Fig. 16. While black work pieces are directly transported to the large sorting conveyor, metallic and white plastic work pieces run through an additional process at the stamp. Metallic and white plastic work pieces are delivered by the crane at the magazine slider of the stamp. The magazine slider retracts and extends the work pieces to and from beneath the stamp. As soon as the retraction is detected, the stamp is lowered for a certain time and with a fixed pressure– depending on the type of work piece detected – raised by setting the 'lower command' to false and followed by the extension of the slider. As soon as the magazine slider is retracted, a pressure profile is selected. Based on the different weights, the stamping pressure of the work pieces is adjusted. Light work pieces are automatically stamped with a light pressure of 4.0 bar, medium work pieces are stamped with a pressure of 5.5 bar and heavy work pieces are stamped with a high-pressure load of 7.0 bar, see Fig. 17 for the Stamp behavior.

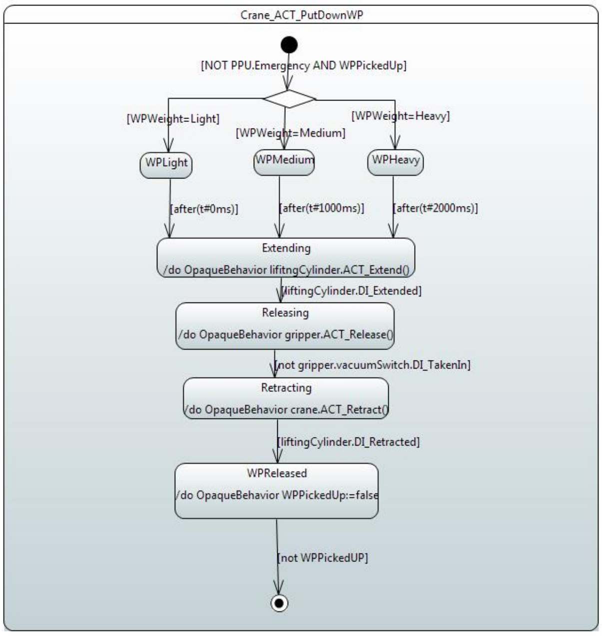

Fig. 16. Crane's activity behavior putting down work pieces in Scenario Sc14

After the metallic or white plastic work piece is placed at the magazine slider, simultaneously the crane is raised and the presence of a black work piece at the stack is checked. If a black work piece is available at the stack, the crane uses the stamping time and starts turning clockwise to pick up the black work piece and places it at the large sorting conveyor. Subsequently, it is checked whether the stamping process is finished and whether another black work piece is at the stack's pickup position.

As long as the stamping process is in progress, all available black work pieces are transported to the large sorting conveyer. However, as soon as the stamping process is completed, the crane handles the stamped metallic or white plastic work piece from the stamp and deposits it at the large sorting conveyor prior to picking up another work piece at the stack's pickup position. If the next available work piece at the stack is a metallic or white plastic piece, while the stamping is still in progress, the crane waits at the stamp until the stamping process is finished. Depending on the time needed for the stamping process, a certain number of black work pieces can be handled until the stamping is finished and the stamped work piece is transported. After the crane places a black, white or a metallic work piece at the large sorting conveyor, the crane moves back to the pickup position at the stack or to the stamp.

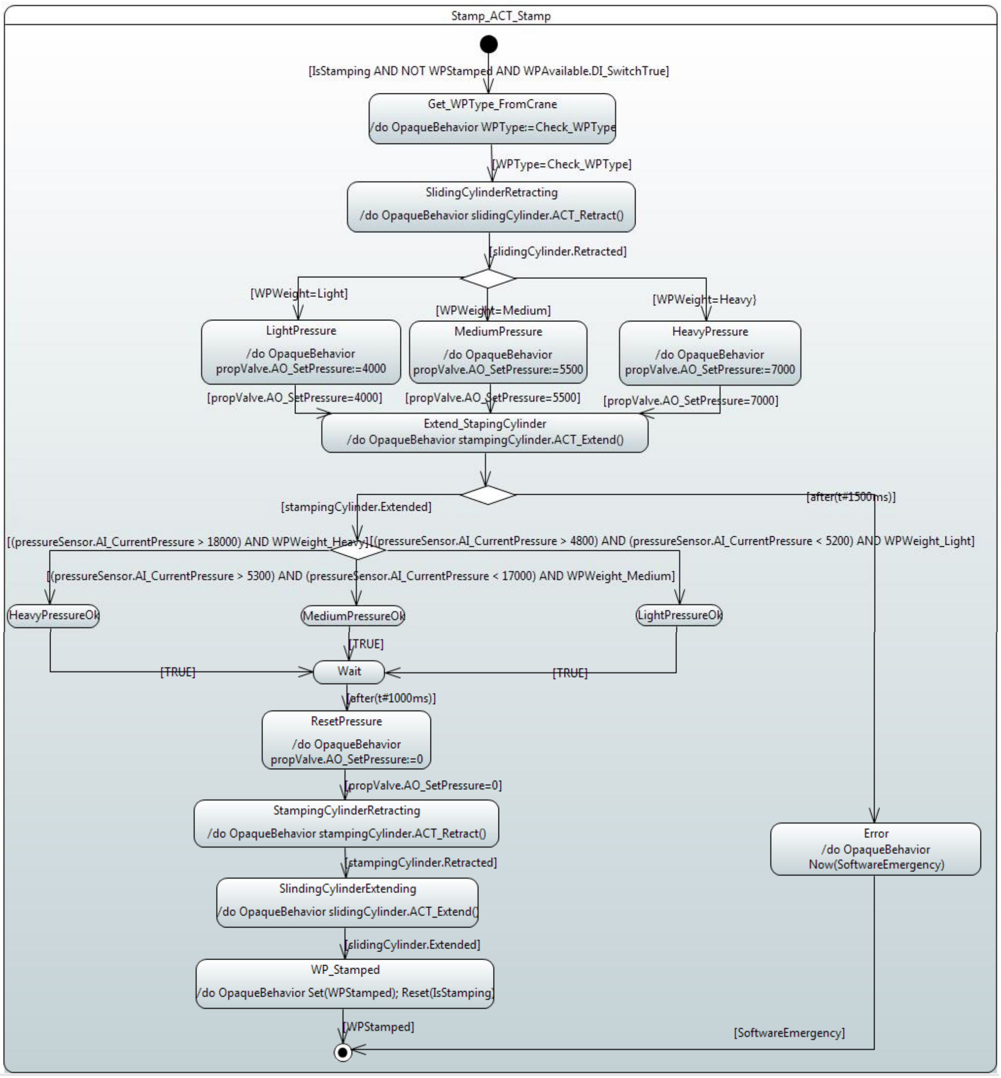

Fig. 17. Stamp's behavior in automatic operation mode in Scenario Sc14

Once the work piece is placed on the large sorting conveyor, it is detected by a sensor. As soon as the work piece reaches the first pair of opposing optical (diffuse sensor – true for light reflecting) and inductive (true for metallic) sensors, located shortly before the first ramp, the specific kind of the work piece is determined. With the installed sensors, it is possible to detect which type of work piece is currently being transported by the large sorting conveyor. Once detected, the white work pieces (optical true, inductive false) and the metallic work pieces (optical true, inductive true) are handled like the black work pieces (as described above): After determining the specific kind, the work piece is transported to one of the ramps not yet containing that certain kind of work piece. Hereby, the lateral ramps are filled by utilizing the pneumatic cylinders as pushers, the one at the end simply by transporting the work piece to the end of the large sorting conveyor. Internal variables are used to record which type of work piece has been stored in which one of the ramps. Once a work piece type has been identified by the sensors and the piece is stored in a ramp, the count of the variable allocated to that specific ramp and that specific type is increased by one. By using those variables, the ramps not yet containing the presently transported work piece type can be determined. For the large sorting conveyor's behavior refer to [1].

If no further work piece is detected at the pickup position, the magazine slider at the stamp is empty and no work piece is present at the large sorting conveyor, the plant stops operating. However, there is no separate sensor at the stack to detect the absence of a work piece. Instead, not sending the 'work piece detected'-signal while the cylinder is extended, indicates the absence of a further object at the pickup position and in the stack. If the sensor detects another work piece the process will restart at the stack.

4.1.2.3 Emergency stop behavior in Scenario Sc14

The xPPU's emergency stop behavior in Scenario Sc14 is the same as in Scenario Sc13 [1].

4.2 Scenario Sc15

Within Scenario Sc15, the xPPU consists of a stack working as a work piece input storage, a large sorting conveyor (LSC) and a small sorting conveyor (SSC) working as a transportation component of work piece to output storage, a PicAlpha conveyor (PAC) and a Refill conveyor (RC) enabling re-feeding for post-processing, a stamp for stamping a work pieces and a crane for transporting work pieces by picking and placing them between the stack, the stamp and the LSC working positions. Moreover, the crane may use the stamp component for buffering purposes. For human interaction, an operation panel provides a start button as well as an emergency stop button.

The xPPU processes six types of work pieces: black plastic work pieces, white plastic work pieces as well as different types of metallic work pieces in this Scenario. One metallic work piece is completely made of brass, one completely made of alloy and two more alloy work pieces have a different lead filling and, thus, have an increased weight. Black work pieces are separated at the stack and subsequently transported directly to the LSC. In contrast, white plastic work pieces and metallic work pieces are transported from the stack to the stamp, processed there and then transported to the LSC.

The xPPU is able to measure the mass of incoming work pieces using the weighing module integrated into the Stack. This is necessary to handle the dynamic effects of different weighing work pieces during transportation. While heavy work pieces need more time to stop commuting after the crane's rotation, light work pieces are ready for further treatment after a shorter period of time. Hence, to optimize the material flow through the xPPU a weight dependent transportation process has been established. Furthermore, it is not sufficient to stamp light, medium and heavy weighing work pieces with the same pressure due to different mechanical properties; hence, being able to carry out three different processes, one for each weight category, is necessary. For this reason, light, medium and heavy weighing work pieces are stamped using different pressure profiles. Within the LSC, three ramps are used as output storages. Two of the ramps are filled using respective pushing cylinders. A third ramp mounted to the end of the LSC is filled by translationally moving the work piece using the conveyor. In the first ramp, only white work pieces should be sorted. The second ramp is for metallic ones as well as the third. First of all, the metallic work pieces should be sorted into the third ramp. If this ramp is full, the second ramp should be used.

For the implementation of more complex processes as well as the re-feeding of work pieces that are detected as being faulty or not fulfilling the quality requirements, the xPPU in this scenario was extended with two separator conveyors (i.e., PAC and RC) and another sorting conveyor the SSC. These conveyors enable re-feeding work pieces from the LSC back into another manufacturing process. An overview of the xPPU in this Scenario is provided in Fig. 18 and Fig. 19.

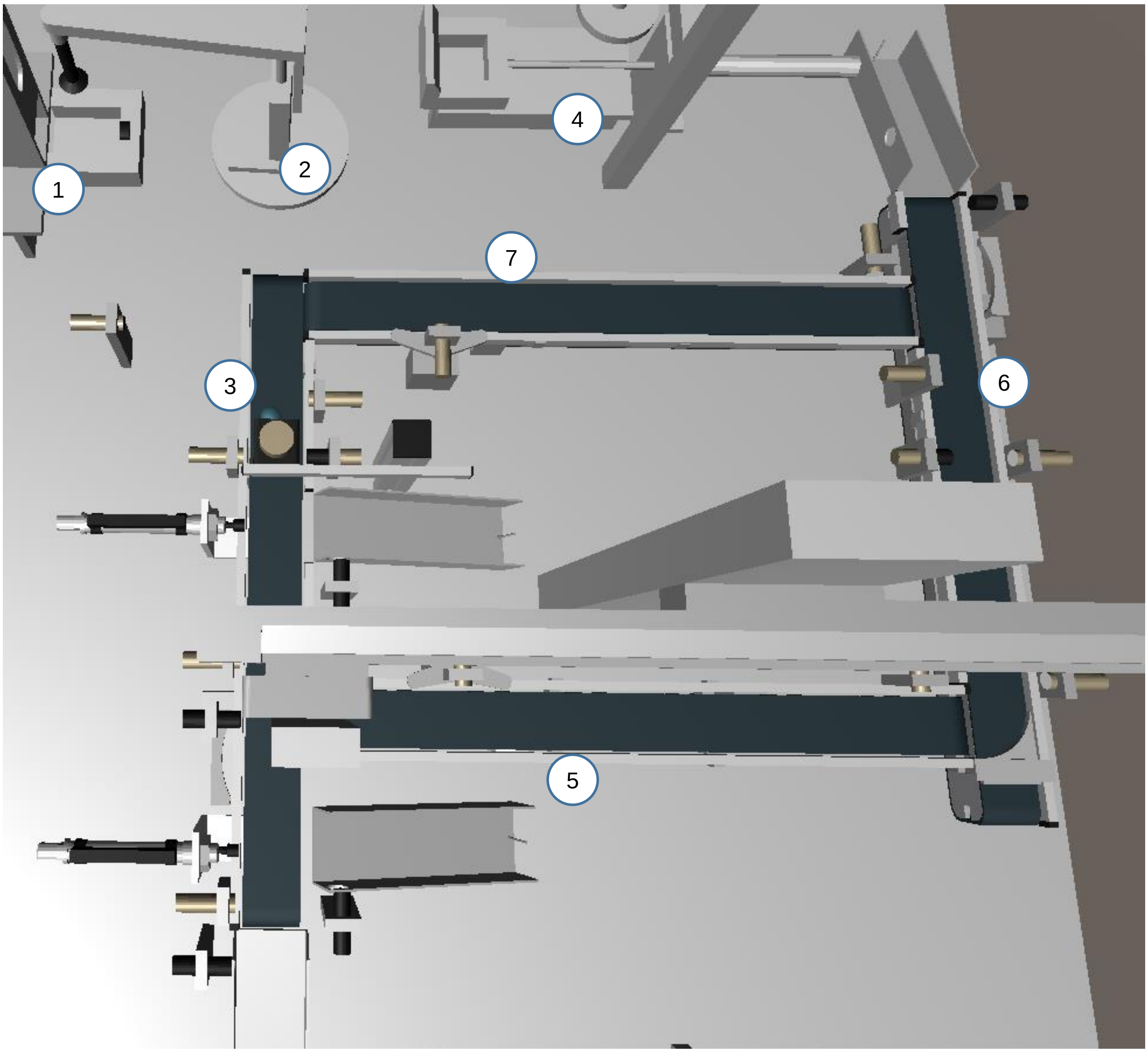

Fig. 18. 3D representation of the xPPU in Scenario Sc15

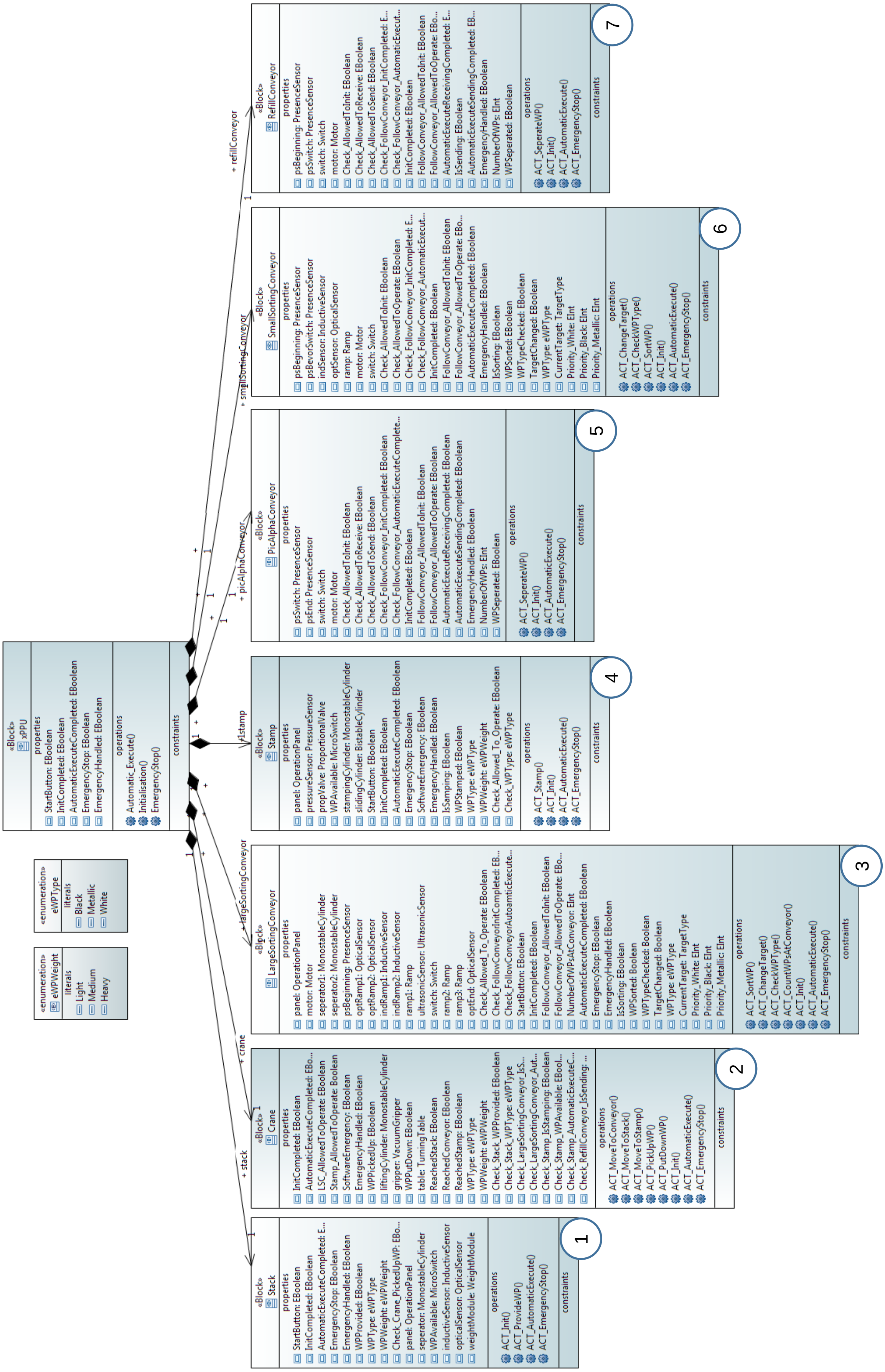

Fig. 19. Overview of the xPPU's Structure in Scenario Sc15

4.2.1 xPPU's structure in Scenario Sc15

In the following subsections, the xPPU's structure, i.e. the composition of the xPPU from its components, is described.

4.2.1.1 Stack's structure in Scenario Sc15

The stack of the xPPU in Scenario Sc15 is the same as in Scenario Sc14. Therefore, for a description of the stack's structure, see section 3.1.1.1.

4.2.1.2 Crane's structure in Scenario Sc15

The crane of the xPPU in Scenario Sc15 is the same as in Scenario Sc13 [1].

4.2.1.3 Stamp's structure in Scenario Sc15

The stamp of the xPPU in Scenario Sc15 is the same as in Scenario Sc13 [1].

4.2.1.4 Large sorting conveyor's structure in Scenario Sc15

The LSC serves as a transportation component in which work pieces are transported into three ramps or to the PAC. In Fig. 20 and Fig. 21, an overview of the LSC components is given. The LSC consists of a motor (no .1) for realizing the translational movement of work pieces and presence sensors (no. 2) mounted to the beginning of the LSC and the ramps detecting whether a work piece was placed on the LSC and whether the ramp is full or not. Three ramps are mounted to the LSC. For the ramps at the beginning as well as at the center of the conveyor, respective pushing cylinders (no. 3) are installed for pushing work pieces into the ramps. These pushing cylinders contain valves for extending or retracting the cylinders as well as end position sensors for detecting whether the cylinder is extended or retracted. Optical sensors (no. 4) detect whether a non-black work piece is at the LSC or not as well as at the RC. Inductive sensors (no. 5) detect whether a work piece is a metallic one or not. In front of the second ramp at the LSC is a Switch (no.6) for transferring the work pieces to the PAC for the re-feeding process. An Ultrasonic sensor positioned at the same level as the PAC measures how many WPs are at the PAC.

Table 3. Component list of the LSC in Scenario Sc15

Posi-tion	Resource	Clamp	Description	Component	Type
4	400	X4	Conveyor		
400	400B1	X4.1	WP at conveyor's beginning (Presence Sensor)	Conveyor	DI
400	400A10	X4.2	Move conveyor backwards (Motor)	Conveyor	DO
400	400A11	X4.3	Move conveyor forwards (Motor)	Conveyor	DO
400	400B4	X4.4	Light WP at ramp 1 (Optical Sensor)	Conveyor	DO
400	400B6	X4.5	Light WP at ramp 2 (Optical Sensor)	Conveyor	DI
400	400B7	X4.6	WP at conveyor's end (Presence Sensor)	Conveyor	DI
400	400B8	X4.7	Separator at ramp 1 extended (Reed Switch)	Conveyor	DI
400	400B9	X4.8	Separator at ramp 1 retracted (Reed Switch)	Conveyor	DI

400	400B10	X4.9	Separator at ramp 2 extended (Reed Switch)	Conveyor	DI
400	400B11	X4.10	Separator at ramp 2 retracted (Reed Switch)	Conveyor	DI
400	400A12	X4.11	Extend separator at ramp 1 (Valve)	Conveyor	DO
400	400A13	X4.12	Extend separator at ramp 2 (Valve)	Conveyor	DO
400	400B3	X4.13	Metallic WP at ramp 1 (Inductive Sensor)	Conveyor	DI
400	400B5	X4.14	Metallic WP at ramp 2 (Inductive Sensor)	Conveyor	DI
400	400B14	X4.15	Ramp 1 full (Presence Sensor)	Conveyor	DI
400	400B15	X4.16	Ramp 2 full (Presence Sensor)	Conveyor	DI
400	400B16	X4.17	Ramp 3 full (Presence Sensor)	Conveyor	DI
400	400B17	X4.18	Switch extended (Reed Switch)	Conveyor	DI
400	400B18	X4.19	Switch retracted (Reed Switch)	Conveyor	DI
400	400A19	X4.20	Extend Switch (Valve)	Conveyor	DO
400	400B20	X4.21	Count WPs at PAC	Conveyor	AI

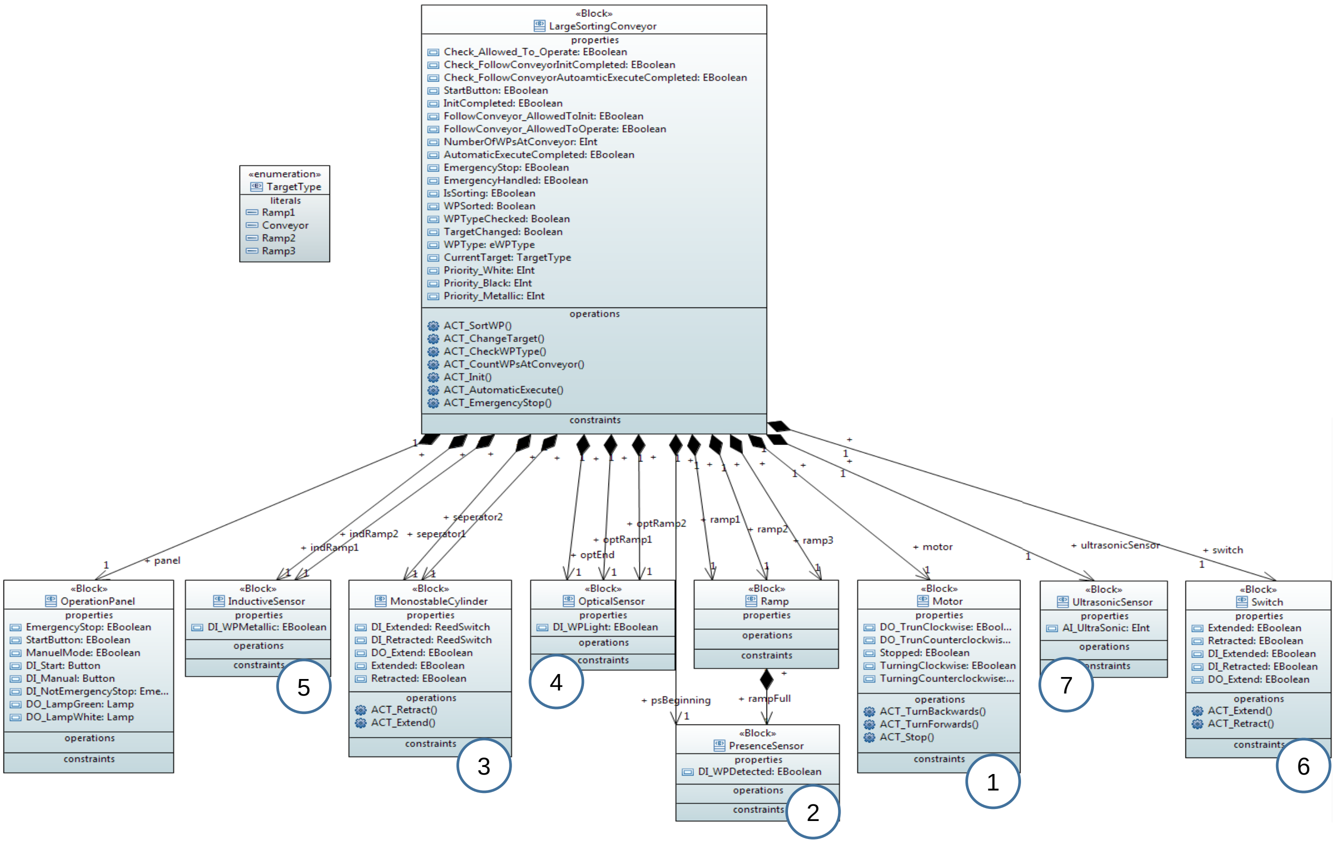

Fig. 20. Overview of the LSC's structure in Scenario Sc15

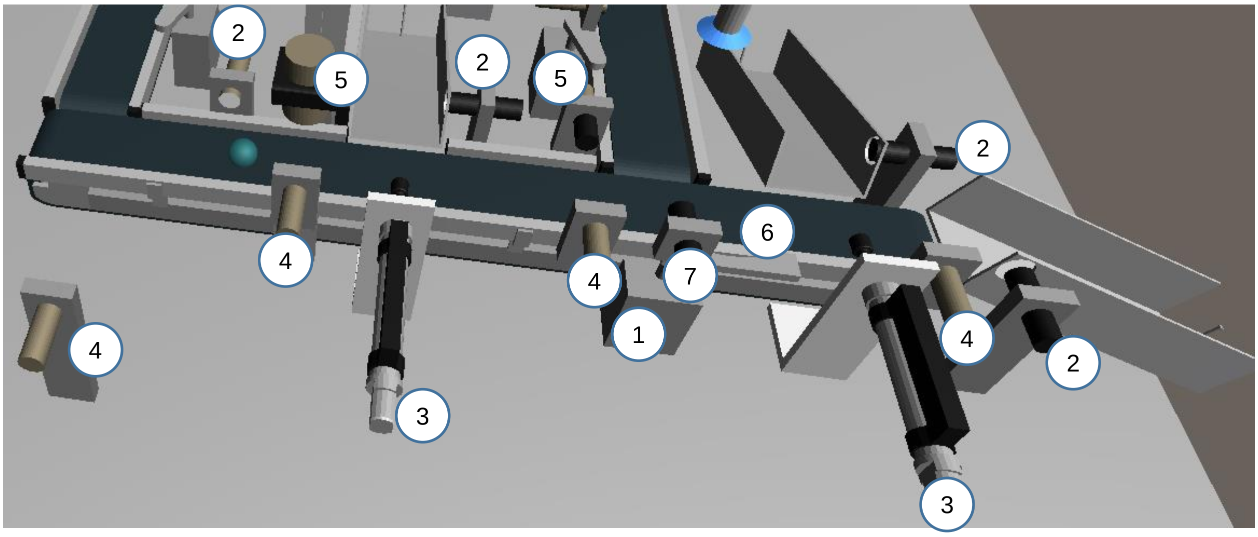

Fig. 21. 3D representation of the LSC in Scenario Sc15

4.2.1.5 PicAlpha conveyor’s structure in Scenario Sc15

The PicAlpha conveyor (PAC) serves as a transportation component in which work pieces are transported into the SSC. In Fig. 22 and Fig. 23, an overview of the PAC component is given. The PAC consists of a motor (no. 1) for realizing the translational movement of work pieces, a switch (no. 3) implemented at the beginning of the conveyor for stopping the work pieces and presence sensors (no. 2) mounted to the position of the switch and the end of the PAC to detect whether a work piece was placed on the PAC.

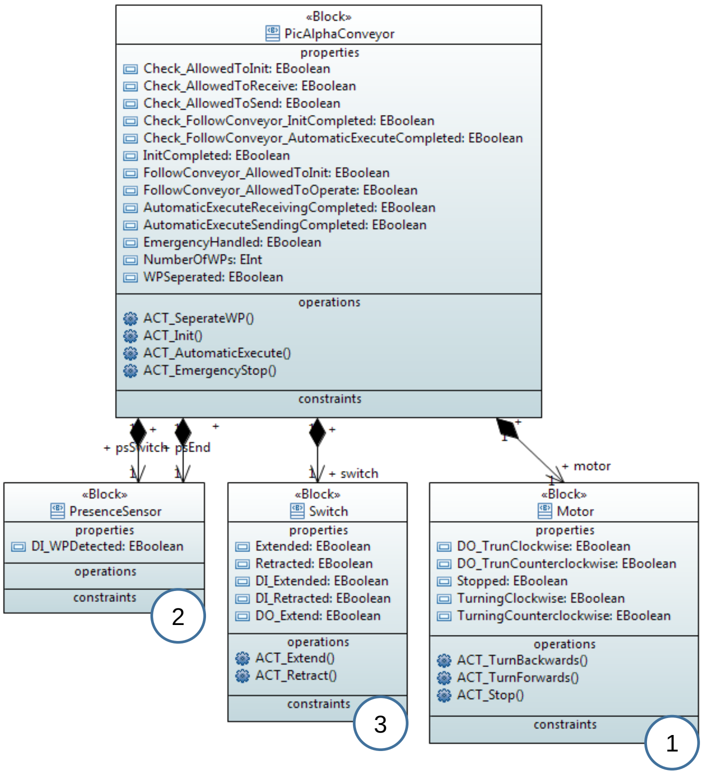

Fig. 22. Overview of the PicAlpha Conveyor's structure in Scenario Sc15

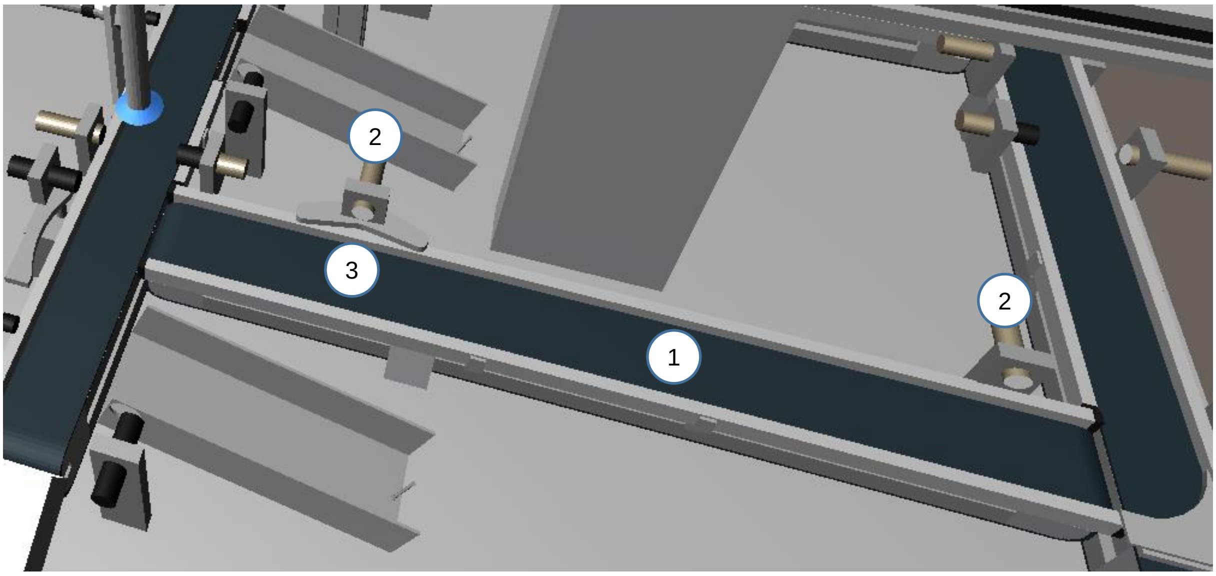

Fig. 23. 3D representation of the PicAlpha Conveyor in Scenario Sc15

Table 4. Component list of the Pic Alpha Conveyor(PAC) in Scenario Sc15

Posi-tion	**Resource**	**Clamp**	**Description**	**Component**	**Type**
5	500	X5	PicAlpha Conveyor		
500	500B1	X5.1	WP at conveyor’s beginning (Presence Sensor	PAC	DI
500	500A2	X5.2	Move conveyor backwards (Motor)	PAC	DO
500	500A3	X5.3	Move conveyor forwards (Motor)	PAC	DO
500	500B4	X5.4	WP at conveyor’s end (Presence Sensor)	PAC	DI
500	500B5	X5.5	Switch extended (Reed Switch)	PAC	DI
500	500B6	X5.6	Switch retracted (Reed Switch)	PAC	DI
500	500A7	X5.7	Extend Switch (Valve)	PAC	DO

4.2.1.6 Small sorting conveyor’s structure in Scenario Sc15

The small sorting conveyor (SSC) serves as a transportation component in which work pieces are transported into a ramp or RC. In Fig. 24 and Fig. 25, an overview of the SSC’s components is given. The SSC consists of a motor (no. 5) for realizing the translational movement of work pieces, a switch (no. 4) transferring work pieces when extended to the RC, presence sensors (no. 1) mounted to the beginning of the SSC, in front of the switch and at the beginning of the ramp detecting whether a work piece is placed on the SSC, at a switch position and whether the ramp is full or not, an optical sensor (no. 3) detecting whether a work piece is a black one or not and an inductive sensor (no. 2) detecting whether a work piece is a metallic one or not. A ramp (no. 6) is mounted to the SSC’s end where work pieces can be stored.

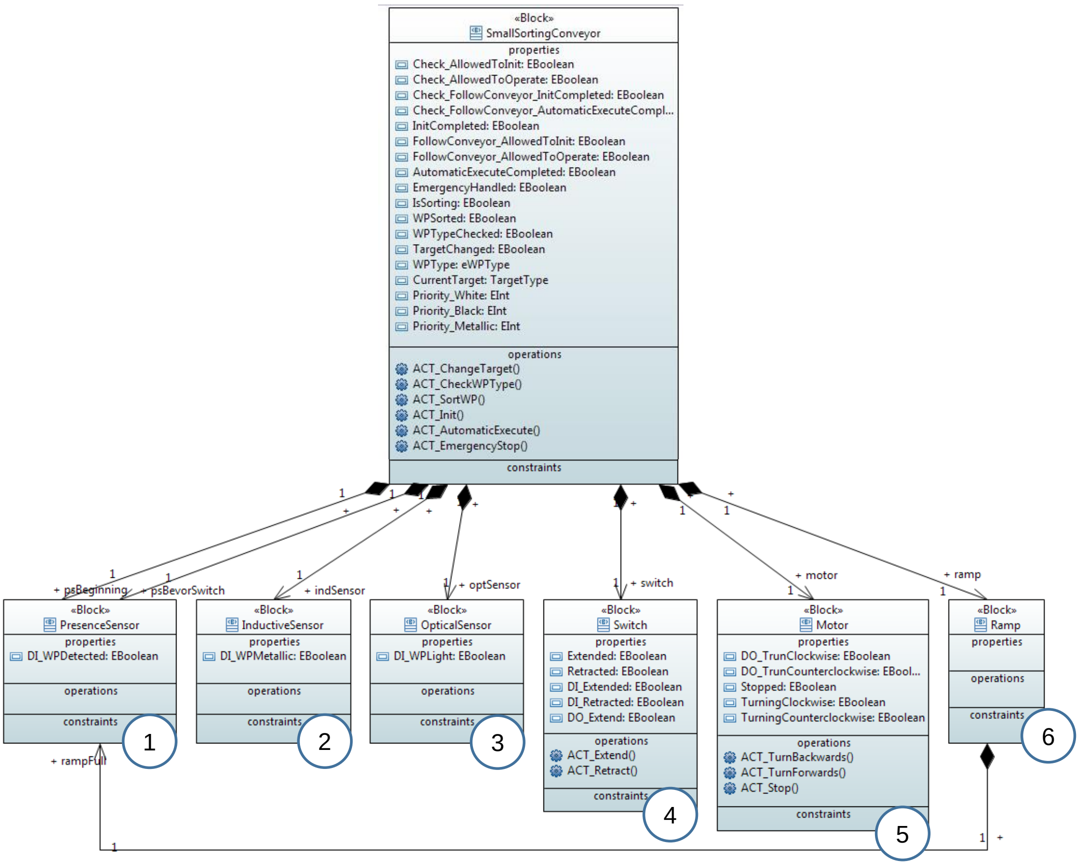

Fig. 24. Overview of the Small Sorting Conveyor's structure in Scenario Sc15

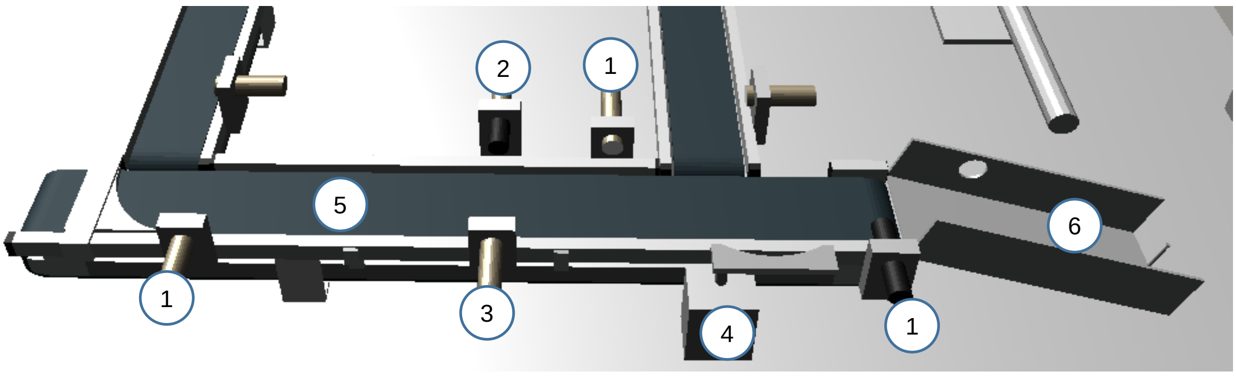

Fig. 25. 3D representation of the Small Sorting conveyor's in Scenario Sc15

Table 5. Component list of the Small Sorting Conveyor in Scenario Sc15

Posi-tion	**Resource**	**Clamp**	**Description**	**Component**	**Type**
6	600	X5	PicAlpha Conveyor		
600	600B1	X5.1	WP at conveyor's beginning (Presence Sensor	PAC	DI
600	600A2	X5.2	Move conveyor backwards (Motor)	PAC	DO
600	600A3	X5.3	Move conveyor forwards (Motor)	PAC	DO
600	600B4	X5.4	WP at conveyor's end (Presence Sensor)	PAC	DI
600	600B5	X5.5	Switch extended (Reed Switch)	PAC	DI

600	600B6	X5.6	Switch retracted (Reed Switch)	PAC	DI
600	600A7	X5.7	Extend Switch (Valve)	PAC	DO
600	600B8	X5.8	WP is light (Optical Sensor)	PAC	DI
600	600B9	X5.9	WP is metallic (Inductive Sensor)	PAC	DI
600	600B10	X5.10	Ramp is full (Presence Sensor)	PAC	DI

4.2.1.7 Refill conveyor’s structure in Sc15

The refill conveyor (RC) serves as a transportation component in which work pieces are transported back into the LSC. In Fig. 26 and Fig. 27, an overview on the RC’s components is given. The RC consists of a motor (no. 3) for realizing the translational movement of work pieces. A switch (no. 2) is implemented at the end of the conveyor for stopping the work pieces when extended. Presence sensors (no. 1) mounted at the beginning of the conveyor and at the switch position detect whether a work piece was placed on the RC or at a switch position.

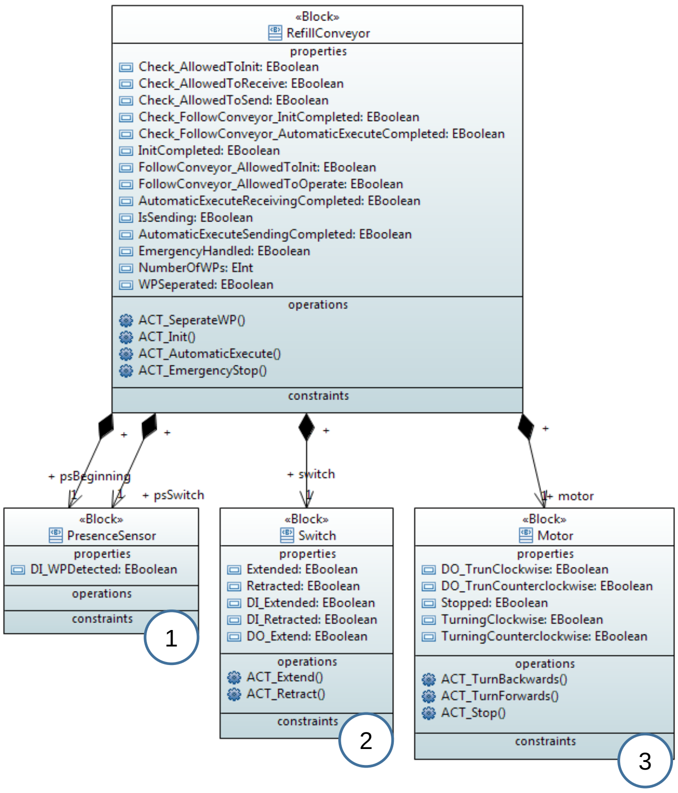

Fig. 26. Overview of the Refill Conveyor's structure in Scenario Sc15

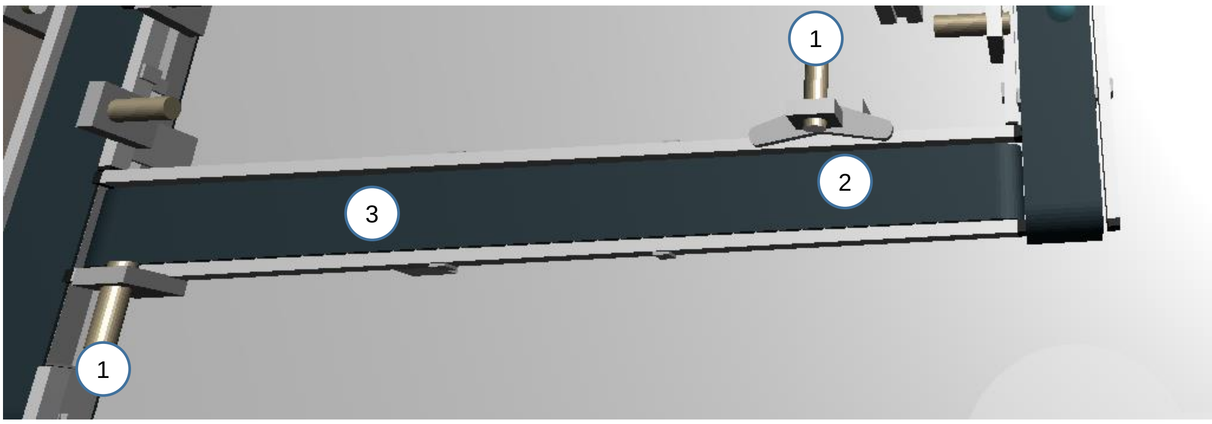

Fig. 27. 3D representation of the Refill Conveyor in Scenario Sc15

Table 6. Component list of the Refill Conveyor in Scenario Sc15

Posi-tion	Resource	Clamp	Description	Component	Type
7	700	X7	PicAlpha Conveyor		
700	700B1	X7.1	WP at conveyor's beginning (Presence Sensor	RC	DI
700	700A2	X7.2	Move conveyor backwards (Motor)	RC	DO
700	700A3	X7.3	Move conveyor forwards (Motor)	RC	DO
700	700B4	X7.4	WP at conveyor's end (Presence Sensor)	RC	DI
700	700B5	X7.5	Switch extended (Reed Switch)	RC	DI
700	700B6	X7.6	Switch retracted (Reed Switch)	RC	DI
700	700A7	X7.7	Extend Switch (Valve)	RC	DO

4.2.2 xPPU's behavior in Scenario Sc15

In the following subsections, the xPPU's behavior, i.e. the initialization behavior, the automatic operation mode behavior and the emergency stop behavior of the xPPU, is described.

4.2.2.1 Initialization behavior in Scenario Sc15

The xPPU is started by pressing one of three available start buttons at the operation panels. In Fig. 28, the main initialization state chart is given. The initialization of the stamp and the crane are executed, as described in [1]. Afterwards, the LSC is initialized together with the PAC, the SSC and the RC (see Fig. 29 and Fig. 30). They operate for a short period of time. In case of an existing work piece on the LSC, the work piece is transported to the PAC and stopped at the switch. If work pieces occur at the PAC after the switch, they are transported to the SSC. Afterwards, the SSC transports the work pieces to the RC and stops them at the switch. Finally, the stack is initialized. A green lamp at each operation panel indicates a successful initialization.

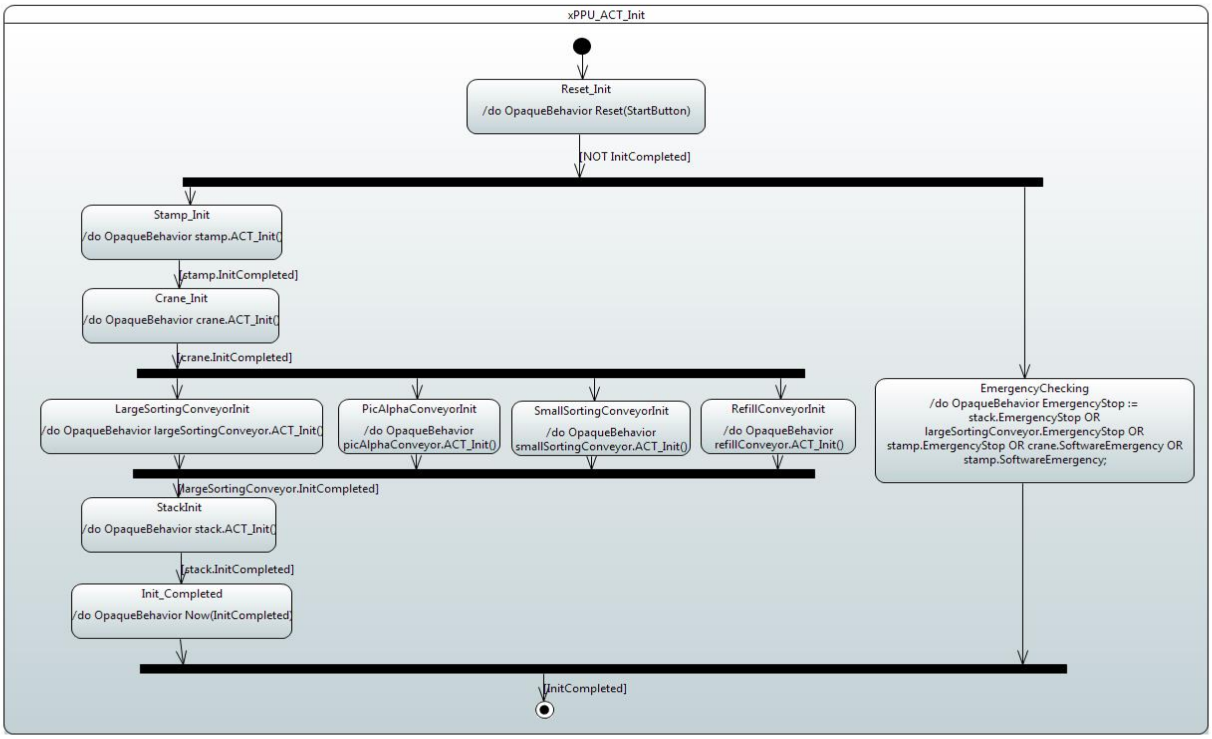

Fig. 28. xPPU's initialization procedure in Scenario Sc15

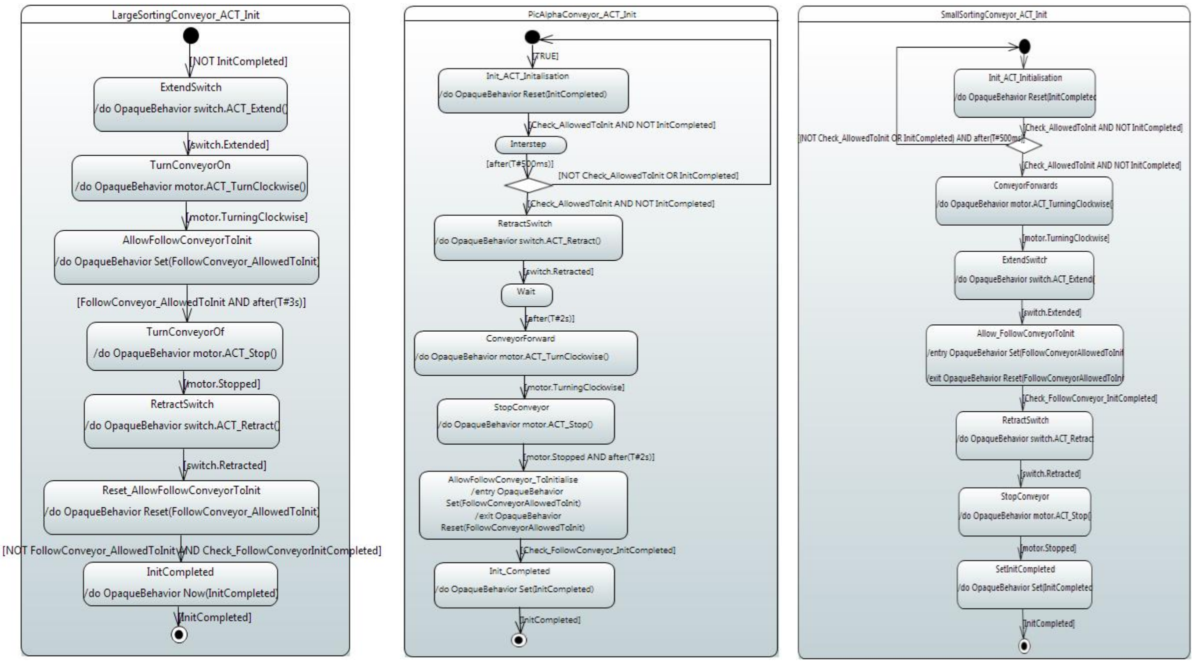

Fig. 29. LSC's, PAC's and SSC's initialization procedure in Scenario Sc15

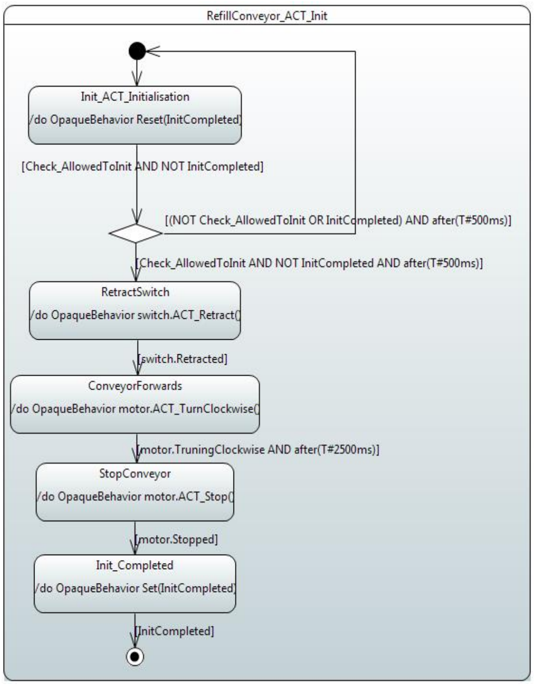

Fig. 30. RSC's initialization procedure in Scenario Sc15

4.2.2.2 Automatic operation mode behavior in Scenario Sc15

Six types of work pieces are used in this scenario and handled differently by the xPPU: black work pieces are directly transported to the LSC, whereas all types of metallic and white plastic work pieces are first stamped and afterwards transported to the LSC. Additionally, the crane shows a different behavior for heavier metallic work pieces due to their increased oscillation after a stop of the crane.

After startup, one of the work pieces stored in the stack is separated and pushed to the pickup position of the crane. In order to ensure the correct position of the work piece, the separating cylinder of the stack remains extended. As soon as a work piece is detected by the digital micro switch at the stack's pickup position, the crane starts turning clockwise and stops at the stack's position. At this time, the weight of the work piece is measured and classified as one of three types: light, medium or heavy. The crane has to turn 90°-counterclockwise to transport black work pieces from the stack directly to the large sorting conveyor. For white plastic and all metallic work pieces, the crane has to turn 180°-counterclockwise to place work pieces at the stamp. An inductive sensor, whose value is true for metallic work pieces, is used to determine the specific kind of the extended work piece at the extension position of the stack. An optical sensor, whose value is true for white work pieces, is used to determine the specific color of the extended work piece at the pickup position. A weight sensor is used to measure the different weights of the metallic work pieces. The crane then picks up the work piece by using the vacuum gripper, lifts, turns to the desired position, lowers, and deposits the work piece at the respective place. Heavy work pieces are put down after 2 seconds and medium work pieces are put down after one second, whereas light work pieces are handled immediately.

Black work pieces are directly transported to the LSC. Due to the additional conveyors extended in this scenario, the crane shows a different behavior. Before moving to the LSC to put down the work piece on the LSC, the crane checks if the RC is sending work pieces to the LSC for reprocessing in order to avoid collisions when placing the black work piece at the LSC, see Fig. 31. If the RC is not sending work pieces to the LSC, the crane places the work piece right away. In case the RC is sending a work piece to the LSC, the crane waits for the LSC to finish sorting the work piece and then places the work piece at the LSC.

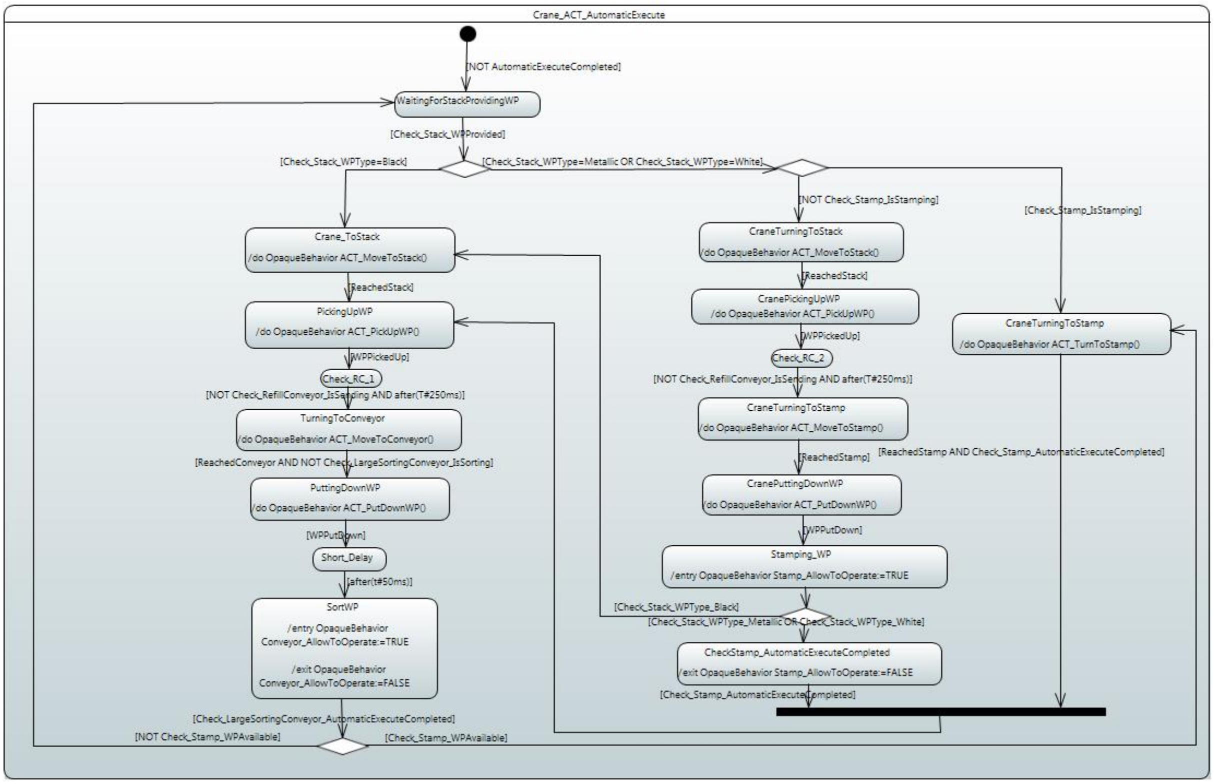

Fig. 31. Crane behavior in Scenario Sc15

Metallic and white plastic work pieces run through an additional process at the stamp. Metallic and white plastic work pieces are delivered by the crane at the magazine slider of the stamp. The magazine slider retracts and extends the work pieces to and from beneath the stamp. As soon as the retraction is detected, the stamp is lowered for a certain time and with a fixed pressure – depending on the type of work piece detected – raised by setting the ‘lower command’ to false, and followed by the extension of the slider. As soon as the magazine slider is retracted, a pressure profile is selected. Based on the different weights the stamping pressure of the work pieces is adjusted. Light work pieces are automatically stamped with a light pressure of 4.0 bar, medium work pieces are stamped with a pressure of 5.5 bar and heavy work pieces are stamped with a high-pressure load of 7.0 bar.

After the metallic or white plastic work piece is placed at the magazine slider, simultaneously the crane is raised and the presence of a black work piece at the stack is checked. If a black work piece is available at the stack, the crane uses the stamping time and starts turning clockwise to pick up the black piece, checks the RC and afterwards places it at the LSC, when the RC is not transporting work pieces. After depositing the work piece at the LSC, it is checked whether the stamping process is finished and whether another black work piece is at the stack. As long as the stamping process is in progress, all available black work pieces are transported to the LSC. However, as soon as the stamping process is completed, the crane handles the stamped metallic or white plastic work piece from the stamp and deposits it at LSC prior to picking up another work piece at the stack’s pickup position. If the next available work piece at the stack is a metallic or white plastic piece, while the stamping is still in progress, the crane waits at the stamp until the stamping process is finished. Depending on the time needed for the stamping progress, a certain number of black work pieces can be handled until the stamping is finished and the stamped work piece is transported. After the crane either placed a black, white or a metallic work piece at the LSC, the crane moves back to the pickup position at the stack or to the stamp.

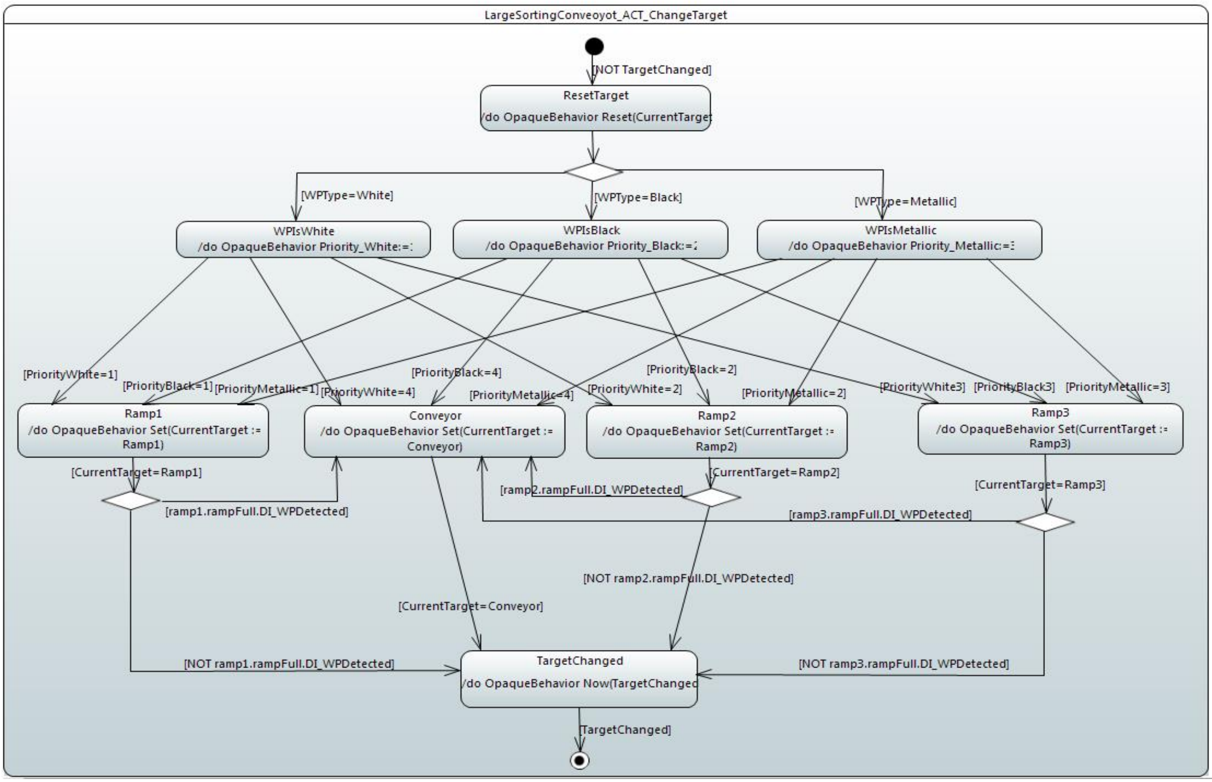

Fig. 32. LSC’s target changing procedure in Scenario Sc15

Once the work piece is placed on the LSC, it is transported forwards until it is detected by a presence sensor. As soon as the work piece reaches the first pair of opposing optical (diffuse sensor – true for light-reflecting) and inductive (true for metallic) sensors, located shortly before the first ramp, the specific kind of the work piece is determined. With the installed sensors, it is possible to detect which type of work piece is currently being transported by the LSC. After determining the specific kind of the work piece, the white work pieces (optical true, inductive false), the metallic work pieces (optical true, inductive true) and the black work pieces (optical false, inductive false) are handled differently. Once the black work piece is detected the switch implemented before the second ramp at the LSC is extended in order to transport the black work piece to the PAC, see the LSC procedure in Fig. 32. White work pieces are sorted to the first ramp. Metallic work pieces are sorted to the ramp mounted at the end of the LSC. When this ramp is full, metallic work pieces are sorted to the second ramp. If first and second ramps are full, the metallic and white work pieces are transported to PAC.

Once the PAC detect a work piece, the switch mounted at the beginning of the conveyor is extended to stop the work piece until it detects three stopped work pieces on the PAC. Then the switch is retracted, one work piece is separated and transported to the SSC, see Fig. 33 for PAC behavior.

When the sorting of the first work piece is done, the second work piece is transported to the SSC and sorted then the third one. Once the SSC detects a work piece by the presence sensor mounted at the beginning of the SSC, it moves the work piece forwards. The work piece passes the inductive and the optical sensor and, therein, can be detected again. If after a certain time none of the sensors detects anything, the work piece is specified as black. Black work pieces (optical false and inductive false) are transported to the ramp mounted at the end of the SSC, see Fig. 34 for the behavior of the SSC. If the work piece is white or metallic, the switch is extended to sort the work piece to the RC. Once a work piece is sorted to the RC, the conveyor moves the work piece to the switch, where it is stopped.

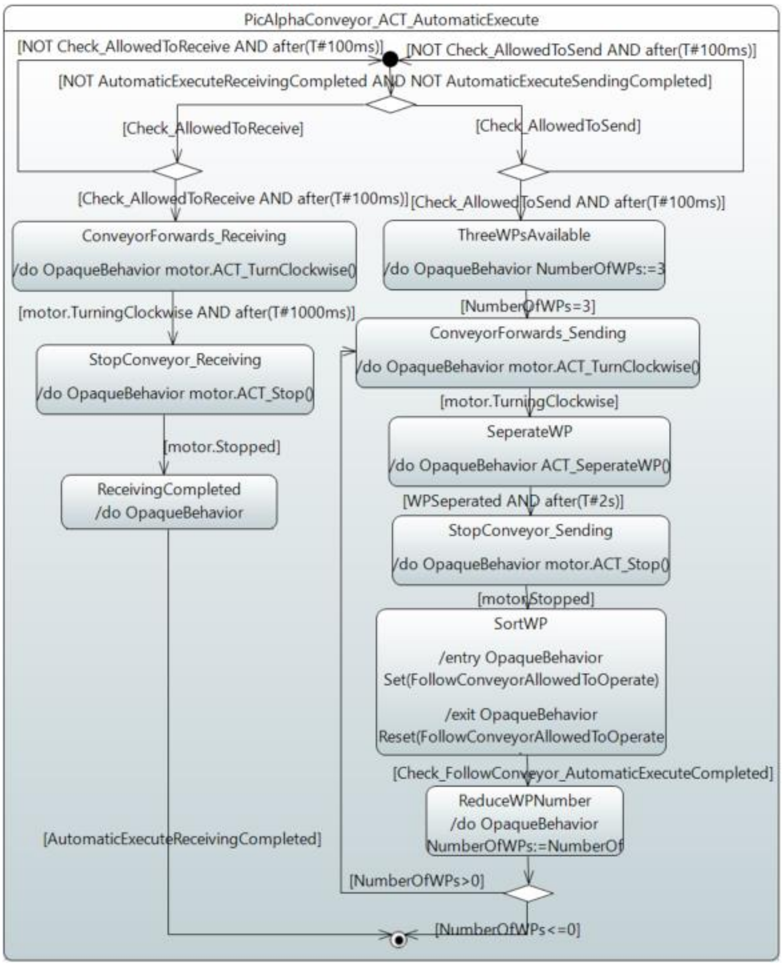

Fig. 33. PAC's Automatic behavior in Scenario Sc15

The presence sensor at the beginning of the RC recognizes whether a work piece is sorted to the RC and counts them. If three work pieces are at the RC and stopped by the switch the conveyor starts re-feeding the work pieces back to the LSC one by one. The LSC therefore specifies the work piece and sorts it, see Fig. 35 for the behavior of the RC.

If no further work piece is detected at the pickup position, the magazine slider at the stamp is empty and no work piece is present at the conveyors, the plant stops operating. However, there is no separate sensor at the stack to detect the absence of a work piece. Instead, not sending the ‘work piece detected’-signal while the cylinder is extended, indicates the absence of a further object at the pickup position and in the stack. If the sensor detects another work piece, the process will restart at the stack.

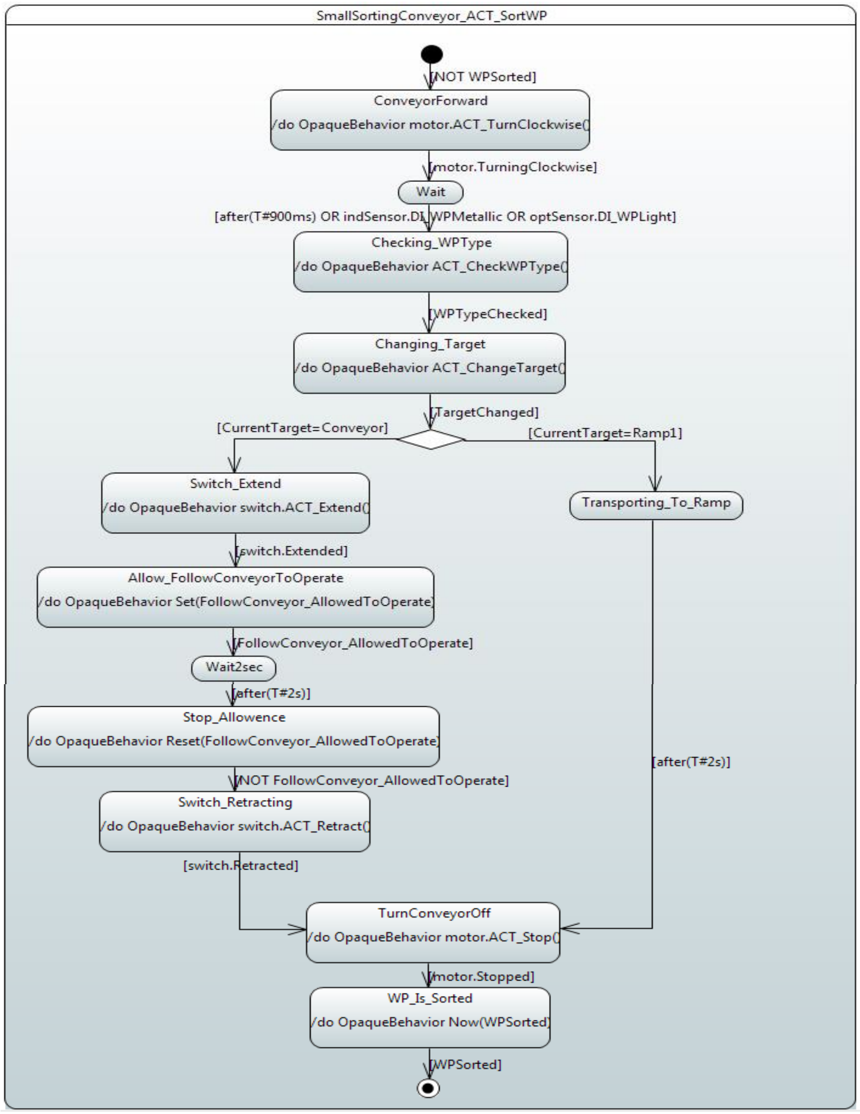

Fig. 34. SSC’s Automatic behavior in Scenario Sc15

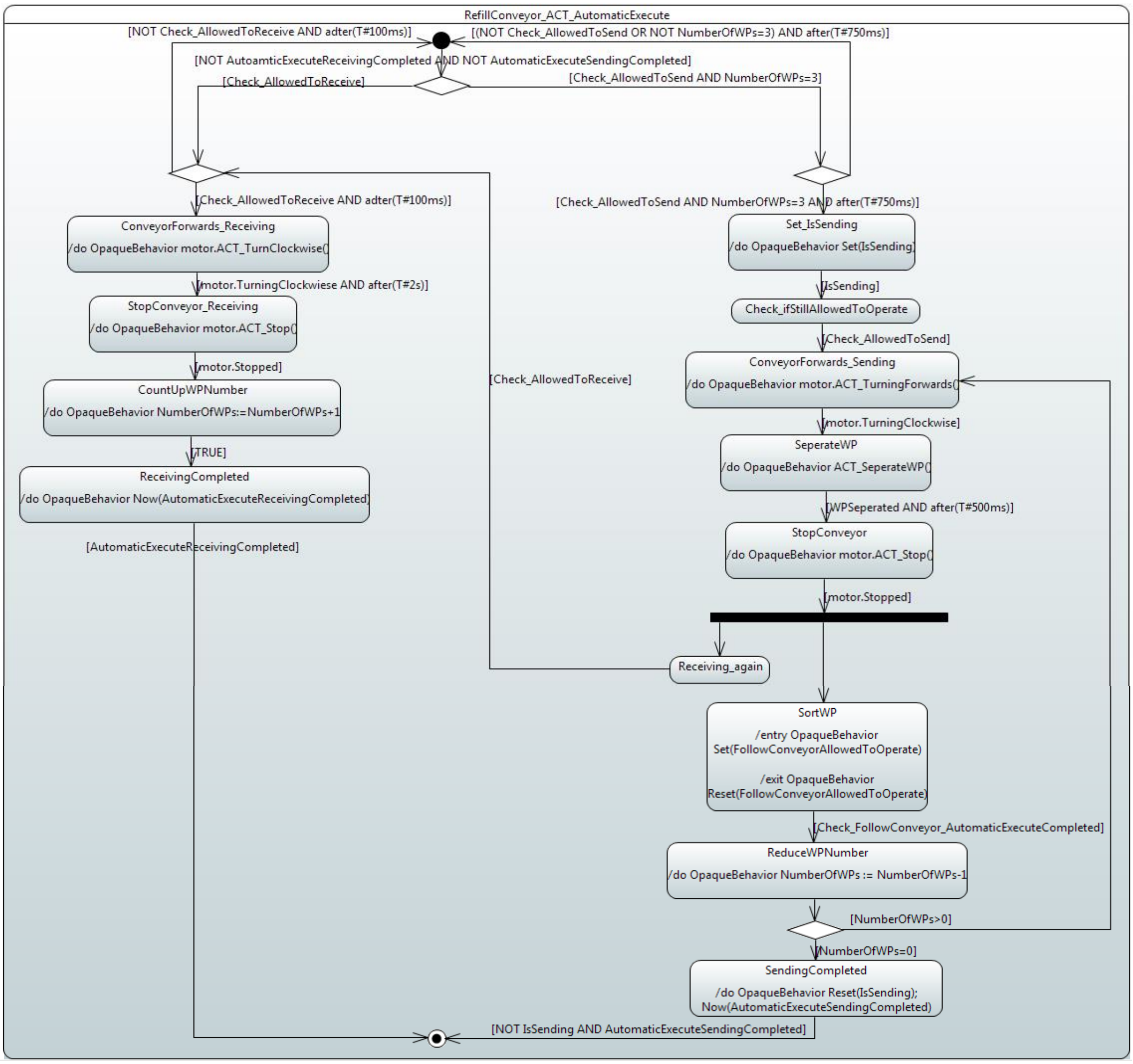

Fig. 35. RC's Automatic behavior in Scenario Sc15

4.2.2.3 Emergency stop behavior in Scenario Sc15

There are three emergency-stop buttons (negative logic), one at the stack, one at the stamp and one at the LSC. In case of an emergency – if at least one emergency button is pushed – the xPPU is set to a safe state. In this safe state, the pneumatic cylinder of the stack is retracted, the crane stops rotating and shuts off the vacuum (if no work piece is gripped), the stamp raises and the magazine slider is extended. Moreover, the pressure of the stamping cylinder is set to zero, the four conveyors are stopped and the pushing cylinders at the LSC are retracted.

4.3 Scenario Sc16

Within the Scenario Sc16, the xPPU consists of a stack working as a work piece input storage, a large sorting conveyor (LSC) and a small sorting conveyor (SSC) working as a transportation component of work piece to output storage, a PicAlpha conveyor (PAC) and a Refill conveyor (RC) enabling re-feeding for post-processing, a stamp for stamping work pieces, a PicAlpha module enabling the manipulation of the work pieces' sequence and a crane for transporting work pieces by picking and placing them between the stack, the stamp and the LSC working positions. Moreover, the crane may use the stamp component for buffering purposes. For human interaction, an operation panel provides a start button as well as an emergency stop button.

The xPPU processes six types of work pieces: black plastic work pieces, white plastic work pieces as well as different types of metallic work pieces in this Scenario. One metallic work piece is completely made of brass, one completely made of alloy and two more alloy work pieces have a different lead filling and thus have an increased weight. Black work pieces are separated at the stack and subsequently transported directly to the LSC. In contrast, white plastic work pieces and metallic work pieces are transported from the stack to the stamp, processed there and then transported to the LSC.

The xPPU is able to measure the mass of incoming work pieces using the weighing module integrated into the Stack. This is necessary to handle the dynamic effects of different weighing work pieces during transportation. While heavy work pieces need more time to stop commuting after the crane's rotation, light work pieces are ready for further treatment after a shorter period of time. Hence, to optimize the material flow through the xPPU a weight dependent transportation process has been established. Furthermore, it is not sufficient to stamp light, medium and heavy weighing work pieces with the same pressure due to different mechanical properties; hence, being able to carry out three different processes, one for each weight category, is necessary. For this reason, light, medium and heavy weighing work pieces are stamped using different pressure profiles. Within the LSC, three ramps are used as output storages. Two of the ramps are filled using respective pushing cylinders. A third ramp mounted to the end of the LSC is filled by translationally moving the work piece using the conveyor. In the first ramp, only white work pieces should be sorted. The second ramp is for metallic ones as well as the third. First of all, the metallic work pieces should be sorted into the third ramp. If this ramp is full, the second ramp should be used.

For the implementation of more complex processes as well as the re-feeding of work pieces that are detected as being faulty or not fulfilling the quality requirements, the xPPU has two separator conveyors (i.e. PAC and RC) and another sorting conveyor the SSC. These conveyors enable re-feeding work pieces from the LSC back into other manufacturing process. For further increase in the flexibility of the possible manufacturing processes as well as the performance of the logistic system, i.e. the conveyors of the xPPU, a PicAlpha module is mounted over the PAC and positioned in alignment with the conveyor belt. On the one hand, this increases the performance of the logistic system and on the other hand, this enables the manipulation of the work piece's sequence, i.e. the resorting of work pieces to process. An overview of the xPPU in this Scenario is provided in Fig. 36.

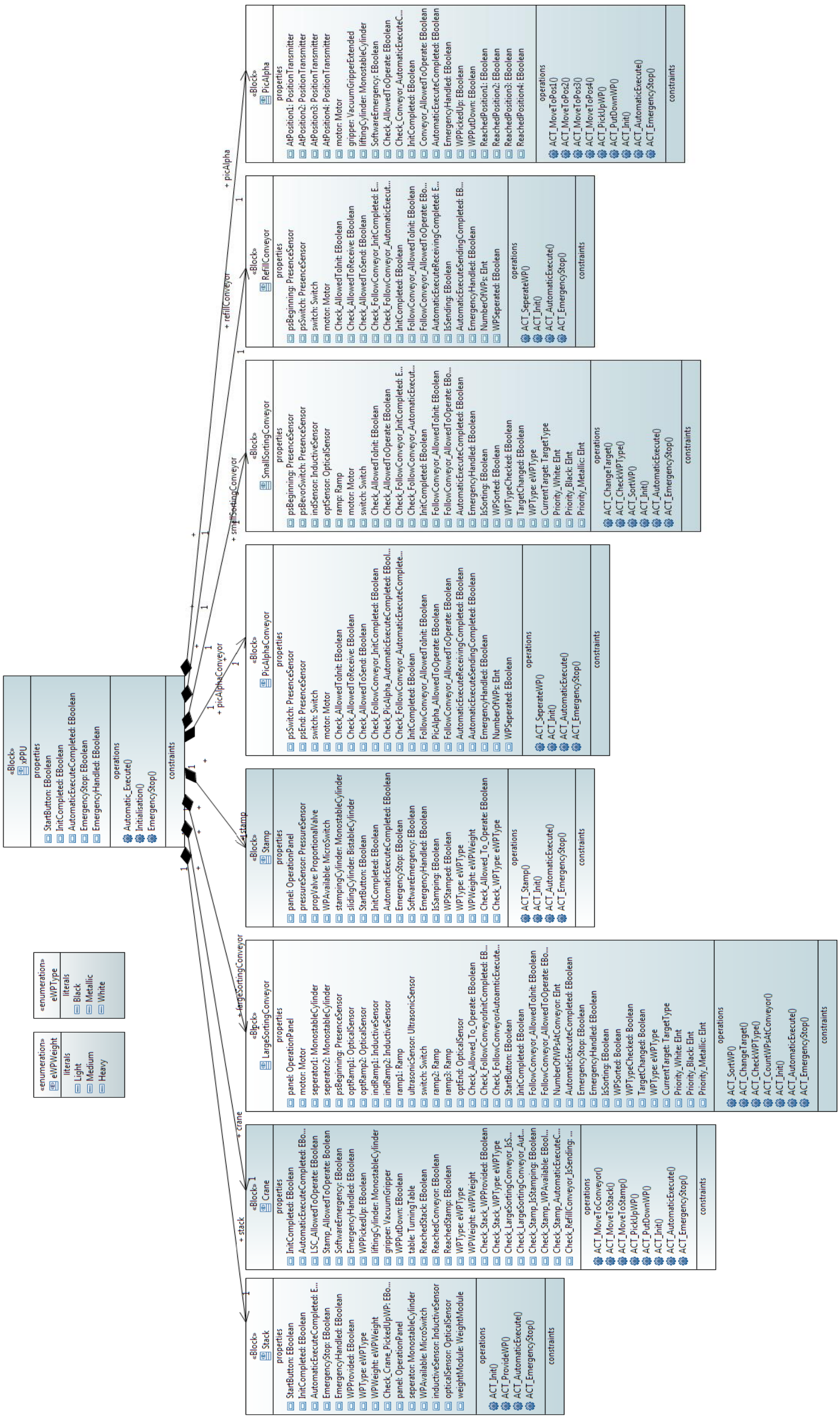

Fig. 36. Overview of the xPPU's structure in Scenario Sc16

4.3.1 xPPU's structure in Scenario Sc16

In the following subsections, the xPPU's structure, i.e. the composition of the xPPU from its components, is described.

4.3.1.1 Stack's structure in Scenario Sc16

The stack of the xPPU in Scenario Sc16 is the same as in Scenario Sc14. Therefore, for a description of the stack's structure, see section 3.1.1.1.

4.3.1.2 Crane's structure in Scenario Sc16

The crane of the xPPU in Scenario Sc16 is the same as in Scenario Sc13 [1].

4.3.1.3 Stamp's structure in Scenario Sc16

The stamp of the xPPU in Scenario Sc16 is the same as in Scenario Sc13 [1].

4.3.1.4 Large sorting conveyor's structure in Scenario Sc16

The large sorting conveyor of the xPPU in Scenario Sc16 is the same as in Scenario Sc15. Therefore, for a description of the large sorting conveyor's structure, see section 3.2.1.4.

4.3.1.5 PicAlpha conveyor's structure in Scenario Sc16

The PicAlpha conveyor of the xPPU in Scenario Sc16 is the same as in Scenario Sc15. Therefore, for a description of the PicAlpha conveyor's structure, see section 3.2.1.5.

4.3.1.6 Small sorting conveyor's structure in Scenario Sc16

The small sorting conveyor of the xPPU in Scenario Sc16 is the same as in Scenario Sc15. Therefore, for a description of the small sorting conveyor's structure, see section 3.2.1.6.

4.3.1.7 Refill conveyor's structure in Sc16

The refill conveyor of the xPPU in Scenario Sc16 is the same as in Scenario Sc15. Therefore, for a description of the refill conveyor's structure, see section 3.2.1.7.

4.3.1.8 PicAlpha's structure in Scenario Sc16

The PicAlpha module facilitates the resorting of work pieces to process. In Fig. 37 and Fig. 38, an overview of the PicAlpha module components is given. The PicAlpha consists of a motor (no. 2) for realizing the translational movement of the handling module. Four position transmitters (no. 1) to detect the position of the handling module and a mono-stable cylinder (no. 4) for lifting and lowering the work pieces. The cylinder includes two binary position sensors (one at each end) to detect whether it is extended or retracted as well as one valve serving as an actuator. At the bottom of this cylinder, an arm with a vacuum gripper is installed. The vacuum gripper (no. 3) is controlled by two valves and contains a micro switch, which indicates whether a work piece is gripped.

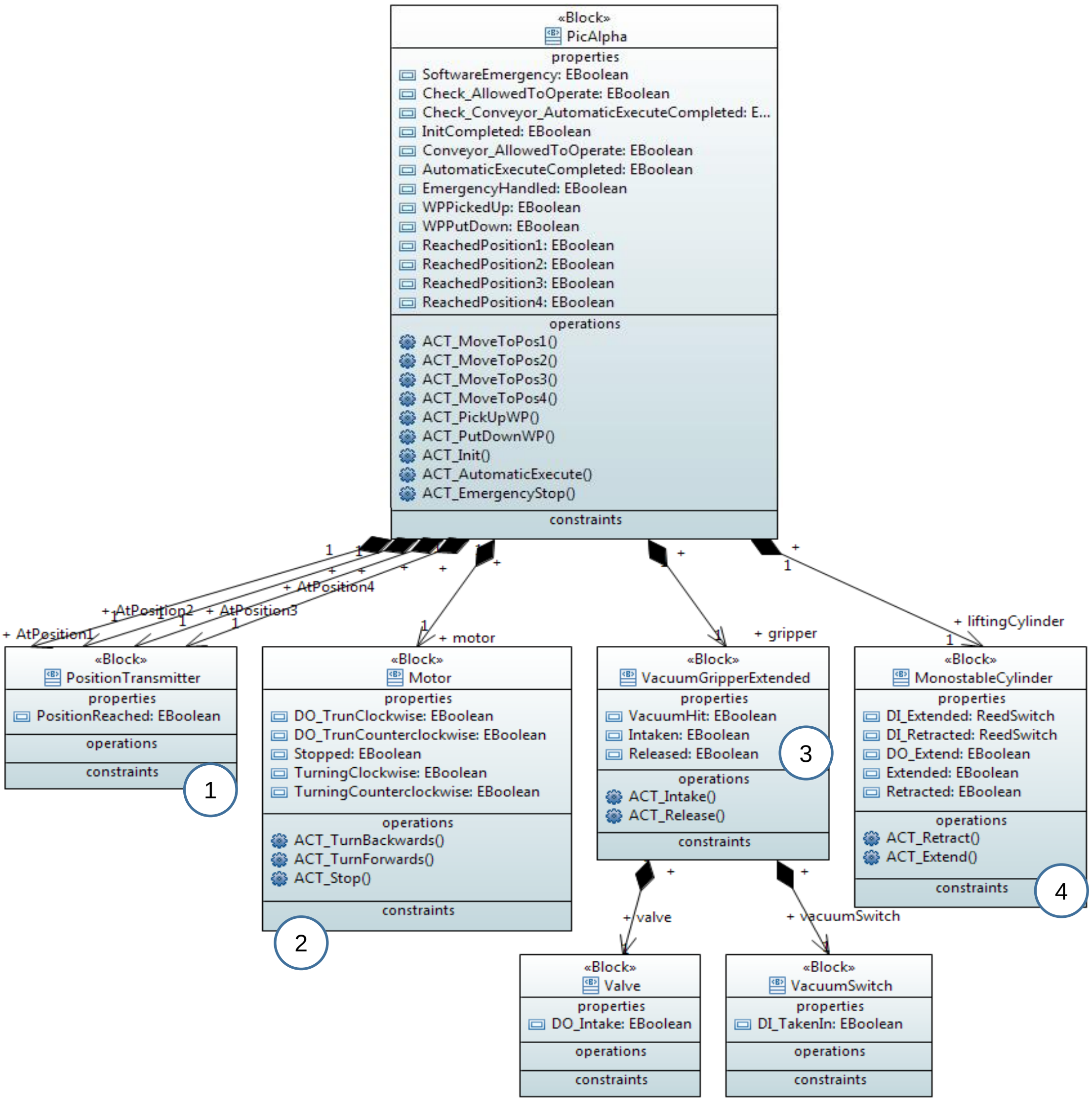

Fig. 37. Overview of the PicAlpha's structure in Scenario Sc16

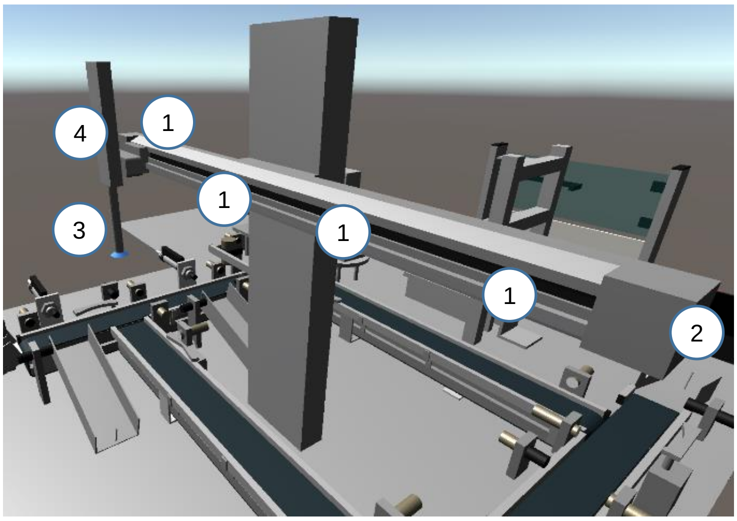

Fig. 38. 3D representation of PicAlpha's components in Scenario Sc16

Table 7. Component list of the PicAlpha in Scenario Sc16

Posi-tion	Resource	Clamp	Description	Component	Type
8	800	X8	PicAlpha		
800	800A1	X8.1	Extend lifting cylinder (Valve)	PicAlpha	DO
800	800B2	X8.2	Lifting cylinder extended (Reed Switch)	PicAlpha	DI
800	800B3	X8.3	Lifting cylinder retracted (Reed Switch)	PicAlpha	DI
800	800A4	X8.4	Intake work piece (Valve)	PicAlpha	DO
800	800A5	X8.5	Release work piece (Valve)	PicAlpha	DO
800	800A6	X8.6	Vacuum Hit (Valve)	PicAlpha	DO
800	800B7	X8.7	WP taken in (Vacuum Switch)	PicAlpha	DI
800	800S8	X8.8	PicAlpha at Position 1 (Position Transmitter)	PicAlpha	DI
800	800S9	X8.9	PicAlpha at Position 2 (Position Transmitter)	PicAlpha	DI
800	800S10	X8.10	PicAlpha at Position 3 (Position Transmitter)	PicAlpha	DI
800	800S11	X8.11	PicAlpha at Position 4 (Position Transmitter)	PicAlpha	DI
800	800A12	X8.12	Turn forwards (Motor)	PicAlpha	DO
800	800A13	X8.13	Turn backwards (Motor)	PicAlpha	DO

4.3.2 xPPU’s behavior in Scenario Sc16

In the following subsections, the xPPU’s behavior, i.e. the initialization behavior, the automatic operation mode behavior and the emergency stop behavior of the xPPU, is described.

4.3.2.1 Initialization behavior in Scenario Sc16

The xPPU is started by pressing one of the three available start buttons at the operation panels. In Fig. 39, the main initialization state chart is given. The PicAlpha’s initialization is allowed after the initialization of the crane is done. Afterwards, it is checked whether a work piece is still picked up by the vacuum gripper. If so, the PicAlpha puts the work piece down. This procedure is visualized in Fig. 40. Afterwards, the LSC is initialized together with the PAC, the SSC and the RC and they operate for a short period. In case of an existing work piece on the LSC, the work piece is transported to the PAC and stopped at the switch. If work pieces exist at the PAC after the switch, it is instead transported to the SSC. Afterwards, the SSC transports the work pieces to the RC and stops them at the switch. Finally, the stack is initialized. A green lamp at each operation panel indicates a successful initialization.

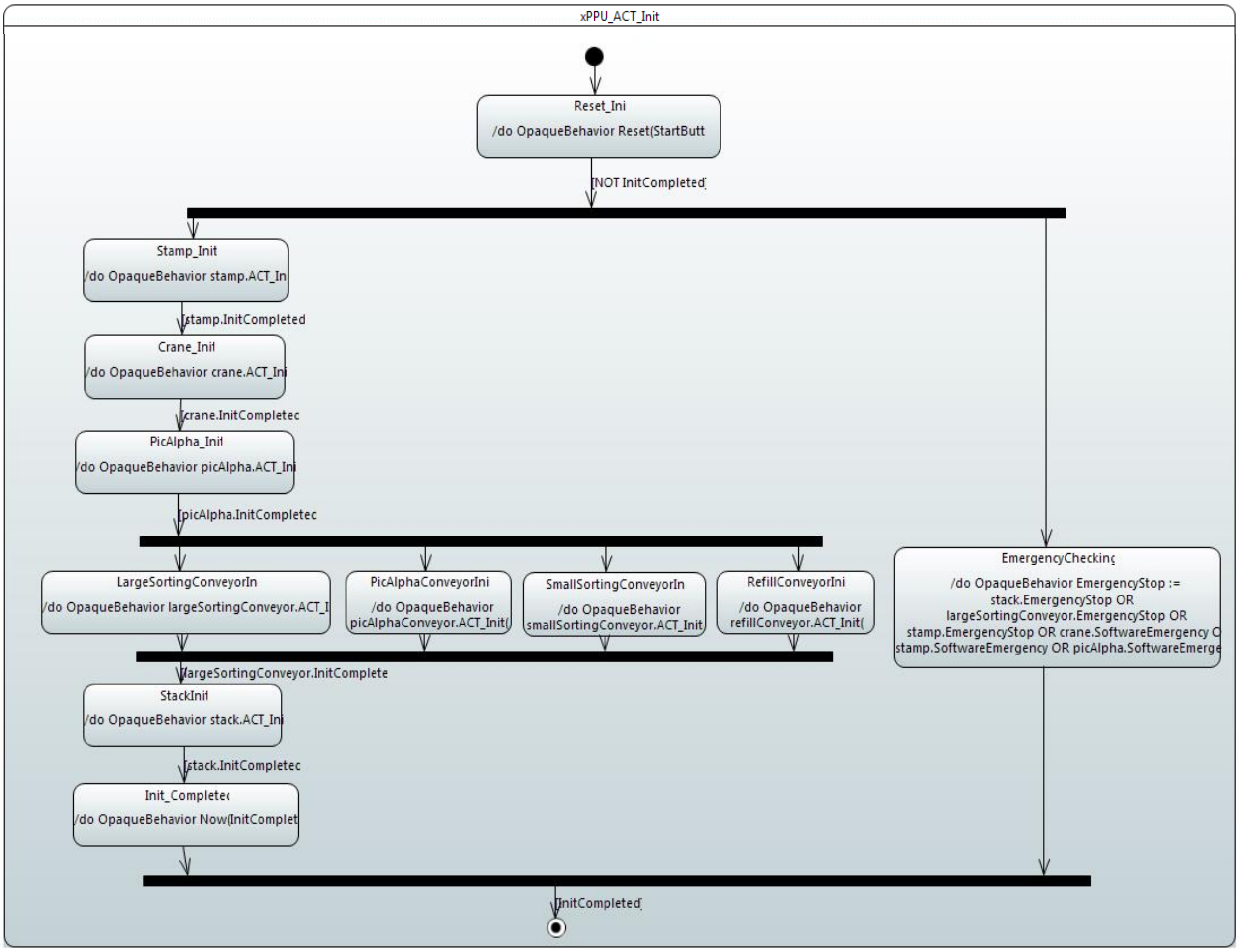

Fig. 39. xPPU’s initialization procedure in Scenario Sc16

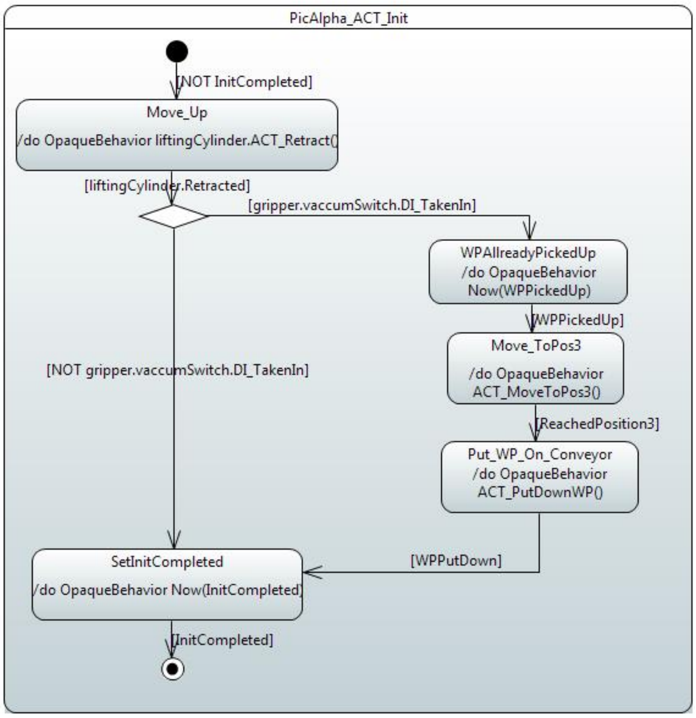

Fig. 40. PicAlpha’s initialization procedure in Scenario Sc16

4.3.2.2 Automatic operation mode behavior in Scenario Sc16

Six types of work pieces are used in this scenario and handled differently by the xPPU: black work pieces are directly transported to the LSC, whereas all types of metallic and white plastic work pieces are firstly stamped and afterwards transported to the LSC. Additionally, the crane shows a different behavior for heavier metallic work pieces due to their increased oscillation behavior after a stop of the crane.

After startup, one of the work pieces stored in the stack is separated and pushed to the pickup position of the crane. In order to ensure the correct position of the work piece, the separating cylinder of the stack remains extended. As soon as a work piece is detected by the digital micro switch at the stack's pickup position, the crane starts turning clockwise and stops at the stack's position. At this time, the weight of the work piece is measured and classified as one of three types: light, medium or heavy. The crane has to turn 90°-counterclockwise to transport black work pieces from the stack directly to the LSC. For white plastic and all metallic work pieces, the crane has to turn 180°-counterclockwise to place work pieces at the stamp. An inductive sensor, whose value is true for metallic work pieces, is used to determine the specific kind of the extended work piece at the extension position of the stack. An optical sensor, whose value is true for white work pieces, is used to determine the specific color of the extended work piece at the pickup position. A weight sensor is used to measure the different weight of the metallic work pieces. The crane then picks up the work piece by using the vacuum gripper, lifts, turns to the desired position, lowers, and deposits the work piece at the respective place.Heavy work pieces are put down after 2 seconds and medium work pieces are put down after one second, whereas light work pieces are handled immediately.

Black work pieces are directly transported to the LSC. Due to the additional conveyors extended in this scenario, the crane shows a different behavior. Before moving to the LSC to put down the work piece, the crane checks if the RC is sending work pieces to the LSC for reprocessing in order to avoid collisions when placing the black work piece at the LSC. If the RC is not sending work pieces to the LSC, the crane places the work piece right away. In case the RC is sending a work piece to the LSC, the crane waits for the LSC to finish sorting the work piece and then places the work piece at the LSC. Metallic and white plastic work pieces run through an additional process at the stamp. Metallic and white plastic work pieces are delivered by the crane at the magazine slider of the stamp. The magazine slider retracts and extends the work pieces to and from beneath the stamp. As soon as the retraction is detected, the stamp is lowered for a certain time and with a fixed pressure – depending on the type of work piece detected – raised by setting the 'lower command' to false, and followed by the extension of the slider. As soon as the magazine slider is retracted, a pressure profile is selected. Based on the different weights the stamping pressure of the work pieces is adjusted. Light work pieces are automatically stamped with a light pressure of 4.0 bar, medium work pieces are stamped with a pressure of 5.5 bar and heavy work pieces are stamped with a high-pressure load of 7.0 bar.

After the metallic or white plastic work piece is placed at the magazine slider, simultaneously the crane is raised and the presence of a black work piece at the stack is checked. If a black work piece is available at the stack, the crane uses the stamping time and starts turning clockwise to pick up the black piece, checks the RC and afterwards places it at the LSC, when the RC is not transporting work pieces. After depositing the work piece at the LSC, it is checked whether the stamping process is finished and whether another black work piece is at the stack. As long as the stamping process is in progress, all available black work pieces are transported to the LSC. However, as soon as the stamping process is completed, the crane handles the stamped metallic or white plastic work piece from the stamp and deposits it at LSC prior to picking up another work piece at the stack's pickup position. If the next available work piece at the stack is a metallic or white plastic piece, while the stamping is still in progress, the crane waits at the stamp until the stamping process is finished. Depending on the time needed for the stamping process, a certain number of black work pieces can be handled until the stamping is finished and the stamped work piece is transported. After the crane either placed a black, white or a metallic work piece at the LSC, the crane moves back to the pickup position at the stack or to the stamp.

Once the work piece is placed on the LSC, it is transported forwards until it is detected by a presence sensor. As soon as the work piece reaches the first pair of opposing optical (diffuse sensor – true for light-reflecting) and inductive (true for metallic) sensors, located shortly before the first ramp, the specific kind of the work piece is determined. With the installed sensors, it is possible to detect which type of work piece is currently being transported by the LSC. After determining the specific kind of the work piece, the white work pieces (optical true, inductive false), the metallic work pieces (optical true, inductive true) and the black work pieces (optical false, inductive false) are handled differently. Once the black work piece is detected, the switch implemented before the second ramp at the LSC is extended in order to transport the black work piece to the PAC, see the LSC behavior in Fig. 32. White work pieces are sorted to the first ramp and metallic work pieces are sorted to the ramp mounted at the end of the LSC. When the latter ramp is full, metallic work pieces are sorted to the second ramp. If the first and second ramp are full, the metallic and white work pieces are transported to the PAC.

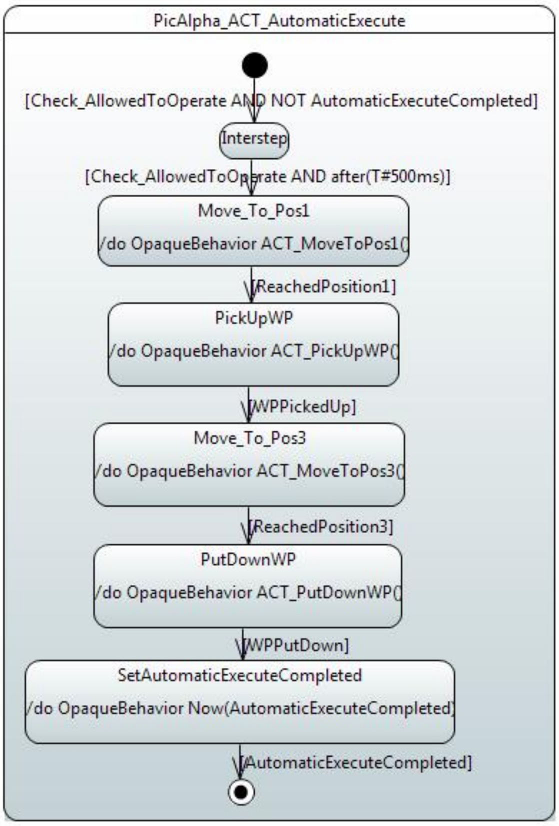

Fig. 41. PicAlpha’s automatic behavior in Scenario Sc16

With the implementation of the PicAlpha module in this scenario, the middle work pieces waiting at the switch can jump in position. The PicAlpha, therefore, has the ability to move its vacuum gripper between two positions detected by position transmitters. The first position is where the middle work piece is placed. Once the handling module is at that position, the cylinder is extended and the work piece is picked up by using the vacuum gripper. Afterwards, the cylinder is retracted again. The handling module then moves to the second position, which is located after the switch on the PAC. The vacuum gripper handling module puts down the work piece by extending the cylinder, turning the vacuum off and giving a short vacuum hit to separate the work piece from the gripper, see Fig. 41 for PicAlpha behavior in this scenario.

The PAC starts working and transporting the work piece to the SSC. After this work piece is sorted the switch is retracted, one work piece is separated and transported to the SSC, see Fig. 42 for the PAC behavior. When the sorting of the work piece is done, the second work piece is transported to the SSC and sorted.

Once the SSC detects a work piece by the presence sensor mounted at the beginning of the SSC, it moves the work piece forwards. The work piece passes the inductive and the optical sensor and, therein, can be detected again. If after a certain time none of the sensors detects anything, the work piece is specified as black. Black work pieces (optical false and inductive false) are transported to the ramp mounted at the end of the SSC, see Fig. 34 for the behavior of the SSC. If the work piece is white or metallic, the switch is extended to sort the work piece to the RC. Once a work piece is sorted to the RC, the conveyor moves the work piece to the switch, where the work piece is stopped.

The presence sensor at the beginning of the RC recognizes whether a work piece is sorted to the RC and counts the work pieces. If three work pieces are at the RC and stopped by the switch the conveyor starts re-feeding the work pieces back to the LSC one by one. The LSC therefore specifies the work piece and sorts it, see Fig. 35 for the behavior of the RC.

If no further work piece is detected at the pickup position, the magazine slider at the stamp is empty and no work piece is present at the conveyors, the plant stops operating. However, there is no separate sensor at the stack to detect the absence of a work piece. Instead, not sending the ‘work piece detected’-signal while the cylinder is extended, indicates the absence of a further object at the pickup position and in the stack. If the sensor detects another work piece, the process will restart at the stack.

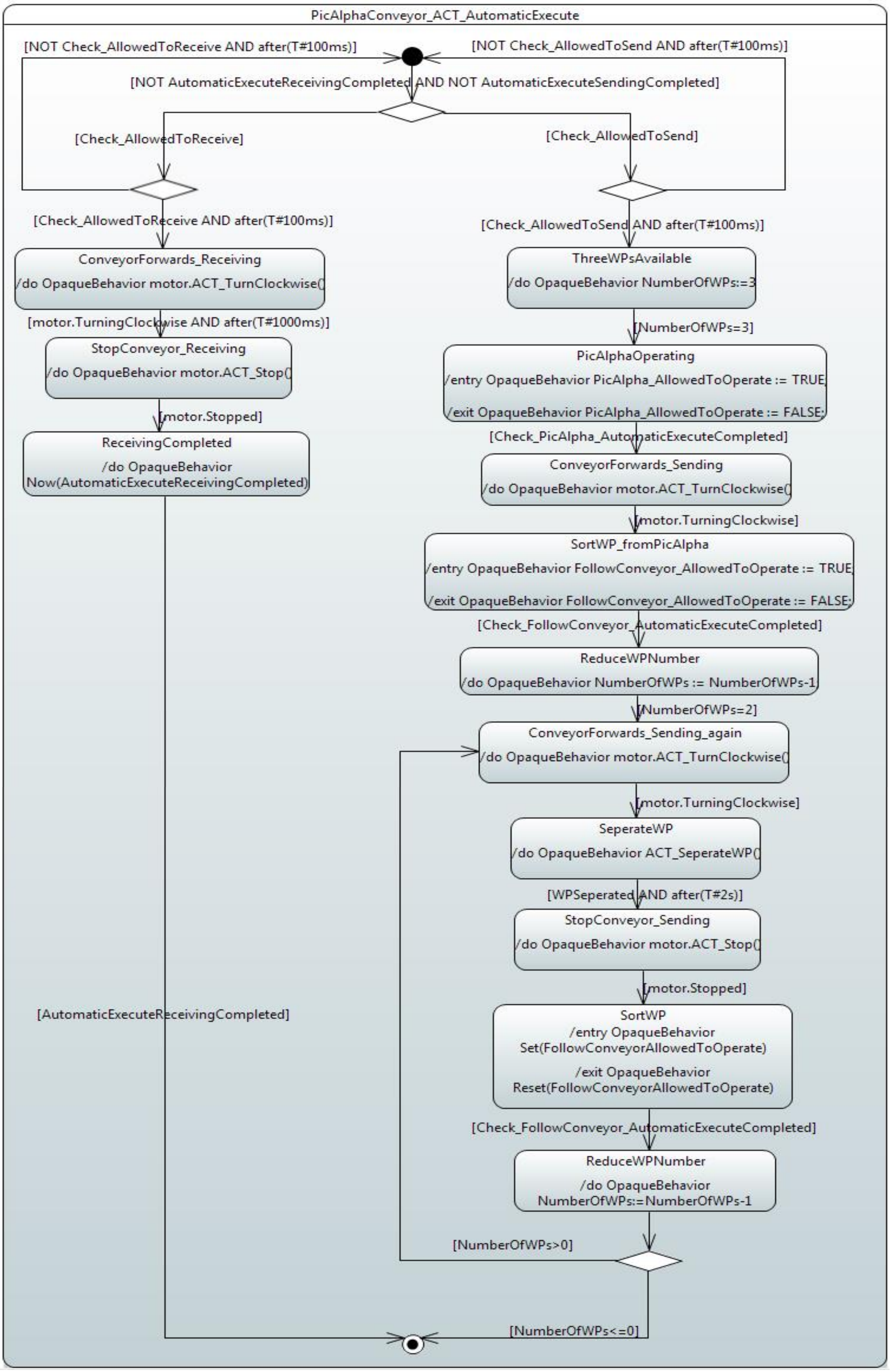

Fig. 42. PAC's automatic behavior in Scenario Sc16

4.3.2.3 Emergency stop behavior in Scenario Sc16

There are three emergency-stop buttons (negative logic), one at the stack, one at the stamp and one at the LSC. In case of an emergency – if at least one emergency button is pushed – the xPPU is set to a safe state. In this safe state, the pneumatic cylinder of the stack is retracted, the crane stops rotating and shuts off the vacuum (if no work piece is gripped), the stamp raises and the magazine slider is extended. Moreover, the pressure of the stamping cylinder is set to zero, the four conveyors are stopped and the pushing cylinders at the LSC are retracted. The PicAlpha module is also stopped and the lifting cylinder is retracted, see Fig. 43.

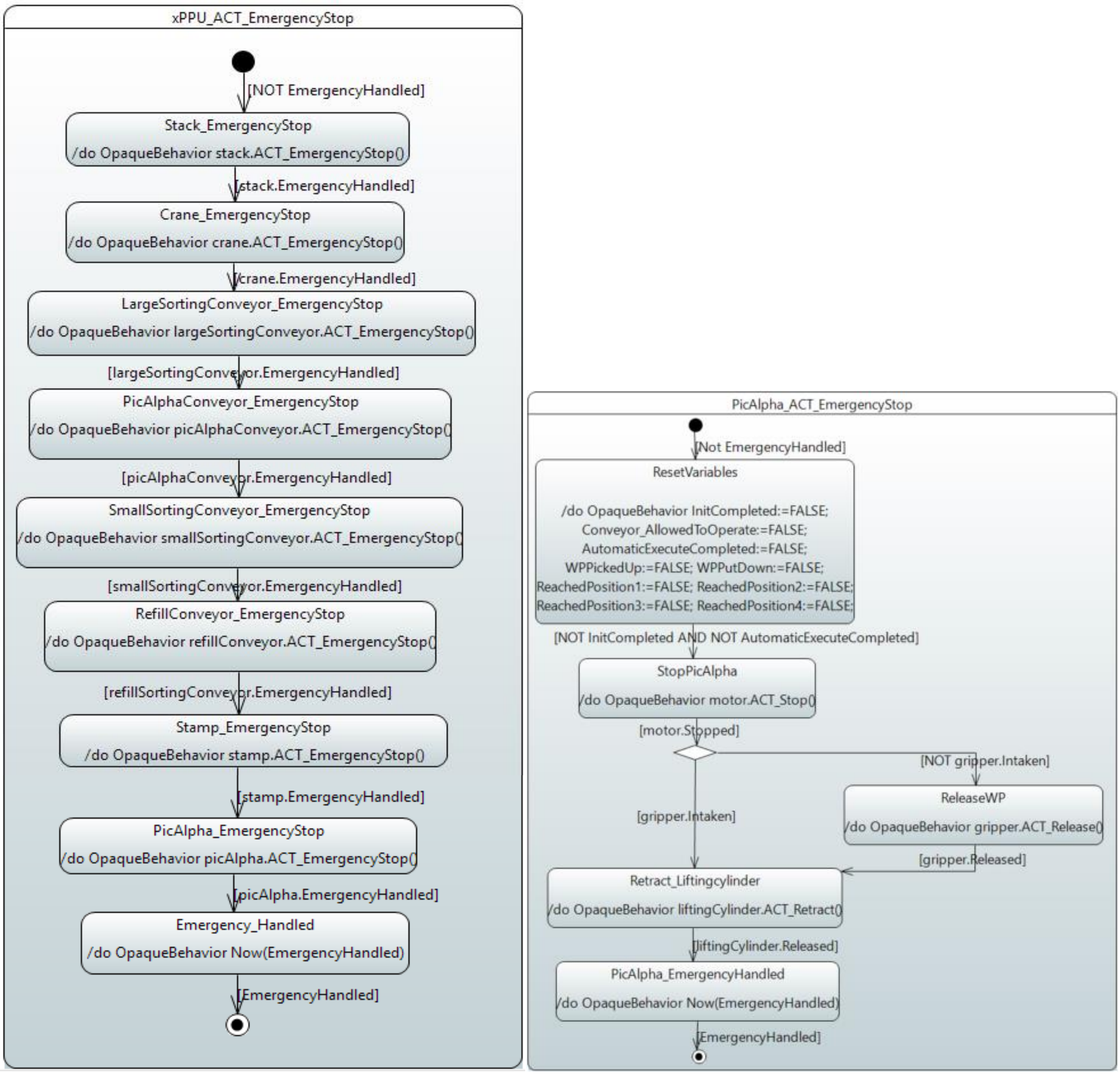

Fig. 43. xPPU's and PicAlpha's emergency behavior in Scenario Sc16

4.4 Scenario Sc17

Within Scenario Sc17, the xPPU consists of a stack working as a work piece input storage and a large sorting conveyor (LSC) and a small sorting conveyor (SSC) working as a transportation component of work piece to output storage, a PicAlpha conveyor (PAC) and a Refill conveyor (RC) enabling re-feeding for post-processing, a stamp for stamping work pieces, a PicAlpha module (PA) enabling the manipulation of the work pieces sequence, a safety door mounted around the stamp module in order to prevent dangerous situations and a crane for transporting work pieces by picking and placing them between the stack, the stamp and the LSC working positions. Moreover, the crane may use the stamp component for buffering purpose. For human interaction, an operation panel provides a start button as well as an emergency stop button.

The xPPU processes six types of work pieces: black plastic work pieces, white plastic work pieces as well as different types of metallic work pieces in this Scenario. One metallic work piece is completely made of brass, one completely made of alloy and two more alloy work pieces have a different lead filling and thus have an increased weight. Black work pieces are separated at the stack and subsequently transported directly to the LSC. In contrast, white plastic work pieces and metallic work pieces are transported from the stack to the stamp, processed there and then transported to the LSC.

The xPPU is able to measure the mass of incoming work pieces using the weighing module integrated into the Stack. This is necessary to handle the dynamic effects of work pieces having different masses during transportation. While heavy work pieces need more time to stop commuting after the crane's rotation, light work pieces are ready for further treatment after a shorter period of time. Hence, to optimize the material flow through the xPPU a weight dependent transportation process has been established. Furthermore, it is not sufficient to stamp light, medium and heavy work pieces with the same pressure due to different mechanical properties; hence, being able to carry out three different processes, one for each weight category, is necessary. For this reason, light, medium and heavy weighing work pieces are stamped using different pressure profiles. Within the LSC, three ramps are used as output storages. Two of the ramps are filled using respective pushing cylinders. A third ramp mounted to the end of the LSC is filled by translationally moving the work piece using the conveyor. In the first ramp, only white work pieces should be sorted. The second ramp is for metallic ones as well as the third. First of all, the metallic work pieces should be sorted into the third ramp. If this ramp is full, the second ramp should be used.

For the implementation of more complex processes as well as the re-feeding of work pieces that are detected as being faulty or not fulfilling the quality requirements, the xPPU has two separator conveyors (i.e. PAC and RC) and another sorting conveyor the SSC. These conveyors enable re-feeding work pieces from the LSC back into other manufacturing process. For further increase in the flexibility of the possible manufacturing processes as well as the performance of the logistic system, i.e. the conveyors of the xPPU, a PicAlpha module is mounted over the PAC and positioned in alignment with the PAC. On the one hand, this increases the performance of the logistic system and on the other hand, this enables the manipulation of the work piece's sequence, i.e. the resorting of work pieces to process.

With the evolution in this scenario, the xPPU is extended with a safety door for prevention of accidents. The mounted hardware incorporates an emergency-stop button as well as additional control elements. An overview of the xPPU in this Scenario is provided in Fig. 44.

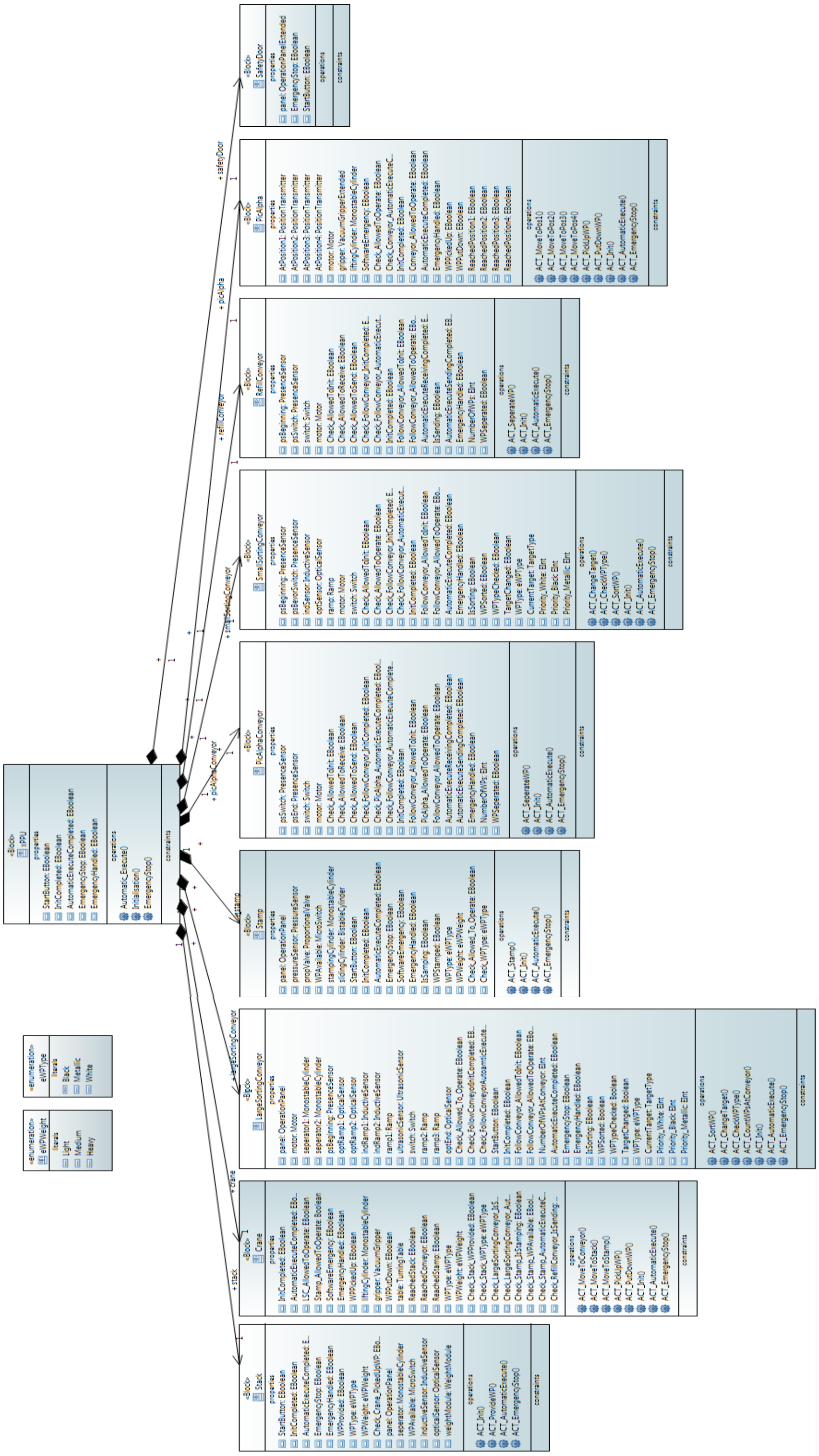

Fig. 44. Overview of the xPPU's structure in Scenario Sc17

4.4.1 xPPU's structure in Scenario Sc17

In the following subsections, the xPPU's structure, i.e. the composition of the xPPU from its components, is described.

4.4.1.1 Stack's structure in Scenario Sc17

The stack of the xPPU in Scenario Sc17 is the same as in Scenario Sc14. Therefore, for a description of the stack's structure, see section 3.1.1.1.

4.4.1.2 Crane's structure in Scenario Sc17

The crane of the xPPU in Scenario Sc17 is the same as in Scenario Sc13 [1].

4.4.1.3 Stamp's structure in Scenario Sc17

The stamp of the xPPU in Scenario Sc17 is the same as in Scenario Sc13 [1].

4.4.1.4 Large sorting conveyor's structure in Scenario Sc17

The large sorting conveyor of the xPPU in Scenario Sc17 is the same as in Scenario Sc15. Therefore, for a description of the large sorting conveyor's structure, see section 3.2.1.4.

4.4.1.5 PicAlpha conveyor's structure in Scenario Sc17

The PicAlpha conveyor of the xPPU in Scenario Sc17 is the same as in Scenario Sc15. Therefore, for a description of the PicAlpha conveyor's structure, see section 3.2.1.5.

4.4.1.6 Small sorting conveyor's structure in Scenario Sc17

The small sorting conveyor of the xPPU in Scenario Sc17 is the same as in Scenario Sc15. Therefore, for a description of the small sorting conveyor's structure, see section 3.2.1.6.

4.4.1.7 Refill conveyor's structure in Sc17

The refill conveyor of the xPPU in Scenario Sc17 is the same as in Scenario Sc15. Therefore, for a description of the refill conveyor's structure, see section 3.2.1.7.

4.4.1.8 PicAlpha's structure in Scenario Sc17

The PicAlpha of the xPPU in Scenario Sc17 is the same as in Scenario Sc16. Therefore, for a description of the PicAlpha's structure, see section 3.3.1.8.

4.4.1.9 Safety door's structure in Scenario Sc17

The safety door comprises a mechanical door and an extended panel. Therefore, the panel has the same mechanical modules as the panels placed at the stack, the stamp and the LSC, but is also extended with a reset button (no. 1) and two extra buttons, Q1 (no. 2) and Q2 (no. 3) (see Fig. 45). The reset button allows to reset the safety relay connected to the safety door. This needs to be done every time the door was opened and closed again.

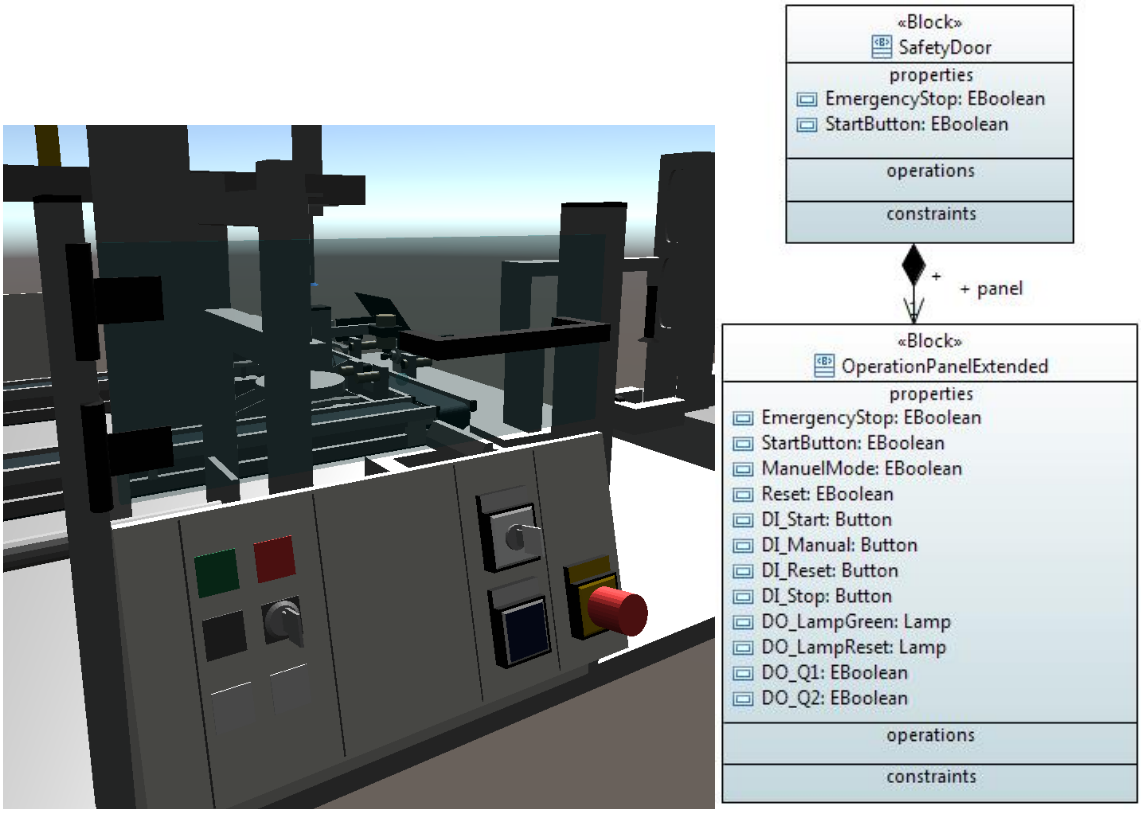

Fig. 45. Overview of the Safety door's structure in Scenario Sc17

Table 8. Component list of the Safety door in Scenario Sc17

Posi-tion	Resource	Clamp	Description	Component	Type
9	900	X9	Safety door		
900	900B1	X9.1	Start button (Button)	Safety door	DI
900	900B2	X9.2	Stop button (Button)	Safety door	DI
900	900B3	X9.3	Manuel button (Button)	Safety door	DI
900	900B4	X9.4	Reset button (Button)	Safety door	DI
900	900A5	X9.5	Lamp Green (Lamp)	Safety door	DO
900	900A6	X9.6	Lamp Reset (Lamp)	Safety door	DO
900	900A7	X9.7	Q1 (Button)	Safety door	DO
900	900A8	X8.8	Q2 (Button)	Safety door	DO

4.4.2 xPPU's behavior in Scenario Sc17

In the following subsections, the xPPU's behavior, i.e. the initialization behavior, the automatic operation mode behavior and the emergency stop behavior of the xPPU, is described.

4.4.2.1 Initialization behavior in Scenario Sc17

The xPPU is started by pressing one of four available start buttons, three of which are located at the operation panels, while the fourth is on the safety door panel. The initialization behavior of the xPPU in Scenario Sc17 is the same as in Scenario Sc16. Therefore, for a description of the xPPU's initialization behavior, see section 3.3.2.1.

4.4.2.2 Automatic operation mode behavior in Scenario Sc17

The xPPU's automation operation mode behavior in Scenario Sc17 is the same as in Scenario Sc16. Therefore, for a description of the xPPU's automatic operation mode behavior, see section 3.3.2.2.

4.4.2.3 Emergency stop behavior in Scenario Sc17

There are four emergency buttons (negative logic), one at the stack, one at the stamp, one at the LSC, and one at the safety door. In case of an emergency – if at least one emergency button is pushed or the safety door is opened – the xPPU is set to a safe state. The emergency button of the safety door as well as the sensor for an open safety door are not connected to any clamp. They are connected right away with a safety relay. The safety relay causes a power off. In this safe state, the pneumatic cylinder of the stack is retracted, the crane stops rotating and shuts off the vacuum (if no work piece is gripped), the stamp raises and the magazine slider is extended. Moreover, the pressure of the stamping cylinder is set to zero, the four conveyors are stopped and the pushing cylinders at the LSC are retracted. The PA module is also stopped, the work piece is released and the lifting cylinder is retracted.

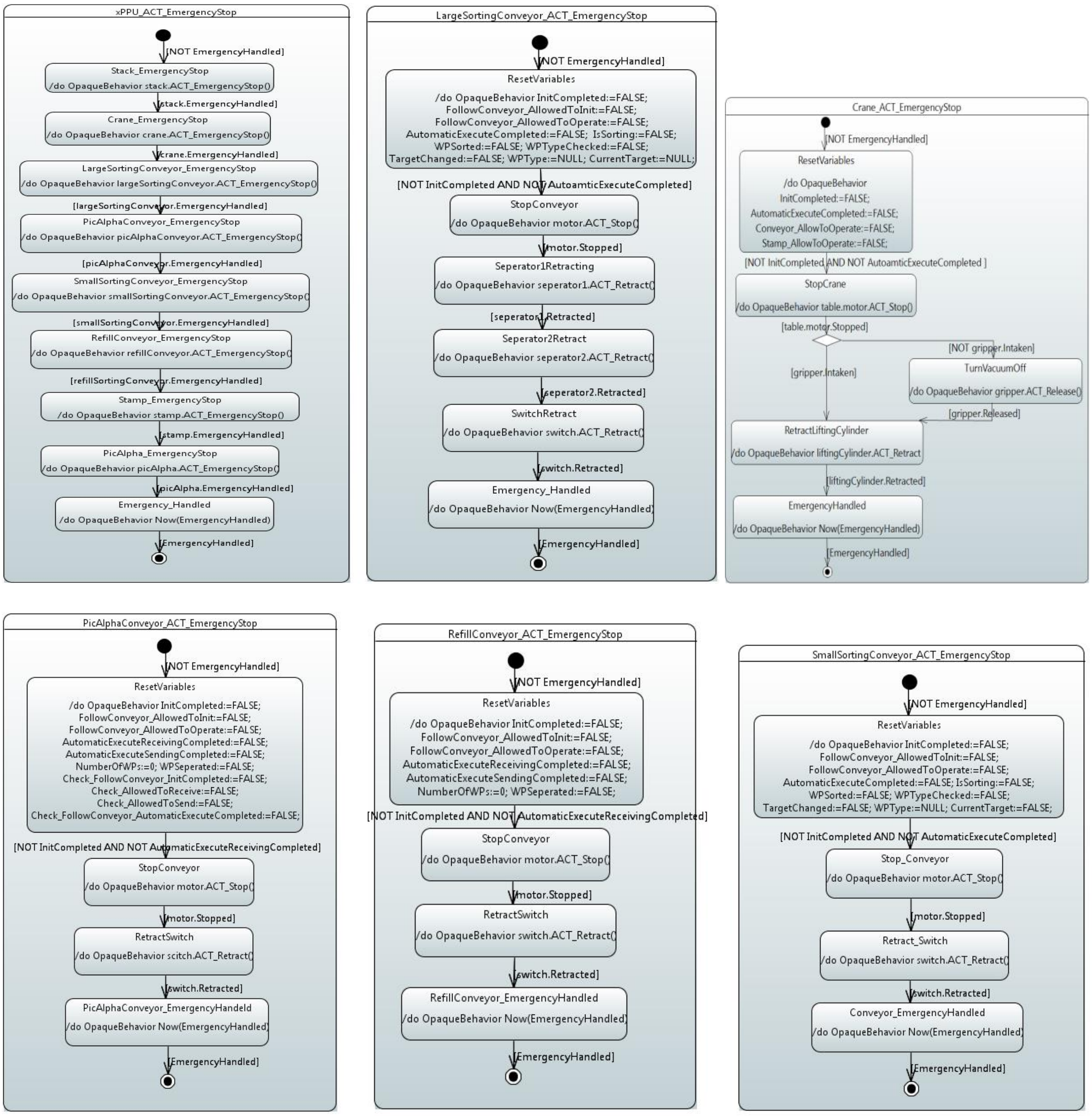

Fig. 46. xPPU's and modules emergency behavior in Scenario Sc17

4.5 Scenario Sc18

Within the Scenario Sc18, the xPPU consists of a stack working as a work piece input storage, a large sorting conveyor (LSC) and a small sorting conveyor (SSC) working as a transportation component of work piece to output storage, a PicAlpha conveyor (PAC) and a Refill conveyor (RC) enabling re-feeding for post-processing, a stamp for stamping work pieces, a PicAlpha module (PA) enabling the manipulation of the work pieces sequence, a light grid mounted around the PA module together with a safety door mounted around the stamp module in order to prevent dangerous situations and a crane for transporting work pieces by picking and placing them between the stack, the stamp and the LSC working positions. Moreover, the crane may use the stamp component for buffering purpose. For human interaction, an operation panel provides a start button as well as an emergency stop.

The xPPU processes six types of work pieces: black plastic work pieces, white plastic work pieces as well as different types of metallic work pieces in this Scenario. One metallic work piece is completely made of brass, one completely made of alloy and two more alloy work pieces have a different lead filling and thus have an increased weight. Black work pieces are separated at the stack and subsequently transported directly to the LSC. In contrast, white plastic work pieces and metallic work pieces are transported from the stack to the stamp, processed there and then transported to the LSC.

The xPPU is able to measure the mass of incoming work pieces using the weighing module integrated into the Stack. This is necessary to handle the dynamic effects of work pieces having different masses during transportation. While heavy work pieces need more time to stop commuting after the crane’s rotation, light work pieces are ready for further treatment after a shorter period of time. Hence, to optimize the material flow through the xPPU a weight dependent transportation process has been established. Furthermore, it is not sufficient to stamp light, medium and heavy work pieces with the same pressure due to different mechanical properties; hence, being able to carry out three different processes, one for each weight category, is necessary. For this reason, light, medium and heavy weighing work pieces are stamped using different pressure profiles. Within the LSC, three ramps are used as output storages. Two of the ramps are filled using respective pushing cylinders. A third ramp mounted to the end of the LSC is filled by translationally moving the work pieces using the conveyor. In the first ramp, only white work pieces should be sorted. The second ramp is for metallic ones as well as the third. First of all, the metallic work pieces should be sorted into the third ramp. If this ramp is full, the second ramp should be used.

For the implementation of more complex processes as well as the re-feeding of work pieces that are detected as being faulty or not fulfilling the quality requirements, the xPPU has two separator conveyors (i.e. PAC and RC) and another sorting conveyor the SSC. These conveyors enable re-feeding work pieces from the LSC back into other manufacturing process. For further increase in the flexibility of the possible manufacturing processes as well as the performance of the logistic system, i.e. the conveyors of the xPPU, a PicAlpha module is mounted over the PAC and positioned in alignment with PAC. On the one hand, this increases the performance of the logistic system and on the other hand, this enables the manipulation of the work piece’s sequence, i.e. the resorting of work pieces to process.

A safety door for the prevention of accidents together with a light grid (i.e. the evolution in this scenario) are mounted to the xPPU. The mounted hardware incorporates an emergency-stop button as well as additional control elements.

4.5.1 xPPU’s structure in Scenario Sc18

In the following subsections, the xPPU’s structure, i.e. the composition of the xPPU from its components, is described.

4.5.1.1 Stack’s structure in Scenario Sc18

The stack of the xPPU in Scenario Sc18 is the same as in Scenario Sc14. Therefore, for a description of the stack’s structure, see section 3.1.1.1.

4.5.1.2 Crane’s structure in Scenario Sc18

The crane of the xPPU in Scenario Sc18 is the same as in Scenario Sc13 [1].

4.5.1.3 Stamp’s structure in Scenario Sc18

The stamp of the xPPU in Scenario Sc18 is the same as in Scenario Sc13 [1].

4.5.1.4 Large sorting conveyor’s structure in Scenario Sc18

The LSC of the xPPU in Scenario Sc18 is the same as in Scenario Sc15. Therefore, for a description of the large sorting conveyor’s structure, see section 3.2.1.4.

4.5.1.5 PicAlpha conveyor’s structure in Scenario Sc18

The PicAlpha conveyor of the xPPU in Scenario Sc18 is the same as in Scenario Sc15. Therefore, for a description of the PicAlpha conveyor’s structure, see section 3.2.1.5.

4.5.1.6 Small sorting conveyor’s structure in Scenario Sc18

The small sorting conveyor of the xPPU in Scenario Sc18 is the same as in Scenario Sc15. Therefore, for a description of the small sorting conveyor’s structure, see section 3.2.1.6.

4.5.1.7 Refill conveyor’s structure in Sc18

The refill conveyor of the xPPU in Scenario Sc18 is the same as in Scenario Sc15. Therefore, for a description of the refill conveyor’s structure, see section 3.2.1.7.

4.5.1.8 PicAlpha’s structure in Scenario Sc18

The PicAlpha of the xPPU in Scenario Sc18 is the same as in Scenario Sc16. Therefore, for a description of the PicAlpha’s structure, see section 3.3.1.8.

4.5.1.9 Safety door’s structure in Scenario Sc18

The safety door of the xPPU in Scenario Sc18 is the same as in Scenario Sc17. Therefore, for a description of the safety door’s structure, see section 3.4.1.9.

4.5.1.10 Light grid's structure in Scenario Sc18

The light grid comprises multiple light detectors observing any movement in the grid and an extended panel. Therefore, the panel has the same mechanical modules as the panels placed at the stack, the stamp, and the LSC with start, manual/automatic and stop buttons, but is also extended with a reset button (no. 1) and two extra buttons, Q1 (no. 2) and Q2 (no. 3) (see Fig. 47). The reset button allows to reset the safety relay connected to the light grid. This needs to be done every time the light grid was intermitted.

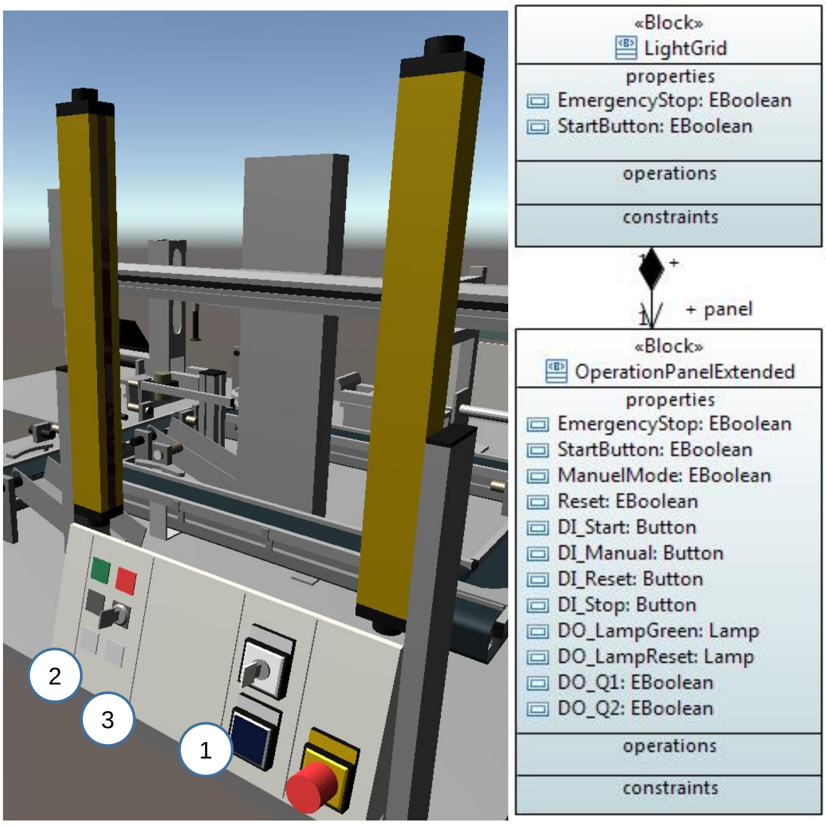

Fig. 47. Overview of the Light grid's structure in Scenario Sc18

4.5.2 xPPU's behavior in Scenario Sc18

In the following subsections, the xPPU's behavior, i.e. the initialization behavior, the automatic operation mode behavior and the emergency stop behavior of the xPPU, is described.

4.5.2.1 Initialization behavior in Scenario Sc18

The xPPU is started by pressing one of five available start buttons, three of which are located at the operation panels, while the other two are on the safety door panel and the light grid panel. The initialization behavior of the xPPU in Scenario Sc18 is the same as in Scenario Sc16. Therefore, for a description of the xPPU's initialization behavior, see section 3.3.2.1.

4.5.2.2 Automatic operation mode behavior in Scenario Sc18

The xPPU's automatic operation mode behavior in Scenario Sc18 is the same as in Scenario Sc16. Therefore, for a description of the xPPU's automatic operation mode behavior, see section 3.3.2.2.

4.5.2.3 Emergency stop behavior in Scenario Sc18

There are five emergency stop buttons (negative logic), one at the stack, one at the stamp, one at the conveyor, one at the safety door and one at the light grid. In case of an emergency – if at least one emergency-stop button is pushed, the safety door is opened or the light grid is intermitted – the xPPU is set to a safe state. The emergency stop button as well as the sensor for an open safety door are not connected to any clamp. They are connected right away with a safety relay. The safety relay causes a power off. However, the emergency button of the light grid is connected to a clamp and, therefore, can be read by the program. In this safe state, the pneumatic cylinder of the stack is retracted, the crane stops rotating and shuts off the vacuum (if no work piece is gripped), the stamp raises and the magazine slider is extended. Moreover, the pressure of the stamping cylinder is set to zero, the four conveyors are stopped and the pushing cylinders at the LSC are retracted. The PA module is also stopped, the work piece is released and the lifting cylinder is retracted.

4.6 Scenario Sc19

Within the Scenario Sc19, the xPPU consists of a stack working as a work piece input storage, a large sorting conveyor (LSC) and a small sorting conveyor (SSC) working as a transportation component of work piece to output storage, a PicAlpha conveyor (PAC) and a Refill conveyor (RC) enabling re-feeding for post-processing, a stamp for stamping work pieces, a PicAlpha module (PA) enabling the manipulation of the work pieces sequence, a light grid mounted around the PA module together with a safety door mounted around the stamp module to prevent dangerous situations and a crane for transporting work pieces by picking and placing them between the stack, the stamp and the LSC working positions. Moreover, the crane may use the stamp component for buffering purposes. For human interaction, an operation panel provides a start button as well as an emergency stop button.

The xPPU processes six types of work pieces: black plastic work pieces, white plastic work pieces as well as different types of metallic work pieces in this Scenario. One metallic work piece is completely made of brass, one completely made of alloy and two more alloy work pieces have a different lead filling and thus have an increased weight. Black work pieces are separated at the stack and subsequently transported directly to the LSC. In contrast, white plastic work pieces and metallic work pieces are transported from the stack to the stamp, processed there and then transported to the LSC.

The xPPU is able to measure the mass of incoming work pieces using the weighing module integrated into the Stack. This is necessary to handle the dynamic effects of different weighing work pieces during transportation. While heavy work pieces need more time to stop commuting after the crane's rotation, light work pieces are ready for further treatment after a shorter period of time. Hence, to optimize the material flow through the xPPU a weight dependent transportation process has been established. Furthermore, it is not sufficient to stamp lightweight, medium and heavyweight work pieces with the same pressure due to different mechanical properties; hence, being able to carry out three different processes, one for each weight category, is necessary. For this reason, light, medium and heavy work pieces are stamped using different pressure profiles. Within the LSC, three ramps are used as output storages. Two of the ramps are filled using respective pushing cylinders. A third ramp mounted to the end of the LSC is filled by translationally moving the work piece using the conveyor. In the first ramp, only white work pieces should be sorted. The second and third ramp are for metallic ones. First of all, the metallic work pieces should be sorted into the third ramp. If this ramp is full, the second ramp should be used.

For the implementation of more complex processes as well as the re-feeding of work pieces that are detected as being faulty or not fulfilling the quality requirements, the xPPU has two separator conveyors (i.e. PAC and RC) and another sorting conveyor, the SSC. These conveyors enable re-feeding work pieces from the LSC back into other manufacturing process. For further increase in the flexibility of the possible manufacturing processes as well as the performance of the logistic system, i.e. the conveyors of the xPPU, a PicAlpha module is mounted over the PAC and positioned in alignment with PAC. On the one hand, this increases the performance of the logistic system and on the other hand, this enables the manipulation of the work piece's sequence, i.e. the resorting of work pieces to process.

A safety door together with a light grid is used for prevention of accidents. The mounted hardware incorporates an emergency-stop button as well as additional control elements. The xPPU in this scenario has an additional button controlling the operation mode and allows the switch between automatic operating mode and additional manual mode. Within the manual mode the operator is allowed to control the xPPU in any required functional sequence.

4.6.1 xPPU's structure in Scenario Sc19

In the following subsections, the xPPU's structure, i.e. the composition of the xPPU from its components, is described.

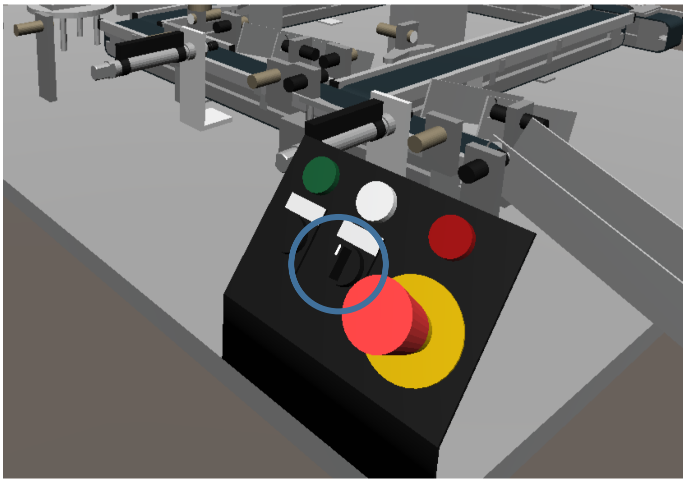

Fig. 48. xPPU's Panel with Operation Mode Selector

4.6.1.1 Stack's structure in Scenario Sc19

The stack of the xPPU in Scenario Sc19 is the same as in Scenario Sc14. Therefore, for a description of the stack's structure, see section 3.1.1.1.

4.6.1.2 Crane's structure in Scenario Sc19

The crane of the xPPU in Scenario Sc19 is the same as in Scenario Sc13 [1].

4.6.1.3 Stamp's structure in Scenario Sc19

The stamp of the xPPU in Scenario Sc19 is the same as in Scenario Sc13 [1].

4.6.1.4 Large sorting conveyor's structure in Scenario Sc19

The large sorting conveyor of the xPPU in Scenario Sc19 is the same as in Scenario Sc15. Therefore, for a description of the large sorting conveyor's structure, see section 3.2.1.4.

4.6.1.5 PicAlpha conveyor's structure in Scenario Sc19

The PicAlpha conveyor of the xPPU in Scenario Sc19 is the same as in Scenario Sc15. Therefore, for a description of the PicAlpha conveyor's structure, see section 3.2.1.5.

4.6.1.6 Small sorting conveyor's structure in Scenario Sc19

The small sorting conveyor of the xPPU in Scenario Sc19 is the same as in Scenario Sc15. Therefore, for a description of the small sorting conveyor's structure, see section 3.2.1.6.

4.6.1.7 Refill conveyor's structure in Sc19

The refill conveyor of the xPPU in Scenario Sc19 is the same as in Scenario Sc15. Therefore, for a description of the refill conveyor's structure, see section 3.2.1.7.

4.6.1.8 PicAlpha's structure in Scenario Sc19

The PicAlpha of the xPPU in Scenario Sc19 is the same as in Scenario Sc16. Therefore, for a description of the PicAlpha's structure, see section 3.3.1.8.

4.6.1.9 Safety door's structure in Scenario Sc19

The safety door of the xPPU in Scenario Sc19 is the same as in Scenario Sc17. Therefore, for a description of the safety door's structure, see section 3.4.1.9.

4.6.1.10 Light grid's structure in Scenario Sc19

The light grid of the xPPU in Scenario Sc19 is the same as in Scenario Sc18. Therefore, for a description of the light grid's structure, see section 3.5.1.10.

4.6.2 xPPU's behavior in Scenario Sc19

In the following subsections, the xPPU's behavior, i.e. the initialization behavior, the automatic operation mode behavior and the emergency stop behavior of the xPPU, is described.

4.6.2.1 Initialization behavior in Scenario Sc19

The xPPU is started by pressing one of five available start buttons, three of which are located at the operation panels, while the other two are on the safety door panel and on the light grid panel. The initialization behavior of the xPPU in Scenario Sc19 is the same as in Scenario Sc16. Therefore, for a description of the xPPU's initialization behavior, see section 3.3.2.1.

4.6.2.2 Automatic operation mode behavior in Scenario Sc19

The xPPU's automatic operation mode behavior in Scenario Sc19 is the same as in Scenario Sc16. Therefore, for a description of the xPPU's automatic operation mode behavior, see section 3.3.2.2.

4.6.2.3 Manual operation mode behavior in Scenario Sc19

With the evolution in this scenario, an additional button was added in order to allow the switch between automatic and manual mode. Once the manual mode is activated, the operator is able to control the xPPU manually and the white and green lights start blinking alternately. The possible functionalities to be controlled manually are: extend and retract all cylinders (except stamping cylinder (pressure set by the software to zero) and manipulation of the vacuum switches), manipulate the movement of the conveyor belts and the PicAlpha module by driving them forwards and backwards. After all mechanical valve switches are turned back to automatic operation mode, the program starts executing the code from the point it was stopped at, before switching to the manual operation mode.

4.6.2.4 Emergency stop behavior in Scenario Sc19

The emergency stop behavior of the xPPU in Scenario Sc19 is the same as in Scenario Sc18. Therefore, for a description of the xPPU's emergency stop behavior, see section 3.5.2.3.

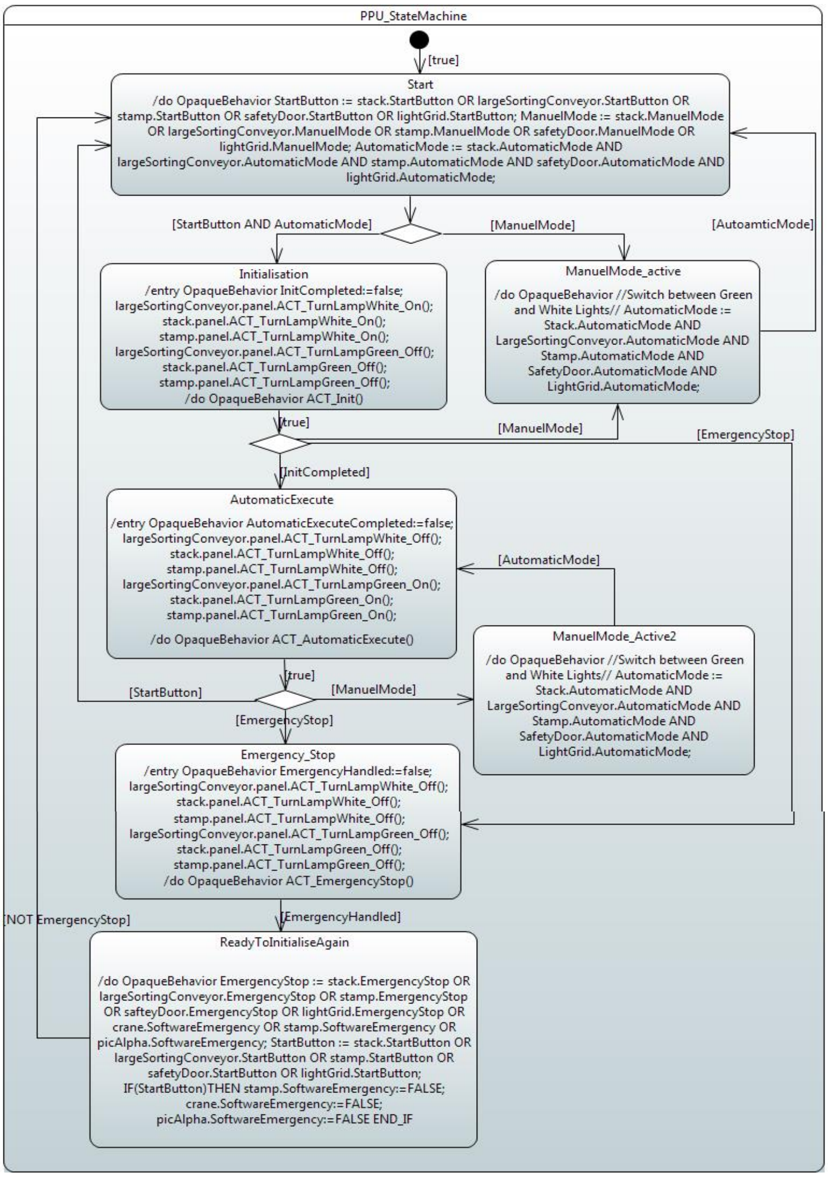

Fig. 49. xPPU's behavior in Scenario Sc19

4.7 Scenario Sc20

Within the Scenario Sc20, the xPPU consists of a stack working as a work piece input storage, a large sorting conveyor (LSC) and a small sorting conveyor (SSC) working as a transportation component of work piece to output storage, a PicAlpha conveyor (PAC) and a Refill conveyor (RC) enabling re-feeding for post-processing, a stamp for stamping work pieces, a PicAlpha module (PA) enabling the manipulation of the work pieces sequence, a light grid mounted around the PA module together with a safety door mounted around the stamp module to prevent dangerous situations and a crane for transporting work pieces by picking and placing them between the stack, the stamp and the LSC working positions. Moreover, the crane may use the stamp component for buffering purposes. For human interaction, an operation panel provides a start button as well as an emergency stop button.

The xPPU processes six types of work pieces: black plastic work pieces, white plastic work pieces as well as different types of metallic work pieces in this Scenario. One metallic work piece is completely made of brass, one completely made of alloy and two more alloy work pieces have a different lead filling and thus have an increased weight. Black work pieces are separated at the stack and subsequently transported directly to the LSC. In contrast, white plastic work pieces and metallic work pieces are transported from the stack to the stamp, processed there and then transported to the LSC.

The xPPU is able to measure the mass of incoming work pieces using the weighing module integrated into the Stack. This is necessary to handle the dynamic effects of different weighing work pieces during transportation. While heavy work pieces need more time to stop commuting after the crane’s rotation, light work pieces are ready for further treatment after a shorter period of time. Hence, to optimize the material flow through the xPPU a weight dependent transportation process has been established. Furthermore, it is not sufficient to stamp light, medium and heavy weighing work pieces with the same pressure due to different mechanical properties; hence, being able to carry out three different processes, one for each weight category, is necessary. For this reason, light, medium and heavy weighing work pieces are stamped using different pressure profiles. Within the LSC, three ramps are used as output storages. Two of the ramps are filled using respective pushing cylinders. A third ramp mounted to the end of the LSC is filled by translationally moving the work piece using the conveyor. In the first ramp, only white work pieces should be sorted. The second ramp is for metallic ones as well as the third. First of all, the metallic work pieces should be sorted into the third ramp. If this ramp is full, the second ramp should be used.

For the implementation of more complex processes as well as the re-feeding of work pieces that are detected as being faulty or not fulfilling the quality requirements, the xPPU has two separator conveyors (i.e. PAC and RC) and another sorting conveyor the SSC. These conveyors enable re-feeding work pieces from the LSC back into other manufacturing process. For further increase in the flexibility of the possible manufacturing processes as well as the performance of the logistic system, i.e. the conveyors of the xPPU, a PicAlpha module is mounted over the PAC and positioned in alignment with PAC. On the one hand, this increases the performance of the logistic system and on the other hand, this enables the manipulation of the work piece’s sequence, i.e. the resorting of work pieces to process.

There is a safety door and a light grid for the prevention of accidents. The mounted hardware incorporates an emergency-stop button as well as additional control elements. An additional button controlling the operation mode allows the operator to switch between automatic operating mode and additional manual mode. Within the manual mode the operator is allowed to control the xPPU in any required functional sequence. An energy monitoring hardware allows to measure the energy consumed by the different clamps. Therefore, three Wattmeter were installed. The electric energy consumed by the plant as well as the air pressure and the air flow through the plant using flow sensors can be monitored. This information can be used to optimize the plant focusing on energy saving aspects. Also, it allows to monitor whether parts consume more energy than usual, what might lead to the conclusion that these parts have to be replaced, due to malfunction. Overview of the xPPU in this Scenario is provided in Fig. 50.

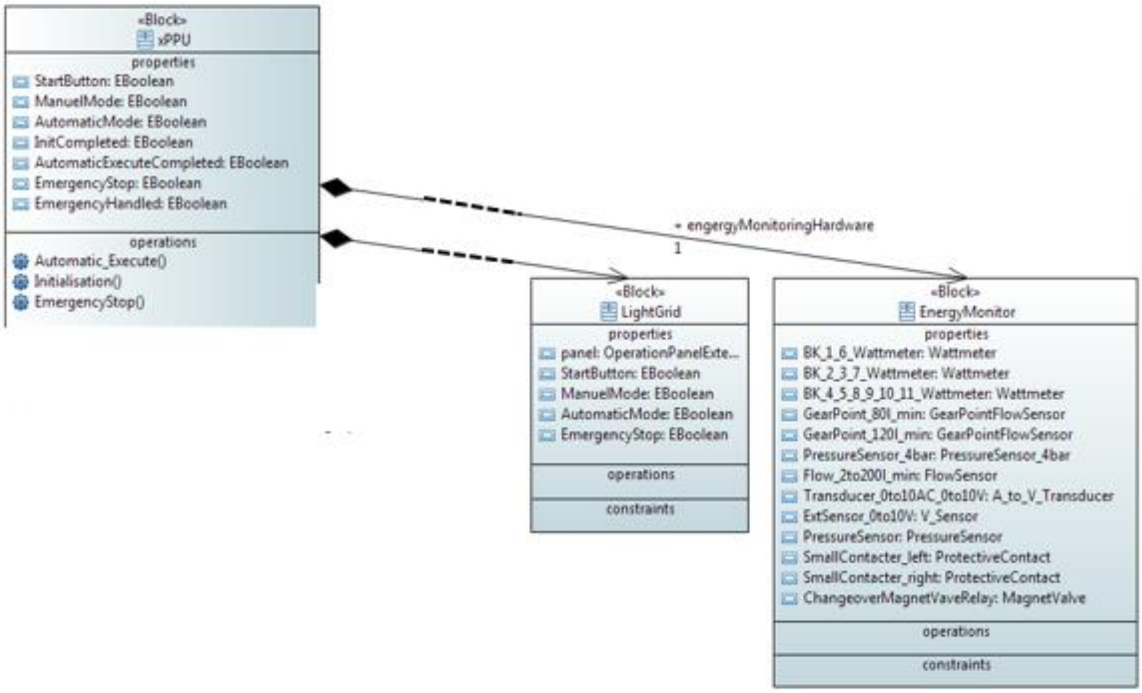

Fig. 50. Excerpt of the xPPU's structure in Scenario Sc20

4.7.1 xPPU’s structure in Scenario Sc20

In the following subsections, the xPPU’s structure, i.e. the composition of the xPPU from its components, is described.

4.7.1.1 Stack’s structure in Scenario Sc20

The stack of the xPPU in Scenario Sc20 is the same as in Scenario Sc14. Therefore, for a description of the stack’s structure, see section 3.1.1.1.

4.7.1.2 Crane’s structure in Scenario Sc20

The crane of the xPPU in Scenario Sc20 is the same as in Scenario Sc13 [1].

4.7.1.3 Stamp’s structure in Scenario Sc20

The stamp of the xPPU in Scenario Sc20 is the same as in Scenario Sc13 [1].

4.7.1.4 Large sorting conveyor’s structure in Scenario Sc20

The large sorting conveyor of the xPPU in Scenario Sc20 is the same as in Scenario Sc15. Therefore, for a description of the large sorting conveyor’s structure, see section 3.2.1.4.

4.7.1.5 PicAlpha conveyor's structure in Scenario Sc20

The PicAlpha conveyor of the xPPU in Scenario Sc20 is the same as in Scenario Sc15. Therefore, for a description of the PicAlpha conveyor's structure, see section 3.2.1.5.

4.7.1.6 Small sorting conveyor's structure in Scenario Sc20

The small sorting conveyor of the xPPU in Scenario Sc20 is the same as in Scenario Sc15. Therefore, for a description of the small sorting conveyor's structure, see section 3.2.1.6.

4.7.1.7 Refill conveyor's structure in Sc20

The refill conveyor of the xPPU in Scenario Sc20 is the same as in Scenario Sc15. Therefore, for a description of the refill conveyor's structure, see section 3.2.1.7.

4.7.1.8 PicAlpha's structure in Scenario Sc20

The PicAlpha of the xPPU in Scenario Sc20 is the same as in Scenario Sc16. Therefore, for a description of the PicAlpha's structure, see section 3.3.1.8.

4.7.1.9 Safety door's structure in Scenario Sc20

The safety door of the xPPU in Scenario Sc20 is the same as in Scenario Sc17. Therefore, for a description of the safety door's structure, see section 3.4.1.9.

4.7.1.10 Light grid's structure in Scenario Sc20

The light grid of the xPPU in Scenario Sc20 is the same as in Scenario Sc18. Therefore, for a description of the light grid's structure, see section 3.5.1.10.

4.7.1.11 Energy Monitor's structure in Scenario Sc20

The energy monitoring module has nine different sensor classes to measure the energy consumed by the xPPU. Three watt meters are available to monitor electric energy consumption. These modules return an analogue value corresponding to the electric energy consumption of clamp blocks. The first wattmeter is responsible for clamp block 1 and 6, the second one for clamp block 2, 3 and 7 and the third one is responsible for every other clamp block. Two gear point sensors are available to detect if the air flow in the xPPU is at 80 liters per minute or at 120 liters per minute. A pressure sensor detects if the air pressure of the xPPU is over 4 bars. An analogue flow sensor returns the current air flow through the xPPU and can measure flows between 2 and 200 liters per minute. With the transducer module it is possible to convert the ampere to volt ratio and with a sensor we can measure the current volt supply. A pressure sensor module returns an analogue value of the current pressure at the xPPU modules. Two protective contacts are also part of the energy monitoring hardware module. The protective contacts can be used to cut out the power for parts that are in the same power circuit as the contactor. With a magnet valve, one of two inputs for air pressure supply can be selected. The different modules can be seen in Fig. 51.

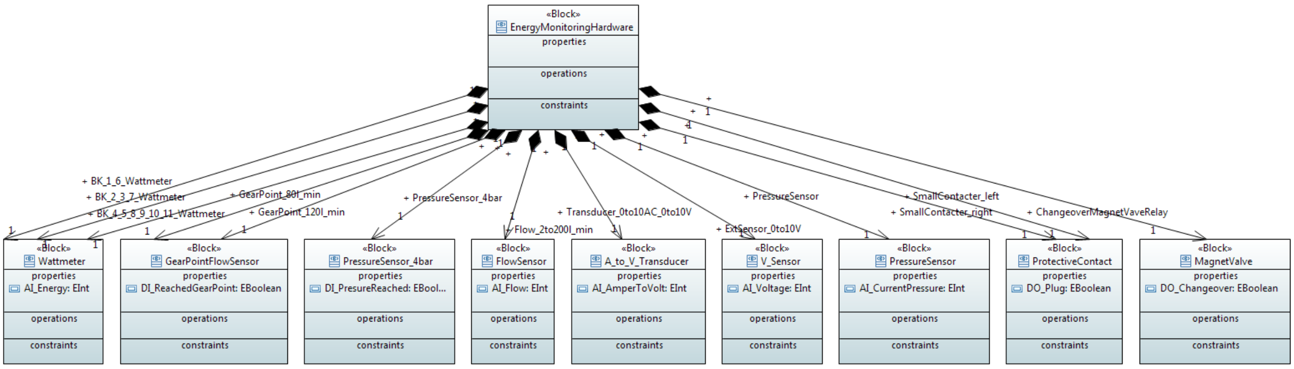

Fig. 51. Overview of the Energy Monitor's structure in Scenario Sc20

4.7.2 xPPU's behavior in Scenario Sc20

The xPPU's behavior in Scenario Sc20 is the same as in Scenario Sc19. Therefore, for a description of the xPPU's behavior see section 3.6.2.

4.8 Scenario Sc21

Within the Scenario Sc21, the xPPU consists of a stack working as a work piece input storage, a large sorting conveyor (LSC) and a small sorting conveyor (SSC) working as a transportation component of work piece to output storage, a PicAlpha conveyor (PAC) and a Refill conveyor (RC) enabling re-feeding for post-processing, a stamp for stamping work pieces, a PicAlpha module (PA) enabling the manipulation of the work pieces sequence, a light grid mounted around the PA module together with a safety door mounted around the stamp module to prevent dangerous situations and a crane for transporting work pieces by picking and placing them between the stack, the stamp and the LSC working positions. Moreover, the crane may use the stamp component for buffering purposes. For human interaction, an operation panel provides a start button as well as an emergency stop button.

The xPPU processes black plastic work pieces and white plastic work pieces as well as metallic work pieces in this Scenario. One metallic work piece is completely made of brass, one completely made of alloy and two more alloy work pieces have a different lead filling and thus have an increased weight. Black work pieces are separated at the stack and subsequently transported directly to the LSC. In contrast, white plastic work pieces and metallic work pieces are transported from the stack to the stamp, processed there and then transported to the LSC.

The xPPU is able to measure the mass of incoming work pieces using the weighing module integrated into the Stack. This is necessary to handle the dynamic effects of work pieces having different masses during transportation. While heavy work pieces need more time to stop commuting after the crane's rotation, light work pieces are ready for further treatment after a shorter period of time. Hence, to optimize the material flow through the xPPU a weight dependent transportation process has been established. Furthermore, it is not sufficient to stamp light, medium and heavy weighing work pieces with the same pressure due to different mechanical properties; hence, being able to carry out three different processes, one for each weight category, is necessary. For this reason, light, medium and heavy work pieces are stamped using different pressure profiles. Within the LSC, three ramps are used as output storages. Two of the ramps are filled using respective pushing cylinders. A third ramp mounted to the end of the LSC is filled by translationally moving the work piece using the conveyor. In the first ramp, only white work pieces should be sorted. The second and the third ramp is for metallic ones. First of all, the metallic work pieces should be sorted into the third ramp. If this ramp is full, the second ramp should be used.

For the implementation of more complex processes as well as the re-feeding of work pieces that are detected as being faulty or not fulfilling the quality requirements, the xPPU has two separator conveyors (i.e. PAC and RC) and another sorting conveyor, the SSC. These conveyors enable re-feeding work pieces from the LSC back into other manufacturing processes. For further increase in flexibility of the possible manufacturing processes as well as the performance of the logistic system, i.e. the conveyors of the xPPU, a PicAlpha module is mounted over the PAC and positioned in alignment with the PAC. On the one hand, this increases the performance of the logistic system and on the other hand, this enables the manipulation of the work piece's sequence, i.e. the resorting of work pieces to process.

There is a safety door and a light grid for prevention of accidents. The mounted hardware incorporates an emergency-stop button as well as additional control elements. An additional button controlling the operation mode allows the operator to switch between an automatic operating mode and an additional manual mode. Within the manual mode the operator is allowed to control the xPPU in any required functional sequence. An energy monitoring hardware allows to measure the energy consumed by the different clamps. Therefore, three Wattmeter were installed. The electric energy consumed by the plant as well as the air pressure and the air flow through the plant using flow sensors can be monitored. This information can be used to optimize the plant focusing on energy saving aspects. Also, it allows to monitor whether parts consume more energy than usual, which might lead to the conclusion that these parts have to be replaced, due to malfunction.

Flow and pressure sensors attached to each of the four valve blocks of the xPPU allow to measure and monitor these values. The first valve block supplies the LSC. The second block controls the SSC and the PAC's pneumatic parts. The Stack and the Crane are controlled by the third valve block and the fourth supplies the air for the Stamp and the RC. The sensors can be used to simulate failures in the air flow as well as turning off the air pressure in specific hardware parts for safety reasons. Digital sensors signal, if a predefined pressure as well as a flow pressure is reached. Analog sensors monitor the current pressure as well as the air flow in the different valve blocks. The values are used to have a redundant system for failure monitoring as well as handling. An overview over the status of the plant as well as the air consumption is given. Therefore, the minimal air pressure to run the plant can be measured. The gained information then is used to reduce the air flow as well as the pressure for a more efficient energy consumption. An overview of the xPPU in this Scenario is provided in Fig. 52.

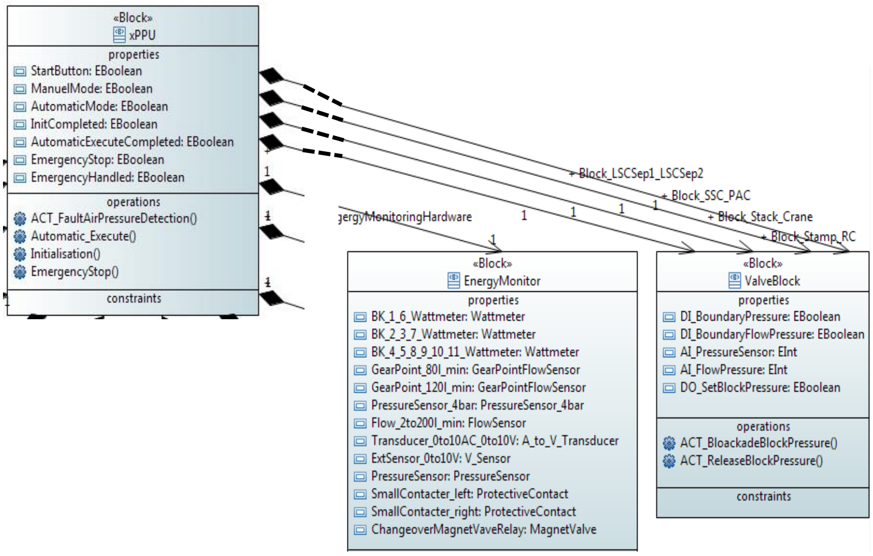

Fig. 52. Excerpt of the xPPU's structure in Scenario Sc21

4.8.1 xPPU's structure in Scenario Sc21

In the following subsections, the xPPU's structure, i.e. the composition of the xPPU from its components, is described.

4.8.1.1 Stack's structure in Scenario Sc21

The stack of the xPPU in Scenario Sc21 is the same as in Scenario Sc14. Therefore, for a description of the stack's structure, see section 3.1.1.1.

4.8.1.2 Crane's structure in Scenario Sc21

The crane of the xPPU in Scenario Sc21 is the same as in Scenario Sc13 [1].

4.8.1.3 Stamp's structure in Scenario Sc21

The stamp of the xPPU in Scenario Sc21 is the same as in Scenario Sc13 [1].

4.8.1.4 Large sorting conveyor's structure in Scenario Sc21

The large sorting conveyor of the xPPU in Scenario Sc21 is the same as in Scenario Sc15. Therefore, for a description of the large sorting conveyor's structure, see section 3.2.1.4.

4.8.1.5 PicAlpha conveyor's structure in Scenario Sc21

The PicAlpha conveyor of the xPPU in Scenario Sc21 is the same as in Scenario Sc15. Therefore, for a description of the PicAlpha conveyor's structure, see section 3.2.1.5.

4.8.1.6 Small sorting conveyor's structure in Scenario Sc21

The small sorting conveyor of the xPPU in Scenario Sc21 is the same as in Scenario Sc15. Therefore, for a description of the small sorting conveyor's structure, see section 3.2.1.6.

4.8.1.7 Refill conveyor's structure in Sc21

The refill conveyor of the xPPU in Scenario Sc21 is the same as in Scenario Sc15. Therefore, for a description of the refill conveyor's structure, see section 3.2.1.7.

4.8.1.8 PicAlpha's structure in Scenario Sc21

The PicAlpha of the xPPU in Scenario Sc21 is the same as in Scenario Sc16. Therefore, for a description of the PicAlpha's structure, see section 3.3.1.8.

4.8.1.9 Safety door's structure in Scenario Sc21

The safety door of the xPPU in Scenario Sc21 is the same as in Scenario Sc17. Therefore, for a description of the safety door's structure, see section 3.4.1.9.

4.8.1.10 Light grid's structure in Scenario Sc21

The light grid of the xPPU in Scenario Sc21 is the same as in Scenario Sc18. Therefore, for a description of the safety door's structure, see section 3.5.1.10.

4.8.1.11 Energy Monitor's structure in Scenario Sc21

The Energy Monitor of the xPPU in Scenario Sc21 is the same as in Scenario Sc20. Therefore, for a description of the Energy Monitor's structure, see section 3.7.1.11.

4.8.2 xPPU's behavior in Scenario Sc21

In the following subsections, the xPPU's behavior, i.e. the initialization behavior, the automatic operation mode behavior and the emergency stop behavior of the xPPU, is described.

4.8.2.1 Initialization behavior in Scenario Sc21

The xPPU's initialization mode behavior in Scenario Sc21 is almost the same as in Scenario Sc19. Therefore, for a description of the xPPU's initialization mode behavior, see section 4.6.2.1. A minor change was made by adding low air pressure detection and handling. Therefore, the function ACT_FaultAirPressureDetection has been added. It is now possible to detect low air pressure at the valve blocks, which would cause the pneumatic actors to fail or show unexpected behavior. Therefore, the air pressure values of the valve block for the two cylinders and the switch of the LSC as well as the valve block for the SSC and the PAC components are checked. If the pressure of a block drops under a specified value, the boundary variable is switched to false. The air pressure of the valve block for the stack and the crane as well as the valve block for the stamp and the RC can be read by the variable presenting the current pressure as an integer value. If this value drops under a specified value (here 10000) the pneumatic modules of the block won't work properly and therefore, the plant must be shut down. If the pressure for the whole plant drops below 4 bar the plant needs to be shut down as well. The functions behavior is shown in Fig. 53.

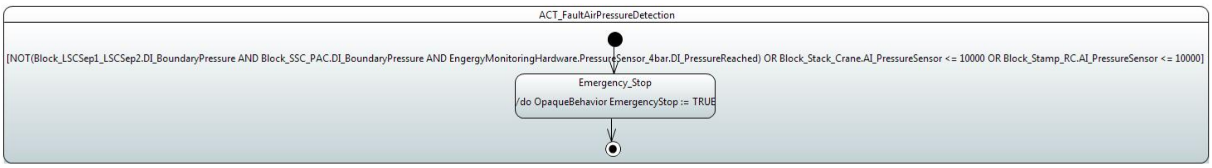

Fig. 53. Overview of the behavior of the fault air pressure detection in Scenario Sc21

4.8.2.2 Automatic operation mode behavior in Scenario Sc21

The xPPU's initialization mode behavior in Scenario Sc21 is almost the same as in Scenario Sc19. Therefore, for a description of the xPPU's initialization mode behavior, see section 4.6.2.2. A minor change was made by adding low air pressure detection and handling. Therefore, the function ACT_FaultAirPressureDetection has been added, to allow permanent air pressure observation. If the pressure drops under a certain value an emergency stop is executed (cf. 4.8.2.1).

4.8.2.3 Emergency stop behavior in Scenario Sc21

The xPPU's emergency stop behavior in Scenario Sc21 is the same as in Scenario Sc19. Therefore, for a description of the xPPU's emergency stop behavior, see section 4.6.2.4.

4.9 Scenario Sc22

Within the Scenario Sc22, the xPPU consists of a stack working as a work piece input storage, a large sorting conveyor (LSC) and a small sorting conveyor (SSC) working as a transportation component of work piece to output storage, a PicAlpha conveyor (PAC) and a Refill conveyor (RC) enabling re-feeding for post-processing, a stamp for stamping work pieces, a PicAlpha module (PA) enabling the manipulation of the work pieces sequence, a light grid mounted around the PA module together with a safety door mounted around the stamp module to prevent dangerous situations and a crane for transporting work pieces by picking and placing them between the stack, the stamp and the LSC working positions. Moreover, the crane may use the stamp component for buffering purposes. For human interaction, an operation panel provides a start button as well as an emergency stop button.

The xPPU processes six types of work pieces: black plastic work pieces, white plastic work pieces as well as different types of metallic work pieces in this Scenario. One metallic work piece is completely made of brass, one completely made of alloy and two more alloy work pieces have a different lead filling and thus have an increased weight. Black work pieces are separated at the stack and subsequently transported directly to the LSC. In contrast, white plastic work pieces and metallic work pieces are transported from the stack to the stamp, processed there and then transported to the LSC.

The xPPU is able to measure the mass of incoming work pieces using the weighing module integrated into the Stack. This is necessary to handle the dynamic effects of work pieces having different masses during transportation. While heavy work pieces need more time to stop commuting after the crane's rotation, light work pieces are ready for further treatment after a shorter period of time. Hence, to optimize the material flow through the xPPU a weight dependent transportation process has been established. Furthermore, it is not sufficient to stamp light, medium and heavy work pieces with the same pressure due to different mechanical properties; hence, being able to carry out three different processes, one for each weight category, is necessary. For this reason, light, medium and heavy work pieces are stamped using different pressure profiles. Within the LSC, three ramps are used as output storages. Two of the ramps are filled using respective pushing cylinders. A third ramp mounted to the end of the LSC is filled by translationally moving the work piece using a conveyor. In the first ramp, only white work pieces should be sorted. The second ramp is for metallic ones as well as the third. First of all, the metallic work pieces should be sorted into the third ramp. If this ramp is full, the second ramp should be used.

For the implementation of more complex processes as well as the re-feeding of work pieces that are detected as being faulty or not fulfilling the quality requirements, the xPPU has two separating conveyors (i.e. PAC and RC) and another sorting conveyor the SSC. These conveyors enable re-feeding work pieces from the LSC back into other manufacturing processes. For further increase in the flexibility of the possible manufacturing processes as well as the performance of the logistic system, i.e. the conveyors of the xPPU, a PicAlpha module is mounted over the PAC and positioned in alignment with PAC. On the one hand, this increases the performance of the logistic system and on the other hand, this enables the manipulation of the work piece's sequence, i.e. the resorting of work pieces to process.

There is a safety door and a light grid for prevention of accidents. The mounted hardware incorporates an emergency-stop button as well as additional control elements. An additional button controlling the operation mode allows the operator to switch between automatic operating mode and additional manual mode. Within the manual mode the operator is allowed to control the xPPU in any required functional sequence. An energy monitoring hardware allows to measure the energy consumed by the different clamps. Therefore, three Wattmeter were installed. The electric energy consumed by the plant as well as the air pressure and the air flow through the plant using flow sensors can be monitored. This information can be used to optimize the plant focusing on energy saving aspects. Also, it allows to monitor whether parts consume more energy than usual, which might lead to the conclusion that these parts have to be replaced, due to malfunction.

Flow and pressure sensors attached to each of the four valve blocks of the xPPU allow to measure and monitor these values. The first valve block supplies the LSC. The second block controls the SSC and the PAC's pneumatic parts. Stack and Crane are controlled by the third valve block and the fourth supplies the air for the Stamp and the RC. The sensors can be used to simulate failures in the air flow as well as turning off the air pressure in specific hardware parts for safety reasons. Digital sensors signal, if a predefined pressure as well as a flow pressure is reached. Analog sensors monitor the current pressure as well as the air flow in the different valve blocks. The values are enable having a redundant system for failure monitoring as well as handling. An overview over the status of the plant as well as the air consumption is given. Therefore, the minimal air pressure to run the plant can be measured. The gained information then is used to reduce the air flow as well as the pressure for a more efficient energy consumption.

Every work piece has been equipped with a rewritable RFID tag. These tags can be used to store process information, customer data or necessary manufacturing steps. Two RFID-Readers/Writers were installed to read and write those tags. One RFID-Reader/Writer was attached to the crane, horizontally to the gripper (Fig. 54 no.1). The other one was positioned above the LSC (Fig. 54 no.2). This enable work pieces to be sorted not only by their mechanical specifications like color or material, but also by specific information written on the tag, like priority or ordering information.

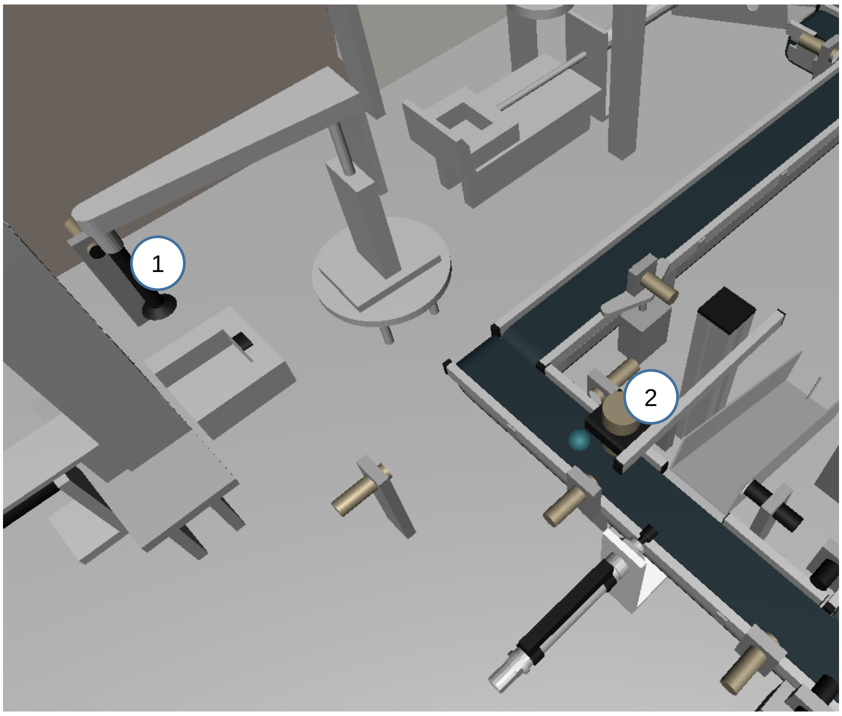

Fig. 54. The RFID Reader/Writer mounted on crane (1) and conveyor (2)

4.9.1 xPPU's structure in Scenario Sc22

In the following subsections, the xPPU's structure, i.e. the composition of the xPPU from its components, is described.

4.9.1.1 Stack's structure in Scenario Sc22

The stack of the xPPU in Scenario Sc22 is the same as in Scenario Sc14. Therefore, for a description of the stack's structure, see section 3.1.1.1.

4.9.1.2 Crane's structure in Scenario Sc22

The crane serves as a transportation unit, transporting the work pieces from the stack to the ramp as well as to the stamp. In Fig. 55, an overview of the crane's components is given. The crane consists of a pneumatic cylinder for lifting and lowering the work pieces. The cylinder consists of two binary position sensors (one at each end) to detect whether the cylinder is extended or retracted as well as one valve serving as an actuator. On top of this cylinder, an arm with a vacuum gripper is installed. The vacuum gripper is controlled by two valves and contains a micro switch which indicates whether a work piece is gripped. These components are mounted onto a turning table for rotational movement. At the bottom of the turning table, a potentiometer is installed. The potentiometer is used to detect the current position of the crane. The rotational movement of the turning table is realized by a motor. The RFID-Reader/Writer is attached to the gripper in parallel and is used to write and read information from the RFID-Tags of the work pieces. As there is no space to mount the reader/writer directly to the gripper, the RFID device had to be mounted horizontally on the gripper. Therefore, three new turning positions had to be defined to be able to read the tags centered in the top of each work piece.

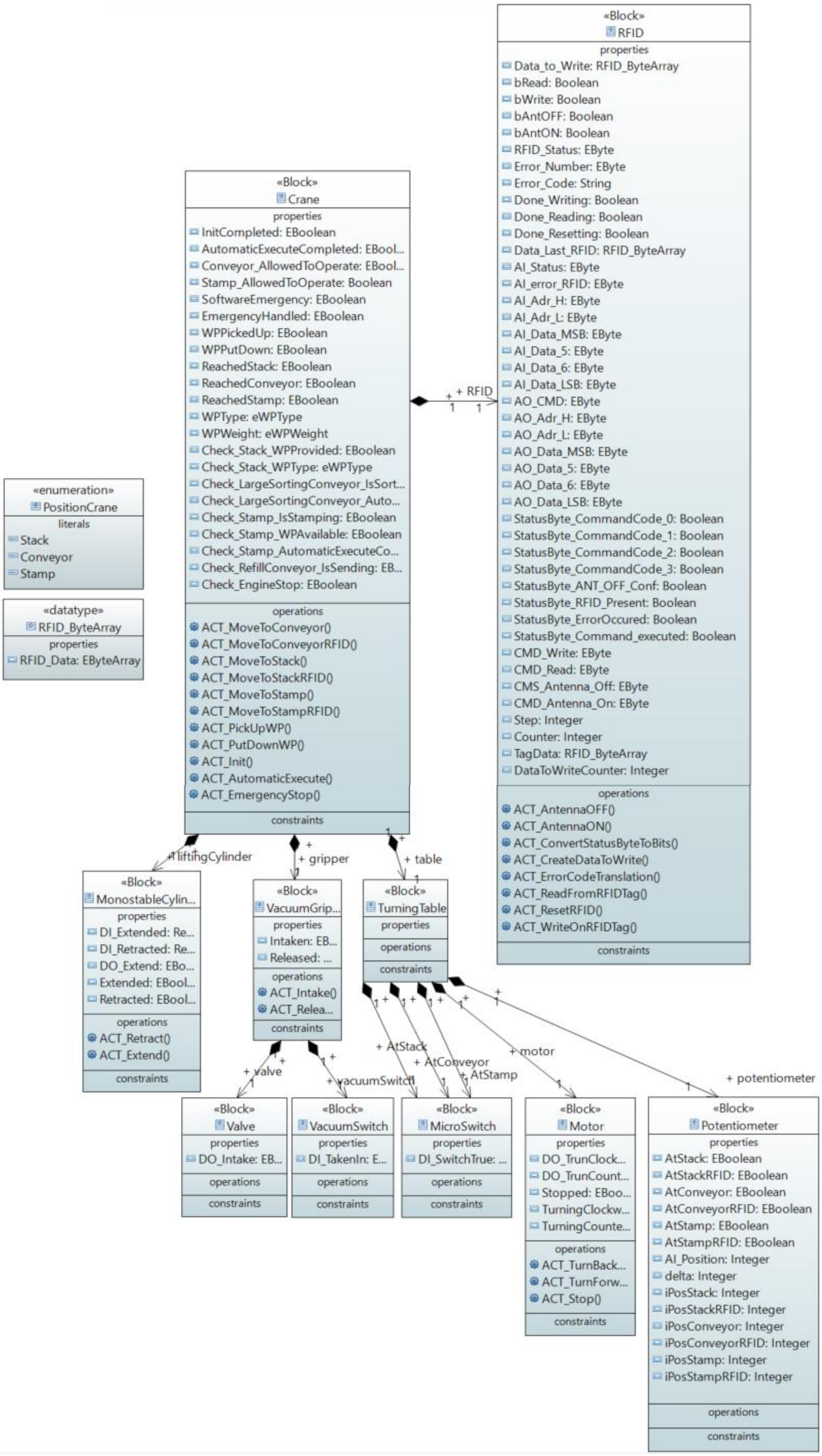

Fig. 55. Overview of the crane's structure in Scenario Sc22

4.9.1.3 Stamp's structure in Scenario Sc22

The stamp of the xPPU in Scenario Sc22 is the same as in Scenario Sc13 [1].

4.9.1.4 Large sorting conveyor's structure in Scenario Sc22

The LSC serves as a transportation component in which work pieces are transported to three ramps or to the PAC. The LSC consists of a motor for realizing the translational movement of work pieces and presence sensors mounted to the beginning of the LSC and at the ramps detecting whether a work piece was placed on the LSC and whether the ramp is full or not. Three ramps are mounted to the LSC. For the ramps at the beginning as well as at the center of the conveyor, respective pushing cylinders are installed for pushing work pieces into the ramps. These pushing cylinders contain valves for extending or retracting the cylinders as well as end position sensors for detecting whether the cylinder is extended or retracted. Optical sensors detect whether a non-black work piece is at the LSC or not as well as at the RC. Inductive sensors detect whether a work piece is a metallic one or not. In front of the second ramp at the LSC, there is a Switch for transferring the work pieces to the PAC for the re-feeding process. An Ultrasonic sensor positioned at the same level as the PAC measures how many WPs are at the PAC. An RFID-Reader/Writer is attached above the conveyor belt. Therefore, the conveyor can read and write the RFID-Tags of work pieces that it is transporting. The structure of the LSC can be seen in Fig. 56.

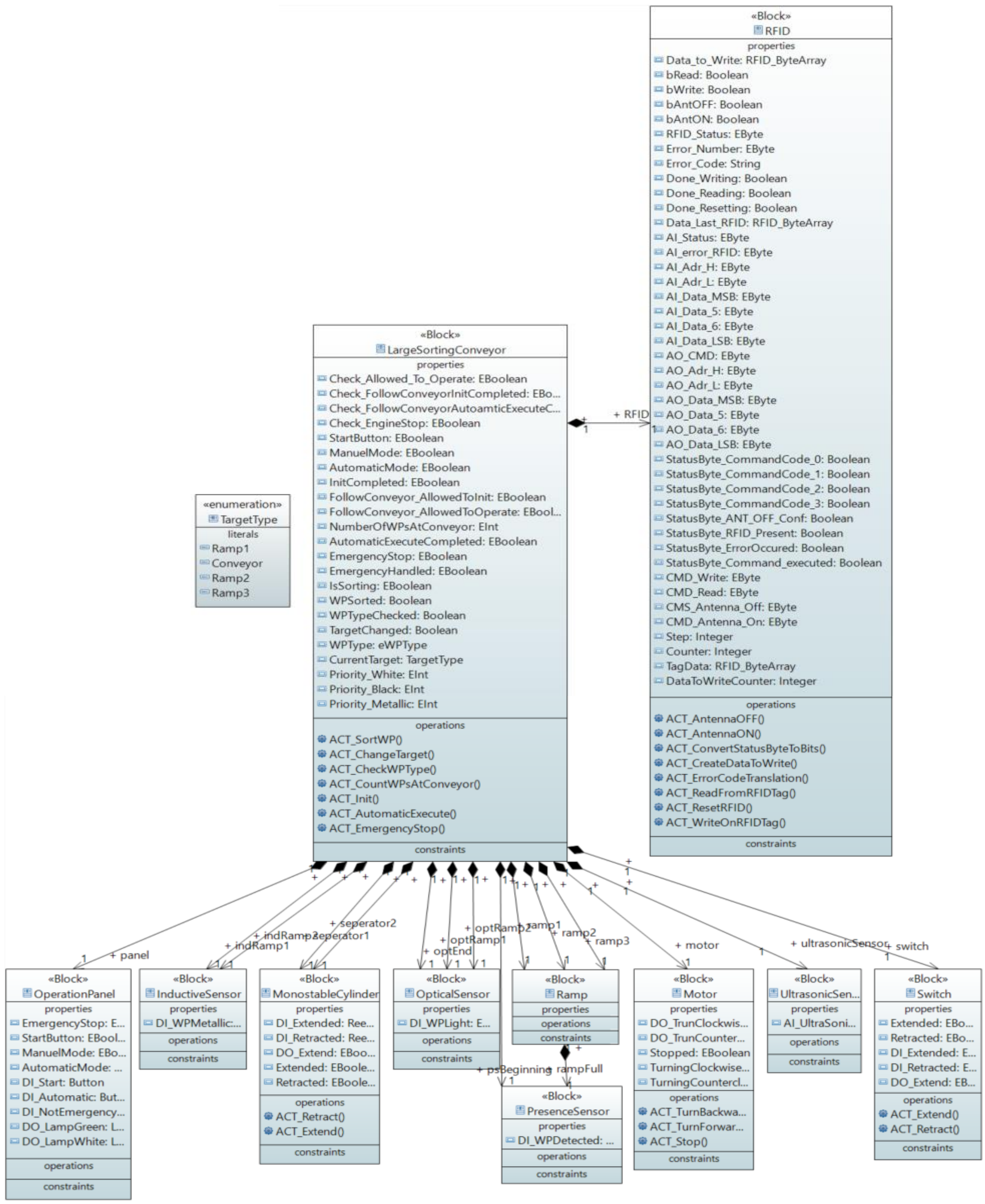

Fig. 56. Overview of the LSC's structure in Scenario Sc22

4.9.1.5 PicAlpha conveyor's structure in Scenario Sc22

The PicAlpha conveyor of the xPPU in Scenario Sc22 is the same as in Scenario Sc15. Therefore, for a description of the PicAlpha conveyor's structure, see section 3.2.1.5.

4.9.1.6 Small sorting conveyor's structure in Scenario Sc22

The small sorting conveyor of the xPPU in Scenario Sc22 is the same as in Scenario Sc15. Therefore, for a description of the small sorting conveyor's structure, see section 3.2.1.6.

4.9.1.7 Refill conveyor's structure in Sc22

The refill conveyor of the xPPU in Scenario Sc22 is the same as in Scenario Sc15. Therefore, for a description of the refill conveyor's structure, see section 3.2.1.7.

4.9.1.8 PicAlpha's structure in Scenario Sc22

The PicAlpha of the xPPU in Scenario Sc22 is the same as in Scenario Sc16. Therefore, for a description of the PicAlpha's structure, see section 3.3.1.8.

4.9.1.9 Safety door's structure in Scenario Sc22

The safety door of the xPPU in Scenario Sc22 is the same as in Scenario Sc17. Therefore, for a description of the safety door's structure, see section 3.4.1.9.

4.9.1.10 Light grid's structure in Scenario Sc22

The light grid of the xPPU in Scenario Sc22 is the same as in Scenario Sc18. Therefore, for a description of the light grid's structure, see section 3.5.1.10.

4.9.1.11 Energy Monitor's structure in Scenario Sc22

The energy monitoring hardware of the xPPU in Scenario Sc22 is the same as in Scenario Sc20. Therefore, for a description of the energy monitoring hardware structure, see section 3.7.1.11.

4.9.2 xPPU's behavior in Scenario Sc22

In the following subsections, the xPPU's behavior, i.e. the initialization behavior, the automatic operation mode behavior and the emergency stop behavior of the xPPU, is described.

4.9.2.1 Initialization behavior in Scenario Sc22

The xPPU is started by pressing one of five available start buttons, three of which are located at the operation panels, while the other two are on the safety door panel and on the light grid panel. The initialization behavior of the xPPU in Scenario Sc22 is the same as in Scenario Sc21. Therefore, for a description of the xPPU's initialization behavior, see section 4.8.2.1.

4.9.2.2 Automatic operation mode behavior in Scenario Sc19

Each work piece is equipped with an RFID-Tag that can be read and overwritten by the RFID-Reader/Writer located at the crane as well as at the LSC. This allows new ways of specifying the work piece. Because of the three defined positions of the work piece in the range of the crane, there are also three positions where the crane module is able to read the information saved on a tag as well as change it. The RFID-Reader/Writer is attached in parallel to the gripper module of the crane. Therefore, three new positions must be defined for the crane, such that an RFID-Tag is under an RFID-Reader/Writer. These positions are declared as AtStackRFID, AtConveyorRFID and AtStampRFID. Because of the lack of micro switches to detect these positions, the potentiometer added in Scenario Sc13 [1] is used. Therefore, we must add the positions to the potentiometer and declare, when each position has been reached. An overview of the behavior of the potentiometer can be seen in Fig. 57. When the crane has reached an RFID position and the task is to read or write information on a tag, at first the crane must be lowered. Afterwards, the RFID module checks if a tag is in the range of the detection field and then the module can read the information saved on the tag or even write or overwrite that information. The behavior of reading and writing on a tag can be seen in Fig. 58 and Fig. 59.

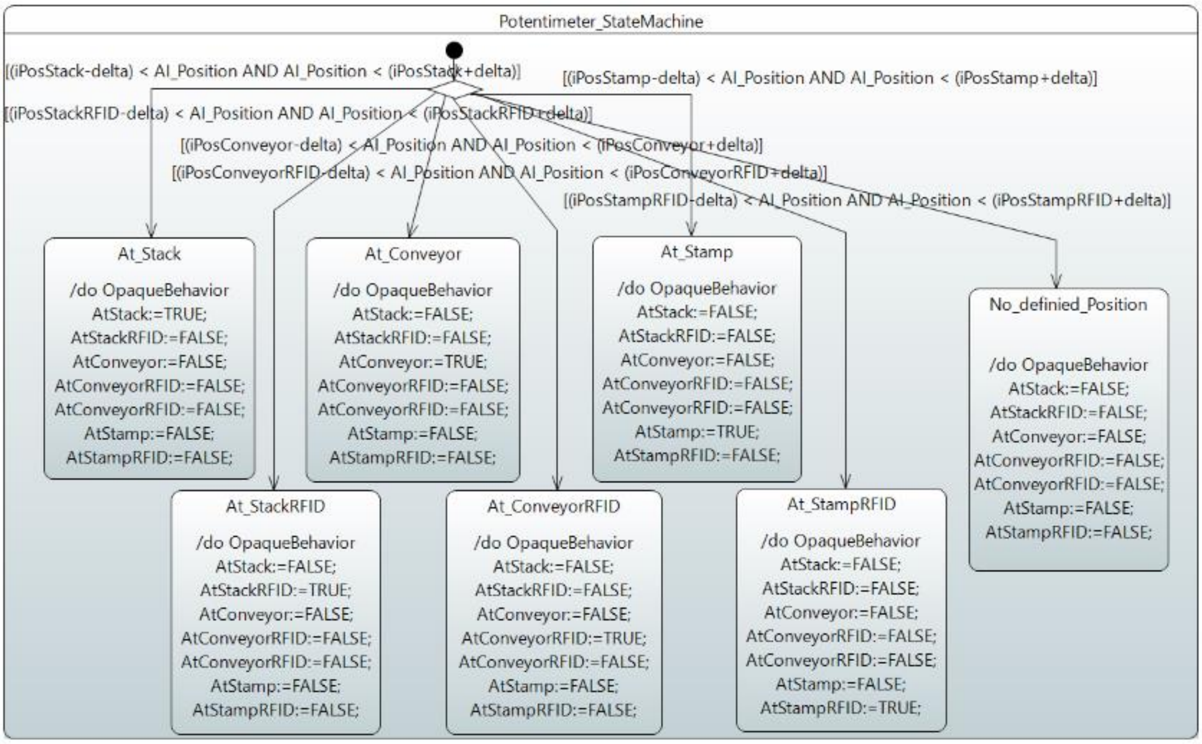

Fig. 57. Overview of the behavior of the potentiometer in Scenario Sc22

With the RFID-Reader/Writer installed at the LSC, we can get a work piece specification by reading the information saved on a work piece tag online. The RFID-Reader/Writer is located at the position where the work pieces get stopped to be specified by an inductive as well as an optical sensor. To read or write some information on a tag, the work piece needs to stay under the reader for as long as it takes to finish the procedure. Using this information, work pieces can now be sorted not only by their color, material or weight, but also by information on their quality saved on the tag, e.g. whether the work piece has been stamped, the priority or even the quality of the work piece.

If errors appear, during reading or writing on a tag, the RFID-module provides an Error-Code. The Error-Code is the translation from the Error-Byte number to strings. Each Error-number as well as the code it stands for was predefined by the hardware manufacturer (see Fig. 60).

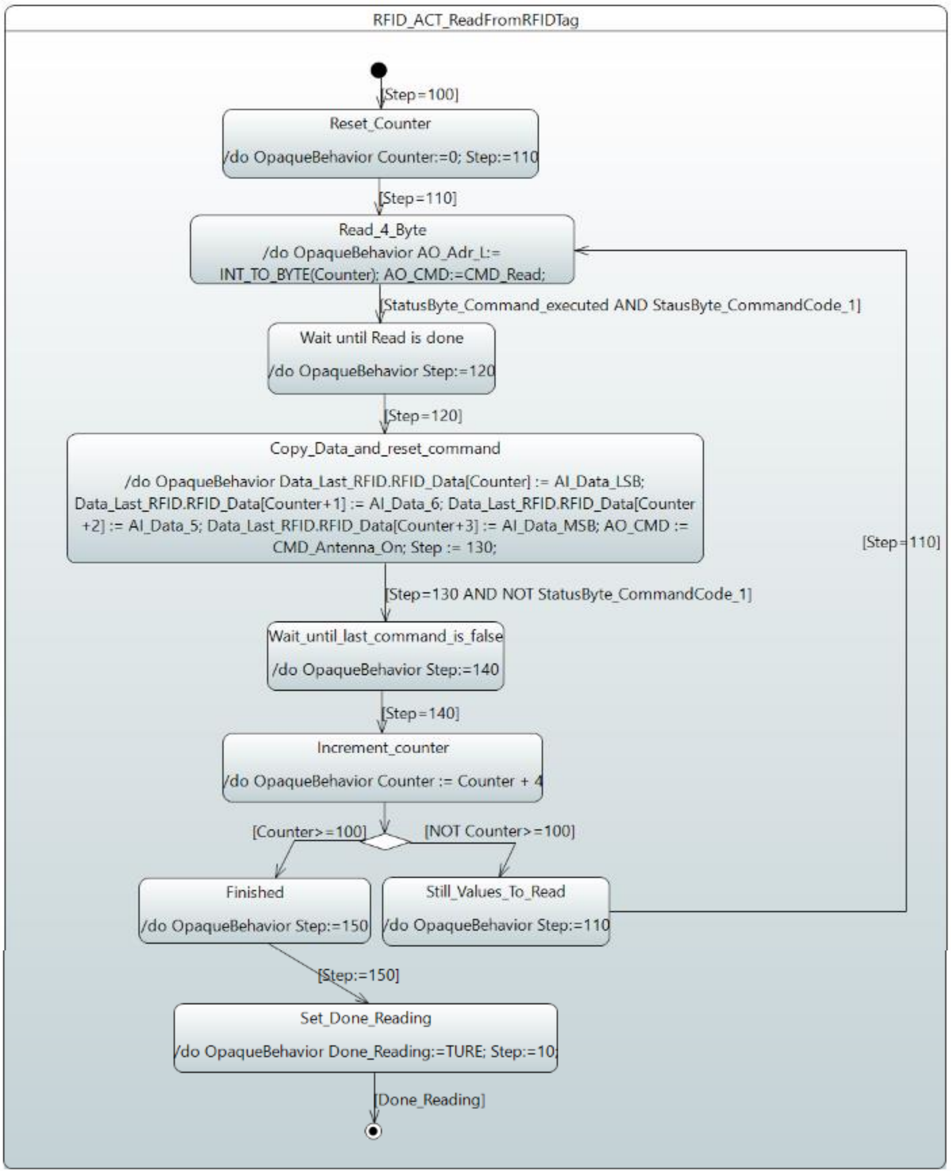

Fig. 58. Overview of the RFID behavior of reading information from a tag in Scenario Sc22

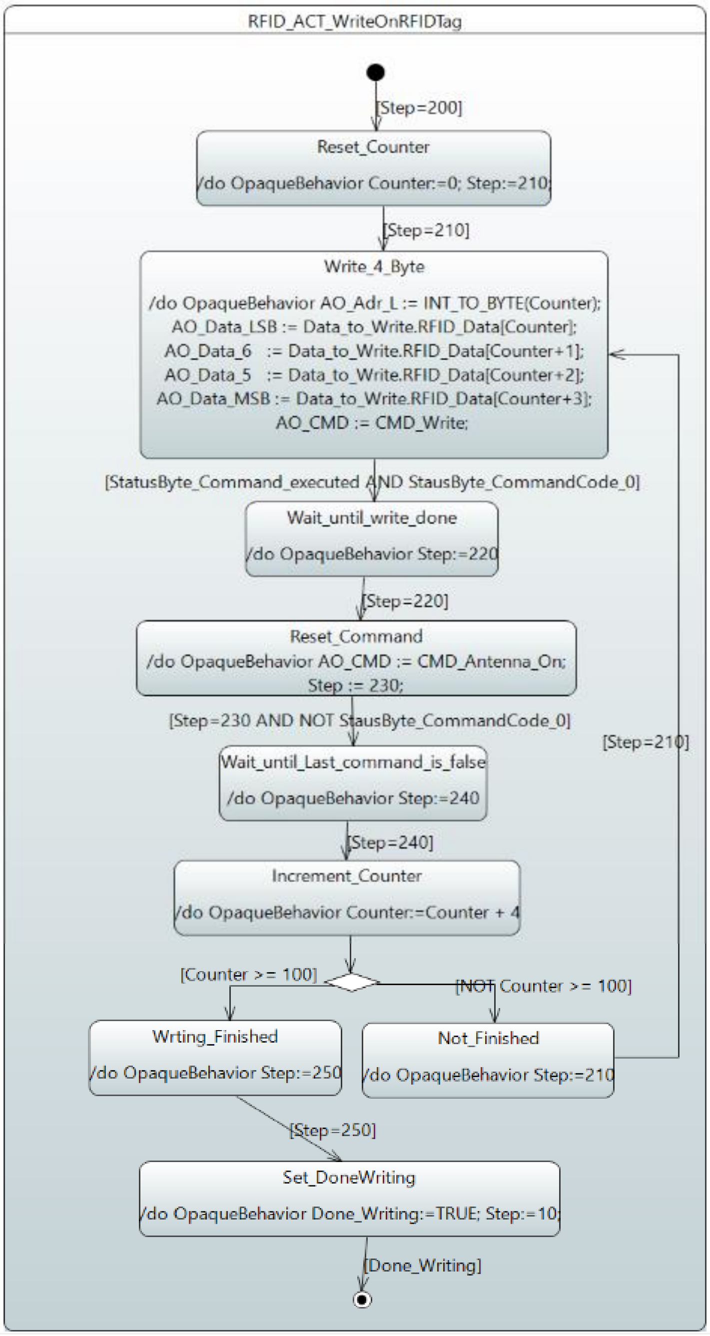

Fig. 59. Overview of the RFID behavior of writing information on a tag in Scenario Sc22

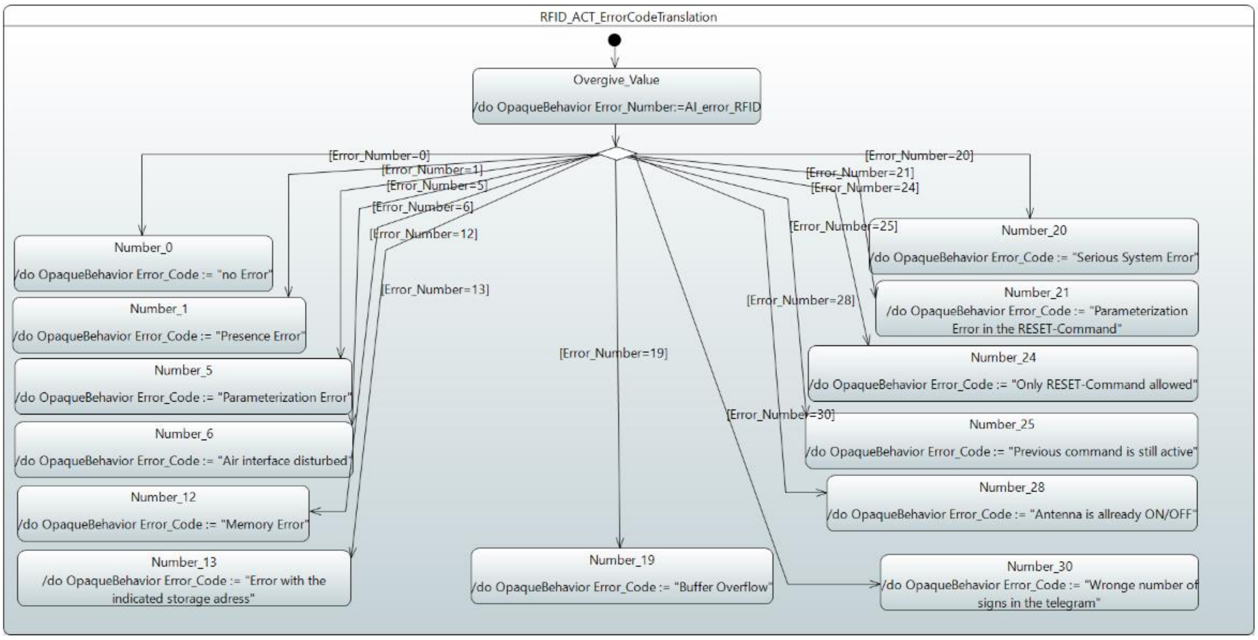

Fig. 60. Overview of the RFID behavior translating the Error-Byte into an Error-Code in Scenario Sc22

4.9.2.3 Emergency stop behavior in Scenario Sc22

The xPPU's emergency stop behavior in Scenario Sc22 is the same as in Scenario Sc19. Therefore, for a description of the xPPU's emergency stop behavior, see section 4.6.2.4.

4.10 Scenario Sc23

Within Scenario Sc23, the xPPU consists of a stack working as a work piece input storage, a large sorting conveyor (LSC) and a small sorting conveyor (SSC) working as a transportation component of work piece to output storage, a PicAlpha conveyor (PAC) and a Refill conveyor (RC) enabling re-feeding for post-processing, a stamp for stamping work pieces, a PicAlpha module (PA) enabling the manipulation of the work pieces sequence, a light grid mounted around the PA module together with a safety door mounted around the stamp module to prevent dangerous situations and a crane for transporting work pieces by picking and placing them between the stack, the stamp and the LSC working positions. Moreover, the crane may use the stamp component for buffering purposes. For human interaction, an operation panel provides a start button as well as an emergency stop.

The xPPU processes six types of work pieces: black plastic work pieces, white plastic work pieces as well as different types of metallic work pieces in this Scenario. One metallic work piece is completely made of brass, one is completely made of alloy and two more alloy work pieces have a different lead filling and thus an increased weight. Black work pieces are separated at the stack and subsequently transported directly to the LSC. In contrast, white plastic work pieces and metallic work pieces are transported from the stack to the stamp, processed there and then transported to the LSC.

The xPPU is able to measure the mass of incoming work pieces using the weighing module integrated into the Stack. This is necessary to handle the dynamic effects of work pieces having different masses during transportation. While heavy work pieces need more time to stop commuting after the crane's rotation, light work pieces are ready for further treatment after a shorter period of time. Hence, to optimize the material flow through the xPPU a weight dependent transportation process has been established. Furthermore, it is not sufficient to stamp light, medium and heavy work pieces with the same pressure due to different mechanical properties; hence, being able to carry out three different processes, one for each weight category, is necessary. For this reason, light, medium and heavy work pieces are stamped using different pressure profiles. Within the LSC, three ramps are used as output storages. Two of the ramps are filled using respective pushing cylinders. A third ramp mounted to the end of the LSC is filled by translationally moving the work piece using the conveyor. Into the first ramp, only white work pieces should be sorted. The second and the third ramp are for metallic ones. First of all, the metallic work pieces should be sorted into the third ramp. If this ramp is full, the second ramp should be used.

For the implementation of more complex processes as well as the re-feeding of work pieces that are detected as being faulty or not fulfilling the quality requirements, the xPPU has two separator conveyors (i.e. PAC and RC) and another sorting conveyor, the SSC. These conveyors enable re-feeding work pieces from the LSC back into other manufacturing processes. For further increase in the flexibility of the possible manufacturing processes as well as the performance of the logistic system, i.e. the conveyors of the xPPU, a PicAlpha module is mounted over the PAC and positioned in alignment with it. On the one hand, this increases the performance of the logistic system and on the other hand, this enables the manipulation of the work piece’s sequence, i.e. the resorting of work pieces to process.

There is a and a light grid for the prevention of accidents. The mounted hardware incorporates an emergency-stop button as well as additional control elements. An additional button controlling the operation mode allows the operator to switch between an automatic operating mode and an additional manual mode. Within the manual mode the operator is allowed to control the xPPU in any required functional sequence. An energy monitoring hardware allows to measure the energy consumed by the different clamps. Therefore, three Wattmeter were installed. The electric energy consumed by the plant as well as the air pressure and the air flow through the plant can be monitored using flow sensors. This information can be used to optimize the plant focusing on energy saving aspects. Also, it allows to monitor whether parts consume more energy than usual, which might lead to the conclusion that these parts have to be replaced due to malfunction.

Flow and pressure sensor attached to each of the four valve blocks of the xPPU allow to measure and monitor these values. The first valve block supplies the LSC. The second block controls the SSC and the PAC’s pneumatic parts. The Stack and the Crane are controlled by the third valve block and the fourth supplies the air for the Stamp and the RC. The sensors can be used to simulate failures in the air flow as well as turning off the air pressure in specific hardware parts for safety reasons. Digital sensors signal, whether a predefined pressure as well as a flow pressure is reached. Analog sensors monitor the current pressure as well as the air flow in the different valve blocks. The values enable having a redundant system for failure monitoring as well as handling. An overview over the status of the plant as well as the air consumption is given. Therefore, the minimal air pressure to run the plant can be measured. The gained information then is used to reduce the air flow as well as the pressure for a more efficient energy consumption.

Every work piece has been equipped with a rewritable RFID tag. These tags can be used to store process information, customer data or necessary manufacturing steps. Two RFID-Readers/Writers were installed to read and write those tags. One RFID-Reader/Writer was attached to the crane, horizontally to the gripper. The other one was positioned above the large sorting conveyor. This enables work pieces to be sorted not only by their mechanical specifications like color or material, but also by specific information written on the tag, like priority or ordering information.

Within Scenario Sc23 an OPC UA connection was enabled to read and write data information from the xPPU to and from an online server. This data is used to monitor the plant as well as control it. Using OPC UA data is transferred to the server if changes happen. This allows us to monitor many variables and values of the plant and still have a short response time. Third party programs can access the online server and the data and use it for monitoring purposes, data collection and data mining projects. With specified algorithms, statements can be made over the reliability of hardware parts. Also, the usage of each hardware part can be optimized, reducing maintenance work, energy consumption and therefore, cost.

4.10.1 xPPU's structure in Scenario Sc23

The components of the xPPU in Scenario Sc23 are the same as in Scenario Sc22. Therefore, for a description of the structure, see section 3.9.1.

4.10.2 xPPU's behavior in Scenario Sc23

The behavior in Scenario Sc23 is the same as in Scenario Sc22. Therefore, for a description of the structure, see section 4.9.2. It is now possible to establish a connection with the plant via OPC UA and to monitor values of the xPPU online from other systems as well.

To establish a connection with a Server using OPC UA additional software needs to be installed. For the Beckhoff PLC the TF6100 package[2] needs to be installed on both the operating system and the PLC. This software allows to establish an OPC UA connection using the PLC as a server.

To specify what data should be transferred three steps need to be taken:

First of all, in front of each variable that should be accessible for reading and writing the term "{Attribute 'OPC.UA.DA' := '1'}" needs to be written (see Fig. 61).

```
PROGRAM MAIN
VAR
    {attribute 'OPC.UA.DA' := '1'}
    xPPU : xPPU;
```

Fig. 61. Enabling OPC UA data exchange

[2] https://www.beckhoff.com/english.asp?twincat/tf6100.htm

The second step is creating a file that saves and exchanges current information. This file is called “TMC (TwinCAT Module Class) File”. TwinCAT automatically writes this file, when the respective feature has been enabled under the project settings (see Fig. 62).

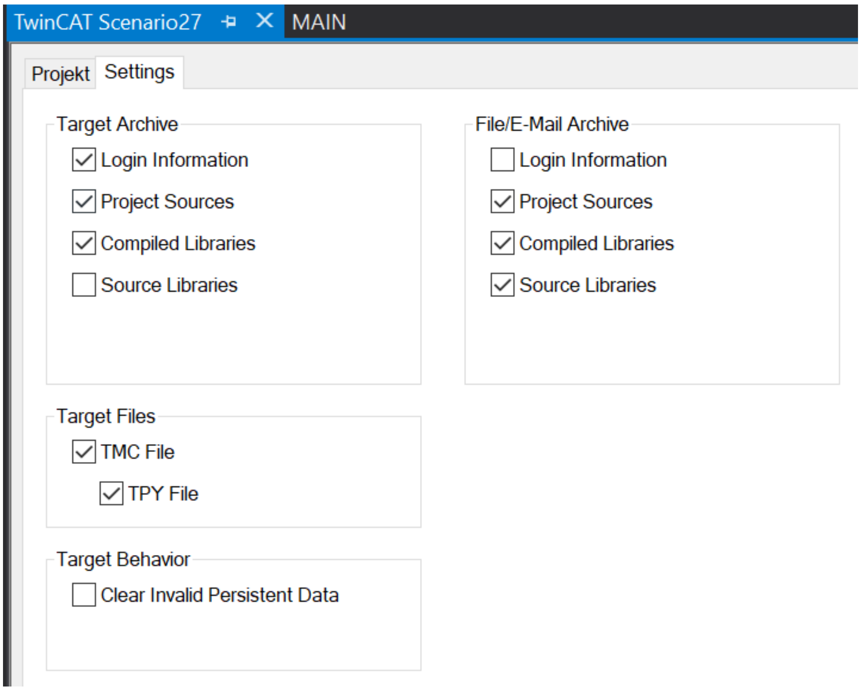

Fig. 62. Enabling automatic TMC File creation in the project Settings

The third step is activating the license for the new TF6100 package (see Fig. 63).

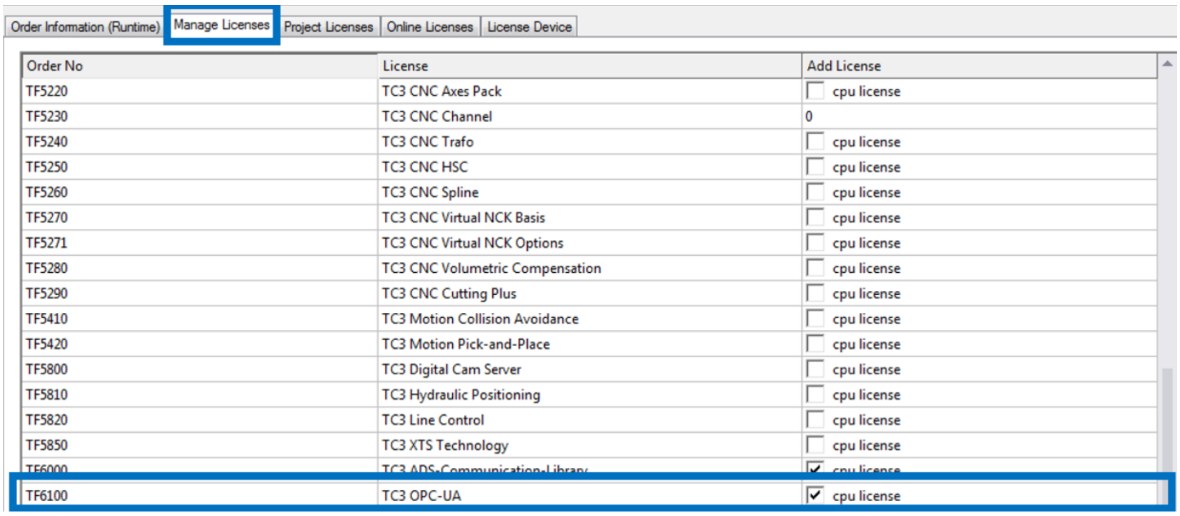

Fig. 63. Activating the license for OPC-UA

5 Self-healing Scenarios of the extended Pick and Place Unit (xPPU)

This section describes self-healing scenarios. These scenarios have the purpose to detect hardware failures and failures in the process, without the need of maintenance staff. This is achieved by using redundant sensors, using time delays as well as using machine parts for other purposes than specified. These scenarios are characterized by a scenario number followed by the letter ‘f’. They have been based on the code of the scenario with the same number as well as previous self-healing scenarios.

5.1 Scenario Sc14f

In Scenario 14f, the micro switch at the stack fails to detect the available work piece. This may be the case if the cylinder is not holding the work piece in place properly, the work piece is damaged or the micro switch is not correctly adjusted. Therefore, failure handling was implemented in the scenario by using a weighing module to check whether there is a work piece. The weighing module at the stack measures the weight of the work piece pressed into the platform. Using this method, we can determine if there is a work piece even when the sensor for detecting work pieces at the stack is not activated or defected.

5.1.1 xPPU’s structure in Scenario Sc14f

In the following subsection, the xPPU’s structure, i.e. the composition of the xPPU from its components, is described.

5.1.1.1 Stack’s structure in Scenario Sc14f

The stack of the xPPU in Scenario Sc14f is the same as in Scenario Sc13 [1].

5.1.1.2 Crane’s structure in Scenario Sc14f

The crane of the xPPU in Scenario Sc14f is the same as in Scenario Sc13 [1].

5.1.1.3 Stamp’s structure in Scenario Sc14f

The stamp of the xPPU in Scenario Sc14f is the same as in Scenario Sc13 [1].

5.1.1.4 Large Sorting Conveyor’s structure in Scenario Sc14f

The conveyer of the xPPU in Scenario Sc14f is the same as in Scenario Sc13 [1].

5.1.2 xPPU’s behavior in Scenario Sc14f

In the following subsection, the xPPU’s behavior, i.e. the initialization behavior, the automatic operation mode behavior and the emergency stop behavior of the xPPU, is described.

5.1.2.1 Initialization behavior in Scenario Sc14f

The xPPU's initialization behavior in Scenario Sc14f is the same as in Scenario Sc12. Therefore, for a description of the xPPU's initialization behavior, see [1].

5.1.2.2 Automatic operation mode behavior in Scenario Sc14f

The xPPU's automatic behavior in Scenario Sc14f is almost the same as in Scenario Sc14. Therefore, for a description of the xPPU's automatic behavior, see section 4.1.2.2. Only minor changes were applied to get the required behavior. The weight module is now also used to detect if a work piece is available. So, the micro switch's value and the weight module's analog value are used to detect a work piece. If the analog value is greater than 10000 we know that a work piece is ready to be picked up. You can see the behavior in Fig. 64.

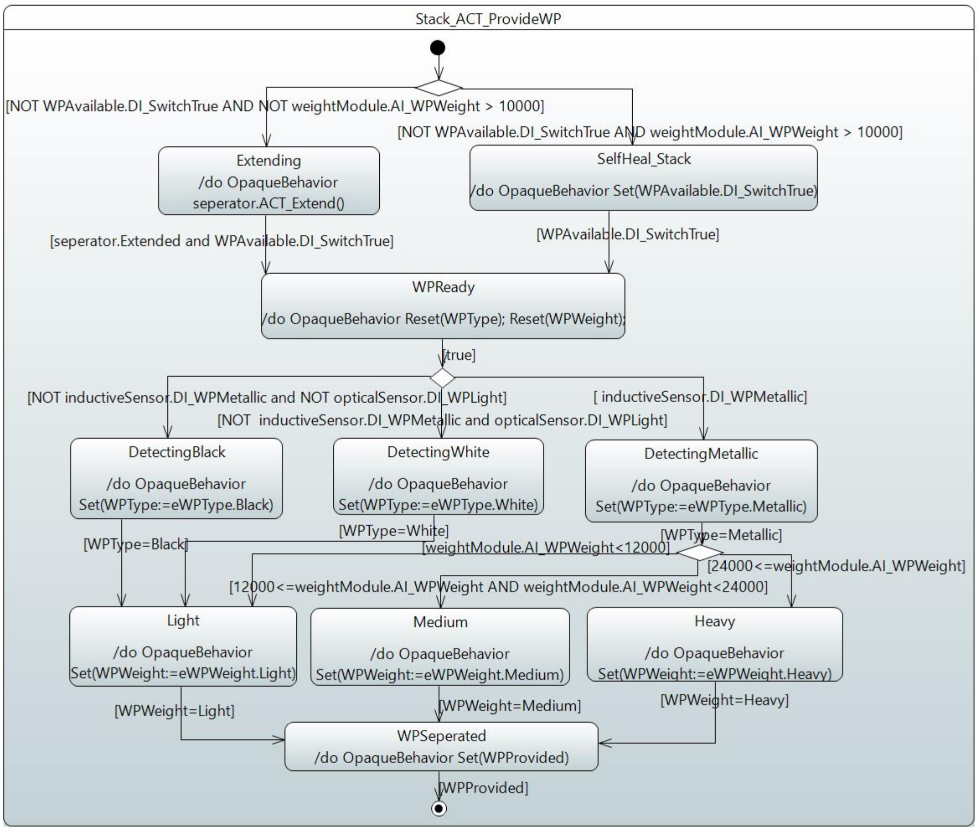

Fig. 64. Stack provide WP behavior in Scenario Sc14f

5.1.2.3 Emergency stop behavior in Scenario Sc14f

The xPPU's emergency stop behavior in Scenario Sc14f is the same as in Scenario Sc12. Therefore, for a description of the xPPU's emergency stop behavior, see [1].

5.2 Scenario Sc16f

In scenario 16f, the plant has to deal with a stuck switch at the PicAlphaConveyor. The pneumatically actuated separator switch fails to move, such that the work pieces are stuck at the PAC. This can be caused by a mechanical defect, a leak in the pneumatic tubes or a broken cable. To handle this failure, a self-healing mode has been included. The PicAlpha is used to pick up the work pieces and transport them to the end of the PAC. The jammed switch is bypassed and the work pieces can be conveyed again.

5.2.1 xPPU's structure in Scenario Sc16f

In the following subsection, the xPPU's structure, i.e. the composition of the xPPU from its components, is described.

5.2.1.1 Stack's structure in Scenario Sc16f

The stack of the xPPU in Scenario Sc16f is the same as in Scenario Sc14. Therefore, for a description of the stack's structure, see section 3.1.1.1.

5.2.1.2 Crane's structure in Scenario Sc16f

The crane of the xPPU in Scenario Sc16f is the same as in Scenario Sc13 [1].

5.2.1.3 Stamp's structure in Scenario Sc16f

The stamp of the xPPU in Scenario Sc16f is the same as in Scenario Sc13 [1].

5.2.1.4 Large sorting conveyor's structure in Scenario Sc16f

The large sorting conveyor of the xPPU in Scenario Sc16f is the same as in Scenario Sc15. Therefore, for a description of the large sorting conveyor's structure, see section 3.2.1.4.

5.2.1.5 PicAlpha conveyor's structure in Scenario Sc16f

The PicAlpha conveyor of the xPPU in Scenario Sc16f is the same as in Scenario Sc15. Therefore, for a description of the PicAlpha conveyor's structure, see section 3.2.1.5.

5.2.1.6 Small sorting conveyor's structure in Scenario Sc16f

The small sorting conveyor of the xPPU in Scenario Sc16f is the same as in Scenario Sc15. Therefore, for a description of the small sorting conveyor's structure, see section 3.2.1.6.

5.2.1.7 Refill conveyor's structure in Sc16f

The refill conveyor of the xPPU in Scenario Sc16f is the same as in Scenario Sc15. Therefore, for a description of the refill conveyor's structure, see section 3.2.1.7.

5.2.1.8 PicAlpha's structure in Scenario Sc16f

The small sorting conveyor of the xPPU in Scenario Sc16f is the same as in Scenario Sc16. Therefore, for a description of the small sorting conveyor's structure, see section 3.3.1.8.

5.2.2 xPPU's behavior in Scenario Sc16f

In the following subsection, the xPPU's behavior, i.e. the initialization behavior, the automatic operation mode behavior and the emergency stop behavior of the xPPU, is described.

5.2.2.1 Initialization behavior in Scenario Sc16f

The xPPU's initialization behavior in Scenario Sc16f is the same as in Scenario Sc16. Therefore, for a description of the xPPU's initialization behavior, see section 4.3.2.1.

5.2.2.2 Automatic operation mode behavior in Scenario Sc16f

The xPPU's automatic behavior in Scenario Sc16f is almost the same as in Scenario Sc16. Therefore, for a description of the xPPU's automatic behavior, see section 1.1.1.1. Changes were made to the behavior of the PicAlphaConveyor module to separate work pieces. If the switch of this module isn't extended after two seconds, we activate the self-healing mode (see Fig. 65). This mode stops the conveyor and gives the PicAlpha module the signal to execute the self-healing mode. After the self-healing mode of the PicAlpha is executed, the conveyor starts operating again and the self-healing mode is finished, see Fig. 66.

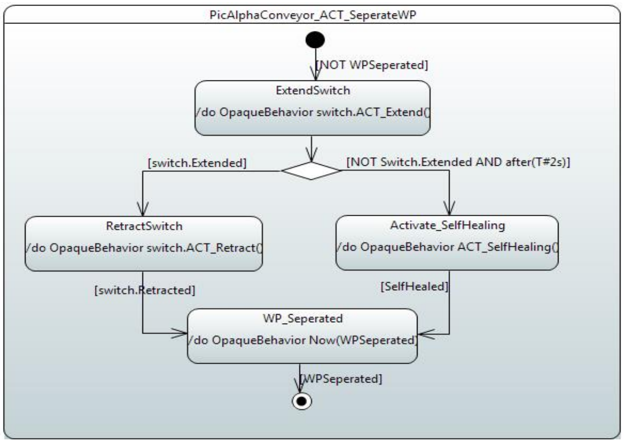

Fig. 65. Separate WP behavior of the PicAlphaConveyor in Scenario Sc16f

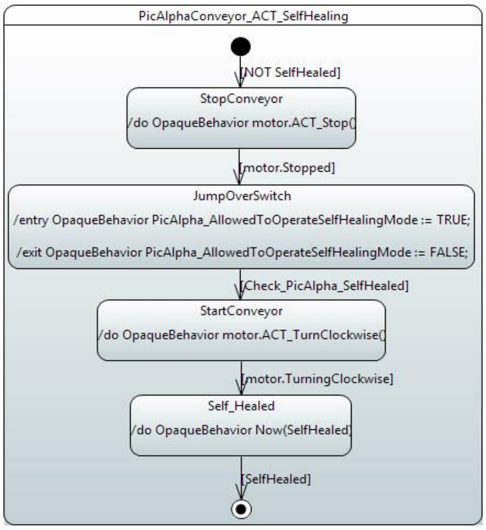

Fig. 66. Self-healing behavior of the PicAlphaConveyor in Scenario Sc16f

The PicAlpha module, therefore, is picking up the work piece waiting at the switch in the second sensor position and puts it down directly on the SmallSortingConveyor, where the fourth sensor position is located. The self-healing behavior of the PicAlpha module can be seen in Fig. 67.

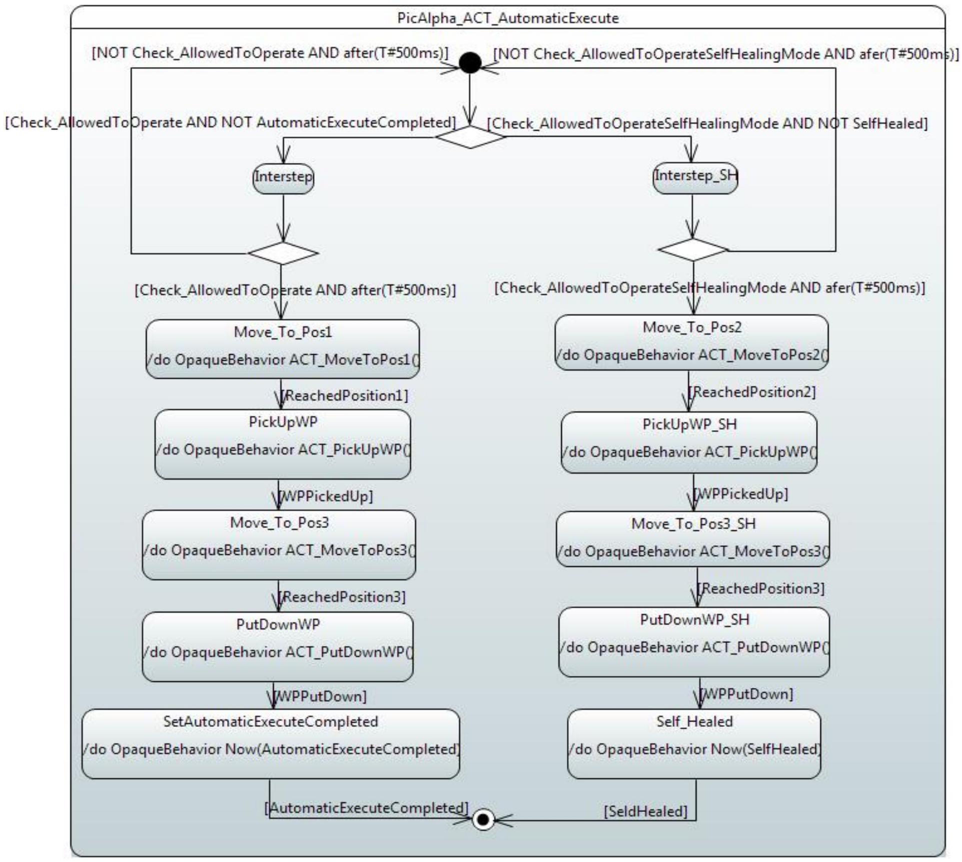

Fig. 67. Automatic mode of the PicAlpha in Scenario Sc16f

5.2.2.3 Emergency stop behavior in Scenario Sc16f

The xPPU’s emergency stop behavior in Scenario Sc16f is the same as in Scenario Sc16. Therefore, for a description of the xPPU’s emergency stop behavior, see Section 1.1.1.1.

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