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Study and development of an artificial intelligence algorithm for revisiting the GEMMA Guide paradigm

Tesis doctoral

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Biography

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RESUMEN

Hoy en día las máquinas industriales y las líneas de producción se vuelven más complejas debido a su necesidad de adaptarse a la última tecnología. Es decir, existe la necesidad de hacer frente a tareas más complicadas y producir productos modernos que requieren sistemas de control complejos. Para proporcionar el control apropiado a las máquinas industriales y líneas de producción, lo necesita incluir un control inteligente y un buen sistema de toma de decisiones que sea capaz de manejar con los complejos problemas de automatización y tomar la decisión correcta según el estado de la máquina.

Este trabajo de investigación se basa en la idea de desarrollar algoritmos de inteligencia artificial para revisar el paradigma de la guía GEMMA. Estos algoritmos incluyen todas las transiciones necesarias entre los modos de GEMMA y proporcionan en conjunto un sistema inteligente de control y sistema toma de decisiones para las máquinas industriales y líneas de producción basado en el paradigma de la guía GEMMA. Los algoritmos fueron desarrollados por el Fuzzy Petri Nets enfoque, que proporciona las capacidades de Fuzzy Logic y Petri Nets. Fuzzy Logic es un enfoque para calcular los grados de verdad en el que los valores de verdad de las variables pueden ser cualquier número real entre 0 y 1 en lugar del "verdadero o falso" habitual. Petri Nets es un lenguaje de modelo matemático que consta de lugares y transiciones que describe y estudia los sistemas de procesamiento de información. Juntos configuran Fuzzy Petri Nets que es un enfoque poderoso para desarrollar algoritmos inteligentes para el sistema de control y toma de decisiones.

Para asegurar que los algoritmos funcionen correctamente y proporcionen un buen sistema de control y toma de decisiones, se diseñó la grúa OPS (Onshore Power Supply) y el proyecto Factory I/O. De esta forma, los algoritmos podrían probarse tanto en el control de máquinas industriales como en líneas de producción. El OPS carne representa una máquina industrial y el proyecto Factory I/O representa una línea de producción. Estas pruebas aseguran que los algoritmos inteligentes funcionarán correctamente y proporcionarán un buen sistema de control y toma de decisiones para cualquier máquina industrial y línea de producción.

Los resultados experimentales muestran que los algoritmos inteligentes funcionan correctamente para controlar una máquina industrial y una línea de producción. Además,

los algoritmos inteligentes proporcionan un sistema inteligente potente de control y toma de decisiones que se puede manejar cualquier situación que pudiera ocurrir y se cubra las necesidades del operador. Por este motivo, los algoritmos inteligentes de GEMMA podrían ser una nueva generación de sistema de control y toma de decisiones para aplicaciones industriales en los próximos años.

ABSTRACT

Nowadays the industrial machines and production lines become more complex due to their need to adapt to the latest technology. That is to say, there is the need to deal with more complicated tasks and produce modern products which require complex control systems. In order to provide the appropriate control for the industrial machines and production lines, it is required to include an intelligent control and good decision-making system that would be able to deal with the complex automation problems and make the proper decision according the machine state.

This research work builds on the idea of developing artificial intelligence algorithms for revisiting the GEMMA Guide Paradigm. These algorithms include all the necessary transitions between the GEMMA modes and provide together a complete intelligent control and decision-making system for the industrial machines and production lines based on the GEMMA Guide Paradigm. The algorithms were developed by the Fuzzy Petri Nets approach which provide the capabilities of both Fuzzy Logic and Petri Nets. Fuzzy Logic is an approach to compute the degree of truth where the truth values of variables may be any real number between 0 and 1 rather than the usual "true or false". Petri Nets is a mathematical model language that consists of places and transitions which describes and studies the information processing systems and used for a system simulation graphically that allows to analyze the parallel events that occur. Both together provide Fuzzy Petri Nets which is a powerful approach to develop intelligent algorithms for control and decision-making.

In order to ensure that the algorithms work properly and provide good control and decision-making system, the OPS (Onshore Power Supply) crane and Factory I/O project were designed. In this way, the algorithms could be tested in both control of industrial machines and production lines. The OPS carne represents an industrial machine and Factory I/O project represents a production line. This ensures that these algorithms will work properly and will provide a good control and decision-making system for any industrial machine and production line.

The experimental results show that the intelligent algorithms work properly for controlling an industrial machine and production line. Moreover, provide a powerful intelligent control and decision-making system, deal with any situation that may happen

and cover the operator needs. For this reason, the intelligent algorithms for GEMMA could be the next generation of control and decision-making system for industrial applications in the coming years.

1. INTRODUCTION

Artificial intelligence (AI) involves developing computer programs to complete tasks that would otherwise require human intelligence. AI algorithms can tackle learning, perception, problem-solving, language-understanding and/or logical reasoning. The research of the AI field started in the 50^{th} and focused on computing and information science. Later on, it expended to more areas as well control and automation. AI is the most important field nowadays; it provides a human system that is able to learn any situation in order to solve problems and to build an appropriate control and decision-making system. This capability provides the machines an intelligent control that is able to mimic the human behavior and to make the proper decision for any situation that may occur. This research is based on the idea of revisiting the GEMMA Guide Paradigm by artificial intelligence algorithm in order to provide an intelligent control and decision-making system to the industrial machines and production lines by implementation of the intelligent algorithms that are developed in this thesis in GEMMA. This first chapter provides the objectives of this research work. Moreover, the aims and limits along with the original contributions of this research are described. At last, the structure of this document is outlined in the last section of this chapter.

1.1. Dissertation Objectives

The main aim of this thesis is to develop and implement intelligent algorithms for the GEMMA Guide Paradigm in order to provide the appropriate control and decision-making system to the industrial machines and production lines. The following objectives are included within the framework of this thesis:

- Fuzzy Petri Nets approach: increase the knowledge of the Fuzzy Petri Nets approach for control and decision-making system.

- GEMMA Guide Paradigm: understanding the GEMMA Guide Paradigm and its modes in order to be able to revisit its transition and develop the proper intelligent algorithms for each transition of GEMMA. Additionally, providing transitions for particular scenarios that may occur during different tasks that GEMMA is not able to deal with.

- Development of artificial intelligence algorithms: the intelligent algorithms require to deal with any situation that may occur. For this reason, it is needed to develop different intelligent algorithms that each of them will be responsible for the transition between certain modes.

- Conversion of the intelligent algorithm: in order to operate the intelligent algorithms of the GEMMA's transitions as a control and decision-making system for industrial machines and production lines, conversion of the algorithm is needed. The best way to convert the algorithm to a control and decision-making system is by Ladder diagram. It allows to develop a complete control system of the different intelligent algorithms.

- Prototype design: the prototype is used to test the control and decision-making system of the intelligent algorithms and to ensure its capability. The design includes an OPS (Onshore power supply) crane and a virtual factory by Factory I/O.

1.2. Dissertation Contributions

The main contributions of this work can be briefly summarized as follows:

- Understanding the artificial intelligence field and intelligent control including the uses and benefits for control of industrial machines and production lines.

- Provide the necessary knowledge of Fuzzy Logic approach and Petri Nets, and their benefits for intelligent control and decision-making systems. Moreover, learning the Fuzzy Petri Nets approach for the development of algorithms that provide an intelligent control and decision-making system.

- Understanding the GEMMA Guide Paradigm and its uses for control systems including its different modes and states.

- Development of the intelligent algorithm for GEMMA transitions based on Fuzzy Petri Nets approach. The different intelligent algorithms were developed based on the Fuzzy Petri Nets approach which provide capability to develop a powerful intelligent control and decision-making system.

- Learning the Ladder diagram and its ability for control. The Ladder diagram provides the best solution to convert the intelligent algorithms to a system of control and decision-making.

- Experimental validation of the intelligent algorithms for controlling industrial machines and production lines. A series of preliminary experiments have been carried to evaluate the control and decision-making system that was developed by the intelligent algorithms.

1.3. Dissertation Outlines

The remainder of this document is organized as follows. Chapter 2 shows the background of this research work in order to provide the necessary knowledge including explanation of the different approaches that are used in order to be prepared and to be able to understand the research work and the development of the intelligent algorithms.

The Fuzzy Petri Nets approach for control and decision-making is presented in Chapter 3. First, the approach is explained including its use for control and decision-making of an industrial applications. Moreover, the explanation includes a mathematical example that shows how to develop the Fuzzy Petri Nets algorithm. Then, the GEMMA Guide Paradigm and its different modes and uses are introduced in order to be familiar with GEMMA and how it deals with the task of solving complex automation problems. At last, the Fuzzy Petri Nets algorithm for the GEMMA Guide Paradigm is presented. This explains the best way to convert the Fuzzy Petri Nets algorithm to a control and decision-making system for the integration of Fuzzy Petri Nets with the GEMMA Guide Paradigm.

Chapter 4 focus on the development of the intelligent algorithms for the transitions of the GEMMA Guide paradigm. In order to provide a good control and decision-making system it is necessary to deal with all the transitions between the modes of GEMMA. That is to say, the intelligent algorithms need to deal with the following transitions: stop to operation procedure, operation procedure modes, operation to stop procedure, operation to failure procedure and failure to stop procedure. During the control of an industrial applications, it is necessary to deal with different situations that GEMMA does not provide. For example, when there is the need to make some action during the startup/shutdown process, the operator has to wait until the process will finish in order to make the needed action. For this reason, by the intelligent algorithms, it is possible to provide the transitions between the startup/shutdown and normal production mode (F1) or running in verification mode disorderly (F4) without to wait that until the process will finish. In Chapter 5 these algorithms are developed.

Then, in order to make the experiments of the intelligent algorithm for control and decision-making based on GEMMA, it is necessary to design industrial applications that can ensure that the control works appropriate and can be proper to the automation of the industrial applications. Chapter 6 presents the design of the OPS (onshore power supply) crane and Factory I/O project. The intelligent algorithms are implemented on these two projects in order to check their control and decision-making system for the different type of industrial applications. Chapter 6 presents also the results obtained from these experiments. Finally, conclusions and future work are given in Chapter 7.

2. BACKGROUND

2.1. Introduction

This chapter presents the background of this thesis and provides the appropriate knowledge for understanding the project. In other words, in order to understand the Fuzzy Petri Nets intelligent algorithm for the GEMMA Guide Paradigm, it is necessary first to be familiar with the important topics that are explained in this chapter.

The first topic explains the decision-making field, it helps to understand the necessary steps that have to be done in order to make a decision. It includes five steps that either the person or the system should do. First of all, the problem has to be defined in order to be allowed dealing with it in the best way. As soon as the problem is clear, the solution for the problem must meet the requirements and conditions. Then, the goals for the solution are determined. While the goals are known, it is necessary to define the different alternatives for the solution which allow to choose the best way to solve the problem. In the last step, the appropriate tool is selected according to the certain problem.

The second topic presents the Artificial Intelligence (AI) including its relation to control system. AI is very important nowadays for any field, the main idea of AI is to allow the system to behave as a human in order to understand the situation, make the decision and solve the problem in the best way. For this reason, AI is very important for the control system, it provides the possibility to control a machine intelligently and to predict problems that may occur. In this way, the control system is able to prevent danger to human life and damage to the machine. Moreover, it is able to learn continuously during the work and to predict the next step which provide a better control with the time, similarly to a person that learns from his experience and mistakes the best way to behave.

The last topic of this chapter presents the structure of the intelligent control that will be used in this thesis. The intelligent control of this project includes the Fuzzy Logic approach and the mathematical model Petri Nets. Fuzzy Logic is an approach that computes the degrees of truth. That is to say, it has a range of truths between the completely true (1) and the completely false (0). In this way, this approach is able to control the exact value, for example controlling a car velocity, the value of the brakes pedal will be regulated according to the need to stop the car. Petri Nets is a mathematical model for the description of a system, it is represented by places and transitions. Each place is represented as a circle, and transition as a bar. Petri Nets is also used for a system simulation graphically and allows to analyze the parallel events that occur.

2.2. Decision Making

As (Harris, 1998) defined, decision making is the study of identifying and choosing alternatives based on the values and preferences of the decision maker where making a decision not only involves different choices to be considered but finding the one that matches better the aims of the study.

The decision-making process should start with the identification of the decision maker and his stakeholders regarding to the decision. In this way, the problem disagreement, requirements, goals and criteria will be reduced. The decision-making process can be divided into 5 steps (Baker, D., Bridges, D., Hunter, R., Johnson, G., Krupa, J., Murphy, J. and Sorenson, K., 2002).

The first step is to define the problem. In this step, at the very least, it is necessary to recognize the root of the problem, to limit as much as possible the assumptions, and different issues (Courtney, 2001). The main purpose in this step is to make the issue clear and to provide one statement that describes the initial and desire condition. Usually, the problem is quite complicated, and it is not possible to express in one statement. Additionally, the statement of the problem has to be summarized and be agreed by all the decision makers. Although, the very long process summarize the statement is necessary in order to proceed to the next step (Churchman, 1971).

The second step is to set the requirements. After the problem has been defined, the solution for the problem must meet the requirements and conditions. The requirements are the way to express the workable solution in order to make the decision to the problem. Moreover, to make clear requirements is very important in order to prevent individual or judgmental assessments in the next steps that may occur (Chase VM, Hertwig R & Gigerenzer G, 1998). In order to avoid it, it is possible to mark the requirements and describe how to check them in a written material.

The third step is to determine the goals. In general, goals are a wide statement and the desirable solutions for the problem. Mathematically, the forced requirements are in contrary to the goals, and the goals are the objectives. For this reason, the goals can be incompatibles, but this is a normal situation that may occur during a decision process.

The fourth step is defining criteria (Mészáros, Cs. and Rapcsák, T., 1996). The different criteria are alternatives that have to be solutions to the goals. Moreover, it is it required to determine the objective as discriminating criteria in order to measure the goals. In this way, it is possible to know how good each alternative is, and if it can achieve the goal. This system makes the goals as criteria and each goal has to represent a criterion. However, situation of a complex goal can be represented by more than one criterion (Baker, D., Bridges, D., Hunter, R., Johnson, G., Krupa, J., Murphy, J. and Sorenson, K., 2002).

The last step is to choose the appropriate tool in order to make the decision. There are many tools that provide a solution for the decision-making of a problem. Choosing of the correct tool for decision-making is very complicated and also it has to be appropriate to the problem and to the objective of the decision maker. Simple problem can be solved by simple method, but surly a complex problem requires a complex method (Beck JM, WJ, Kiani R, Hanks T, Churchland AK, Roitman J, Shadlen MN, Latham PE, Pouget A, 2008).

The general decision-making process that is explained in this chapter can be used to a decision making in any field, as well as control systems. In order to make a decision for a control system it is necessary to follow the same steps. Simple control systems may not have complex decision problems and will not require many goals to achieve. When the system starts to be complex it will be necessary to solve many decision problems and to achieve many goals. Moreover, the developer or the intelligent control system will have to follow these steps similarly to the general decision-making process in order to achieve the goals and to solve the decision-making problem (Balci F, Simen P, Niyogi R, Saxe A, Hughes JA, Holmes P, Cohen JD, 2011).

2.3. Artificial Intelligence

2.3.1. What is Artificial Intelligence?

In the 50^{th} started the research of the artificial intelligence (AI) field, it was started with computing and information science. Afterwards, the AI started to focus on more fields and as well the control and automation. AI behaves in a way that it is able to understand the different situations and to build a human system in order to solve the problems and to make decisions. In other words, AI is a computer system that shows the complex of living systems like behaviors. For example, the AI systems could mimic different animals like insect swarm, and colony, microbiology, and even a neural system in order to handle with different scenarios and solve problems (Buchanan, 2005).

The AI field has two main categories:

The first one is a symbolic AI – this means, a knowledge-based system that is able to make decisions in a particular area. In other words, development of a system that uses the knowledge from a human in order to have its experience about the area and to know how to make the decision in the best way (Castrounis, 2017).

The second category is computational intelligence – this category is an application with a capability to learn a specific task from its data or from experiments. Usually it composes of 3 methods, fuzzy system, neural network and evolutionary computing.

The main difference between the two categories is that the computational intelligence generates the output without knowledge based like frames, rules, cases etc. (Brook, 1991).

The AI applications have many advantages that is deployed to a lot of fields. The main advantage is the ability to get the connection between various variable in the complex environment. Moreover, understanding the uncertain environment when the complex mathematical relationship is not founded.

AI is able to overcome the uncertainty by using its existing knowledge involving probability and make the best conclusions for the certain situation. Additionally, significant advantage of the AI field is its permanent ability. In other words, it has the necessary knowledge as long as this specific problem occurs, or the decision occasion does not change, and its learning capability always can be extended.

AI is widely used in control systems in order to solve different problems in the real world much better and faster than people, and usually to make a simulation of a human intelligence. Moreover, the practical control system and the computers are able to deal with about 10 billion of instruction per second and can provide a memory of around

300 GB per 2 cm. Contrary to the human intelligence, the computer is much more trustworthy because is unfeeling and cannot change its behavior due to different acts like being jealous, angry, fall in love etc. and they will always follow their orders.

Nowadays, there are many intelligence strategies of control systems and tools, such as artificial neural networks, back propagation algorithms, fuzzy logic, herding control, intelligent agents, text miming and much more. Each strategy is appropriate to a different machine, scenario and situation. These strategies bring the AI to be very powerful and allow to arrive to a wide range of fields in order to help the human to solve complex problems and deal with difficult tasks (Vassilyev SN, Zherlov AK, Fedosov EA, Fedunov BE, 2000).

2.3.2. Why to Use Artificial Intelligence in Control Systems?

Nowadays control systems are very important and are involved in a lot of inventions, the progress of the modern technologies depends on the control system fields. This field plays an important role in the human daily activities and arrives to any place of our life, such as the domicile applications as refrigerators, washing machines, dishwasher etc. The importance of the control systems surely arrives to the industry as well like production factories, robotics and so on (M. Wollschlaeger, T. Sauter, a J. Jasperneite, 2017) (Brooks, 1990). Also, the control system can be found in many sectors, such as the military service, medical field, electricity generation field etc. Additionally, the control system is founded in the human body, such as the heart control that circulate the body blood, the lymph that regulates the glucose of the body, and more than all the human brain which controls all the body and allows the person to make an appropriate decision for a certain situation. Of course, it is possible to see the control system anywhere in the nature as well like in the body of the animals similarly to the human body, trees and plants etc. (Russell SJ, 2010) (Vassilyev SN, Zherlov AK, Fedosov EA, Fedunov BE, 2000). The natural control is the most important for the human life. For example, in a situation that one of systems is stopped working or is not working well the person will be unstable and even in a life threatening. In the same way, it also affects the machines, when the control system of a machine does not work well, the machine will act in a different way and it may lead to problems and even to a life threatening. Thus, with a good control system the machine will work in the correct way and will be able to perform certain tasks automatically (Y. LeCun, Y. Bengio, and G. Hinton, 2015).

The control system in the AI field is very different from other applications and the stakes are higher. For example, one part of the control system in the AI field is the prediction need like in the performance monitoring system of the engine aircraft, in this case if the system finds a faulty in the engine, technicians and engineers must replace it in order to keep up the company flights and it can cost to the company around $200,000 easily. The stakes are high due to the reason that it could be a poor accuracy and the replacement is not needed. Surely, this cost is much higher than the cost of Netflix that has some error and broadcasts a wrong movie or Ebay ships the wrong product. Moreover, the prediction model development is more complicated than developing a recommender application. There are significant amount of data sensors that require maintenance, and also the data must be checked in the simulation, and of course in the production as well. This process also musts include expert operators like system maintenance and performance engineers that it makes the process to be very complicated and dependent (M. Wollschlaeger, T. Sauter, a J. Jasperneite, 2017) (Castrounis, 2017) .

The use of AI in control system provides to the machine a better performance and allows the machine to make the necessary tasks automatically. The main difference between control system with AI and a traditional control system is that the system can solve many problems before they occur due to the prediction of the system. Moreover, the AI system can save life by prediction of the failure in the correct time, and to make the correct decision for the next step. Another reason to use a control system with AI is the work's improvement of different factories, the intelligent control system can learn during the work and adjust to the different necessities. For example, in a production line it learns the products necessities, predicts the correct results, and improves significant its work and can save the factory time and money (L. Magni, D. M. Raimondo, and F. Allg¨ower, Eds., 2009).

2.3.3. Applications of Artificial Intelligence in Control

In any control system there are intellectualization problems, the intellectualization of control system is necessary in order to prevent control problems. It has seen that AI field faced with the intellectualization problem. The major achievement of AI is increasing the abilities of computer technology and hardware implementation. For example, SHARP has been increased its computer technology and hardware performance by implementation the AI field in the company's systems (Antsaklis, 1994).

The intelligence control means an integration of both hardware and software. It is included the general information process, manual or autonomous operation, and in this way is able to realize the control target in order to find the best ways to get this target. In a traditional control system, the achievement of the target carried out by both, the human and the machine. Contrary, the intelligence control systems are able to realize the control target and the find best way in order to achieve it by themselves (Castrounis, 2017).

Development of control system for an industrial process may be complicated, it must include interaction of different settings and to adjust them to each other. An AI intelligence control may help to handle it and to provide a better control for the different industrial processes. For example, controlling an industrial conveyor oven. The oven has a moving belt that makes the product’s transportation through the several heating zones. Each zone heats the product for different time and in different temperature to soldering the different connections. In a traditional control system, the operator must learn the steps of the heater process, such as putting the product in the first step, get the temperature and time from the sensors, regulate the heater setting of the system, wait for the new settings from the oven and to repeat this process until it will be close enough to the desire results, and this will change again for any product. By the intelligence control system this process is much faster, it can do it automatically without the need of the operator and to achieve the perfect results for any process. First, the intelligence system will learn the dynamics of the oven in order to create the correct policy that will update the heater setting automatically under the conditions. Second, the system will follow the policy in order to find the appropriate heater setting, this will provide the adjustment between the actual and the desire profile (Antsaklis, 1994).

2.4. Intelligent Control

2.4.1. Fuzzy Logic Approach

The English meaning of the word "fuzzy" is "blurred, confused or vague". This word implies something about the technical idea of Fuzzy systems and how they work. The Fuzzy systems are inaccurate systems but are must be defined accurately, as well the

Fuzzy control. In other words, Fuzzy logic computes the truth degree wider than the usual of Boolean true or false (1 or 0), it includes the Boolean 0 or 1 but only for the extreme cases, and also includes various states of true between. Normally the control systems are linear, and this word defined them technically. In the same way, the word fuzzy defined the Fuzzy systems. Actually, despite the inaccurate that presents the technical of these systems, the Fuzzy systems are accurate systems that achieve precise control (G. Chen and T. T. Pham, 2006).

The research of Fuzzy logic started first in 1965 by Lotfi A. Zadeh and it was founded as a powerful control system for different processes like the industrial process, household, diagnosis of systems etc. The quick growth of these systems has been found first in Japan and then they arrived to the rest of the world. Due to the non-linear and changing the response in time of the Fuzzy systems, they are very useful for many fields that require complex control systems. Usually, the traditional control systems are not able to provide the appropriate control for these complex applications. Surly, the Fuzzy logic systems must receive the data by the operator that has the knowledge of the correct inputs and condition in order to provide the system the possibility to know the application in a good way and control it correctly (G. Chen and T. T. Pham, 2006).

Nowadays, the Distributes Control Systems (DCS) are the most common in the industry. Usually, they are used to control different production lines like chemical plants, pharmaceutical factories etc. that in these processes the control is continually. In the beginning, the goal of the Programmable logic controller (PLC) was to replace the relay technology and they are used for control of events such as, automotive and electronics. Currently, they have a huge instruction books that consists all the necessary knowledge for continues control. However, they are still missing the appropriate instructions for the intelligent control (I. S. Shaw, 2013).

The use of Fuzzy logic systems has a huge justification for control systems. The human experience and research during the years has made the person in a stage to have enough knowledge in order to control his need (Kentli, 2011). However, the human ability is limited to understand the world, and for this reason the person will arrive to some situation that he does not have enough knowledge and information, especially in inaccuracy information. Another human limitation is the communication and how the person describes the information that may cause to inaccuracy as well, the person is not able to communicate and to get accurate as the machine accurate. In other words, the human language is limited and vague. The human perception of the world is preventive by defined facts that provide the person to understand the situation, such as old, young, tall, short etc. These facts are correct and help the human understanding the situation. Nevertheless, these facts are inaccurate, for the human they are sufficient in order to understand each other or a certain situation but for machines they will not do the work, the machine will not be precise and they will not be able to their tasks. The programing languages are very poor compare to the natural languages, but they are very precise, and the natural languages are not precise, they are "fuzzy" (A COURSE IN'FUZZY,).

2.4.1.1. Fuzzy Logic for Control Systems

The use of Fuzzy systems is very important for control of many industrial processes due to their large number of advantages, such as technology is very simple, their results are very simple and can be transported easily between the different products, and also, they have smooth and robust behavior of the controller. Moreover, their abilities are very significant. For example, translating easily the inaccurate knowledge of human and controlling unstable systems (C. C. Lee, 1990).

Fuzzy systems are very successful for control of applications. Nowadays most of the control applications are based on Fuzzy systems. For example, controlling the room temperature, anti-braking systems of vehicles, traffic lights systems, watching machines, economic systems, etc. (C. C. Lee, 1990).

While using a traditional control system, it is necessary to know the model, the accurate terms and target. This may be very complicated in a lot of application. However, while using a Fuzzy system for control, it is possible to use the human experience and expertise in order to design the control system. The best way to design the Fuzzy logic for control is applying the basic role of IF THEN (W SilerH Ying, 1989).

In order to design the Fuzzy system for control, there are few assumptions that have to be made. The first assumption is observable and controllable application, the inputs must be considered, and the outputs need to be available in order to predict the control the target. The second assumption is assuming that there is knowledge with principles and a set of input and output data that will provide these principles, and also assuming that the solution is existed. Another assumption, the precision range of the

Fuzzy system must be acceptable. Moreover, the stability and optimality of the system have to be open and not being treated clearly (Sugeno, 1985).

2.4.2. Petri Nets

Petri Nets in one of the best mathematical modeling tool for control systems and was founded first by Carl Adam Petri in 1962. He proved that this tool is very reliable and effective in order to model and simulate control systems (Luis Diego Murillo, 2008). Petri Nets is normally used to model, control, and analyze the different events in a dynamic system. It is defined by event distribution, driven process, conflicts, parallelism and asynchronous processes. Petri Nets are especially for modelling and analyzing a manufacturing process due to their accurate ability and the efficient analysis that is provided from the interaction between the events (Costelha & Lima, Oct 2007). Moreover, they work logically from their knowledge of the way that the system has to work and provide the solution for a certain model conflict, and also, they execute the real time analysis. Petri Nets is used for graphical modelling and analytical testing of parallel events that occur in the system, and surly that is very appropriate for modelling and analyzing a manufacturing system (Girault & Valk, 2003).

The Petri Nets models describe graphically the structure of a system and how it distributes. Petri Nets consist two different nodes that are connected by directed arcs with a weight. The structure of Petri Net is very useful in order to show the system and clarify how it works. The Petri Nets' graph is constructed from circles and bars. The circles represent the places/states of the graph, and the bars represent the transitions/events. The arcs between the places and the transitions of the graph represent the input and output relationship. Each arc is connected from a place (p_j) to a transition (t_j) and determine the place as an input of the transition. In a case of more the one input to a transition, there will be more than one arc, each arc will indicate one input to the transition. The output of a place is defined by an arc that goes out from the place to the transition, in a case of more than one output, there will be more than one arc similarly to the inputs (Luis Diego Murillo, 2008).

The normal Petri Nets (P/T) model is defined as a four tuple and can be represented by:

$$PN = (P, T, I, O) \quad (2.1)$$

Where:

$P = (P_1, P_2, \dots, P_n) -$ is the set of places, and $T = (t_1, t_2, \dots, t_n)$ – is the set of transitions. When I is the input function and O is the output function. The set of places and transitions are disjointed and presented as:

$$P \cap T = \emptyset \tag{2.2}$$

The input is represented by:

$$I \subseteq (P \times T) \tag{2.3}$$

And the output:

$$O \subseteq (T \times P) \tag{2.4}$$

The place p_j is the t_j transition input while:

$$p_j \in I(t_j) \tag{2.5}$$

and p_j is the output while:

$$p_j \in O(t_j) \tag{2.6}$$

The basic structure of Petri Net is defined by the different places, transitions, input and output function. The Petri Nets structure is illustrated in the figure below.

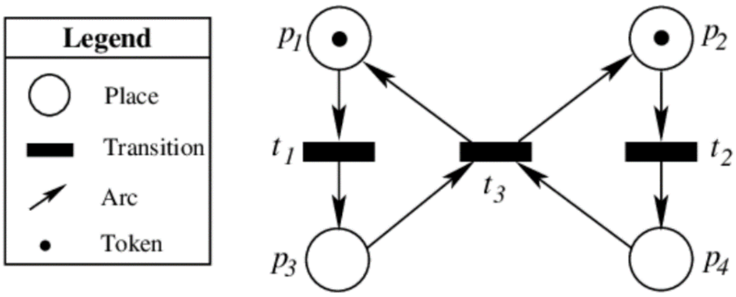

Figure 2.1: Petri Nets structure

2.4.2.1. Integration of Petri Nets and Artificial Intelligence

The AI is a significant field for a manufacturing process, it reduces the production costs, increases the efficiency and improves the product quality. AI can be very efficient and creative field in order to perform an intelligence system and help to the designer with the product development. Thus, in order to achieve the appropriate system and the correct solutions for the product, the parallel and intelligent production activities are necessary. The integration of the intelligence system provides the correct information for fast intelligence decision making from the beginning of the design process in order to help the designer during all the process (S.I. Ahson, 1995).

The Petri Nets intelligence methodology integrates the design of the process planning. This may include the assembly appreciation of the redesign as well. Petri Nets combines the knowledge based on the system and Fuzzy logic, and transmits it to a Petri Nets model as a place and transition. In this way, it can be represented as the modeling of the design process. Petri Nets methodology has the ability of learning in order to solve conflicts and different problems, and also the product design and the composition of the planning can be performed at once intelligently by parallel computer (K. Venkatesh, O. Masory and A. Pandya, 1993).

2.5. Applications of Fuzzy Logic & Petri Nets to Control System

Petri Nets is a very effectual method for graphical and mathematical modeling of a system and makes the simulation for control systems. However, in cases of complex system that usually can be found in the industry and communication systems, Petri Nets starts to have difficulties to deal with the data imprecision, and the uncertainty problem. This problem made the researchers to a clear conclusion, combination of Petri Nets with Fuzzy logic in order to create a new tool that calls Fuzzy Petri Nets (FPN) (J. Cardoso, R. Valette, and D. Dubois, 1996).

Fuzzy Petri Nets is much more intelligent, effective and powerful in the real-world control system and is able to learn and be trained in order to adjust the control system to certain situations similarly to Neural Networks. Fuzzy Petri Nets can be found in many fields, such as manufacturing, communication, electronics, traffic control, braking system of vehicles etc. The use of Fuzzy Petri Nets must include the diagnosis of the process in order to control the decision making in the correct way (J. Cardoso, R. Valette, and D. Dubois, 1996).

For example, Fuzzy Petri Nets has been used for optimum the electricity power supply for short circuit and other exceptional cases by Hong-Tzer Yang and Chao-Ming Huanh in Taiwan. They applied the system on the distribution power system of Taiwan Power Company. They understood that Fuzzy Petri Net is able to carry out a good control system for the distribution power supply, and they decided to use the combination of the operators OR, IF and THEN role included with AND. At last, they applied the idea that the leader takes for the final output place, and they made 3 types of places instead of one, as it is possible to see in Figure 2.2. This way gave them the best solution for controlling the power system distribution (Hong-Tzer Yang, and Chao-Ming Huanh, 2002).

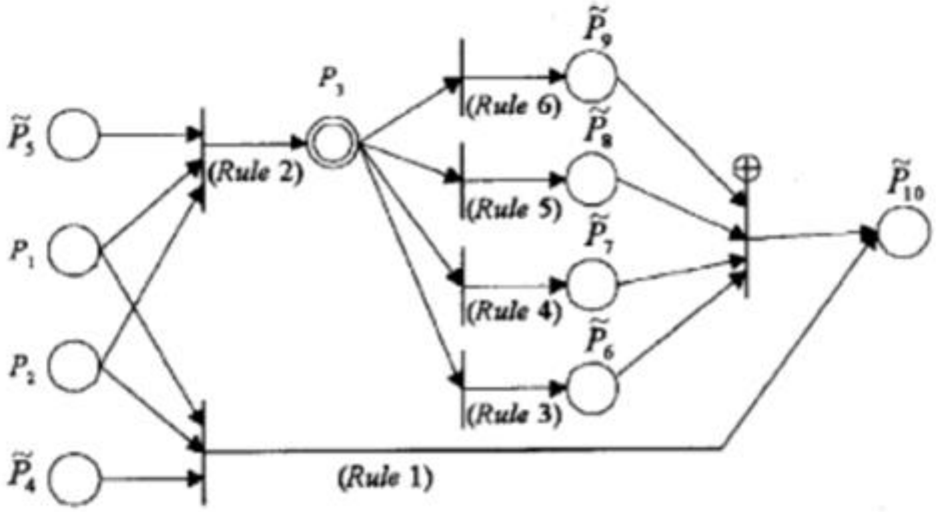

Figure 2.2: Example of Fuzzy Petri Nets for optimum the electricity power supply

In their system they decided to define the places in a different way. P1 and P2 are the normal places, P3 is the distribution place, and the rest of the places are Fuzzy places. P1 and P2 could also be called Fuzzy places but with 1 degree of membership, and P3 is used as a buffer place. Then, they verified the results of this Fuzzy Petri Nets model with human experts in order to compare the system with the traditional system and to get insights. Despite the fact that the research paper does not clarify a lot their Fuzzy Petri Nets system, it proves that the use of Fuzzy petri Nets for a power supply system is very effective, intelligent and decreases considerably the complexity of the control system (Hong-Tzer Yang, and Chao-Ming Huanh, 2002).

2.6. Conclusion

The aim of this chapter is to explain the bases of this thesis in order to be able to understand this project in the best way. The first section explained the decision-making rules. It was possible to see that the decision-making is very important for dealing with problems in the appropriate way. The strategy teaches the right steps that have to be taken in order to deal with a problem that occur in the life. Moreover, it is possible to learn from it how a control system has to deal with a problem. Something that allows the control system to work intelligently and to deal with a problem that occurs similarly to the human behavior.

The second section explained what Artificial Intelligence (AI) is and also its integration with control systems. It is possible to learn from it that the AI is very significant for control systems. It provides a better control system by mimicking the human behavior, learning from mistakes and improving the control system continuously.

The last section presents the Fuzzy Petri approach and Petri Nets mathematical model. As it was explained, Fuzzy Petri Nets is an approach that provides the possibility to control a system accurately. In other words, in each situation the control can be regulated according to the needs, and not to be controlled absolutely by truth or false. It provides a wide range of truths, something that allows to control a certain situation in the best way. Petri Nets is a mathematical model that simulates and describes the system. As it was explained, Petri Nets is a graphical tool which includes places and transitions. Each place presents a certain system's situation, and each transition a certain condition. This allows to simulate the process of the system and to learn better their conditions and steps.

The main idea of this chapter is to provide the knowledge for understanding the important topics of AI for control system. Moreover, the intelligent control is the combination of these topics that have been explained in this chapter. In the next chapter the intelligent control for this thesis is explained theoretically and mathematically. Additionally, the GEMMA Guide paradigm is presented including its different modes and states.

3. ARTIFICIAL INTELLIGENCE ALGORITHMS FOR THE GEMMA GUIDE PARADIGM

3.1. Introduction

In order to construct the intelligent algorithm for each transition of the GEMMA Guide Paradigm, it is necessary first to understand the Fuzzy Petri Nets approach and its capabilities for control and decision-making system. Then, to be familiar with the GEMMA Guide Paradigm, its modes and uses. While the Fuzzy Petri Nets and GEMMA Guide Paradigm are understood, the last subchapter introduces the integration of Fuzzy Petri Nets and GEMMA including an example of an intelligent algorithm for the GEMMA transitions.

In this chapter the structure of Fuzzy Petri Nets approach is explained including its mathematical calculations. Then, while the idea of Fuzzy Petri Nets approach for the decision-making is clear, the GEMMA Guide Paradigm is explained and described graphically including its different modes and uses in the industry. In this way, it is possible to understand why it is important to use the GEMMA Guide Paradigm for control of industrial applications and its abilities. Also, how the Fuzzy Petri Nets approach could be the solution for the intelligent algorithm of the GEMMA Guide paradigm, and allows the intelligent control and decision-making system according the GEMMA modes and the machine's situation.

3.2. An Approach of Fuzzy Petri Nets for Decision making

Nowadays, the mathematical models are very important in the real world and especially for science and engineering, there are many mathematical models that are applied to program the knowledge of the experts. For example, Neural Networks, Semantic Network, Machine Learning, Petri Nets etc. These different models provide intelligent support system for decision making (J. Cardoso, R. Valette, and D. Dubois, 1996).

The control with Fuzzy Logic was developed in order to help the human operator or replace him. The proportional logic is used in Fuzzy logic and it is a very effective method for real time decision making and for control applications. This method requires an additional structure in order to conjunct or disjunct the rule of the condition. Normally these methods are working rapidly and automatically without the human intervention. For this reason, they are able to provide a very good solution for the real time control systems. The mathematical model Petri Nets is a general model and is able to be modified to a more intelligent model by combine it with Fuzzy reasoning model and its propositional logic (J. Cardoso, R. Valette, and D. Dubois, 1996).

Fuzzy Petri Nets are graphical models with a degree of parallel structure that were proved as very effective and with significant abilities for representing and reasoning the decision-making of systems. The Fuzzy Petri Nets are able to transform the vectors of Fuzzy truth state with the Fuzzy rules to a Petri Nets model. This provides a new model that reminds the Neural Networks, the transition bar behaves as a neuron and the node as a condition. The different conditions can be conjunct in order to fire the neurons, when they combine the truths, it applies as AND. The changes that have been made to the traditional Petri Nets allow the Petri Nets to work with the Fuzzy logic rues and to be able to make a logical reasoning to the system. The different values of Fuzzy permit the truths of the conditions, the multiple copies of the truth tokens are fired through the arrows and get out from the node or the transition while the truth exists (Witold Pedrycz, and Heloisa Camargo, 2003).

3.2.1. Generalized Fuzzy Petri Nets

Fuzzy Petri Nets is a very useful method for a decision-making system and is based on the Fuzzy rule, IF condition THEN action. By this rule, when a condition consumes, the action produces. The knowledge of the decision-making system is based on the collections rules. Each transition of the Fuzzy Petri Nets is defined as a rule that provides a change in a certain state (Looney, 1988).
The Fuzzy Petri Net is tuple and is represented mathematically in the following way.

$$FPN = (P, T, S, I, O, \alpha, \beta, \lambda, M_0) \tag{3.1}$$

Where the finite set of places is the following:

$$P = \{p_1, p_2, \dots, p_n\},\ n > 0 \tag{3.2}$$

The finite set of transitions is represented by:

$$T = \{t_1, t_2, \dots, t_m\}, m > 0 \tag{3.3}$$

And the finite set of statements is expressed as:

$$S = \{s_1, s_2, \dots, s_n\} \tag{3.4}$$

The sets P, T, S are pairwise disjoint. In other words, the different sets are not comparable, and they have empty intersection:

$$P \cap T = P \cap S = T \cap S = \emptyset \tag{3.5}$$

Where the definitions of the function are the following.

The input function of the directed arc from the place to transition:

$$I: P \to \mathrm{T} \tag{3.6}$$

The output function of the directed arc from the transition to place is:

$$O: P \to \mathrm{T} \tag{3.7}$$

The statement binding function is represented by:

$$\alpha: P \to S \tag{3.8}$$

The truth degree and threshold functions are the following respectively:

$$\beta: T \to [0, 1] \tag{3.9}$$

$$\lambda: T \to [0, 1] \tag{3.10}$$

And the initial marking of the function is:

$$M_0: P \to [0, 1] \tag{3.11}$$

The graphical description of the Fuzzy Petri Nets is similar to the Petri Nets graphical interpretation. This means, the places id defined as circles and the transitions as rectangles. Each place is a certain state, and each transition is the state that is changed based on the conditions. The I function represents the input function, it is the direction of the arc that is connecting to the place with the transition, each transition is a part of the state that the system should be, and the change that will occur depends on the transition. The O function represents the output function, it is the direction of the arc that connects the transition with the place, each transition is a part of the state that the system will be next in the moment that the transition will fire. The place is called an input place of the transition where $I_{(t)} = \{p\}$, and the place is called an output place of the transition where $O_{(t)} = \{p\}$. The initial marking of the Fuzzy Petri Net M_0 is the initial state of the tokens in the place, and it can be described as a dimension vector or real numbers. $M_0 = \{p\}$ represents the initial state of a certain place in the system. The initial state value can be described as the truth value of the statement S with a certain place by the binding function $\alpha_{(p)} = s$. The tokens of each place are represented as dots like a traditional Petry Nets. However, in Fuzzy Petri Nets they are replaced with the appropriate real numbers and are located inside the circle of each place. The threshold function value $\lambda_{(t)}$ limits the firing of a transition and it is located as well under the transition. The transition is enabled to be fired only if the minimum value of the inputs is equal or greater than the threshold function value as it is shown in the equation below (Looney, 1988) (Chen, S.M., Ke, J.S., and Chang, J.F, 1990).

$$Firing\ of\ the\ transition = \begin{cases} Enabled & minM(t_i) \geq \lambda_{p_i} \\ Disabled & otherwise \end{cases} \tag{3.12}$$

The value of each truth function $\beta_{(t)}$ is located under each transition, and it defines the truth degree of the transition. If the transition is enabled to be fired, the output that will be transmitted to the next step will be the multiplication of minimum/maximum value of the inputs depending on the transition type by $\beta_{(t)}$. Fuzzy Petri Nets has two modes of transitions that provide a powerful way for the decision-making system. The first mode is the minimum type, this transition will provide as an output the multiplication of $\beta_{(t)}$ by the minimum value of the inputs. The second mode is the maximum transition type, this transition will provide as an output the multiplication of $\beta_{(t)}$ by the maximum value of the inputs. The transition type is indicated below the transition as a max/min, and the transition type is selected according to the operator necessities. It is possible to see these two types of transitions mathematically in the equation below.

$$M'_{(p)} = \begin{cases} mode\ 1 & min\left(M_{(t_i)}\right) * \beta_{(t_i)} \\ mode\ 2 & max\left(M_{(t_i)}\right) * \beta_{(t_i)} \end{cases} \tag{3.13}$$

The transitions can fire only when they are enabled. After the transition is fired, the token of the input will be removed and will be transmitted to the output depending on the transition conditions. This fact is very partial to a certain transition, it actions will only affect the inputs and outputs of a certain transition. In other words, the transition's firing has a very simple action, it removes the token from the inputs and transmits them to the outputs. For this reason, the Fuzzy Petri Nets is a mathematical tool that is able a parallel working (Looney, 1988).

In the figure below it is possible to see a graphical example of the Fuzzy Petri Nets with its different mode of transitions, and its mathematical example.

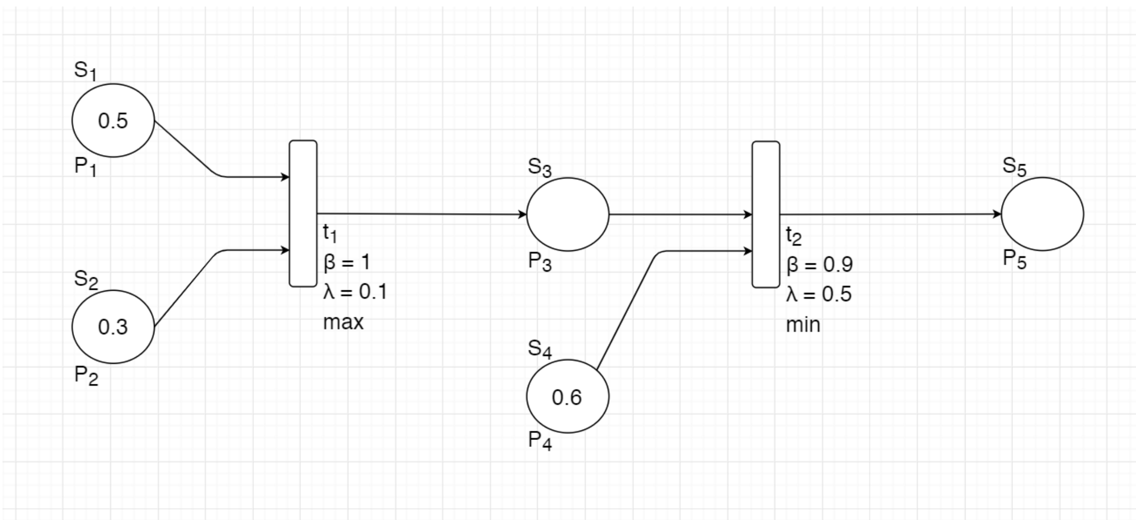

Figure 3.1: Graphical example of Fuzzy Petri Nets including its place, transitions and their values

$$FPN = (P, T, S, I, O, \alpha, \beta, \lambda, M_0) \tag{3.14}$$

The set of places:

$$P = \{p_1, p_2, p_3, p_4, p_5\} \tag{3.15}$$

The transitions set of the algorithm:

$$T = \{t_1, t_2\} \tag{3.16}$$

The statements set of the algorithm:

$$S = \{s_1, s_2, s_3, s_4, s_5\} \tag{3.17}$$

The input functions of the algorithm:

$$I_{(t_1)} = \{p_1, p_2\},\ I_{(t_2)} = \{p_3, p_4\} \tag{3.18}$$

The output functions of the algorithm:

$$O_{(t_1)} = \{p_3\},\ O_{(t_2)} = \{p_5\} \tag{3.19}$$

The statement binding functions of the algorithm:

$$\alpha_{(p_1)} = s_1,\ \alpha_{(p_2)} = s_2,\ \alpha_{(p_3)} = s_3,\ \alpha_{(p_4)} = s_4, \\ \alpha_{(p_5)} = s_5 \tag{3.20}$$

The truth degree function of the algorithm:

$$\beta_{(t_1)} = 1,\ \beta_{(t_2)} = 0.9 \tag{3.21}$$

The threshold function of the algorithm:

$$\lambda_{(t_1)} = 0.1,\ \lambda_{(t_2)} = 0.5 \tag{3.22}$$

The initial marking of the algorithm:

$$M_0 = \left\{ \underbrace{0.5}_{M_{0,(p_1)}}, \underbrace{0.3}_{M_{0,(p_2)}}, \underbrace{\emptyset}_{M_{0,(p_3)}}, \underbrace{0.6}_{M_{0,(p_4)}}, \underbrace{\emptyset}_{M_{0,(p_5)}} \right\} \tag{3.23}$$

Transition 1 (max):

$$minM(t_1) = 0.3 \tag{3.24}$$

$$\lambda_{(t_1)} = 0.1 \tag{3.25}$$

$$minM(t_1) > \lambda_{(t_1)} \Rightarrow Enabled \tag{3.26}$$

$$M'_{(p_3)} = max\left(M_{(t_1)}\right) \cdot \beta_{(t_1)} = 0.5 \cdot 1 = 0.5 \tag{3.27}$$

Transition 2 (min):

$$minM(t_2) = 0.5 \tag{3.28}$$

$$\lambda_{(t_2)} = 0.5 \tag{3.29}$$

$$minM(t_2) = \lambda_{(t_2)} \Rightarrow Enabled \tag{3.30}$$

$$M'_{(p_5)} = min\big(M_{(t_2)}\big) \cdot \beta_{(t_2)} = 0.5 \cdot 0.9 = 0.45 \tag{3.31}$$

In this simple example it is possible to see graphically and mathematically the Fuzzy Petri Nets algorithm and how it works in an appropriate way for a decision making of systems. In a situation with two different transitions with a mutual place that in one of them the minimum value of the inputs is equal to the threshold value $minM(t_i) = \lambda_{p_i}$ and the other one is greater than the threshold value $minM(t_i) > \lambda_{p_i}$. According to the Fuzzy Petri Net firing roles both can be enabled, but in this case the greater is preferable and only the grater will fire. As it is shown in the figure below.

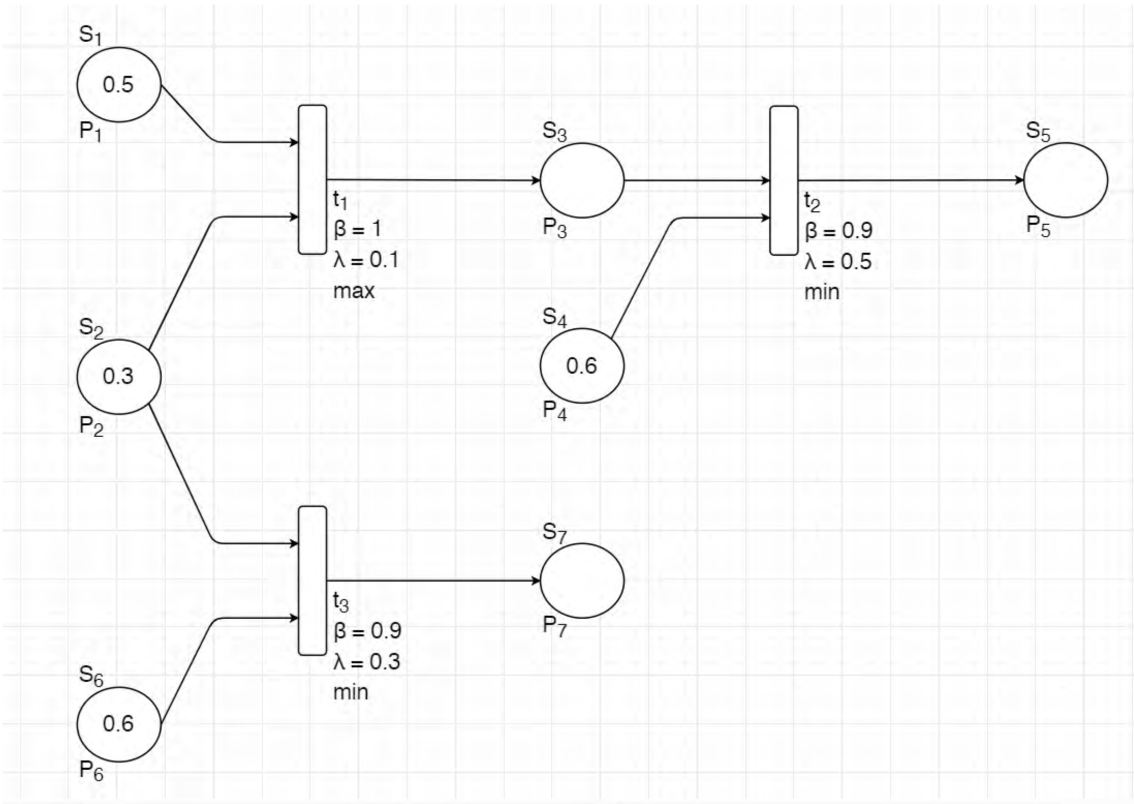

Figure 3.2: Fuzzy Petri Nets example for decision making

In this case transitions 2 and 3 has mutual input, place 2. It is possible to assume that both of the transitions will be enabled and will fire due to their conditions:

$$minM(t_1) > \lambda_{(t_1)} \Rightarrow Enabled \tag{3.32}$$

$$minM(t_2) = \lambda_{(t_2)} \Rightarrow Enabled \tag{3.33}$$

But according to the Fuzzy Petri Nets firing rules, only the greater will be preferable, and it will be the only transition that will fire. So, in this example, transition 1 is enabled and transition 3 in disabled.

3.3. The GEMMA Guide Paradigm

The GEMMA Guide Paradigm (Guide d'Etude des Modes de Marche et d'Arrêt) was born in order to develop a tool that facilitates the automation of production systems. It was developed in 1984 by ADEPA (Agence Nationale pour le Developpement de la Production Automatisée) (Rochouse, 1987) in France. The GEMMA is presented as a block diagram that is typified by different states and the possible conditions of the evolution between them. An important problem of dealing with the automation of a process is to define correctly what will be the different working modes and what each of them will do. The GEMMA Guide paradigm allows to review the different operating modes that may or may not be developed. It is very useful in order to analysis the stages. Since it provides a pattern that includes all the possible modes of the operation, it is possible to choose the modes that meet the needs as part of the functional specification (Cloutier, 1988). The use of the GEMMA Guide Paradigm combines the communication between the operator and the system, and it avoids misunderstandings that can appear between them. In other words, avoiding the delay and the failure of the project that may occur by bad communication (ADEPA, 1981).

The automation of machines and industrial processes must consider all the possible states that the machine or the process can be found, including normal operation, failure situations, emergency stop, reset and startup process and the difference verifications and test modes. An automation program must give a priority for detecting the possible failures in the operating part and preforming the emergency stop while a failure is occurred. Also, a very important issue is to return the machine to the normal production when it is possible, considering the case that the production must continue. However, when it is no possible to continue, the process must be started again. Each automation program must consider these cases, with the aim of reducing the machine downtime to minimum. Moreover, making simple the restart process and changes in the operating mode. For example, changing the system from a manual control to an automatic control (Rochouse, 1987).

3.3.1. The Different Modes of the GEMMA Guide

The GEMMA Guide Paradigm provides a very organize way to develop the automation modes. For this reason, the following automation modes must implement:

- Normal production.
- Verification mode (provides to control the machine manually).
- Test mode.
- Initial stop state (provides to place the machine in initial state).
- Failure procedure (the management of the emergency stop).
- Stop procedure (the management to stop and reset the machine).

The GEMMA Guide Paradigm "guide for studying the running and stop modes", is a very organized representation of the different modes and states that can be found in an automated production process. It also represents the jumps or transitions that occur between the states (Rochouse, 1987). These states are organized into three main groups:

- Stop procedure (A) – this procedure includes various shutdown processes and is activated at the request of the operator for different reasons. One of them is shutdown that is requested at the end of the cycle, and another one is a shutdown in a certain state of the machine. It also includes the startup processes of the machine such as placing the system in the initial state or a certain state.
- Operating procedure (F) – this procedure indicates the necessary processes of the operation in order to produce the products or operate the machine. In addition to the normal production mode, it also includes the start-up and shut down processes to the initial state, and the different verification and test modes.
- Failure procedure (D) – this procedure includes the failure processes and is activated automatically by a failure of the machine or manually by the request of the operator when the emergency button is pressed.

The operation procedure is described by a rectangle that contain all the possible production modes. It can be in the operation procedure for both, the operating process and startup/shutdown process. This group contains also all the operating modes in which the system is stopped. The modes that lead to stop the system and allow the system to move from the fault state to stop state in order to restart the system. These processes are normally carried out by the request of the operator.

In each group there are few modes that can be activated in a certain situation. The different modes are the following:

The stop procedures:

- A1 – Stop in the initial state – this is the first and base mode of the machine. It is represented by a double rectangle, and normally the machine is represented in this mode.
- A2 – Requested stop at the end of the cycle – this is a temporal mode of the machine, the machine arrives to this mode from F1 (normal production). It must be activated until the end of the cycle and then to be deactivated in the moment that it transmits to the initial state mode. This mode is able to memorize the stop that is requested by the operator until the machine is able to finish to perform the cycle and then to return to the initial stop state mode.
- A3 – Requested stop (non-initial state) – this mode is memorized the requested stop by the operator, the machine stops in an intermediate state of the cycle and placed at the stop mode (non-initial state).
- A4 – Stop mode (non-initial state) – this mode is an intermediate state of the machine cycle, similarly to the initial state.

Depending on the machine, different stop modes can be implemented, it depends on the required intermediate modes of the manufacturing process. Therefore, there are several options on the control panel and the operator is able to make the proper request.

- A5 – Preparation for startup after a failure – In this mode, the necessary actions must be taken in order to correct the failure or defect that have led to the execution of the emergency stop. This can be performed by the maintenance workers, and the system is able to indicate approximately where the fault exists. Once the process is complete, the operator can choose how to restart the machine. In other words, the operator is able to decide if to switch the machine to A6 (Reset to initial state) in order to place it in the initial state or to switch the machine to A7 (Setting to non-initial state) in order to place the machine in same certain state as before the failure.
- A6 – Reset to initial state – The machine will automatically make the appropriate preparation for the initial state by the programmable logic controller.
- A7 – Setting to non-initial state – this mode is temporal mode of the machine, the machine arrives to this mode from A5 (Preparation for startup after a failure). In this step it was decided by the operator to place the machine in a different state

from the initial state, it is important in a case that the production must continue and not start from the beginning. Usually, in a case of failure the machine has stopped the production process in a certain place, and it could not finish the production properly.

Operating procedure:

- F1 – Normal production – this mode indicates the normal production process of the machine. It is the most important state, and it is described by a ticker rectangle. The normal production mode is usually an automatic operation.
- F2 – Start up process – this mode automatically performs the necessary actions that should be made in order to place the machine in the normal production mode, such as heating the oven or preparing the necessary components for the production.
- F3 – Shutdown process – this mode is automatically preparing the machine to the initial state after the production process has completed, such as emptying or cleaning the machine.
- F4 – Running in verification mode disorderly – the machine is placed at a manual control, and the operator can control the machine manually. These movements must be carried out with the safety conditions of the machine. It is usually used to regulate correctly the components of the machine, such as sensors, or to place the machine in a required state of the production.
- F5 – Running in verification mode orderly – in this mode the machine performs the complete cycle of the operation orderly. Generally, it is used in order to validate the machine production process.
- F6 – Test mode – the automated control system checks the correct operation of the machine and its components.

Failure procedure:

- D1 – Emergency stop – in this mode the machine must be placed at a safe situation for both, the operator and the production. Normally, this mode involves a rapid stopping for the entirety machine. The automated control system must memorize the state of the previous mode in order to be able to place the machine again in the same point after the failure (if it will be necessary), in this way the machine will be able to continue the production exactly from the same state that it has stopped.

- D2 – Diagnosis and/or treatment of the failure – the automated control system is able to guide the operator in order to indicate approximately where the defect is. However, the failure will be repaired by the operator or by the maintenance workers.
- D3 – Production despite the failure – in cases that is necessary to continue the producing even when the system does not work correctly. This mode can be activated in the cases that there is no danger for the operator and the machine. For example, if the operation fails and it can be fixed by the operator or when there is a position fail of the manufacturing line, but when the production is duplicated it can be continued.

The figure below describes the GEMMA Guide Paradigm with its different states and modes as was explaining in the last two chapters.

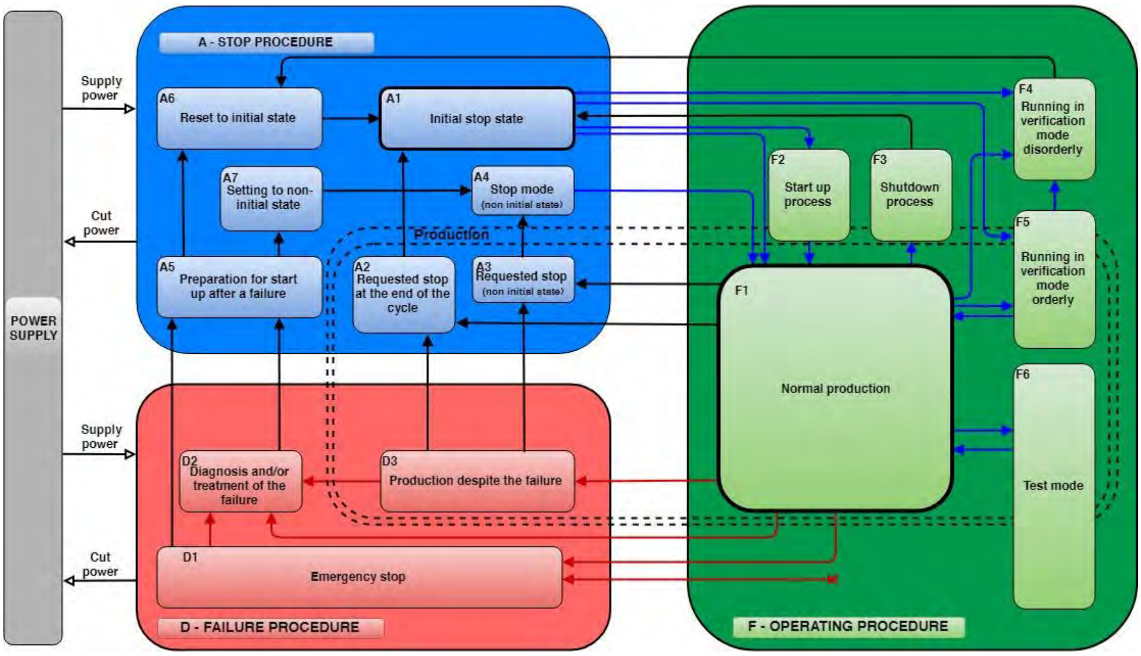

Figure 3.3: GEMMA Guide Paradigm

3.3.2. GEMMA Guide Uses

The GEMMA guide paradigm has been revolutionary in its field thanks to the easy representation of the operating, stop and failure states. It became to be the basis of numerous research works on substantial applications in the process automation field.

Moreover, these research works have a place for new and revolutionary technologies, such as the communication of the industrial processes, robotics, fault diagnosis, supervision systems, etc. One of the biggest difficulties when it comes to the capturing systematic production tasks in an automated system is the integration of the human operator (Cloutier, 1988). The GEMMA Guide paradigm contains almost all the possible situations for an automated control system, as well as the transitions between them. It provides a standard that will perform appropriately the steps that are needed in each state. The GEMMA Guide Paradigm has been revolutionary in the control and automation field thanks to the simple representation of each step, and its good integration with the human operator (ADEPA, 1981).

3.4. Fuzzy Petri Nets Algorithms for the GEMMA Guide Paradigm

Nowadays the Ladder Logic Diagram is the most common language for programming a control system with PLCs. This language contains graphical basic elements, and it is based on an analog to physical relay diagrams. For this reason, it is very familiar in the industry. However, the Ladder Logic Diagram has also disadvantaged, such as the program may be cumbersome to design and complex for applying to sequential tasks.

In order to integrate the Fuzzy Petri Nets approach with the GEMMA Guide Paradigm, it is necessary first to understand how to make the best control system from a Fuzzy Petri Net algorithm. In other words, while the Fuzzy Petri Nets algorithm is already developed, its conversion to a control system is needed. The best way to convert a Fuzzy Petri Nets algorithm to a control system is by Ladder Logic Diagram due to its best use for control system, and the appropriate structure for the Fuzzy Petri Nets approach.

The Fuzzy Petri Net allows the transition to a Ladder Logic Diagram structure for easy execution under programming techniques in PLCs. Each location in a Fuzzy Petri Nets represents a state, condition, or resource, and it is associated in a Ladder Logic Diagram with one of the steps. It allows to mark the control at a certain location. The transitions that are correspond to events or actions allow the evolution of marking and are associated with the contacts. The procedures for the design of sequential systems that are used in Fuzzy Petri Nets must have a methodology for their implementation in a digital equipment in order to make the conversation of the system model into a standardized PLC language. Figure 3.4 and 3.5 presents the simple conversation of a Fuzzy Petri Nets to a Ladder Logic Diagram. In this example, figure 3.4 shows the connection and represents ”AND” function, and figure 3.5 represents ”OR” function.

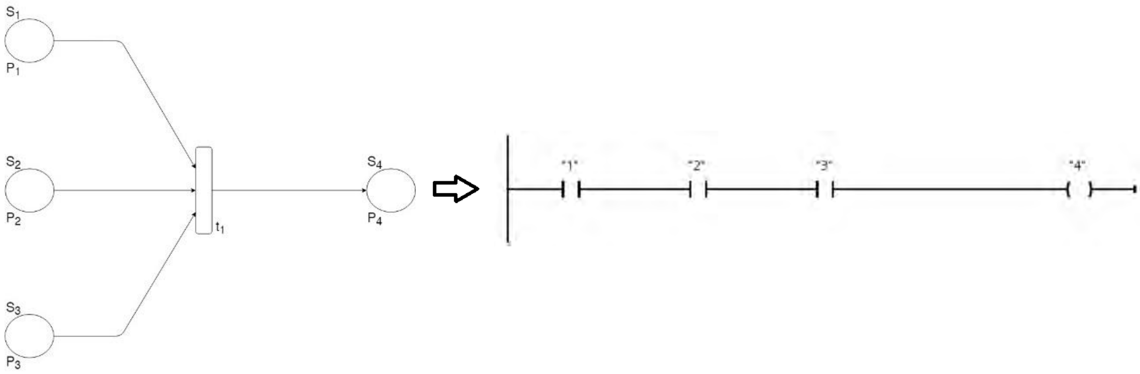

Figure 3.4: Fuzzy Petri Net conversion, ”AND” function

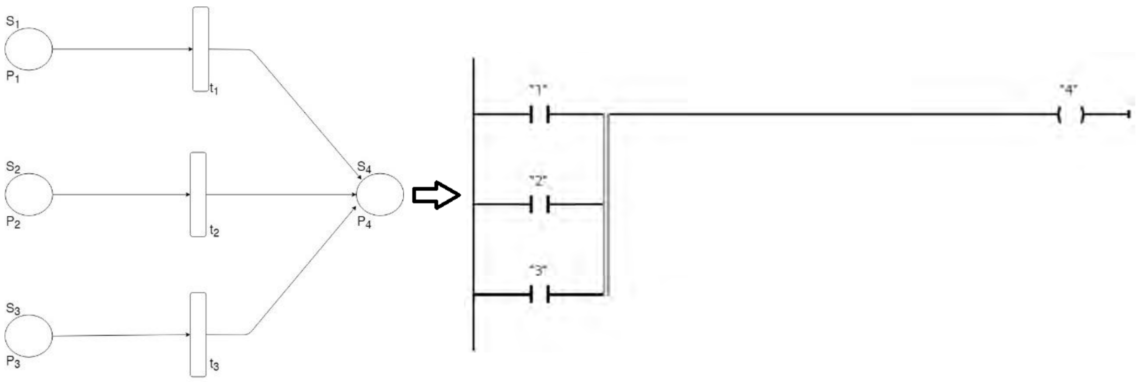

Figure 3.5: Fuzzy Petri Net conversion, ”OR” function

In this way it is possible to convert also the complicated Fuzzy Petri Nets algorithms to a Ladder Logic Diagrams in order to make a control system that is capable to work with PLCs and is based on the programmed Fuzzy Petri Nets algorithm. The following example describes the Fuzzy Petri Nets algorithm conversion to a Ladder Logic diagram for the stop to operation procedure of the GEMMA Guide Paradigm.

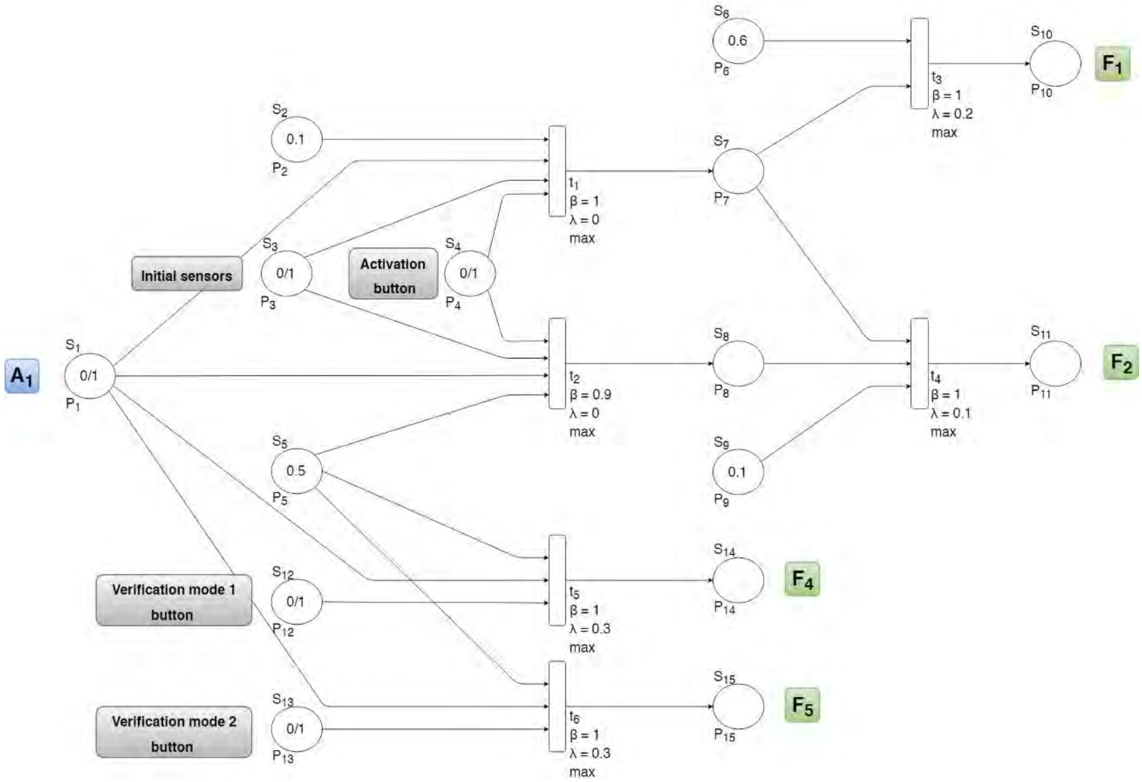

Figure 3.6: Fuzzy Petri Nets algorithm for the stop procedure to operation procedure of GEMMA

Figure 3.6 presents the Fuzzy Petri Nets intelligent algorithm for the stop procedure to operation procedure of GEMMA. In the next chapter this algorithm and its elements are developed and described. In order to make this algorithm useful for control and decision-making system, it is needed to convert the algorithm to a Ladder Logic Diagram as it is explained in this chapter. Figures 3.7 and 3.8 show the conversion of this algorithm to a Ladder Logic Diagram that is appropriate for the decision-making of the GEMMA Guide Paradigm, it has been programmed by the software Tia Portal of Siemens.

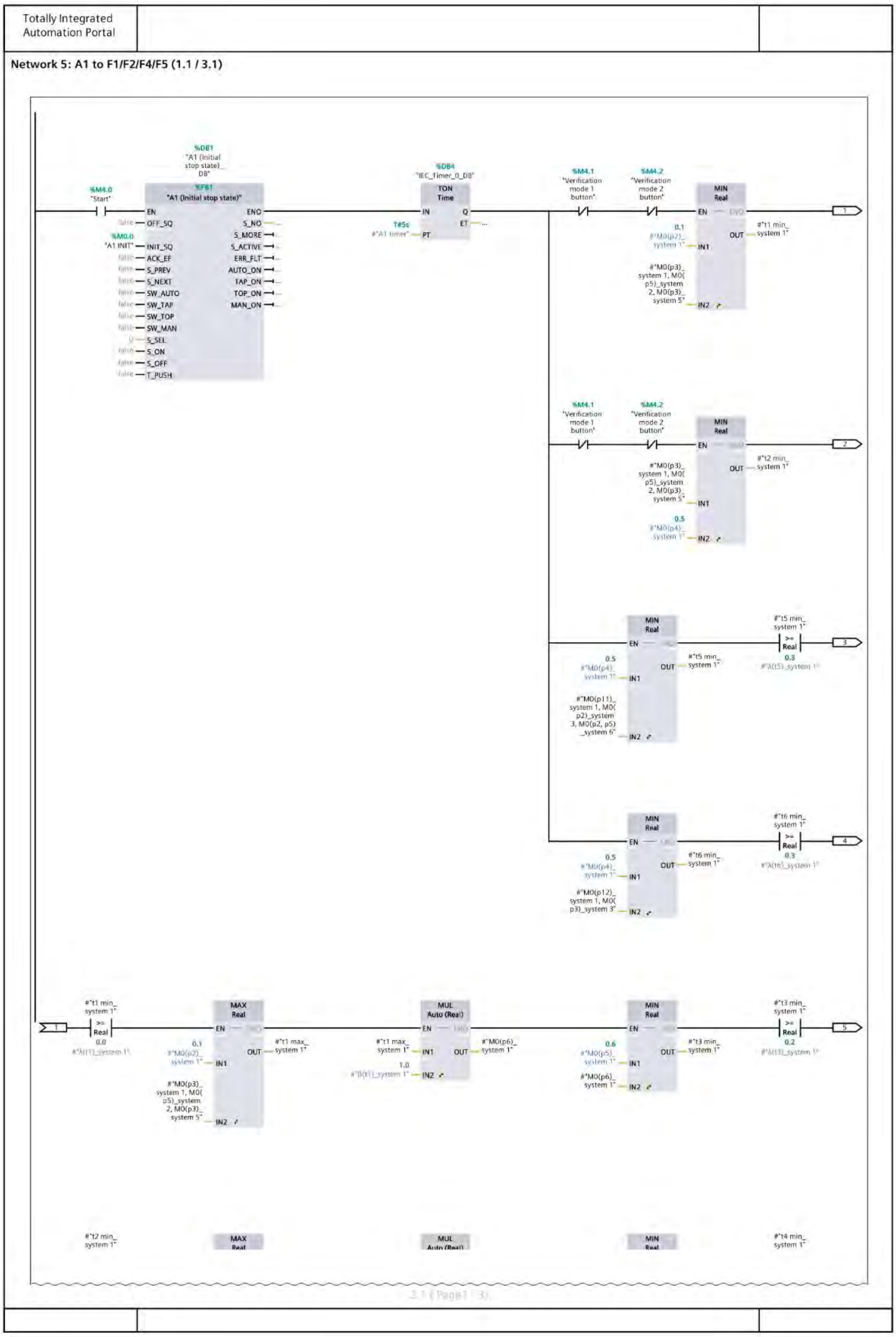

Figure 3.7: Fuzzy Petri Nets algorithm conversion to Ladder Logic Diagram (stop procedure to operation procedure of GEMMA), page 1

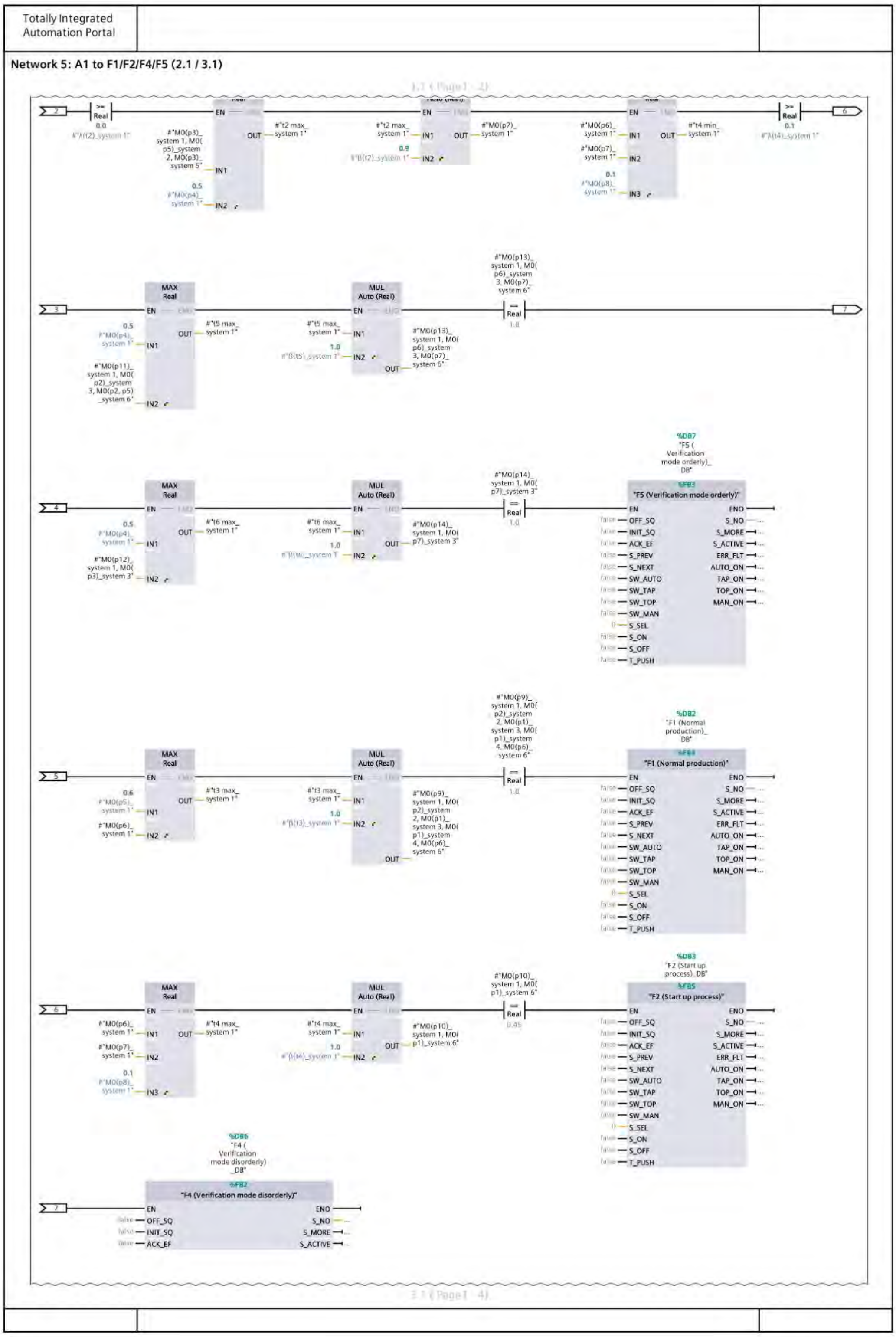

Figure 3.8: Fuzzy Petri Nets algorithm conversion to Ladder Logic Diagram (stop procedure to operation procedure of GEMMA), page 2

From figures 3.7 and 3.8 it is possible to understand how a complicated Fuzzy Petri Nets algorithm has been converted into Ladder logic Diagram. First, the activation of the transition is set by mathematical comparison operations. It receives the minimum value of the transition inputs and compares it with the threshold function of the transition (λ). When the minimum value of the places is greater than the threshold function, the transition will be activated. The different transitions of Fuzzy Petri Nets algorithm are presented as mathematical blocks depending on the transition requirements, such as Min, Max, and Multiple function. Moreover, the different places and values of the transition's inputs are set as inputs of the mathematical blocks, and their values are either constant or variable depending on the transition requirements. In this way the necessary calculations of each transition are made. At last, the different modes of GEMMA are presented by Grafcet blocks of Tia portal. While the Ladder Logic diagram activates one of the modes, the Grafcet control system that is programed within the block is activated and the control system of the certain GEMMA mode is activated as well.

3.5. Conclusion

The propose of this chapter has been to introduce the Fuzzy Petri Nets approach and its advantage for control and decision making, and the GEMMA guide Paradigm including its graphical structure, modes and uses in the industry. Moreover, the integration of Fuzzy Petri Nets in the GEMMA Guide Paradigm has been explained.

The intelligent algorithm that has been explained in this chapter presents the capability of the Fuzzy Petri Nets for making the decision for the transitions between the different modes of the GEMMA Guide Paradigm according to the machine's state and situation. Additionally, the conversion of the intelligent algorithm to a control system has been presented. That is to say, the most efficient way to convert the Fuzzy Petri Nets intelligent algorithm to a control system is by Ladder Logic Diagram due to its best capabilities for control system, and its appropriate structure for the Fuzzy Petri Nets approach.

The Fuzzy Petri Nets intelligent algorithm that has been presented in this chapter is for stop procedure to operation procedure of the GEMMA Guide Paradigm. This intelligent algorithm needs to control the transitions between the stop modes to operation modes of GEMMA and to provide the decision making according the machine's state and situation. The introducing of this intelligent algorithm has been important in this chapter in order to show the integration of the Fuzzy Petri Nets approach with the GEMMA Guide

Paradigm for control and decision-making system. Additionally, the conversion of the intelligent algorithm to a Ladder logic Diagram has been clarified including the explanation of the different Fuzzy Petri Nets places and transition in the Ladder Logic Diagram.

4. ARTIFICIAL INTELLIGENCE ALGORITHMS FOR THE TRANSITIONS OF THE GEMMA GUIDE PARADIGM

4.1. Introduction

This chapter presents the development of Fuzzy Petri Nets intelligent algorithms for the transitions between the GEMMA Guide modes. These intelligent algorithms provide the operator a safe control and automatic transitions between the different modes according to the machine sate and situation.

Each algorithm is related to a different state of the GEMMA Guide Paradigm and machine. That is to say, the algorithms are divided into five categories in order to provide the best decision making and control system. The first intelligent transition is responsible to the transitions between the stop to operation procedure. It allows to place the machine in the appropriate mode of the operation procedure according the operator need and machine state. The second intelligent algorithm that is shown is in charge of operation procedure which makes sure that the machine will be placed at the appropriate operation mode. In other words, the transitions between the normal production mode (F1) to the different verification and test modes (F4, F5, F6) of the GEMMA Guide Paradigm. The third intelligent algorithm that is developed in this chapter is the operation to stop procedure, this algorithm insures that the machine will be placed at the necessary stop mode while there is the need to stop the machine from some reason. The next intelligent algorithm is the operation to failure procedure, this algorithm is the most important for the safety of human and for preventing machine damage. By this intelligent algorithm the machine will stop automatically and immediately in a situation of failure and will be placed at the appropriate mode according the failure. Moreover, in an emergency situation the operator will be able to stop immediately the machine and it will be placed at the right place according the machine state and situation. The last intelligent algorithm that is developed in this chapter is the failure to stop procedure. This transition is responsible to make the decision and place the machine automatically in the necessary mode after the failure has fixed. It provides an efficient control for the machine and may save money in a situation that the failure appears at some point of the production and the completion of the process is needed.

4.2. Stop Procedure to Operation Procedure

The transition between the stop procedure A1 mode and the different operation modes (F1, F2, F4, F5) is very important in order to have the appropriate control of the machine. While the machine is in the initial stop state (A1), it has the possibility to pass to 3 different modes, and it is decided by the operator due to his requirement. In a situation that the operator desires to place the program in the normal production mode in order to start the production, the program can be placed at 2 different modes, normal production (F1) or start-up process (F2). The decision of the correct mode will be done automatically by the control. That is to say, while the necessary initial sensors are on, the control will place the program in the normal production mode. However, in a case that not all the initial sensors of the machine are on or the machine is not ready to start the production due to different issue, such as machine cleaning is required. In this case, the control will place the program in a start-up process mode in order to let the machine prepare itself for the production. Moreover, when the operator desires to place the program in either verification mode 1 (F4) or verification mode 2 (F5), he is able to do it by the control directly from the initial state (A1).

The Fuzzy Petri Nets algorithm provides an intelligence and safe algorithm to control these transitions of the program. By this algorithm, the operator is able to place the program in the desired mode in order to either start the production or make some verifications of the machine. In the figure below it is possible to see the Fuzzy Petri Net algorithm of the transition between the initial state and the different operation modes.

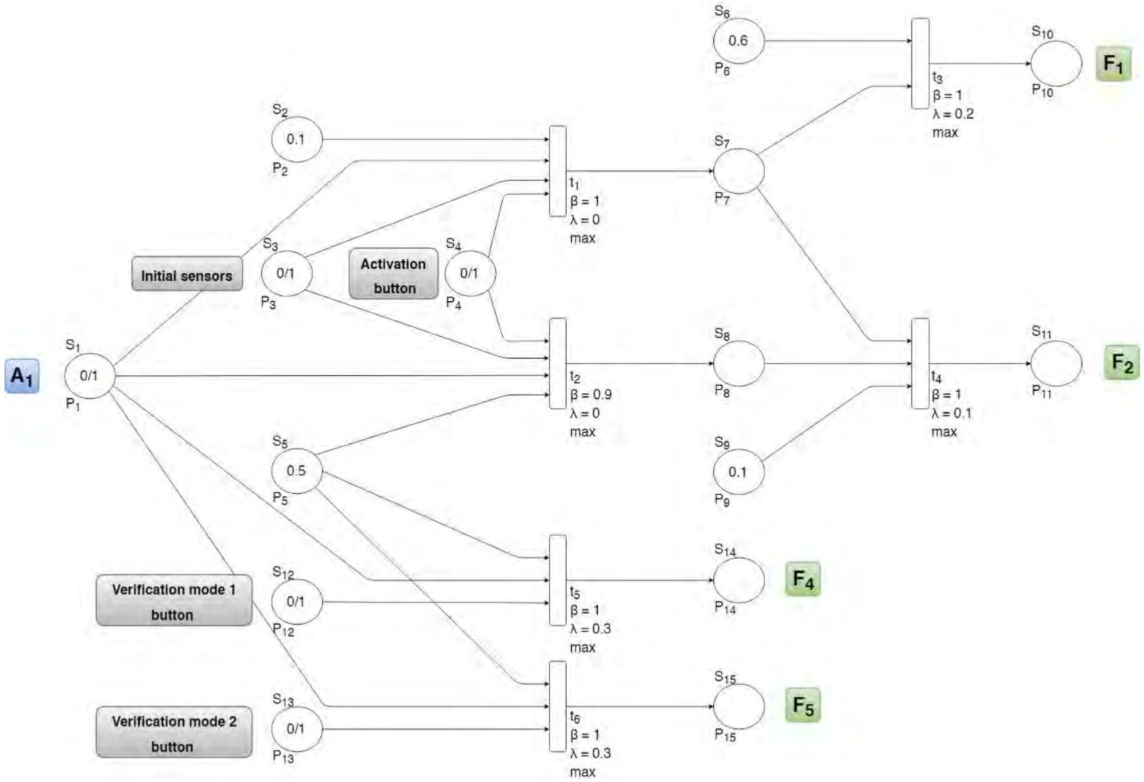

Figure 4.1: Fuzzy Petri Nets algorithm for the stop procedure to operation procedure of GEMMA

In figure 4.1 it is possible to see that this Fuzzy Petri Nets algorithm allows the operator to choose what he desires to do next, for example to place the program in one of the verification modes by pressing the either verification mode 1 or 2. Also, to start the production by pushing the activation mode button. In this case the algorithm will place the machine automatically in the appropriate mode (F1 or F2) in order to start the production correctly. The following calculations prove the transitions between the different modes.

$$FPN = (P, T, S, I, O, \alpha, \beta, \lambda, M_0) \tag{4.1}$$

The set of places of the algorithm:

$$P = \{p_1, p_2, p_3, p_4, p_5, p_6, p_7, p_8, p_9, p_{10}, p_{11}, p_{12}, p_{13}, p_{14}, p_{15}\} \tag{4.2}$$

The transitions set of the algorithm:

$$T = \{t_1, t_2, t_3, t_4, t_5, t_6\} \tag{4.3}$$

The statements set of the algorithm:

$$S = \{s_1, s_2, s_3, s_4, s_5, s_6, s_7, s_8, s_9, s_{10}, s_{11}, s_{12}, s_{13}, s_{14}, s_{15}\} \tag{4.4}$$

The input functions of the algorithm:

$$\begin{aligned} &I_{(t_1)} = \{p_1, p_2, p_3, p_4\},\ I_{(t_2)} = \{p_1, p_3, p_4, p_5\},\ I_{(t_3)} = \{p_6, p_7\}, \\ &I_{(t_4)} = \{p_7, p_8, p_9\},\ I_{(t_5)} = \{p_1, p_5, p_{12}\},\ I_{(t_6)} = \{p_1, p_5, p_{13}\} \end{aligned} \tag{4.5}$$

The output functions of the algorithm:

$$\begin{aligned} &O_{(t_1)} = \{p_7\},\ O_{(t_2)} = \{p_8\},\ O_{(t_3)} = \{p_{10}\},\ O_{(t_4)} = \{p_{11}\}, \\ &O_{(t_5)} = \{p_{14}\},\ O_{(t_6)} = \{p_{15}\} \end{aligned} \tag{4.6}$$

The statement binding functions of the algorithm:

$$\begin{aligned} &\alpha_{(p_1)} = s_1,\ \alpha_{(p_2)} = s_2,\ \alpha_{(p_3)} = s_3,\ \alpha_{(p_4)} = s_4,\ \alpha_{(p_5)} = s_5, \\ &\alpha_{(p_6)} = s_6,\ \alpha_{(p_7)} = s_7,\ \alpha_{(p_8)} = s_8,\ \alpha_{(p_9)} = s_9,\ \alpha_{(p_{10})} = s_{10}, \\ &\alpha_{(p_{11})} = s_{11},\ \alpha_{(p_{12})} = s_{12},\ \alpha_{(p_{13})} = s_{13},\ \alpha_{(p_{14})} = s_{14},\ \alpha_{(p_{15})} = \\ &s_{15} \end{aligned} \tag{4.7}$$

The truth degree function of the algorithm:

$$\beta_{(t_1)} = 1,\ \beta_{(t_2)} = 0.9,\ \beta_{(t_3)} = 1,\ \beta_{(t_4)} = 1,\ \beta_{(t_5)} = 1,\ \beta_{(t_6)} = 1 \tag{4.8}$$

The threshold function of the algorithm:

$$\begin{aligned} &\lambda_{(t_1)} = 0,\ \lambda_{(t_2)} = 0,\ \lambda_{(t_3)} = 0.2,\ \lambda_{(t_4)} = 0.1,\ \lambda_{(t_5)} = 0.3,\ \lambda_{(t_6)} = \\ &0.3 \end{aligned} \tag{4.9}$$

The initial marking of the algorithm:

$$M_0 = \left\{ \begin{matrix} \underbrace{0/1}_{M_{0,(p_1)}}, \underbrace{0.1}_{M_{0,(p_2)}}, \underbrace{0/1}_{M_{0,(p_3)}}, \underbrace{0/1}_{M_{0,(p_4)}}, \underbrace{0.5}_{M_{0,(p_5)}}, \underbrace{0.6}_{M_{0,(p_6)}}, \underbrace{\emptyset}_{M_{0,(p_7)}}, \underbrace{\emptyset}_{M_{0,(p_8)}}, \\ \underbrace{0.1}_{M_{0,(p_9)}}, \underbrace{\emptyset}_{M_{0,(p_{10})}}, \underbrace{\emptyset}_{M_{0,(p_{11})}}, \underbrace{0/1}_{M_{0,(p_{12})}}, \underbrace{0/1}_{M_{0,(p_{13})}}, \underbrace{\emptyset}_{M_{0,(p_{14})}}, \underbrace{\emptyset}_{M_{0,(p_{15})}} \end{matrix} \right\} \tag{4.10}$$

In the table 4.1 it is possible to see the Fuzzy Petri Nets transitions from A1 to F1/F2 modes of GEMMA (while the activation button is on, $M_0(p_4) = 1$):

Table 4.1: Fuzzy Petri Nets calculations for the transitions of GEMMA between the modes A1 and F1/F2

While the initial sensors are off, $M_0(p_3) = 0$:	While the initial sensors are on, $M_0(p_3) = 1$:
Transition 1 (max): $minM(t_1) = 0$ $\lambda_{(t_1)} = 0$ $minM(t_1) = \lambda_{(t_1)} \Longrightarrow Enabled$ $M'_{(p_7)} = max\left(M_{(t_1)}\right) \cdot \beta_{(t_1)} = 0.1 \cdot 1 = 0.1$ Transition 2 (max): $minM(t_2) = 0$ $\lambda_{(t_2)} = 0$ $minM(t_2) = \lambda_{(t_2)} \Longrightarrow Enabled$ $M'_{(p_8)} = max\left(M_{(t_2)}\right) \cdot \beta_{(t_2)} = 0.5 \cdot 0.9 = 0.45$ Transition 3 (max): $minM(t_3) = 0.1$ $\lambda_{(t_3)} = 0.2$ $minM(t_3) < \lambda_{(t_3)} \Longrightarrow Disabled$ Transition 4 (max): $minM(t_4) = 0.1$ $\lambda_{(t_4)} = 0.1$ $minM(t_4) = \lambda_{(t_4)} \Longrightarrow Enabled$	Transition 1 (max): $minM(t_1) = 0.1$ $\lambda_{(t_1)} = 0$ $minM(t_1) > \lambda_{(t_1)} \Longrightarrow Enabled$ $M'_{(p_7)} = max\left(M_{(t_1)}\right) \cdot \beta_{(t_1)} = 1 \cdot 1 = 1$ Transition 2 (max): $minM(t_2) = 0.5$ $\lambda_{(t_2)} = 0$ $minM(t_2) > \lambda_{(t_2)} \Longrightarrow Enabled$ $M'_{(p_8)} = max\left(M_{(t_2)}\right) \cdot \beta_{(t_2)} = 1 \cdot 0.9 = 0.9$ Transition 3 (max): $minM(t_3) = 0.6$ $\lambda_{(t_3)} = 0.2$ $minM(t_3) > \lambda_{(t_3)} \Longrightarrow Enabled$ $\Downarrow$ $M'_{(p_{10})} = max\left(M_{(t_3)}\right) \cdot \beta_{(t_3)} = 1 \cdot 1 = 1$ Transition 4 (max): $minM(t_4) = 0.1$

$M'_{(p_{11})} = max\big(M_{(t_4)}\big) \cdot \beta_{(t_4)} = 0.45 \cdot 1 = 0.45$ $\Downarrow$ **F2 state of the GEMMA guide is on.**	$\lambda_{(t_4)} = 0.1$ $minM(t_4) = \lambda_{(t_4)} \Longrightarrow Enabled$ $\Downarrow$ **F1 state of the GEMMA guide is on.** In this case, transition 3 and transition 4 can fire due to the Fuzzy Petri Nets firing rules $minM(t_i) \geq \lambda_{p_i}$. However, when there is a case that in one transition $minM(t_i) = \lambda_{p_i}$ and in the other transition $minM(t_i) > \lambda_{p_i}$. The bigger will be preferable, and in this case, only transition 3 will fire and F1 state of the GEMMA guide will be on.

Table 4.2 shows the Fuzzy Petri Nets calculations for the transitions of GEMMA between the modes A1 and F4, the transition 5 type is max:

Table 4.2: Fuzzy Petri Nets calculations for the transitions of GEMMA between the modes A1 and F4

While the verification mode 1 button is off, $M_0(p_{11}) = 0$: $minM(t_5) = 0$ $\lambda_{(t_5)} = 0.3$ $minM(t_5) < \lambda_{(t_5)} \Longrightarrow Disabled$	While the verification mode 1 button is on, $M_0(p_{11}) = 1$: $minM(t_5) = 0.5$ $\lambda_{(t_5)} = 0.3$ $minM(t_5) > \lambda_{(t_5)} \Longrightarrow Enabled$ $M'_{(p_{14})} = max\big(M_{(t_5)}\big) \cdot \beta_{(t_5)} = 1 \cdot 1 = 1$ $\Downarrow$ **F4 state of the GEMMA guide is on.**

In the table below the Fuzzy Petri Nets transitions of GEMMA for the modes A1 and F5 are presented, the type of transition 6 is max:

Table 4.3: Fuzzy Petri Nets calculations for the transitions of GEMMA between the modes A1 and F5

While the verification mode 2 button is off, $M_0(p_{12}) = 0$:	While the verification mode 2 button is on, $M_0(p_{12}) = 1$:
$minM(t_6) = 0$ $\lambda_{(t_6)} = 0.3$ $minM(t_6) < \lambda_{(t_6)} \Rightarrow Disabled$	$minM(t_6) = 0.5$ $\lambda_{(t_6)} = 0.3$ $minM(t_6) = \lambda_{(t_6)} \Rightarrow Enabled$ $M'_{(p_{15})} = max\big(M_{(t_6)}\big) \cdot \beta_{(t_6)} = 1 \cdot 1 = 1$ $\Downarrow$ **F5 state of the GEMMA guide is on.**

The calculations of the different transitions for the stop procedure to operation procedure of the GEMMA Guide Paradigm show that the decision-making system for these transitions is working properly regarding to the GEMMA requirements. In other words, each mode of the GEMMA will be activated in the appropriate moment and situation regarding to the GEMMA needs.

4.3. Operation Procedure

There are several significant transitions in the operation procedures, these different transitions are decided by the operator according to the situation and requirement. In a case that the operator desires in a certain point of the production to make some verification of the machine, he is able to make it by chosen the appropriate mode according to his needs. In other words, he can place the program during the production either in the different verification modes (F4, F5) or the test mode (F6). When he finishes to verify the machine, he is able to either return to the production (from F5 and F6) or restart the machine to the initial state (from F4 and F5) depends on his needs.

The Fuzzy Petri Nets algorithm for the operation procedure makes safe transitions for the operator needs and prevents problems that may occur during the transitions. By this algorithm, the operator is able to choose in which mode to place the program, and also to return to a certain point of the production or restart the machine to the initial state. The figure below describes the Fuzzy Petri Nets algorithm of the operation procedure including the Fuzzy Petri Nets places, transitions and their values.

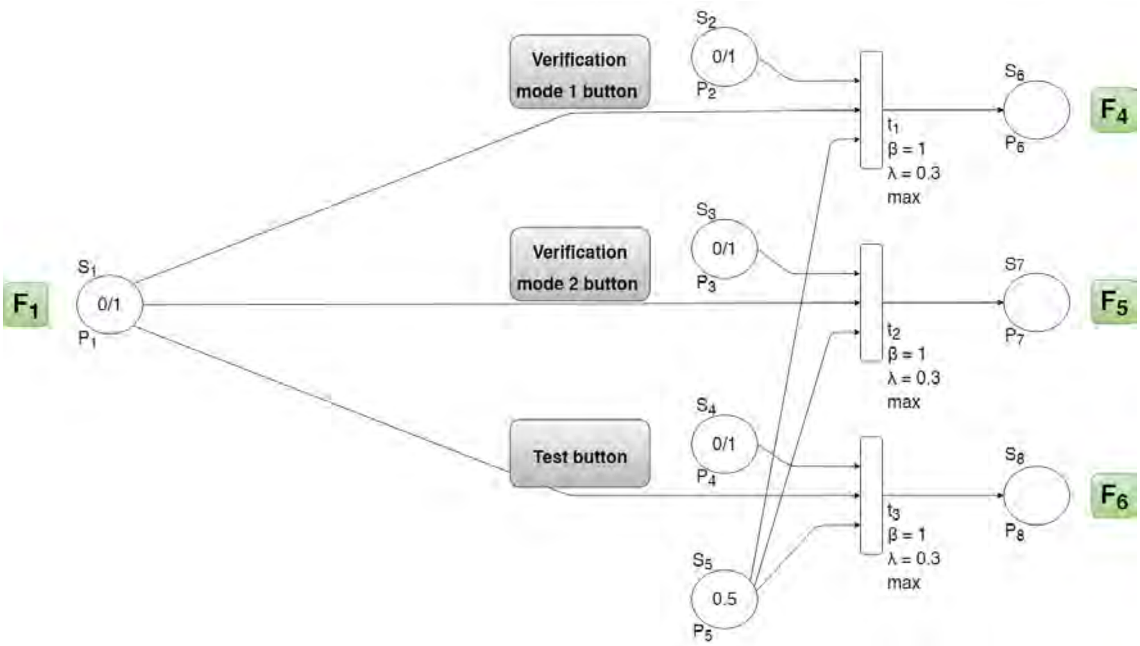

Figure 4.2: Fuzzy Petri Nets algorithm for the operation procedure of GEMMA

From figure 4.2 it is possible to notice that the operator is able to choose in which mode to place the program according to his needs. For example, while the program is placed at the normal production mode and either the verification button 1 or 2 is pressed, the program will be placed at either verification mode 1 or 2, respectively. In the same way, placing the program in the test mode by the test button. The following calculation proves the transitions between the different modes.

$$FPN = (P, T, S, I, O, \alpha, \beta, \lambda, M_0) \tag{4.11}$$

The set of places of the algorithm:

$$P = \{p_1, p_2, p_3, p_4, p_5, p_6, p_7, p_8\} \tag{4.12}$$

The transitions set of the algorithm:

$$T = \{t_1, t_2, t_3\} \tag{4.13}$$

The statements set of the algorithm:

$$S = \{s_1, s_2, s_3, s_4, s_5, s_6, s_7, s_8\} \tag{4.14}$$

The input functions of the algorithm:

$$I_{(t_1)} = \{p_1, p_2, p_5\},\ I_{(t_2)} = \{p_1, p_3, p_5\},\ I_{(t_3)} = \{p_1, p_4, p_5\} \tag{4.15}$$

The output functions of the algorithm:

$$O_{(t_1)} = \{p_6\},\ O_{(t_2)} = \{p_7\},\ O_{(t_3)} = \{p_8\} \tag{4.16}$$

The statement binding functions of the algorithm:

$$\begin{aligned} &\alpha_{(p_1)} = s_1,\ \alpha_{(p_2)} = s_2,\ \alpha_{(p_3)} = s_3,\ \alpha_{(p_4)} = s_4,\ \alpha_{(p_5)} = s_5,\ \alpha_{(p_6)} = s_6, \\ &\alpha_{(p_7)} = s_7,\ \alpha_{(p_8)} = s_8 \end{aligned} \tag{4.17}$$

The truth degree function of the algorithm:

$$\beta_{(t_1)} = 1,\ \beta_{(t_2)} = 1,\ \beta_{(t_3)} = 1 \tag{4.19}$$

The threshold function of the algorithm:

$$\lambda_{(t_1)} = 0.3,\ \lambda_{(t_2)} = 0.3,\ \lambda_{(t_3)} = 0.3 \tag{4.20}$$

The initial marking of the algorithm:

$$M_0 = \left\{ \begin{matrix} \underbrace{0/1}_{M_{0,(p_1)}}, & \underbrace{0/1}_{M_{0,(p_2)}}, & \underbrace{0/1}_{M_{0,(p_3)}}, & \underbrace{0/1}_{M_{0,(p_4)}}, \\ \underbrace{0.5}_{M_{0,(p_5)}}, & \underbrace{\emptyset}_{M_{0,(p_6)}}, & \underbrace{\emptyset}_{M_{0,(p_7)}}, & \underbrace{\emptyset}_{M_{0,(p_8)}} \end{matrix} \right\} \tag{4.21}$$

The table below presents the Fuzzy Petri Nets calculations for the transitions of GEMMA between the modes F1 to F4. In this case the type of transition 1 is max.

Table 4.4: Fuzzy Petri Nets calculations for the transitions of GEMMA between the modes F1 and F4

While the verification mode 1 button is off, $M_0(p_2) = 0$:	While the verification mode 1 button is on, $M_0(p_2) = 1$:

$minM(t_1) = 0$ $\lambda_{(t_1)} = 0.3$ $minM(t_1) < \lambda_{(t_1)} \Rightarrow Disabled$	$minM(t_1) = 0.5$ $\lambda_{(t_1)} = 0.3$ $minM(t_1) > \lambda_{(t_1)} \Rightarrow Enabled$ $M'_{(p_6)} = max(M_{(t_1)}) \cdot \beta_{(t_1)} = 1 \cdot 1 = 1$ $\Downarrow$ **F4 state of the GEMMA guide is on.**

The table below presents the Fuzzy Petri Nets calculations for the transitions of GEMMA between the modes F1 and F5. In this case the type of transition 2 is max.

Table 4.5: Fuzzy Petri Nets calculations for the transitions of GEMMA between the modes F1 and F5

While the verification mode 2 button is off, $M_0(p_3) = 0$: $minM(t_2) = 0$ $\lambda_{(t_2)} = 0.3$ $minM(t_2) < \lambda_{(t_2)} \Rightarrow Disabled$	While the verification mode 2 button is on, $M_0(p_3) = 1$: $minM(t_2) = 0.5$ $\lambda_{(t_2)} = 0.3$ $minM(t_2) > \lambda_{(t_2)} \Rightarrow Enabled$ $M'_{(p_7)} = max(M_{(t_2)}) \cdot \beta_{(t_2)} = 1 \cdot 1 = 1$ $\Downarrow$ **F5 state of the GEMMA guide is on.**

The table below presents the Fuzzy Petri Nets calculations for the transitions of GEMMA between the modes F1 and F6. In this case the type of transition 3 is max.

Transition 3 (max):

Table 4.6: Fuzzy Petri Nets calculations for the transitions of GEMMA between the modes F1 and F6

While the test button is off, $M_0(p_4) = 0$:	While the test button is on, $M_0(p_4) = 1$:
$minM(t_3) = 0$ $\lambda_{(t_3)} = 0.3$ $minM(t_3) < \lambda_{(t_3)} \Rightarrow Disabled$	$minM(t_3) = 0.5$ $\lambda_{(t_3)} = 0.3$ $minM(t_3) > \lambda_{(t_3)} \Rightarrow Enabled$ $M'_{(8)} = max\left(M_{(t_3)}\right) \cdot \beta_{(t_3)} = 1 \cdot 1 = 1$ $\Downarrow$ **F6 state of the GEMMA guide is on.**

After all the calculation have been made, it is possible to notice that the Fuzzy Petri Nets algorithm for the operation procedure works appropriately. Additionally, it provides the operator safe and easy transitions between the different operation modes of GEMMA according to his needs.

4.4. Operation Procedure to Stop Procedure

The operation procedure to stop procedure transitions are very important for the control system of the machine and to the machine processes. For example, it can reduce the production cost in a case that there is some error in the production, and it is needed to modify some details in order to correct the production instate of throwing it and start over. Moreover, in a case that the operator desires to shut the machine down, by these transitions he is able to do it and the control will place the program automatically in the appropriate mode. That is to say, if the machine finished the production correctly, the program will be placed at the requested stop at the end of the cycle mode (A2). Additionally, in a case that the shutdown button is pressed, and the production did not finish correctly, the program will be placed at the shutdown process (F3) in order to prepare the machine to the initial stop state (A1).

The Fuzzy Petri Nets algorithm for the transitions between the operation procedure to stop procedure provides an intelligence and safe control. Moreover, by this algorithm the program will be placed at the correct mode according to the operator needs. It will allow him to stop the production and when it is necessary to return to the same production point in order to continue, and to shut down the machine either for starting over or turning off the machine. Figure 4.3 shows the Fuzzy Petri Nets algorithm for these different transitions. Including the Fuzzy Petri Nets places, transitions and their values.

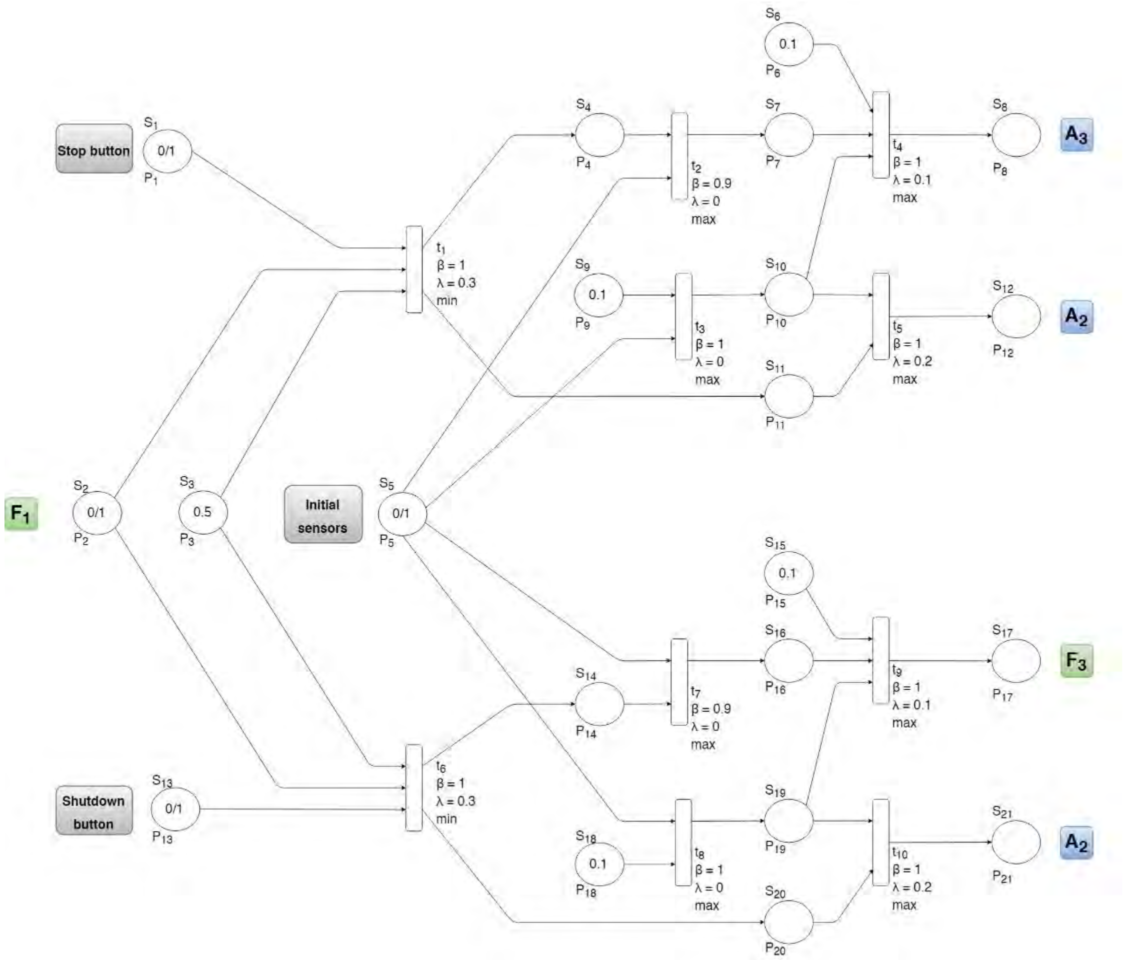

Figure 4.3: Fuzzy Petri Nets algorithm for the operation procedure to stop procedure of GEMMA

From the figure it is possible to see the different transitions of the operation procedure to stop procedure and when they will occur. For example, when the operator desires to stop the machine, the program will be placed either in the requested stop at the end of the cycle mode (A2) or in requested stop (non-initial state) mode (A3) automatically depending on the machine situation. In a similar way, the machine will shut down when the operator will require it. The Fuzzy Petri Nets calculations for this algorithm are presented below.

$$FPN = (P, T, S, I, O, \alpha, \beta, \lambda, M_0) \quad (4.22)$$

The set of places of the algorithm:

$$P = \begin{Bmatrix} p_1, p_2, p_3, p_4, p_5, p_6, p_7, p_8, p_9, p_{10}, \\ p_{11}, p_{12}, p_{13}, p_{14}, p_{15}, p_{16}, p_{17}, p_{18}, p_{19}, p_{20}, p_{21} \end{Bmatrix} \quad (4.23)$$

The transitions set of the algorithm:

$$T = \{t_1, t_2, t_3, t_4, t_5, t_6, t_7, t_8, t_9, t_{10}\} \quad (4.24)$$

The statements set of the algorithm:

$$S = \begin{Bmatrix} s_1, s_2, s_3, s_4, s_5, s_6, s_7, s_8, s_9, s_{10}, \\ s_{11}, s_{12}, s_{13}, s_{14}, s_{15}, s_{16}, s_{17}, s_{18}, s_{19}, s_{20}, s_{21} \end{Bmatrix} \quad (4.25)$$

The input functions of the algorithm:

$$I_{(t_1)} = \{p_1, p_2, p_3\},\ I_{(t_2)} = \{p_4, p_5\},\ I_{(t_3)} = \{p_5, p_9\},\ I_{(t_4)} = \{p_6, p_7, p_{10}\},\ I_{(t_5)} = \{p_{10}, p_{11}\},\ I_{(t_6)} = \{p_2, p_3, p_{13}\},\ I_{(t_7)} = \{p_5, p_{14}\},\ I_{(t_8)} = \{p_5, p_{18}\},\ I_{(t_9)} = \{p_{15}, p_{16}, p_{19}\},\ I_{(t_{10})} = \{p_{19}, p_{20}\} \quad (4.26)$$

The output functions of the algorithm:

$$O_{(t_1)} = \{p_4, p_{11}\},\ O_{(t_2)} = \{p_7\},\ O_{(t_3)} = \{p_{10}\},\ O_{(t_4)} = \{p_8\},\ O_{(t_5)} = \{p_{12}\},\ O_{(t_6)} = \{p_{14}, p_{20}\},\ O_{(t_7)} = \{p_{16}\},\ O_{(t_8)} = \{p_{19}\},\ O_{(t_9)} = \{p_{17}\},\ O_{(t_{10})} = \{p_{21}\} \quad (4.27)$$

The statement binding functions of the algorithm:

$$\alpha_{(p_1)} = s_1,\ \alpha_{(p_2)} = s_2,\ \alpha_{(p_3)} = s_3,\ \alpha_{(p_4)} = s_4,\ \alpha_{(p_5)} = s_5,\ \alpha_{(p_6)} = s_6,\ \alpha_{(p_7)} = s_7,\ \alpha_{(p_8)} = s_8,\ \alpha_{(p_9)} = s_9,\ \alpha_{(p_{10})} = s_{10},\ \alpha_{(p_{11})} = s_{11},\ \alpha_{(p_{12})} = s_{12},\ \alpha_{(p_{13})} = s_{13},\ \alpha_{(p_{14})} = s_{14},\ \alpha_{(p_{15})} = s_{15},\ \alpha_{(p_{16})} = s_{16},\ \alpha_{(p_{17})} = s_{17},\ \alpha_{(p_{18})} = s_{18},\ \alpha_{(p_{19})} = s_{19},\ \alpha_{(p_{20})} = s_{20},\ \alpha_{(p_{21})} = s_{21} \quad (4.28)$$

The truth degree function of the algorithm:

$$\beta_{(t_1)} = 1,\ \beta_{(t_2)} = 0.9,\ \beta_{(t_3)} = 1,\ \beta_{(t_4)} = 1,\ \beta_{(t_5)} = 1,\ \beta_{(t_6)} = 1,\ \beta_{(t_7)} = 0.9,\ \beta_{(t_8)} = 1,\ \beta_{(t_9)} = 1,\ \beta_{(t_{10})} = 1 \quad (4.29)$$

The threshold function of the algorithm:

$$\lambda_{(t_1)} = 0.3,\ \lambda_{(t_2)} = 0,\ \lambda_{(t_3)} = 0,\ \lambda_{(t_4)} = 0.1,\ \lambda_{(t_5)} = 0.2,\ \lambda_{(t_6)} = 0.3,\ \lambda_{(t_7)} = 0,\ \lambda_{(t_8)} = 0,\ \lambda_{(t_9)} = 0.1,\ \lambda_{(t_{10})} = 0.2 \quad (4.30)$$

The initial marking of the algorithm:

$$M_0 = \left\{ \begin{matrix} \underbrace{0/1}_{M_{0,(p_1)}}, \underbrace{0/1}_{M_{0,(p_2)}}, \underbrace{0.5}_{M_{0,(p_3)}}, \underbrace{\emptyset}_{M_{0,(p_4)}}, \underbrace{0/1}_{M_{0,(p_5)}}, \underbrace{0.1}_{M_{0,(p_6)}}, \underbrace{\emptyset}_{M_{0,(p_7)}}, \\ \underbrace{\emptyset}_{M_{0,(p_8)}}, \underbrace{0.1}_{M_{0,(p_9)}}, \underbrace{\emptyset}_{M_{0,(p_{10})}}, \underbrace{\emptyset}_{M_{0,(p_{11})}}, \underbrace{\emptyset}_{M_{0,(p_{12})}} \underbrace{0/1}_{M_{0,(p_{13})}}, \underbrace{\emptyset}_{M_{0,(p_{14})}}, \\ \underbrace{0.1}_{M_{0,(p_{15})}}, \underbrace{\emptyset}_{M_{0,(p_{16})}}, \underbrace{\emptyset}_{M_{0,(p_{17})}}, \underbrace{0.1}_{M_{0,(p_{18})}}, \underbrace{\emptyset}_{M_{0,(p_{19})}}, \underbrace{\emptyset}_{M_{0,(p_{20})}}, \underbrace{\emptyset}_{M_{0,(p_{21})}} \end{matrix} \right\} \tag{4.31}$$

The calculations below describe the transitions of Fuzzy Petri Nets algorithm for GEMMA between the modes F1 and A2/A3. In this algorithm, the type of transition 1 is min.

Table 4.7: Fuzzy Petri Nets calculations for the transitions of GEMMA between the modes F1 and A2/A3 a

While the stop button is off, $M_0(p_1) = 0$:	While the stop button is on, $M_0(p_1) = 1$:
$minM(t_1) = 0$ $\lambda_{(t_1)} = 0.3$ $minM(t_1) < \lambda_{(t_1)} \Longrightarrow Disabled$	$minM(t_1) = 0.5$ $\lambda_{(t_1)} = 0.3$ $minM(t_1) > \lambda_{(t_1)} \Longrightarrow Enabled$ $\Downarrow$ $M'_{(p_4)} = M'_{(p_{11})} = min\left(M_{(t_1)}\right) \cdot \beta_{(t_1)} = 0.5 \cdot 1 = 0.5$

$\Downarrow$

- While the initial sensors are off, $M_0(p_5) = 0$:
  Transition 2 (max):

$$minM(t_2) = 0$$

$$\lambda_{(t_2)} = 0$$

$$minM(t_2) = \lambda_{(t_2)} \Longrightarrow Enabled$$

$$M'_{(p_7)} = max\left(M_{(t_2)}\right) \cdot \beta_{(t_2)} = 0.5 \cdot 0.9 = 0.45$$

Transition 3 (max):

$$minM(t_3) = 0$$

$$\lambda_{(t_3)} = 0$$

$$minM(t_3) = \lambda_{(t_3)} \Longrightarrow Enabled$$

$$M'_{(p_{10})} = max\big(M_{(t_3)}\big) \cdot \beta_{(t_3)} = 0.1 \cdot 1 = 0.1$$

Transition 4 (max):

$$minM(t_4) = 0.1$$

$$\lambda_{(t_4)} = 0.1$$

$$minM(t_4) = \lambda_{(4)} \Longrightarrow Enabled$$

$$M'_{(p_8)} = max\big(M_{(t_4)}\big) \cdot \beta_{(t_4)} = 0.45 \cdot 1 = 0.45$$

$$\Downarrow$$

A3 state of the GEMMA guide is on.

Transition 5 (max):

$$minM(t_5) = 0.1$$

$$\lambda_{(t_5)} = 0.2$$

$$minM(t_5) < \lambda_{(t_5)} \Longrightarrow Disabled$$

- While the initial sensors are on, $M_0(p_5) = 1$:

Table 4.8: Fuzzy Petri Nets calculations for the transitions of GEMMA between the modes F1 and A2/A3 b

Transition 2 (max):	Transition 3 (max):
$minM(t_2) = 0.5$ $\lambda_{(2)} = 0$ $minM(t_2) > \lambda_{(t_2)} \Longrightarrow Enabled$ $\Downarrow$	$minM(t_3) = 0.1$ $\lambda_{(t_3)} = 0$ $minM(t_3) > \lambda_{(t_3)} \Longrightarrow Enabled$ $\Downarrow$ $M'_{(p_{10})} = max\big(M_{(t_3)}\big) \cdot \beta_{(t_3)} = 1 \cdot 1 = 1$

$M'_{(p_7)} = max\big(M_{(t_2)}\big) \cdot \beta_{(t_2)} = 1 \cdot 0.9 = 0.9$	
Transition 4 (max): $minM(t_4) = 0.1$ $\lambda_{(t_4)} = 0.1$ $minM(t_4) = \lambda_{(t_4)} \Longrightarrow Enabled$	Transition 5 (max): $minM(t_5) = 0.5$ $\lambda_{(t_5)} = 0.2$ $minM(t_5) > \lambda_{(t_5)} \Longrightarrow Enabled$

$$\Downarrow$$

In this case, transition 4 and transition 5 can fire due to the Fuzzy Petri Nets firing rules $minM(t_i) \geq \lambda_{p_i}$. However, when there is a case that in one transition $minM(t_i) = \lambda_{p_i}$ and in the other transition $minM(t_i) > \lambda_{p_i}$. The bigger will be preferable, and in this case, only transition 5 will fire and A2 state of the GEMMA guide will be on.

$$\Downarrow$$

$$M'_{(p_{12})} = max\big(M_{(t_5)}\big) \cdot \beta_{(t_5)} = 1 \cdot 1 = 1$$

$$\Downarrow$$

A2 state of the GEMMA guide is on.

The calculations of the Fuzzy Petri Nets regarding to the transition of GEMMA between the modes F1 and F3/A2 are presented below. In this algorithm the type of transition 6 is min.

Table 4.9: Fuzzy Petri Nets calculations for the transitions of GEMMA between the modes F1 and F3

While the shutdown button is off, $M_0(p_{13}) = 0$: $minM(t_6) = 0$ $\lambda_{(t_6)} = 0.3$ $minM(t_6) < \lambda_{(t_6)} \Longrightarrow Disabled$	While the shutdown button is on, $M_0(p_{13}) = 1$: $minM(t_6) = 0.5$ $\lambda_{(t_6)} = 0.3$ $minM(t_6) > \lambda_{(t_6)} \Longrightarrow Enabled$ $\Downarrow$

	$M'_{(p_{14})} = M'_{(p_{20})} = min\left(M_{(t_6)}\right) \cdot \beta_{(t_6)} = 0.5 \cdot 1$ $= 0.5$

$$\Downarrow$$

- While the initial sensors are off, $M_0(p_5) = 0$:

  Transition 7 (max):

$$minM(t_7) = 0$$

$$\lambda_{(t_7)} = 0$$

$$minM(t_7) = \lambda_{(t_7)} \Longrightarrow Enabled$$

$$M'_{(p_{16})} = max\left(M_{(t_7)}\right) \cdot \beta_{(t_7)} = 0.5 \cdot 0.9 = 0.45$$

  Transition 8 (max):

$$minM(t_8) = 0$$

$$\lambda_{(t_8)} = 0$$

$$minM(t_8) = \lambda_{(t_8)} \Longrightarrow Enabled$$

$$M'_{(p_{19})} = max\left(M_{(t_8)}\right) \cdot \beta_{(t_8)} = 0.1 \cdot 1 = 0.1$$

  Transition 9 (max):

$$minM(t_9) = 0.1$$

$$\lambda_{(t_9)} = 0.1$$

$$minM(t_9) = \lambda_{(9)} \Longrightarrow Enabled$$

$$M'_{(p_{17})} = max\left(M_{(t_9)}\right) \cdot \beta_{(t_9)} = 0.45 \cdot 1 = 0.45$$

$$\Downarrow$$

F3 state of the GEMMA guide is on.

  Transition 10 (max):

$$minM(t_{10}) = 0.1$$

$$\lambda_{(t_{10})} = 0.2$$

$$minM(t_{10}) < \lambda_{(t_{10})} \Longrightarrow Disabled$$

- While the initial sensors are on, $M_0(p_5) = 1$:

Table 4.10: Fuzzy Petri Nets calculations for the transitions of GEMMA between the modes F1 and A2

Transition 7 (max): $minM(t_7) = 0.5$ $\lambda_{(7)} = 0$ $minM(t_7) > \lambda_{(t_7)} \Longrightarrow Enabled$ $\Downarrow$ $M'_{(p_{16})} = max\left(M_{(t_7)}\right) \cdot \beta_{(t_7)} = 1 \cdot 0.9 = 0.9$	Transition 8 (max): $minM(t_8) = 0.1$ $\lambda_{(t_8)} = 0$ $minM(t_8) > \lambda_{(t_8)} \Longrightarrow Enabled$ $\Downarrow$ $M'_{(p_{19})} = max\left(M_{(t_8)}\right) \cdot \beta_{(t_8)} = 1 \cdot 1 = 1$
Transition 9 (max): $minM(t_9) = 0.1$ $\lambda_{(t_9)} = 0.1$ $minM(t_9) = \lambda_{(t_9)} \Longrightarrow Enabled$	Transition 10 (max): $minM(t_{10}) = 0.5$ $\lambda_{(t_{10})} = 0.2$ $minM(t_{10}) > \lambda_{(t_{10})} \Longrightarrow Enabled$

$$\Downarrow$$

In this case, transition 9 and transition 10 can fire due to the Fuzzy Petri Nets firing rules $minM(t_i) \geq \lambda_{p_i}$. However, when there is a case that in one transition $minM(t_i) = \lambda_{p_i}$ and in the other transition $minM(t_i) > \lambda_{p_i}$. The bigger will be preferable, and in this case, only transition 10 will fire and A2 state of the GEMMA guide will be on.

$$\Downarrow$$

$$M'_{(p_{21})} = max\left(M_{(t_{10})}\right) \cdot \beta_{(t_{10})} = 1 \cdot 1 = 1$$

$$\Downarrow$$

A2 state of the GEMMA guide is on.

From the calculations of this algorithm, it is possible to see that in a case the operator desires to either stop or shutdown the machine, the algorithm will place the program in the appropriate place according to the situation. That is to say, when the operator desires to stop the machine, the algorithm will recognize automatically if the machine has to be placed either in the initial stop state (A1) in order to start over or in the stop mode (non-initial state) to return to the same point that the machine has been stopped. In the same way, the algorithm works when the operator wants to shut the machine down.

4.5. Operation Procedure to Failure Procedure

The most important procedure in the control system of any machine is the failure procedure, this procedure stops the machine in a case that some failure occurs which can lead to protect the machine. Moreover, this procedure can prevent danger to the human life by stopping the machine when there is a dangerous situation. The transitions between the operation procedure to failure procedure can occur either automatically by the control system or by manually the operator. In other words, in a situation of either damage to the machine or danger to the human life, the control system must stop the machine. Differently, in a case that the operator notices some failure and it is not critical that the control system will stop the machine automatically, the operator is able to make the decision and to stop the machine by pressing the emergency button. Once the failure has been fixed, the operator can choose either to return to the normal production mode (F1), in the same point that the machine was stopped in order to continue the production or to restart the machine to the initial stop state (A1).

The Fuzzy Petri Nets algorithm for the operation procedure to failure procedure ensures dealing with the different failures in an intelligence and safe way in order to prevent a damage to the machine and danger to the human life. This algorithm is divided into two important branches, the emergency button that is controlled by the operator and the different types of failures that are controlled automatically by the algorithm. The Fuzzy Petri Nets algorithm of the operation procedure to failure procedure is described in figure 4.4.

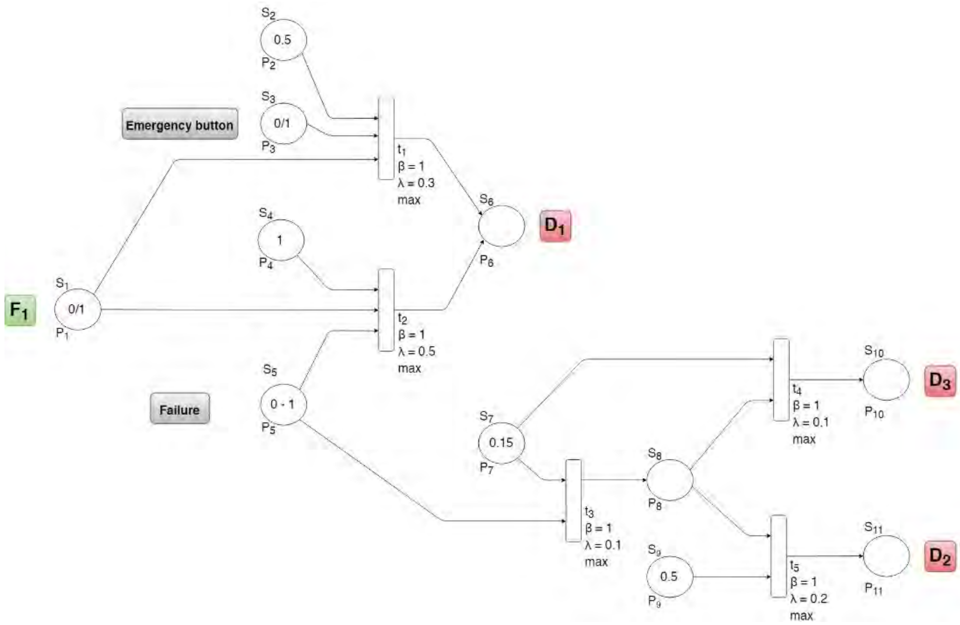

Figure 4.4: Fuzzy Petri Nets algorithm for the operation procedure to failure procedure of GEMMA

The algorithm divides the critical failures into three parts in order to place the machine in the appropriate failure mode (D1, D2, D3). The value of the critical failure is ranged from zero to one. When its value equals to zero, the machine is working properly. When the failure is not very critical, and the machine can continue the production meanwhile the failure exists. Its value range is greater than 0 and less than or equal to 0.2 ($0 < \text{failure} \leq 0.2$), in this case the algorithm will stop the machine automatically and will place the program in production despite the failure mode (D3). When the program is placed at this mode, the operator can decide either if to continue the production or to restart the machine. The next level of failure is when its value range is greater than 0.2 and smaller than 0.6 ($0.2 < \text{failure} < 0.6$), this case means that the failure is more critical, and the machine cannot continue the production. In this case, the program will be placed at diagnosis and/or treatment of the failure mode (D2) in order to detect where the failure occurs and to repair it. Once the failure had been fixed, the operator is able to start over the program to the initial stop state (A1), and to restart the machine to its initial state. The last level and the most critical is when its value range is greater than 0.5 and less than or equal to 1 ($0.5 < \text{failure} \leq 1$). When this level of failure occurs, the algorithm stops the machine immediately and places the program in the emergency stop mode (D1) in order to detect the failure and repair it. These different failure levels are set specially for each machine in the control programming stage and they depend on its conditions. The calculations of this algorithm clarify the different levels of failure, and the algorithm reaction for each one.

$$FPN = (P, T, S, I, O, \alpha, \beta, \lambda, M_0) \tag{4.32}$$

The set of places of the algorithm:

$$P = \{p_1, p_2, p_3, p_4, p_5, p_6, p_7, p_8, p_9, p_{10}, p_{11}\} \tag{4.33}$$

The transitions set of the algorithm:

$$T = \{t_1, t_2, t_3, t_4, t_5\} \tag{4.34}$$

The statements set of the algorithm:

$$S = \{s_1, s_2, s_3, s_4, s_5, s_6, s_7, s_8, s_9, s_{10}, s_{11}\} \tag{4.35}$$

The input functions of the algorithm:

$$I_{(t_1)} = \{p_1, p_2, p_3\},\ I_{(t_2)} = \{p_1, p_4, p_5\},\ I_{(t_3)} = \{p_1, p_5, p_7\},\ I_{(t_4)} = \{p_7, p_8\},\ I_{(t_5)} = \{p_8, p_9\} \tag{4.36}$$

The output functions of the algorithm:

$$O_{(t_1)} = \{p_6\},\ O_{(t_2)} = \{p_6\},\ O_{(t_3)} = \{p_8\},\ O_{(t_4)} = \{p_{10}\},\ O_{(t_5)} = \{p_{11}\} \tag{4.37}$$

The statement binding functions of the algorithm:

$$\alpha_{(p_1)} = s_1,\ \alpha_{(p_2)} = s_2,\ \alpha_{(p_3)} = s_3,\ \alpha_{(p_4)} = s_4,\ \alpha_{(p_5)} = s_5,\ \alpha_{(p_6)} = s_6,\ \alpha_{(p_7)} = s_7,\ \alpha_{(p_8)} = s_8,\ \alpha_{(p_9)} = s_9,\ \alpha_{(p_{10})} = s_{10},\ \alpha_{(p_{11})} = s_{11} \tag{4.38}$$

The truth degree function of the algorithm:

$$\beta_{(t_1)} = 1,\ \beta_{(t_2)} = 1,\ \beta_{(t_3)} = 1,\ \beta_{(t_4)} = 1,\ \beta_{(t_5)} = 1 \tag{4.39}$$

The threshold function of the algorithm:

$$\lambda_{(t_1)} = 0.3,\ \lambda_{(t_2)} = 0.5,\ \lambda_{(t_3)} = 0.1,\ \lambda_{(t_4)} = 0.1,\ \lambda_{(t_5)} = 0.2 \tag{4.40}$$

The initial marking of the algorithm:

$$M_0 = \begin{Bmatrix} \underbrace{0/1}_{M_{0,(p_1)}}, \underbrace{0.5}_{M_{0,(p_2)}}, \underbrace{0/1}_{M_{0,(p_3)}}, \underbrace{1}_{M_{0,(p_4)}}, \underbrace{0-1}_{M_{0,(p_5)}}, \underbrace{\emptyset}_{M_{0,(p_6)}}, \\ \underbrace{0.15}_{M_{0,(p_7)}}, \underbrace{\emptyset}_{M_{0,(p_8)}}, \underbrace{0.5}_{M_{0,(p_9)}}, \underbrace{\emptyset}_{M_{0,(p_{10})}}, \underbrace{\emptyset}_{M_{0,(p_{11})}} \end{Bmatrix} \tag{4.41}$$

The calculations in the table below proves the Fuzzy Petri Nets algorithm for the transitions between the modes F1 and D1 while the emergency button is pressed. In this case, the type of transition 1 is max.

Table 4.11: Fuzzy Petri Nets calculations for the transitions of GEMMA between the modes F1 and D1 (Emergency button)

While the emergency button is off, $M_0(p_3) = 0$:	While the emergency button is on, $M_0(p_3) = 1$:
$minM(t_1) = 0$ $\lambda_{(t_1)} = 0.3$ $minM(t_1) < \lambda_{(t_1)} \Longrightarrow Disabled$	$minM(t_1) = 0.5$ $\lambda_{(t_1)} = 0.3$ $minM(t_1) > \lambda_{(t_1)} \Longrightarrow Enabled$ $M'_{(p_6)} = max(M_{(t_1)}) \cdot \beta_{(t_1)} = 1 \cdot 1 = 1$ $\Downarrow$ **D1 state of the GEMMA guide is on.**

The calculations below present the Fuzzy Petri Nets algorithm for the transitions between the modes F1 and D2/D3 of GEMMA for the different levels of failure that may appear.

Production despite failure:

- While the failure is 0 ($M_0(p_5) = 0$):

Table 4.12: Fuzzy Petri Nets calculations for the transitions of GEMMA between the modes F1 and D3 (failure is 0)

Transition 2 (max):	Transition 3 (max):

$minM(t_2) = 0$ $\lambda_{(t_2)} = 0.5$ $minM(t_2) < \lambda_{(t_2)} \Longrightarrow Disabled$	$minM(t_3) = 0$ $\lambda_{(t_3)} = 0.1$ $minM(t_3) < \lambda_{(t_3)} \Longrightarrow Disabled$

- When the failure is between 0 to 0.5 ($0 < M_0(p_5) < 0.5$):

Transition 2 (max):

$$0 < minM(t_2) < 0.5$$

$$\lambda_{(t_2)} = 0.5$$

$$minM(t_2) < \lambda_{(t_2)} \Longrightarrow Disabled$$

Transition 3 (max):

$$minM(t_3) = 0.1/0.15$$

$$\lambda_{(t_3)} = 0.1$$

$$minM(t_3) \geq \lambda_{(t_3)} \Longrightarrow Enabled$$

$$\Downarrow$$

- When the failure is 0.1 ($M_0(p_5) = 0.1$):

$$M'_{(p_8)} = max\big(M_{(t_3)}\big) \cdot \beta_{(t_3)} = 0.15 \cdot 1 = 0.15$$

$$\Downarrow$$

Table 4.13: Fuzzy Petri Nets calculations for the transitions of GEMMA between the modes F1 and D3 (failure is 0.1)

Transition 4 (max):	Transition 5 (max):
$minM(t_4) = 0.15$ $\lambda_{(t_4)} = 0.1$	$minM(t_5) = 0.15$ $\lambda_{(t_5)} = 0.2$

$minM(t_4) = \lambda_{(t_4)} \Rightarrow Enabled$ $M'_{(p_{10})} = max(M_{(t_4)}) \cdot \beta_{(t_4)} = 0.15 \cdot 1$ $= 0.15$ $\Downarrow$ **D3 state of the GEMMA guide is on.**	$minM(t_5) < \lambda_{(t_5)} \Rightarrow Disabled$

- When the failure is 0.2 ($M_0(p_5) = 0.2$):

Table 4.14: Fuzzy Petri Nets calculations for the transitions of GEMMA between the modes F1 and D3 (failure is 0.2)

Transition 4 (max):	Transition 5 (max):
$minM(t_4) = 0.15$ $\lambda_{(t_4)} = 0.1$ $minM(t_4) > \lambda_{(t_4)} \Rightarrow Enabled$	$minM(t_5) = 0.2$ $\lambda_{(t_5)} = 0.2$ $minM(t_5) = \lambda_{(t_5)} \Rightarrow Enabled$

$$\Downarrow$$

In this case, transition 4 and transition 5 can fire due to the Fuzzy Petri Nets firing rules $minM(t_i) \geq \lambda_{p_i}$. However, when there is a case that in one transition $minM(t_i) = \lambda_{p_i}$ and in the other transition $minM(t_i) > \lambda_{p_i}$. The bigger will be preferable, and in this case, only transition 4 will fire and D2 state of the GEMMA guide will be on.

$$\Downarrow$$

$$M'_{(p_{10})} = max(M_{(t_4)}) \cdot \beta_{(t_4)} = 0.15 \cdot 1 = 0.15$$

$$\Downarrow$$

D3 state of the GEMMA guide is on.

- When the failure is 0.3 or 0.4 ($M_0(p_5) = 0.3/0.4$):

Table 4.15: Fuzzy Petri Nets calculations for the transitions of GEMMA between the modes F1 and D2 (failure is 0.3/0.4)

Transition 4 (max):	Transition 5 (max):
$minM(t_4) = 0.15$ $\lambda_{(t_4)} = 0.1$ $minM(t_4) > \lambda_{(t_4)} \Longrightarrow Enabled$	$minM(t_5) = 0.3/0.4$ $\lambda_{(t_5)} = 0.2$ $minM(t_5) > \lambda_{(t_5)} \Longrightarrow Enabled$

$\Downarrow$

In this case the bigger is preferable and only transition 5 will be fired

$\Downarrow$

$$M'_{(p_{11})} = max\big(M_{(t_5)}\big) \cdot \beta_{(t_5)} = 0.5 \cdot 1 = 0.5$$

$\Downarrow$

D2 state of the GEMMA guide is on.

- When the failure is 0.5 ($M_0(p_5) = 0.5$):

Table 4.16: Fuzzy Petri Nets calculations for the transitions of GEMMA between the modes F1 and D2 (failure is 0.5) a

Transition 2 (max):	Transition 3 (max):
$minM(t_2) = 0.5$ $\lambda_{(t_2)} = 0.5$ $minM(t_2) = \lambda_{(t_2)} \Longrightarrow Enabled$	$minM(t_3) = 0.15$ $\lambda_{(t_3)} = 0.1$ $minM(t_3) > \lambda_{(t_3)} \Longrightarrow Enabled$

$\Downarrow$

In this case the bigger is preferable and only transition 3 will be fired

$\Downarrow$

$$M'_{(p_8)} = max\left(M_{(t_3)}\right) \cdot \beta_{(t_3)} = 0.5 \cdot 1 = 0.5$$

$$\Downarrow$$

Table 4.17: Fuzzy Petri Nets calculations for the transitions of GEMMA between the modes F1 and D2 (failure is 0.5) b

Transition 4 (max):	Transition 5 (max):
$minM(t_4) = 0.15$ $\lambda_{(t_4)} = 0.1$ $minM(t_4) > \lambda_{(t_4)} \Longrightarrow Enabled$	$minM(t_5) = 0.5$ $\lambda_{(t_5)} = 0.2$ $minM(t_5) > \lambda_{(t_5)} \Longrightarrow Enabled$

$$\Downarrow$$

In this case, transition 4 and transition 5 can fire due to the Fuzzy Petri Nets firing rules $minM(t_i) \geq \lambda_{p_i}$. However, when there is a case that in one transition $minM(t_i) = \lambda_{p_i}$ and in the other transition $minM(t_i) > \lambda_{p_i}$. The bigger will be preferable, and in this case, only transition 5 will fire and D3 state of the GEMMA guide will be on.

$$\Downarrow$$

$$M'_{(p_{11})} = max\left(M_{(t_{11})}\right) \cdot \beta_{(t_{11})} = 0.5 \cdot 1 = 0.5$$

$$\Downarrow$$

D2 state of the GEMMA guide is on.

- When the failure is bigger than 0.5 ($M_0(p_5) > 0.5$):

Table 4.18: Fuzzy Petri Nets calculations for the transitions of GEMMA between the modes F1 and D1 (failure is greater than 0.5)

Transition 2 (max):	Transition 3 (max):
$0.5 < minM(t_2) \leq 1$ $\lambda_{(t_2)} = 0.5$	$minM(t_3) = 0.15$ $\lambda_{(t_3)} = 0.1$

$minM(t_2) > \lambda_{(t_2)} \Longrightarrow Enabled$	$minM(t_3) > \lambda_{(t_3)} \Longrightarrow Enabled$

$\Downarrow$

In this case the bigger is preferable and only transition 2 will be fired

$\Downarrow$

$$M'_{(p_6)} = max\big(M_{(t_2)}\big) \cdot \beta_{(t_2)} = 1 \cdot 1 = 1$$

$\Downarrow$

D1 state of the GEMMA guide is on.

The calculations of the Fuzzy Petri Nets algorithm for the transitions between operation procedure to failure procedure show that the algorithm works appropriately for these transitions of GEMMA. Moreover, it provides to the operator and the machine safety while a failure appears, and also allows to save money due to its intelligent transitions. That is to say, while the algorithm detects some failure, it places the program in the appropriate mode due to the level of the failure in order to either stat over the machine or return it to the production point that it has been stopped when the failure occurred. In this way, the algorithm may save money due to the prevention of stopping the production in a certain place and throwing everything in order to start the production again.

4.6. Failure Procedure to Stop Procedure

The different transitions between the failure procedure to stop procedure allow the operator to make his decision depending on the situation. In this way, the operator is able to choose either if to continue the production after the failure is repaired or to restart the machine and start over the program to the initial stop state (A1). Moreover, in a non-critical failure, the production despite the failure is possible. The Fuzzy Petri Nets algorithm for the transitions between failure procedure and stop procedure makes the control both smarter and safer, and it allows to make the best decision automatically without the operator decision. The algorithm is presented below.

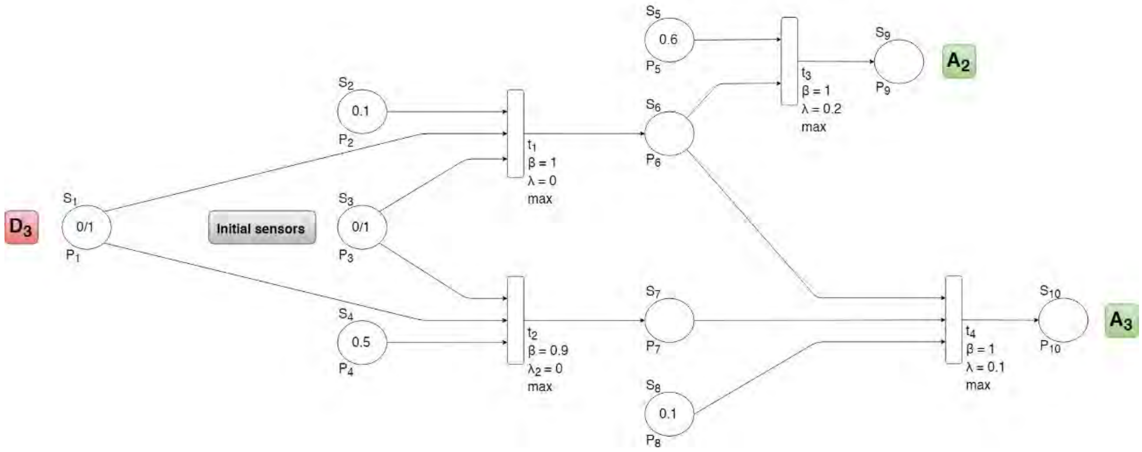

Figure 4.5: Fuzzy Petri Nets algorithm for the failure procedure to stop procedure of GEMMA

From the algorithm, it is possible to realize that when the machine had some medium critical failure level and it was placed at the production despite the failure mode (D3), the control will place the program automatically in the appropriate mode. In other words, the program will be placed either in the requested stop at the end of the cycle mode (A2) or in requested stop (non-initial state) mode (A3) depending on the situation of the machine. If the machine finished the production correctly and then the failure occurred, the machine is ready to the initial stop state. However, if the failure occurred in a certain point of the production, the control allows the program to return to the normal production mode (F1) in order to continue the production. The calculations below clarify the transitions' conditions in the different situations.

$$FPN = (P, T, S, I, O, \alpha, \beta, \lambda, M_0) \tag{4.42}$$

The set of places of the algorithm:

$$P = \{p_1, p_2, p_3, p_4, p_5, p_6, p_7, p_8, p_9, p_{10}\} \tag{4.43}$$

The transitions set of the algorithm:

$$T = \{t_1, t_2, t_3, t_4\} \tag{4.44}$$

The statements set of the algorithm:

$$S = \{s_1, s_2, s_3, s_4, s_5, s_6, s_7, s_8, s_9, s_{10}\} \tag{4.45}$$

The input functions of the algorithm:

$$I_{(t_1)} = \{p_1, p_2, p_3\},\ I_{(t_2)} = \{p_1, p_3, p_4\},\ I_{(t_3)} = \{p_5, p_6\},\ I_{(t_4)} = \{p_6, p_7, p_8\} \tag{4.46}$$

The output functions of the algorithm:

$$O_{(t_1)} = \{p_6\},\ O_{(t_2)} = \{p_7\},\ O_{(t_3)} = \{p_9\},\ O_{(t_4)} = \{p_{10}\} \tag{4.47}$$

The statement binding functions of the algorithm:

$$\alpha_{(p_1)} = s_1,\ \alpha_{(p_2)} = s_2,\ \alpha_{(p_3)} = s_3,\ \alpha_{(p_4)} = s_4,\ \alpha_{(p_5)} = s_5,\ \alpha_{(p_6)} = s_6,\ \alpha_{(p_7)} = s_7,\ \alpha_{(p_8)} = s_8,\ \alpha_{(p_9)} = s_9,\ \alpha_{(p_{10})} = s_{10} \tag{4.48}$$

The truth degree function of the algorithm:

$$\beta_{(t_1)} = 1,\ \beta_{(t_2)} = 0.9,\ \beta_{(t_3)} = 1,\ \beta_{(t_4)} = 1 \tag{4.49}$$

The threshold function of the algorithm:

$$\lambda_{(t_1)} = 0,\ \lambda_{(t_2)} = 0,\ \lambda_{(t_3)} = 0.2,\ \lambda_{(t_4)} = 0.1 \tag{4.50}$$

The initial marking of the algorithm:

$$M_0 = \left\{ \begin{array}{l} \underbrace{0/1}_{M_{0,(p_1)}},\ \underbrace{0.1}_{M_{0,(p_2)}},\ \underbrace{0/1}_{M_{0,(p_3)}},\ \underbrace{0.5}_{M_{0,(p_4)}},\ \underbrace{0.6}_{M_{0,(p_5)}}, \\ ,\ \underbrace{\emptyset}_{M_{0,(p_6)}},\ \underbrace{\emptyset}_{M_{0,(p_7)}},\ \underbrace{0.1}_{M_{0,(p_8)}},\ \underbrace{\emptyset}_{M_{0,(p_9)}},\ \underbrace{\emptyset}_{M_{0,(p_{10})}} \end{array} \right\} \tag{4.51}$$

The table below proves the calculations of the Fuzzy Petri Nets algorithm for the transitions between the modes D3 and A2/A3 of the GEMMA.

Table 4.19: Fuzzy Petri Nets calculations for the transitions of GEMMA between the modes D3 and A2/A3

While the initial sensors are off, $M_0(p_3) = 0$:	While the initial sensors are on, $M_0(p_3) = 1$:
Transition 1 (max): $minM(t_1) = 0$ $\lambda_{(t_1)} = 0$	Transition 1 (max): $minM(t_1) = 0.1$ $\lambda_{(t_1)} = 0$

<table>
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$$minM(t_1) = \lambda_{(t_1)} \Longrightarrow Enabled$$

$$M'_{(p_6)} = max\big(M_{(t_1)}\big) \cdot \beta_{(t_1)} = 0.1 \cdot 1 = 0.1$$

Transition 2 (max):

$$minM(t_2) = 0$$

$$\lambda_{(t_2)} = 0$$

$$minM(t_2) = \lambda_{(t_2)} \Longrightarrow Enabled$$

$$M'_{(p_7)} = max\big(M_{(t_2)}\big) \cdot \beta_{(t_2)} = 0.5 \cdot 0.9 = 0.45$$

Transition 3 (max):

$$minM(t_3) = 0.1$$

$$\lambda_{(t_3)} = 0.2$$

$$minM(t_3) < \lambda_{(t_3)} \Longrightarrow Disabled$$

Transition 4 (max):

$$minM(t_4) = 0.1$$

$$\lambda_{(t_4)} = 0.1$$

$$minM(t_4) = \lambda_{(t_4)} \Longrightarrow Enabled$$

$$M'_{(p_{10})} = max\big(M_{(t_4)}\big) \cdot \beta_{(t_4)} = 0.45 \cdot 1 = 0.45$$

$$\Downarrow$$

A3 state of the GEMMA guide is on.

</td>
<td>

$$minM(t_1) > \lambda_{(t_1)} \Longrightarrow Enabled$$

$$M'_{(p_6)} = max\big(M_{(t_1)}\big) \cdot \beta_{(t_1)} = 1 \cdot 1 = 1$$

Transition 2 (max):

$$minM(t_2) = 0.5$$

$$\lambda_{(t_2)} = 0$$

$$minM(t_2) > \lambda_{(t_2)} \Longrightarrow Enabled$$

$$M'_{(p_7)} = max\big(M_{(t_2)}\big) \cdot \beta_{(t_2)} = 1 \cdot 0.9 = 0.9$$

Transition 3 (max):

$$minM(t_3) = 0.1$$

$$\lambda_{(t_3)} = 0.2$$

$$minM(t_3) > \lambda_{(t_3)} \Longrightarrow Enabled$$

$$\Downarrow$$

$$M'_{(p_9)} = max\big(M_{(t_3)}\big) \cdot \beta_{(t_3)} = 1 \cdot 1 = 1$$

Transition 4 (max):

$$minM(t_4) = 0.1$$

$$\lambda_{(t_4)} = 0.1$$

$$minM(t_4) = \lambda_{(t_4)} \Longrightarrow Enabled$$

$$\Downarrow$$

A2 state of the GEMMA guide is on.

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	In this case, transition 3 and transition 4 can fire due to the Fuzzy Petri Nets firing rules $minM(t_i) \geq \lambda_{p_i}$. However, when there is a case that in one transition $minM(t_i) = \lambda_{p_i}$ and in the other transition $minM(t_i) > \lambda_{p_i}$. The bigger will be preferable, and in this case, only transition 3 will fire and A2 state of the GEMMA guide will be on.

From the calculations of Fuzzy Petri Nets algorithm for the transitions between the modes D3 and A2/A3 of GEMMA, it is possible to notice that the algorithm works properly. When the program is placed at production despite the failure mode (D3) due to the failure that appeared, the algorithm will place the program in the appropriate mode in order either continue the production or start over the machine. Assuming that the machine was in some point of the production, the algorithm will place the program in requested stop (non-initial state) (A3) in order to continue the production at the same point that it stopped. In contrast, if the machine has been finished the production in the moment that the failure appeared, and it is ready for starting over. In this situation, the algorithm will place the program in requested stop at the end of the cycle mode (A2).

4.7. Conclusion

In this chapter the intelligent algorithms for the GEMMA Guide Paradigm were developed. The propose of the different algorithms is to provide both safety for the human life and prevention of equipment damage. Moreover, providing the machine an intelligent control and good decision-making system for the different situations that may occur. That is to say, these algorithms control the transitions between the different modes of GEMMA and place the machine in the appropriate mode according the situation.

The different algorithms that were developed is this chapter including all the important transitions of GEMMA in order to ensure a properly and safe control. In order to do that, all the modes have to be included. For this reason, the following algorithms were developed; Stop to operation procedure, operation procedure, operation to stop procedure, operation to failure procedure and failure to stop procedure.

The name of each procedure implies its responsibilities for the control and decision-making system of the machine. The first algorithm that was developed is the stop to operation procedure algorithm and it is responsible the transitions between the initial stop state (A1) and the different operation modes, normal production mode (F1), startup process (F2), running in verification mode disorderly (F4) and running in verification mode orderly (F5). This algorithm ensures a proper transition to the different operation modes according the operator needs. The second is the operation procedure algorithm and it is in charge of the necessary transitions between the operation mode, F1, F4, F5 and F6 (test mode). That means, the algorithm assures the appropriate transitions between the normal production mode and the different verification and test modes of GEMMA according the operator needs. The next algorithm refers the operation to stop procedure and responsible of the transition between F1 and requested stop at the end of the cycle (A2), requested stop (non-initial state) (A3) and shutdown process (F3). This algorithm makes sure to have an appropriate stop and shutdown processes of the machine. The fourth algorithm is the operation to failure procedure transitions, and it is responsible of the transitions between F1 and all the emergency modes of GEMMA (D1 D2 and D3). This algorithm is the most important due to its significance to the human life safety and machines damage prevention. The last algorithm that was developed is failure to stop procedure which makes sure that the machine would return to work properly and at the time. That means, it is responsible to return the machine to work after the failure has been fixed and in the right machine's situation (i.e. continue at the same production point). This algorithm is very important as well due to its time and situation responsibilities; it can prevent many problems of "returning to work after failure" and save a lot of money.

This chapter presents the different intelligent algorithms graphically and their mathematical development. Moreover, it was seen that the algorithms work properly for the transitions of GEMMA and are able to provide the appropriate control and decision-making system for each situation that may occur by making the proper transition according the situation.

5. ARTIFICIAL INTELLIGENCE ALGORITHMS FOR PARTICULAR SCENARIOS OF THE GEMMA GUIDE PARADIGM

5.1. Introduction

In this chapter the artificial intelligence algorithms for particular scenarios are developed. There are two scenarios that cover together all the special needs of the operator and situation that may occur, and the traditional GEMMA does not provide the necessary transitions for them. By these algorithms, the operator is able to prevent danger to human life and damage to the machine. Additionally, they could save time and money due to their transition's capabilities.

The first intelligent algorithm is responsible for the startup process mode of the GEMMA Guide Paradigm. That is to say, this algorithm provides the operator to place the machine easily in either normal production mode (F1) or running in verification mode disorderly (F4) at any moment of the startup process without the need of waiting to the termination of the process. Similarly, the second algorithm is in charge of the shutdown process mode of GEMMA. By this algorithm, the operator is able to place the machine in either F1 or F4 at any moment of the shutdown process immediately.

By these two algorithms, the operator is able to make any action that is needed immediately while the machine is at some point of either the startup process or shutdown process. It allows the operator to prevent some damage or danger that may occur without entering to the emergency situation. Also, if the operator needs to make some action immediately and the machine is at startup/shutdown process, he is able to do it by the appropriate transition, and to place the machine in the necessary mode (F1/F4) in order to make the action that is needed.

5.2. The Intelligent Algorithm for Scenario A

The GEMMA Guide Paradigm is very useful for controlling different machines, it provides a safe and easy control system. However, while the program is placed at the startup process mode (F2) and there is the need of an urgent action of the machine, the traditional GEMMA does not provide a direct transition from the startup process mode (F2) to either normal production mode (F1) or running in verification mode disorderly (F4). In other words, the operator has to wait until the startup process will finish in order to control the machine and make the desired action. The intelligent algorithm for scenario A provides to the operator the possibility of stopping the startup process and directly place the program in either F1 or F4 mode in order to make the required action. Moreover, by this intelligent algorithm, the operator does not have to wait until the startup process will finish, and he is able to do it at any moment.

This algorithm is very important for the control system of a machine, it can be very useful and save time and money. In order to understand the importance of this algorithm, some example can describe a situation that it is needed, the OPS (On Shore power supply) carne that is explained in this thesis can be a good example. When the system is in the startup process mode, and the crane is prepared for the normal production (the crane is in closing process). Assuming that at this moment either something is happening on the ship or the carne is going to hit something and can cause to either damage or danger. At that moment, the operator is able to place the program directly in running in verification mode disorderly (F4), and can stop the carne, change the direction of rotation and anything that is necessary in order to prevent the system from entering to the emergency state. By this action, the operator can save a lot of time, which at some moments are very important. Additionally, preventing the machine from being in emergency which may lead to stopping the machine and waiting for the maintenance worker for solving the failure. Figure 5.1 shows the intelligent algorithm for scenario A including its values and parameters.

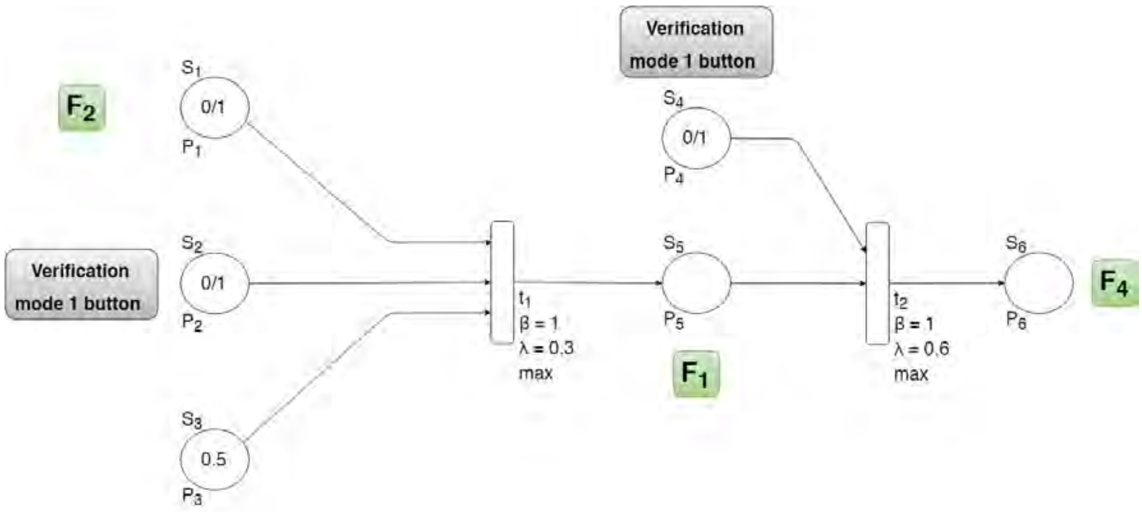


Figure 5.1: Fuzzy Petri Nets algorithm for the intelligent algorithm for scenario A of GEMMA

The figure shows the algorithm for the transition between startup process mode (F2) and either normal production mode (F1) or running in verification mode disorderly (F4) of GEMMA. It is possible to notice that while that machine is at some point of the startup process and the operator has the need to place the program directly in F1 or F4 mode, he is able to do it by pressing the verification mode 1 button. At that moment, the algorithm will place the program in F1 mode, and if that button will continue being activated, the program will be placed at F4 mode. In this way, the operator will be able to make the necessary action at the desired time, and at any point of the startup process. The calculations below clarify it and check the algorithm.

$$FPN = (P, T, S, I, O, \alpha, \beta, \lambda, M_0) \tag{5.1}$$

The set of places of the algorithm:

$$P = \{p_1, p_2, p_3, p_4, p_5, p_6\} \tag{5.2}$$

The transitions set of the algorithm:

$$T = \{t_1, t_2\} \tag{5.3}$$

The statements set of the algorithm:

$$S = \{s_1, s_2, s_3, s_4, s_5, s_6\} \tag{5.4}$$

The input functions of the algorithm:

$$I_{(t_1)} = \{p_1, p_2, p_3\},\ I_{(t_2)} = \{p_4, p_5\} \tag{5.5}$$

The output functions of the algorithm:

$$O_{(t_1)} = \{p_5\},\ O_{(t_2)} = \{p_6\} \tag{5.6}$$

The statement binding functions of the algorithm:

$$\alpha_{(p_1)} = s_1,\ \alpha_{(p_2)} = s_2,\ \alpha_{(p_3)} = s_3,\ \alpha_{(p_4)} = s_4,\ \alpha_{(p_5)} = s_5,\ \alpha_{(p_6)} = s_6 \tag{5.7}$$

The truth degree function of the algorithm:

$$\beta_{(t_1)} = 1,\ \beta_{(t_2)} = 1 \tag{5.8}$$

The threshold function of the algorithm:

$$\lambda_{(t_1)} = 0.3,\ \lambda_{(t_2)} = 0.6 \tag{5.9}$$

The initial marking of the algorithm:

$$M_0 = \left\{ \begin{array}{c} \underbrace{0/1}_{M_{0,(p_1)}},\ \underbrace{0/1}_{M_{0,(p_2)}},\ \underbrace{0.5}_{M_{0,(p_3)}}, \\ \underbrace{0/1}_{M_{0,(p_4)}},\ \underbrace{\emptyset}_{M_{0,(p_5)}},\ \underbrace{\emptyset}_{M_{0,(p_6)}} \end{array} \right\} \tag{5.10}$$

The Fuzzy Petri Nets algorithm for the transitions between the modes F2 and F1/F4 is calculated in the table below.

Table 5.1: Fuzzy Petri Nets calculations for the transitions of GEMMA between the modes F2 and F1/F4

While the verification mode 1 button is off, $M_0(p_2) = 0$: Transition 1 (max): $minM(t_1) = 0$ $\lambda_{(t_1)} = 0.3$ $minM(t_1) < \lambda_{(t_1)} \Rightarrow Disabled$	While the verification mode 1 button is on, $M_0(p_2) = 1$: Transition 1 (max): $minM(t_1) = 0.5$ $\lambda_{(t_1)} = 0.3$ $minM(t_1) > \lambda_{(t_1)} \Rightarrow Enabled$ $\Downarrow$ $M'_{(p_5)} = max\left(M_{(t_1)}\right) \cdot \beta_{(t_1)} = 1 \cdot 1 = 1$ $\Downarrow$ **F1 state of the GEMMA guide is on.** $\Downarrow$ Transition 2 (max): $minM(t_2) = 1$ $\lambda_{(t_2)} = 0.3$ $minM(t_2) > \lambda_{(t_2)} \Rightarrow Enabled$

	$\Downarrow$ $M'_{(p_6)} = max\left(M_{(t_2)}\right) \cdot \beta_{(t_2)} = 1 \cdot 1 = 1$ $\Downarrow$ **F4 state of the GEMMA guide is on.**

From the calculations above it is possible to notice that the intelligent algorithm for scenario A works properly. Moreover, as it is explained in this chapter, it is possible to see that it allows the operator to place the program in either F1 or F4 at any point of the startup process. In this way, the operator will be able to make the desired action without waiting that the startup process will finish.

5.3. The Intelligent Algorithm for Scenario B

The intelligent algorithm for scenario B allows the operator to place the program in either normal production mode (F1) or running in verification mode disorderly (F4) directly from the shutdown process at any moment. Similarly, to the intelligent scenario A, this algorithm provides to the operator to make an urgent action while the machine is in the shutdown process. In the last subsection, an example for the need of the intelligent scenario is presented. To make it even clearer, the next example will describe the use of this intelligent algorithm. The control of a coffee machine is required a showdown process after the machine has been finished in order to prepare the coffee. While the machine prepares the coffee, the program is located in the normal production mode (F1), and at the moment that it finishes to prepare the coffees that were ordered, the system is placed at the shutdown process mode (F3) in order to wash automatically the machine. While the machine is in the shutdown process and the operator wants to prepare a coffee without waiting that the shutdown process will finish, he is able to place the program in the normal production mode (F1) at any moment of the shutdown process. This example shows a necessary case of this intelligent algorithm. Also, it shows a situation of making the life easier and more comfortable. Figure 5.2 illustrates the intelligent algorithm for scenario B including its values and parameters.

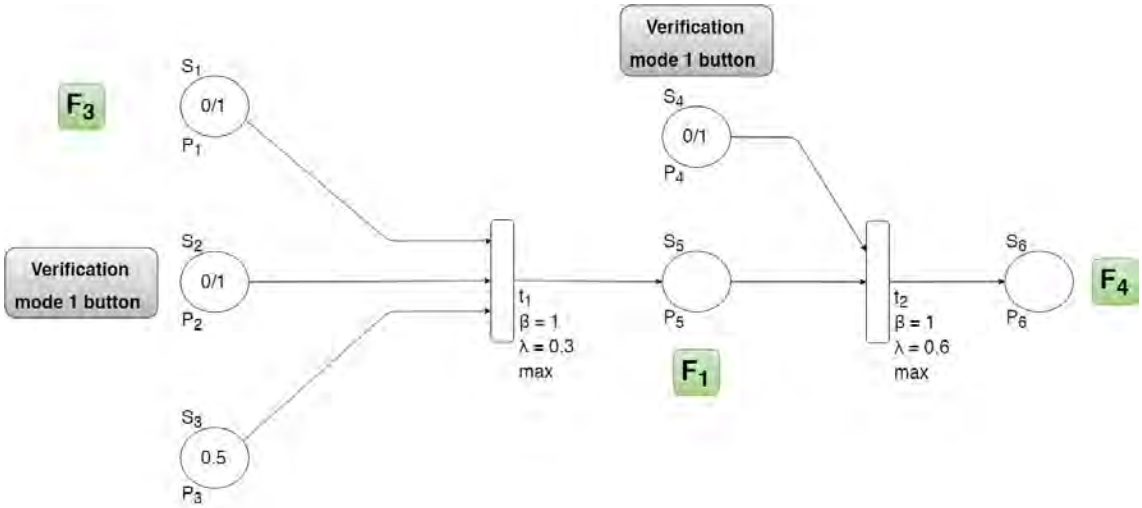


Figure 5.2: Fuzzy Petri Nets algorithm for the intelligent algorithm for scenario B of GEMMA

From the figure above, it is possible to notice that indeed the algorithm is appropriate for this type of cases and allow to the operator place the program either in normal production mode (F1) or running in verification mode disorderly (F4) directly from the shutdown process at any moment. It will happen when the program is placed at shutdown process mode (F3), and the operator presses the verification mode 1 button at any moment of the shutdown process. The calculations below clarify and verify it.

$$FPN = (P, T, S, I, O, \alpha, \beta, \lambda, M_0) \quad (5.11)$$

The set of places of the algorithm:

$$P = \{p_1, p_2, p_3, p_4, p_5, p_6\} \quad (5.12)$$

The transitions set of the algorithm:

$$T = \{t_1, t_2\} \quad (5.13)$$

The statements set of the algorithm:

$$S = \{s_1, s_2, s_3, s_4, s_5, s_6\} \quad (5.14)$$

The input functions of the algorithm:

$$I_{(t_1)} = \{p_1, p_2, p_3\},\ I_{(t_2)} = \{p_4, p_5\} \quad (5.15)$$

The output functions of the algorithm:

$$O_{(t_1)} = \{p_5\},\ O_{(t_2)} = \{p_6\} \quad (5.16)$$

The statement binding functions of the algorithm:

$$\alpha_{(p_1)} = s_1,\ \alpha_{(p_2)} = s_2,\ \alpha_{(p_3)} = s_3,\ \alpha_{(p_4)} = s_4,\ \alpha_{(p_5)} = s_5,\ \alpha_{(p_6)} = s_6 \tag{5.17}$$

The truth degree function of the algorithm:

$$\beta_{(t_1)} = 1,\ \beta_{(t_2)} = 1 \tag{5.18}$$

The threshold function of the algorithm:

$$\lambda_{(t_1)} = 0.3,\ \lambda_{(t_2)} = 0.6 \tag{5.19}$$

The initial marking of the algorithm:

$$M_0 = \begin{Bmatrix} \underbrace{0/1}_{M_{0,(p_1)}}, & \underbrace{0/1}_{M_{0,(p_2)}}, & \underbrace{0.5}_{M_{0,(p_3)}}, \\ \underbrace{0/1}_{M_{0,(p_4)}}, & \underbrace{\emptyset}_{M_{0,(p_5)}}, & \underbrace{\emptyset}_{M_{0,(p_6)}} \end{Bmatrix} \tag{5.20}$$

The table below shows the calculations of the intelligent algorithm for scenario B of the GEMMA and verify the algorithm. Moreover, it is possible to notice how the transitions occurs for this type of cases that is explained in this section.

Table 5.2: Fuzzy Petri Nets calculations for the transitions of GEMMA between the modes F3 and F1/F4

While the verification mode 1 button is off, $M_0(p_2) = 0$:	While the verification mode 1 button is on, $M_0(p_2) = 1$:
Transition 1 (max): $minM(t_1) = 0$ $\lambda_{(t_1)} = 0.3$ $minM(t_1) < \lambda_{(t_1)} \Longrightarrow Disabled$	Transition 1 (max): $minM(t_1) = 0.5$ $\lambda_{(t_1)} = 0.3$ $minM(t_1) > \lambda_{(t_1)} \Longrightarrow Enabled$ $\Downarrow$ $M'_{(p_5)} = max\big(M_{(t_1)}\big) \cdot \beta_{(t_1)} = 1 \cdot 1 = 1$ $\Downarrow$ **F1 state of the GEMMA guide is on.** $\Downarrow$ Transition 2 (max): $minM(t_2) = 1$ $\lambda_{(t_2)} = 0.3$ $minM(t_2) > \lambda_{(t_2)} \Longrightarrow Enabled$ $\Downarrow$ $M'_{(p_6)} = max\big(M_{(t_2)}\big) \cdot \beta_{(t_2)} = 1 \cdot 1 = 1$

	⇓ **F4 state of the GEMMA guide is on.**

For the calculations above it is possible to notice that the intelligent algorithm for scenario B is working properly. Moreover, the desired transitions are place the program in the appropriate mode. It allows to the operator to make the necessary action at the desired moment during the shutdown process as it is explained in this section.

5.4. Conclusion

In this chapter the artificial intelligence algorithm for the particular scenarios of GEMMA Guide Paradigm was developed. As it is explained in this chapter, there are two different algorithms. One of them provides the operator the possibilities to make any action that is needed while the machine is at any moment of the startup process. Similarly, the second algorithm refers to the shutdown process and allows the operator to make the needed action immediately. That is to say, while the machine is either in startup process or shutdown process, the operator does not have to wait that the process will finish in order to make the action that is needed. This can save a lot of money and time due to the fact that the operator is able to prevent emergency stage of the machine by placing the program either in normal production mode (F1) or running in verification mode disorderly (F4) , and making the necessary action in the moment that he sees that some failure may occur. Moreover, he is able to make the needed action immediately without waiting the termination of the startup/shutdown process which can be very useful in a situation that a production of a product is needed immediately or for example, in the OPS (On shore power supply) crane some action is needed like supplying the cable, rotating the crane, etc. The transitions that these algorithms provide, between F2 (Startup process)/F3 (Shut down process) and F1/F4 are not provided by the traditional GEMMA Guide Paradigm, and make an intelligent control and decision-making system.

This chapter presents the development of the algorithms graphically and mathematically. As it can be seen, the algorithms proved their proper capabilities and work in the different situation and ensure that the algorithms provide the appropriate transitions for the different situation and will place the program in the necessary mode according the certain situation. It means that these algorithms will provide the best control and decision-making system in order to allow the operator to make the urgent action while the machine is at any point of the startup/shutdown process.

6. EXPERIMENTAL RESULTS

6.1. OPS (On-Shore Power Supply) Crane

6.1.1. Introduction

Nowadays the cruise tourism is continuously growing and generates a significant income to the ports and port's cities. However, these ships have a huge energy consumption and usually during their anchoring the energy is generated onboard by diesel engines. This energy production generates a harmful emission to the environment and noise.

Onshore Power supply (OPS) is a way to replace the power that is generated on the ship by the diesel generators with onshore generated power. Thusly, improving the life quality by reducing the emission and noise in the ports and the cities around. Habitually, the ports do not have the required equipment in order to supply power to the vessels. Moreover, the vessels usually are not equipped in this way of receiving onshore power. The figure below shows the difference between onboard power supply to onshore power supply.

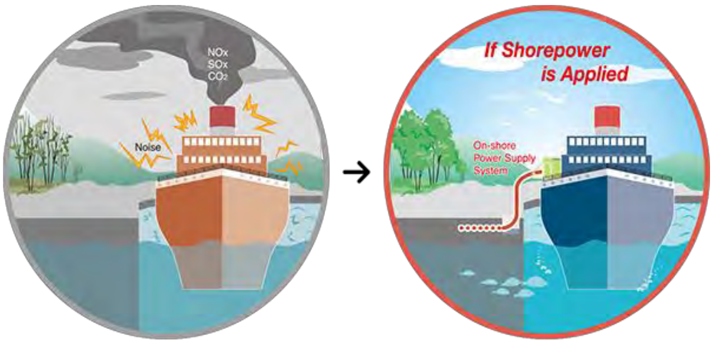


Figure 6.1: Onboard power supply to onshore power supply

This subchapter is divided into three main subsections. The first one describes the design of the OPS crane including its different components and the details of each one. The different components of the crane are composed of six major parts: base, column, arm, pulleys, cable & storage system, safety & fairing, and control. The second subsection presents the OPS crane prototype including its operation. In other words, the operation modes of the OPS crane are explained including the control presentation and examples of each operation and action of the crane. The operation of the crane includes mainly two operation modes: Manual mode and Cycle by Cycle mode. Each operation mode allows to operate the crane in a different way depending on the operator needs. Moreover, this section clarifies each stage that may occur during the operation of the crane, describes and proves them by figures of the prototype and control of each stage. In the last subsection the experiments of each intelligent algorithm that was developed and proved in Chapter 4 are shown. The main idea of this section is to validate that each algorithm is working properly for the control and decision-making system of the OPS crane.

6.1.2. OPS Crane Design

The OPS (Onshore Power Supply) crane is developed with a rotation mechanism that is located in its base and a telescopic arm which is assembled on a 4-meters column. The telescopic arm moves horizontally, and it arrives up to a distance of 3 meters. The column of the crane consists of an electrical cable storage that can store up to 12 meters. The cable can be delivered or collected by a special mechanism that is based on two tandems of pulleys. A fixed three-pulley tandem and a mobile two-pulley tandem that is responsible for collecting or delivering the cable. The design of the crane has been made by the software INVENTOR 2017. Figure 6.2 illustrates the OPS crane including all its parts. The components of the crane are divided into the following parts, to facilitate its specification:

- Base
- Column
- Upper arm
- Pulleys and cable control system
- Safety and fairing
- Control

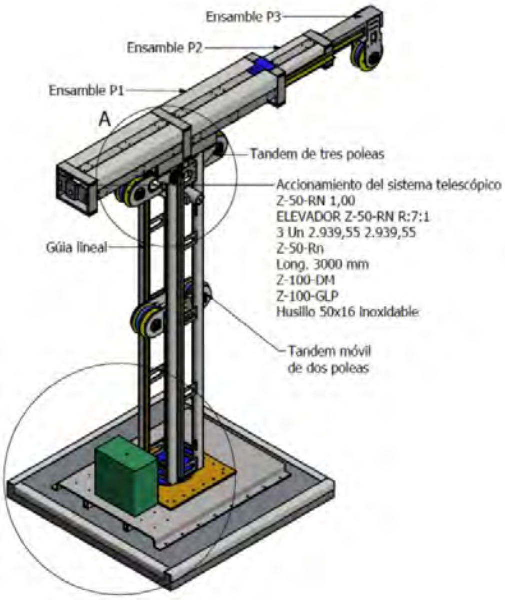


Figure 6.2: The OPS crane including all its parts

6.1.2.1. Base and Column

The base of the crane is formed by 3 parts: The main base, metal base and upper base.

The upper base is made of concrete and it transmits the support to the crane. The metal base of the crane connects between the main base and the upper base. The lower part of the crane rotates on its base +/- 30º by a rotation system with a mechanism that is controlled with limit switches.

The crane column consists of iron tubes that are connected and reinforced with iron plates. The column is connected to the base of the crane by the upper base and to the arm by the upper plate of the column. The figure below shows the base and the column of the carne including their different parts.

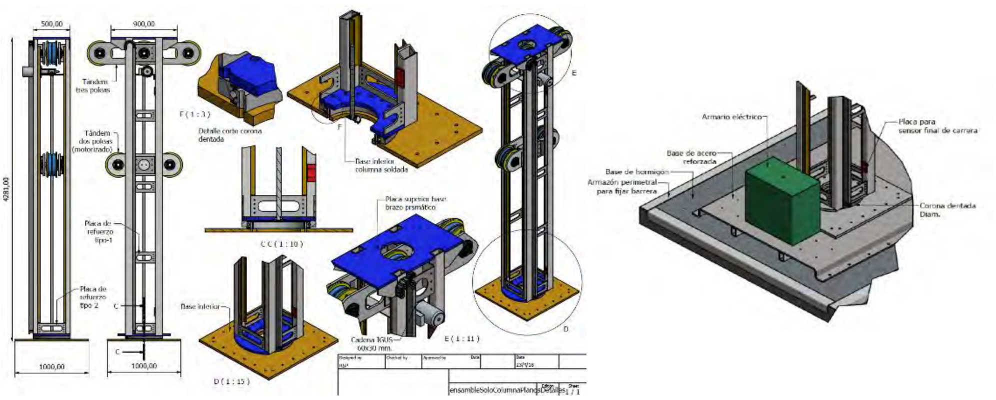


Figure 6.3: The base and column of the crane

6.1.2.2. Arm

The telescopic arm of the crane is assembled at the top of the column. The arm is formed by three links - P1, P2 and P3 in the manufacturing planes. Link P1 is fixed, links P2 and P3 are moving by linear guides. The link P3 is the first one that moves and when it arrives to its end P2 is moving until the limit point that it stops by the limit switch. In the figure below it is possible to see the arm of the carne as it is explained.

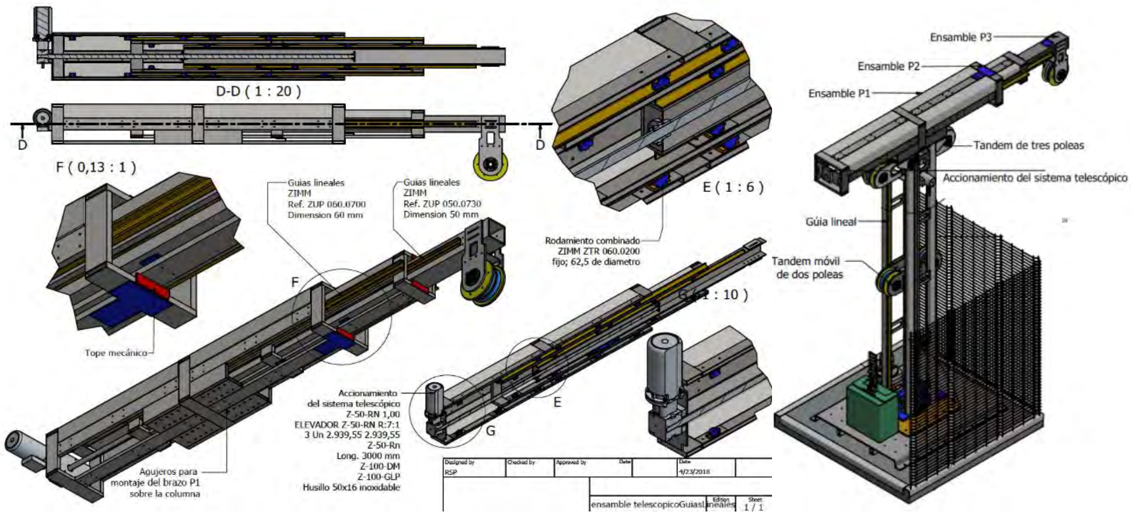


Figure 6.4: The arm of the crane

6.1.2.3. Pulleys and Cable Storage System

The crane includes a mechanism of two tandems which allows to deliver and collect the cable in a simple way. A fixed tandem of three pulleys and a mobile tandem of two pulleys with a linear guide that goes up and down in order to take out and insert the electrical cable. The tandem of 2 pulleys is located in the lower part of the column when all the cable is stored in the crane.

The mobile tandem goes up in order to supply the required length of cable. In this way, the system allows to store the excess cable and supply it when it is necessary simply and easily. Figure 6.5 illustrates the cable storage system of the crane including its pulleys.

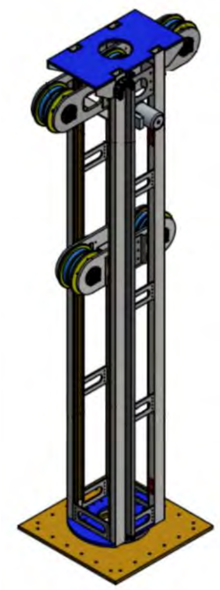


Figure 6.5: The electrical cable storage system of the crane

In order to calculate the electrical cable storage, it is necessary to take into account the total number of pulleys in the tandems of the crane and the crane heights. Figure 6.6 illustrates the cable storage system that is composed of a few numbers of pulleys.

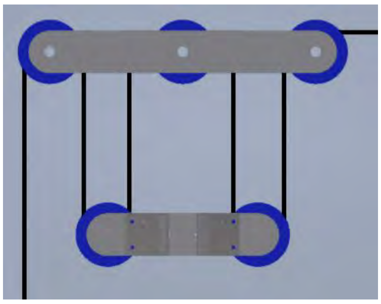


Figure 6.6: The number of pulleys in the tandem

The length of the cable is calculated in the following way:

$$\ell = (n_p - 1) * (h_{ft} - hmin_{mt}) \tag{6.1}$$

Where:

n_p – The total number of pulleys in the crane´s tandems

ℓ – The cable length (storage)

h_{ft} – The fixed tandem height

$hmin_{mt}$ – The minimum mobile tandem height

In order to understand the idea, a few examples have been made. The different examples include a few crane heights and pulleys numbers. The table below shows the different parameters of each example, and their solutions (the cable length).

Table 6.1: Electrical cable storage for the OPS crane

Crane height (m) ℓ	**Fixed tandem height (m)** h_{ft}	**The minimum mobile tandem height (m)** $hmin_{mt}$	**Total number of pulleys (m)** n_p	**The cable length (m)** ℓ
2	1.6	0.5	5	**4.4**
2	1.6	0.5	7	**6.6**
4	3.6	0.5	5	**12.4**
4	3.6	0.5	7	**18.6**
6	5.6	0.5	5	**20.4**
6	5.6	0.5	7	**30.6**

6.1.2.4. Security System of the Electrical Cable

The security system of the electrical cable is located on the electrical closet. It contains the support plate, sliding guides, arm, load cell and base. The support plate includes multiple fastening points in order to avoid relative sliding of the cable, and the sliding guides regulates the height and connects the support plate to the arm. The connection between the cell to the fixed base and support plate is made by the arm. The base of the system is fixed, and it composed of the electrical closet, the load cell supports the mechanical loads and electrical cable tension. Figure 6.7 illustrates the security system of the electrical cable.

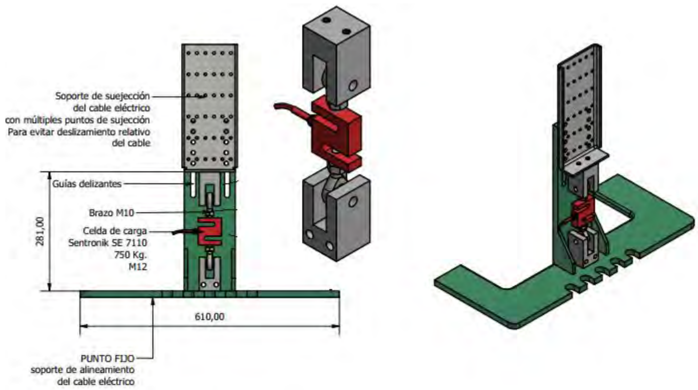


Figure 6.7: The security system of electrical cable

6.1.2.5. Control System

The control system of the of the OPS crane is made by a Siemens - SIMATIC series controllers, S7 1500 PLC. The control system consists of three electric drives with PID controller that controls the speed and position frequency. The central processing units (CPU) are the heart of the PLC. Moreover, they execute the user program and network with other automation components. The control system of the crane also contains various components that are made for this PLC like digital and analog output and input. In figure 6.8 it is possible to see the controller that is used for the OPS carne.

Figure 6.8: The control system of the OPS crane

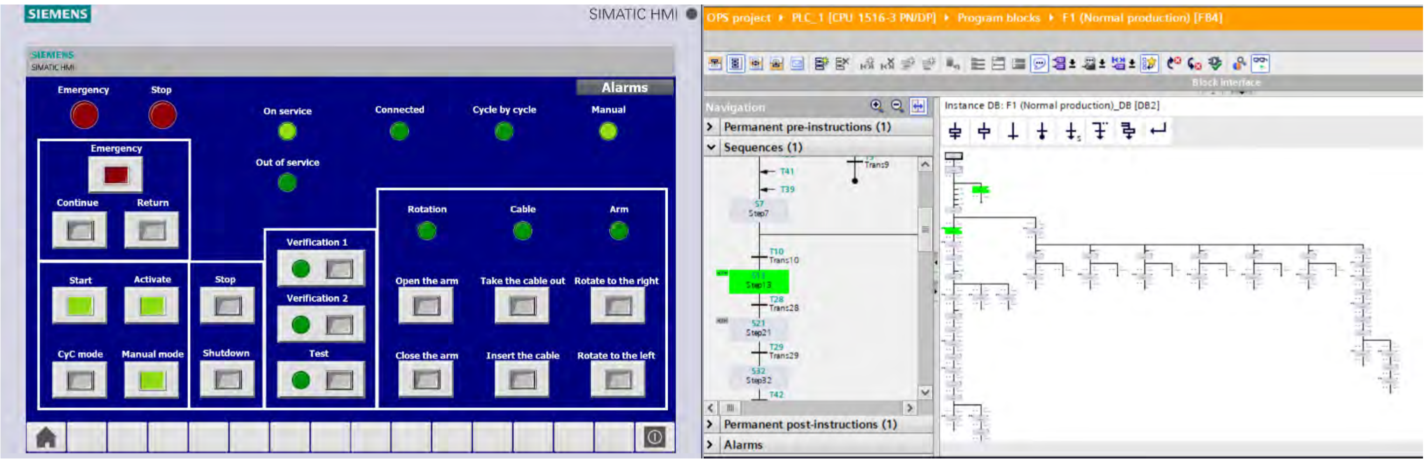
6.1.3. Prototype Operation

The control system of the crane is designed in a way that allows the operator an easy and safe operation. It designed by the programming language Grafcet and it is based on the GEMMA guide paradigm. Grafcet is a very useful graphical programing language for control and automation. It is based on steps and transitions, which each step indicates a place in the control system and allows the activation of an output. Moreover, each transition indicates a condition in the control system and its activation depends on the input.

The normal production mode (F1) of the GEMMA Guide Paradigm as it is explained in this thesis allows the operator to operate the crane in the desired way in order to supply the cable to the ship appropriately and safely. The normal production mode (F1) that has been designed for the crane is divided into two parts: Manual mode and Cycle by Cycle mode.

The Manual mode operates the crane semi-automatically, this provides to operate each part in the necessary order. In other words, first the operator is able only to rotate the crane in order to reach the appropriate point. While the crane has been rotated to the required point, he is able to open the arm for reaching the closet point to the electrical socket of the ship. In the last step, he is able to take out more cable if it is necessary.

Figure 6.9 illustrates the screen, program, and crane while the normal production Manual mode of the crane is activated. At this moment, the operator has pressed the Manual mode button in order to start the manual mode activation of the crane.

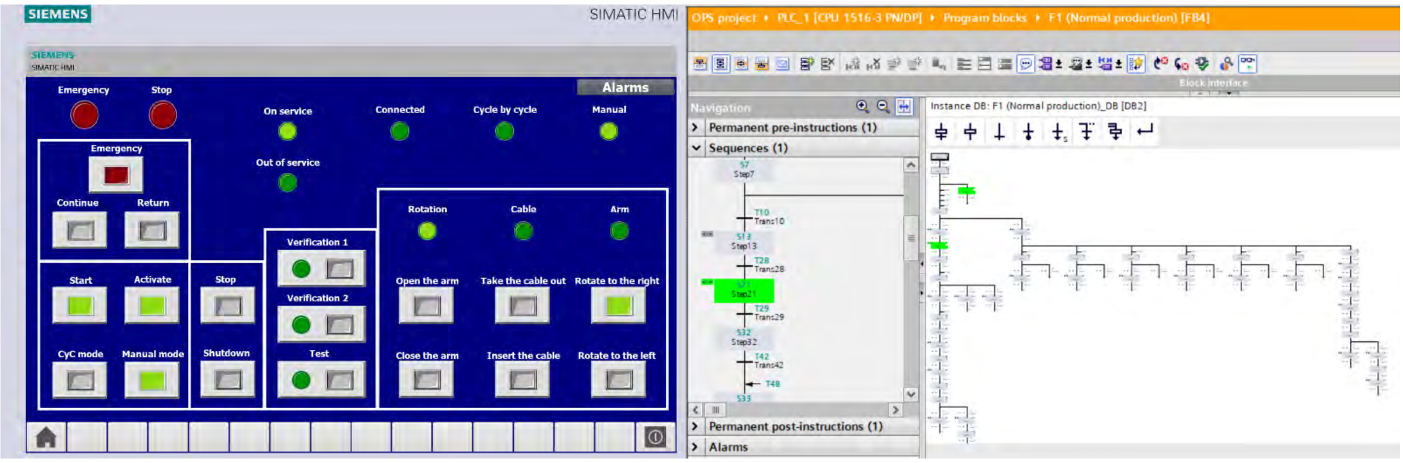


(a) (b)

(c)

Figure 6.9: The program is placed at the normal production mode (F1) of GEMMA, manual mode. (a) the screen, (b) the program, (c) the crane

Figure 6.10 describes the first stage of the Manual mode operation. At this stage, the operator is able to rotate the crane, in this example the operator has chosen to rotate the crane to the right in order to reach the best angle and to be close to the ship as much as possible. The figure shows the operation screen as it is possible to see that the rotation motor is working, the program, and the crane at the end of this stage.



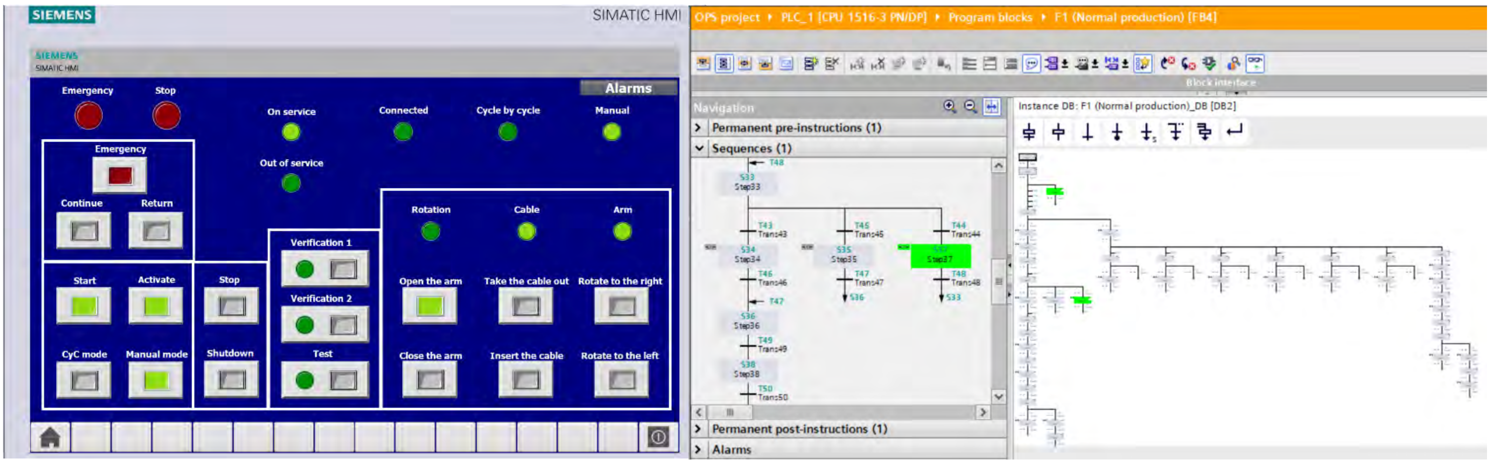
(a)

(b)

(c)

Figure 6.10: The program is placed at the normal production mode (F1) of GEMMA, manual mode, rotate to the right is activated. (a) the screen, (b) the program, (c) the crane

The figure below shows the second stage of the Manual mode. At this stage, the operator is able to open the arm of the crane in order to get close to the ship. The figure describes the operation screen while the button is pressed, and the arm is going out, as it is possible to see in the screen, the arm and cable's motors are working. Moreover, it shows the program and the crane at the end of this stage.

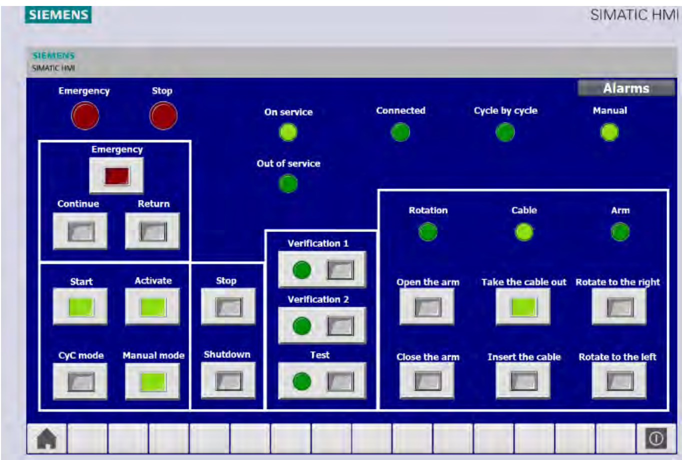


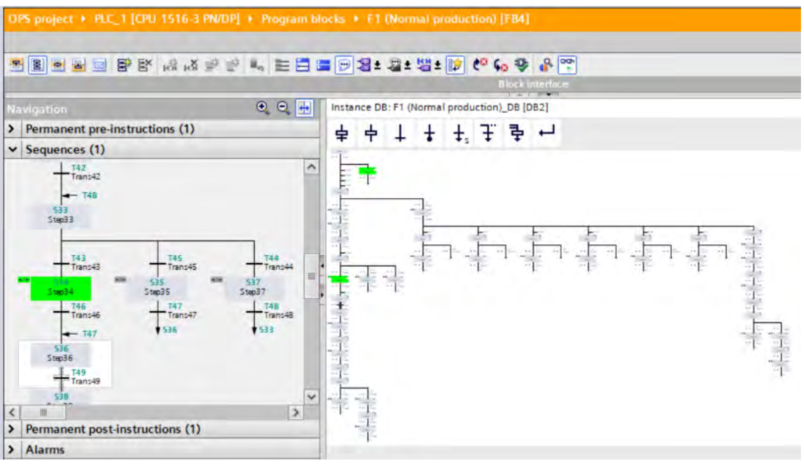
(a) (b)

(c)

Figure 6.11: The program is placed at the normal production mode (F1) of GEMMA, manual mode, while open the arm is activated. (a) the screen, (b) the program, (c) the crane

Figure 6.12 illustrates the next stage of the Manual mode operation. At this stage, the operator is able to take out more cable in order to reach the socket of the ship. It is possible to see the operation screen while take the cable out button is activated, and the responsible motor is activated as well. Also, it shows the program at that stage, and the crane position after the stage has been finished.



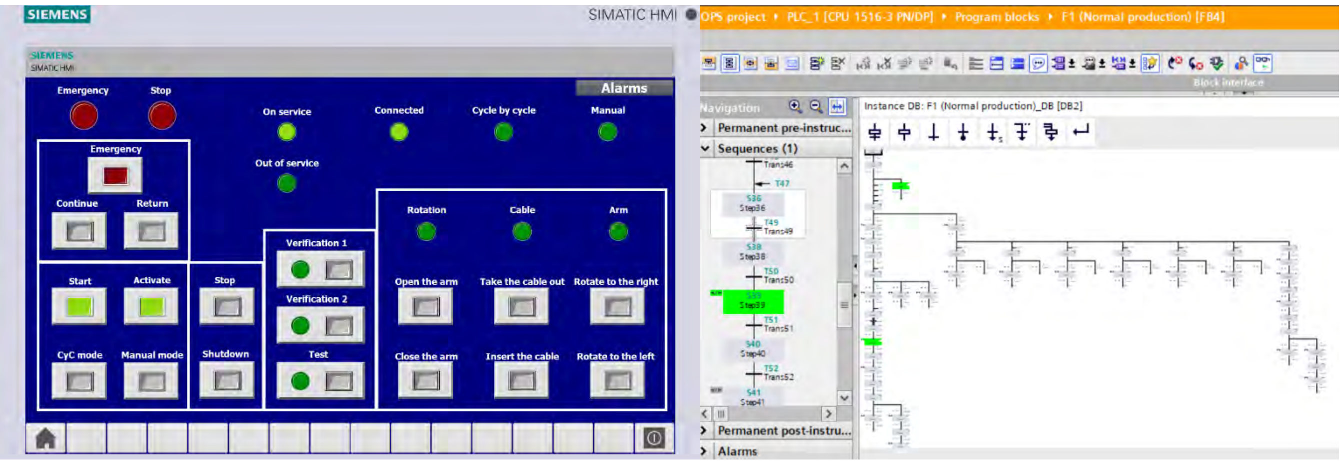


(a) (b)

(c)

Figure 6.12: The program is placed at the normal production mode (F1) of GEMMA, manual mode, while take the cable out is activated. (a) the screen, (b) the program, (c) the crane

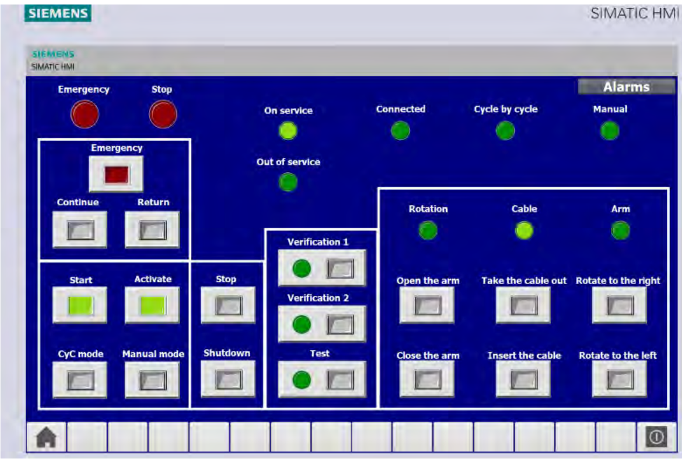
The figure below shows the point that the manual mode operation has been finished, and the plug is connected to the socket of the ship. At that moment, the electricity of the port is supplied to the ship. In this figure, it is possible so see the operation screen which shows that the plug is connected (connected led is on), and the program at that stage.



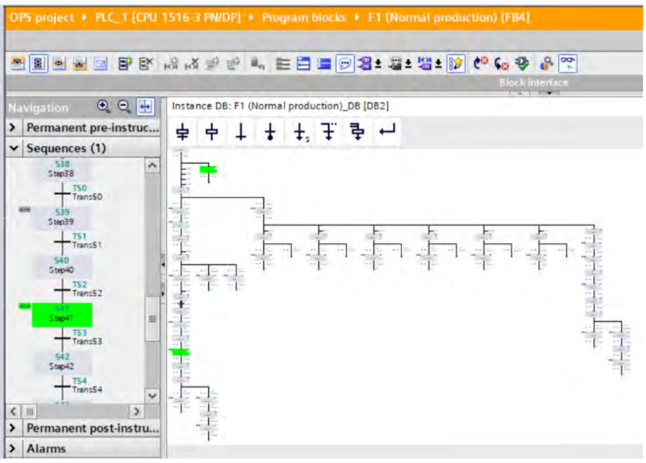
(a) (b)

Figure 6.13: The program is placed at the normal production mode (F1) of GEMMA, while the crane plug is connected. (a) the screen, (b) the program

Figure 6.14 indicates the carne position after the plug has been disconnected and the cable goes in. At the moment that the plug is disconnected, the closing process of the Manual mode is operated automatically. At this stage, the cable goes in. The figure shows the operation screen that indicates the activation of the responsible motor, the program, and the crane after the all the additional cable is inside.



(a)

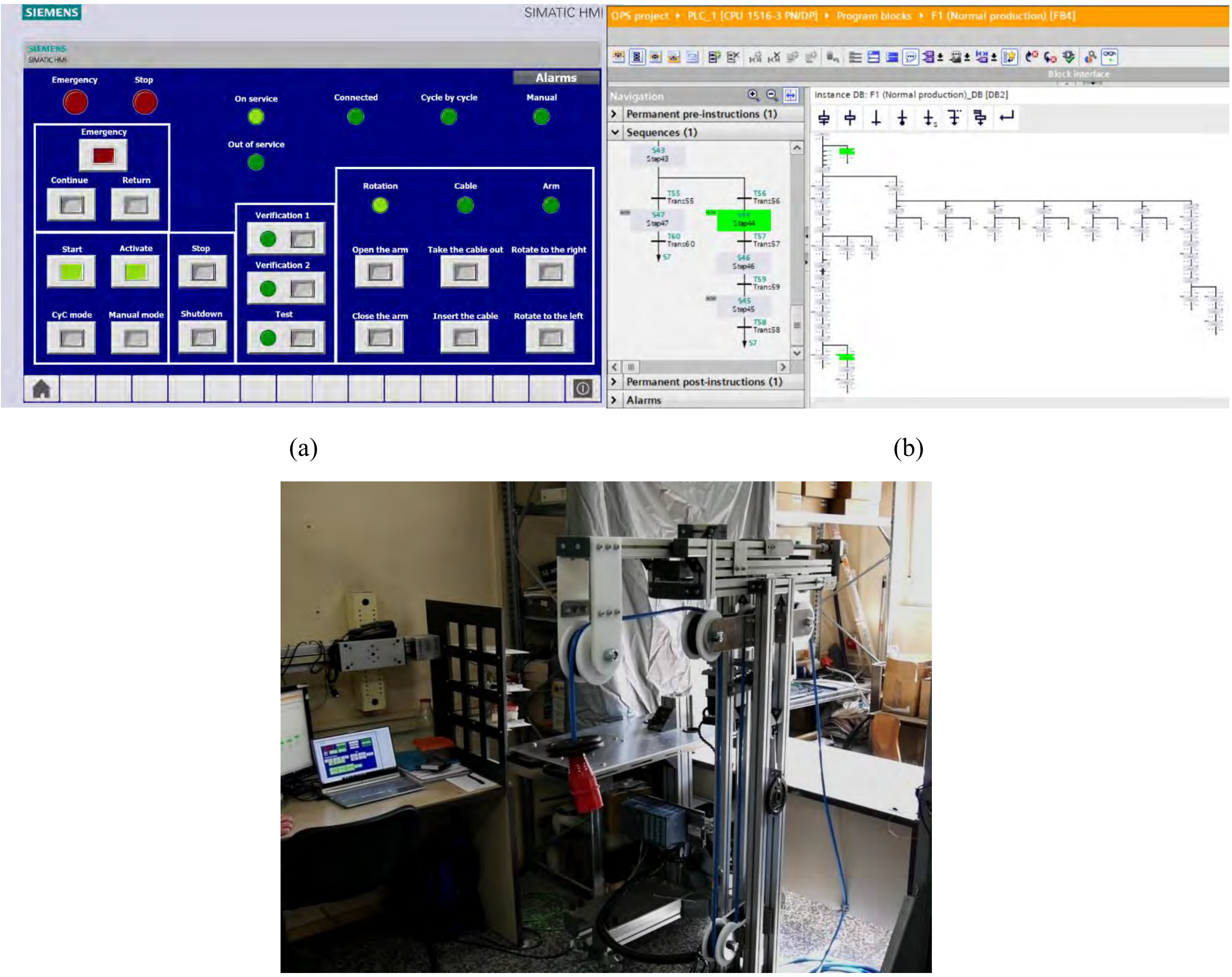


(b)

(c)

Figure 6.14: The program is placed at the normal production mode (F1) of GEMMA, at the moment that the crane's plug is disconnected and the crane closing process is operated, the cable goes in. (a) the screen, (b) the program, (c) the crane

Figure 6.15 shows the next stage of the Manual mode closing process. At this stage, the crane rotates back to its initial state. It is possible to see the operation screen at that stage, while the rotation motor is activated. Moreover, the program at this stage, and the crane at the moment that the rotation has finished, and it arrives to its initial state.

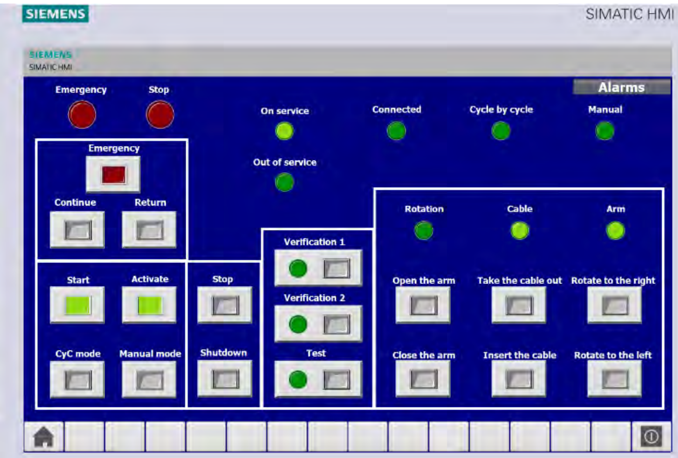


(a) (b)

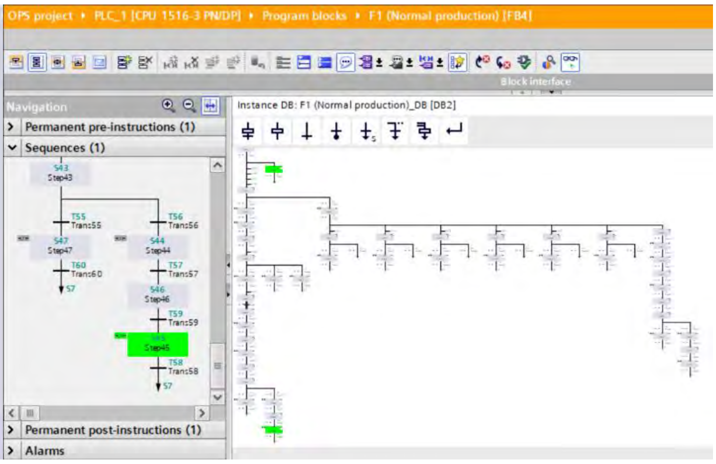
(c)

Figure 6.15: The program is placed at the normal production mode (F1) of GEMMA, at the moment that the crane plug is disconnected and the crane closing process is operated, the crane is rotating to its initial state. (a) the screen, (b) the program, (c) the crane

The figure below describes the last stage of the Manual mode closing process. At this stage, the closing arm is operated, and the arm is closing to its initial state. It is possible to see the operation screen, while the closing arm is activated (the responsible motors are working, arm and cable). Additionally, the program at that stage and the crane after the stage has finished and it is located in its initial state.



(a)

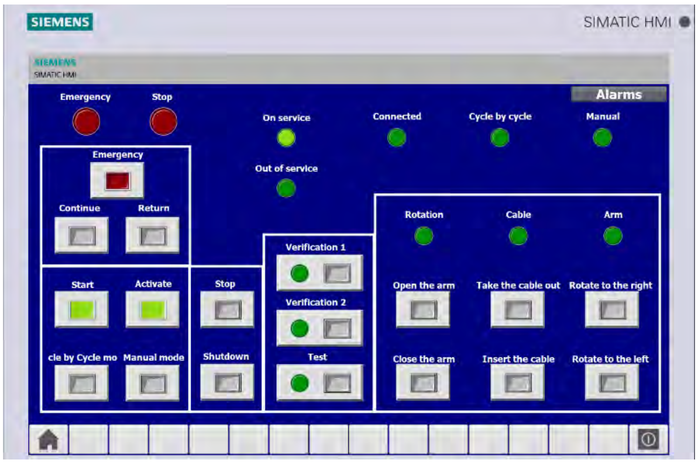


(b)

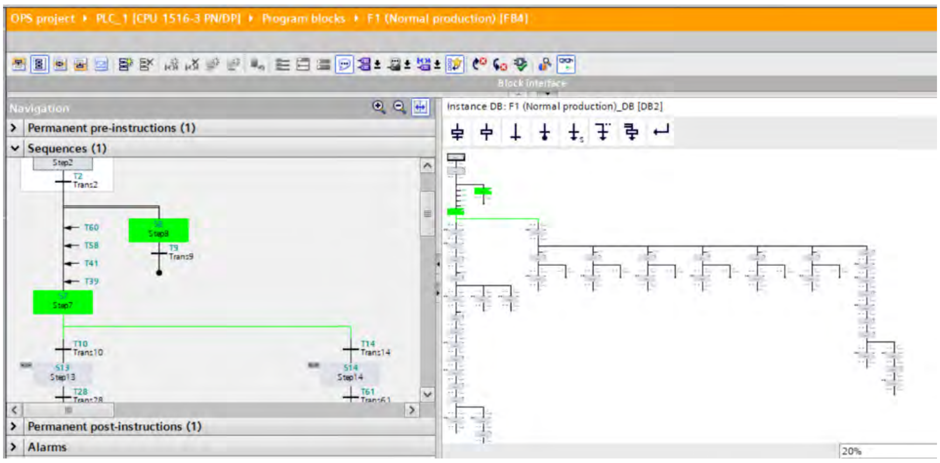
(c)

Figure 6.16: The program is placed at the normal production mode (F1) of GEMMA, at the moment that the crane socket is disconnected and the crane closing process is operated, the arm is closing. (a) the screen, (b) the program, (c) the crane

After the Manual mode closing process has been finished, the program returns to the initial point of the normal production mode (F1), and it is ready for the next operation. The figure below shows the operation screen, and the program.



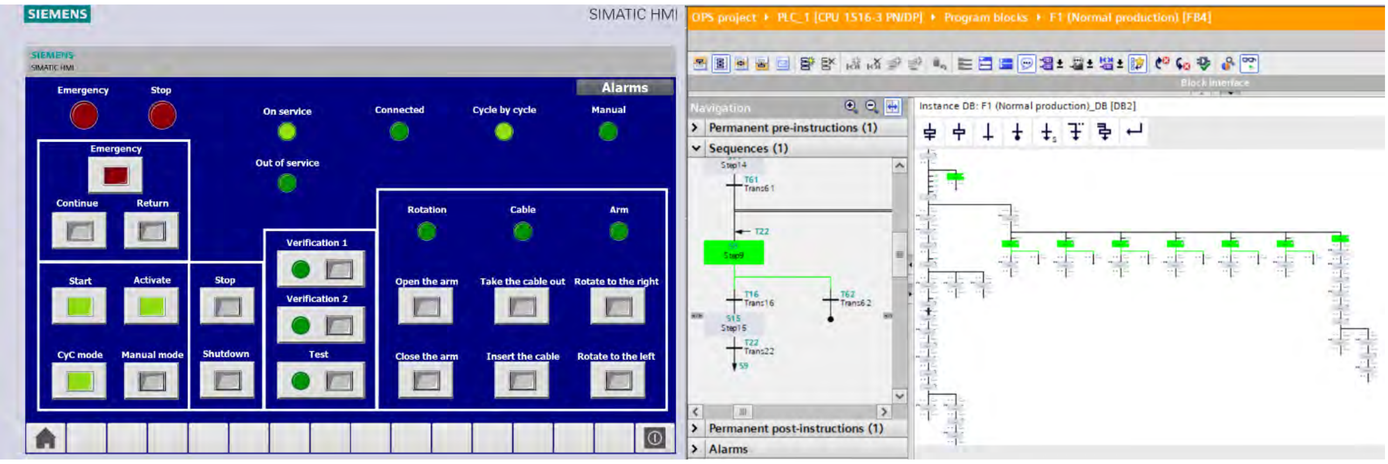
(a)



(b)

Figure 6.17: The program is placed at the normal production mode (F1) of GEMMA, after the crane closing process has been finished. (a) the screen, (b) the program

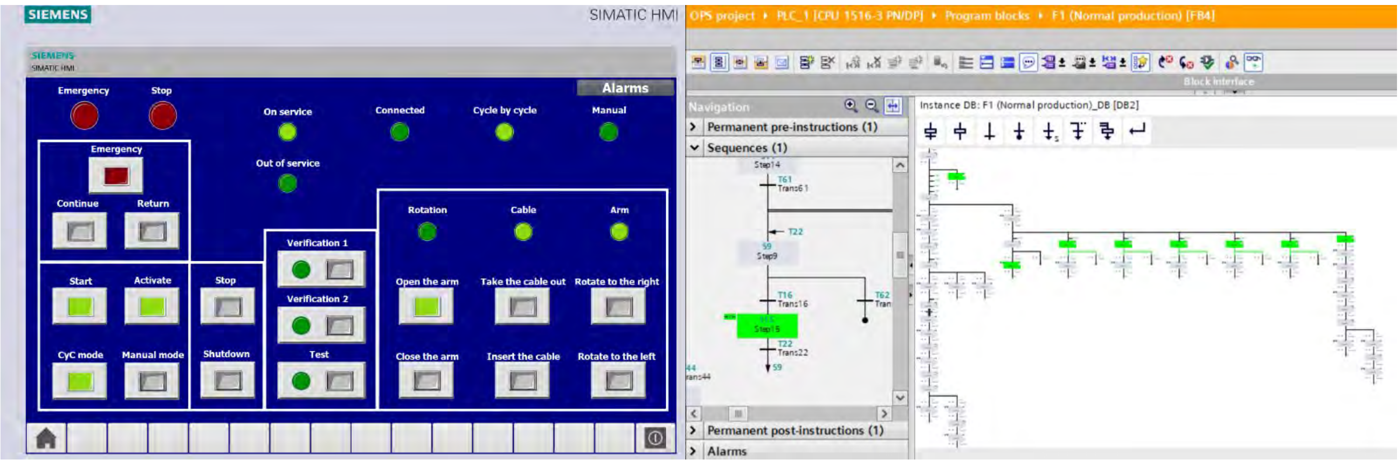
The second part of the crane normal production mode (F1) is Cycle by Cycle mode. This mode allows the operator to activate each motor without limitation. In other words, it allows the operator to activate each part of the crane as he desires without order. This mode is very useful while the crane has to reach the ship and the order of the manual mode is not suitable. The figure below illustrates the operation screen and the program while the operator has pressed the Cycle by Cycle mode button. At that moment, the crane is ready for the different actions.



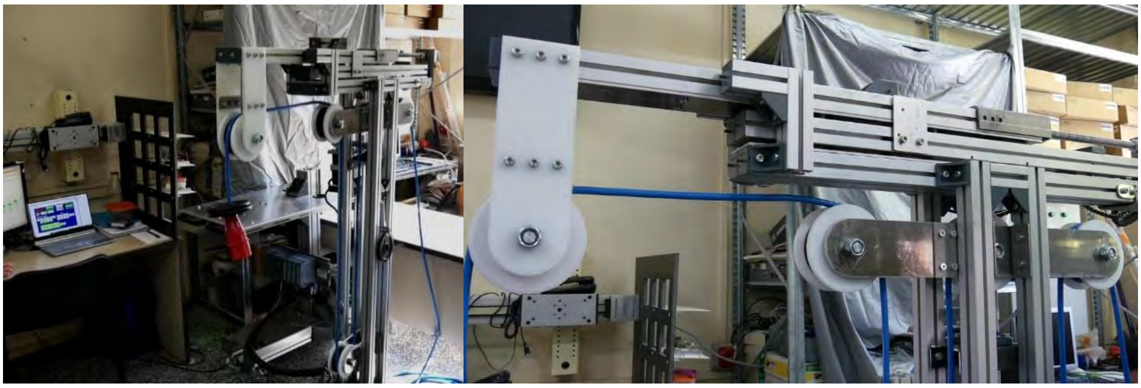
(a) (b)

Figure 6.18: The program is placed at the normal production mode (F1) of GEMMA, cycle by cycle mode. (a) the screen, (b) the program

While the program is placed at the Cycle by Cycle mode, the operator is able to activate each part of the crane as he desires. Moreover, more than one part at the same time. In the figure below it is possible to see that the operator activates the arm opening of the crane. The figure shows the operation screen while open the arm button, the arm and cable's motors are activated. Also, it shows the program at that stage, and the crane after the arm has finished to open.



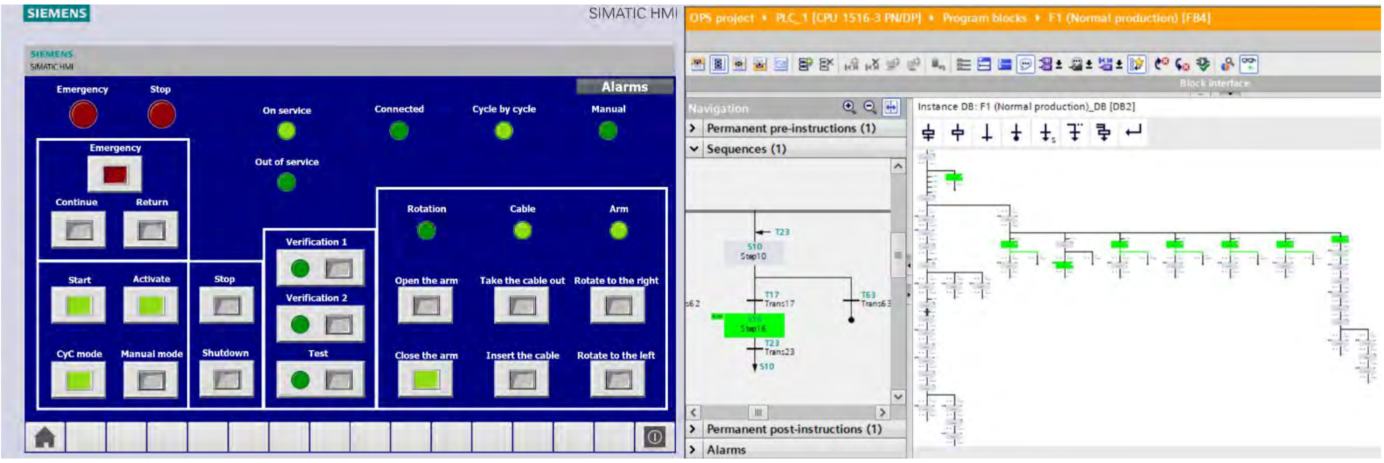
(a) (b)



(c)

Figure 6.19: The program is placed at the normal production mode (F1) of GEMMA, cycle by cycle mode while open the arm is activated. (a) the screen, (b) the program, (c) the crane

After the operator opened the arm of the crane, he is able as well to close it either if the arm opened more than he needs or if he desires to close the arm to the initial state. In the figure below it is possible to see the stage of Cycle by Cycle mode for closing the arm. The figure shows the operation screen while the arm is closing including the motors that are working, the program at that moment, and the crane after the closing arm has finished.

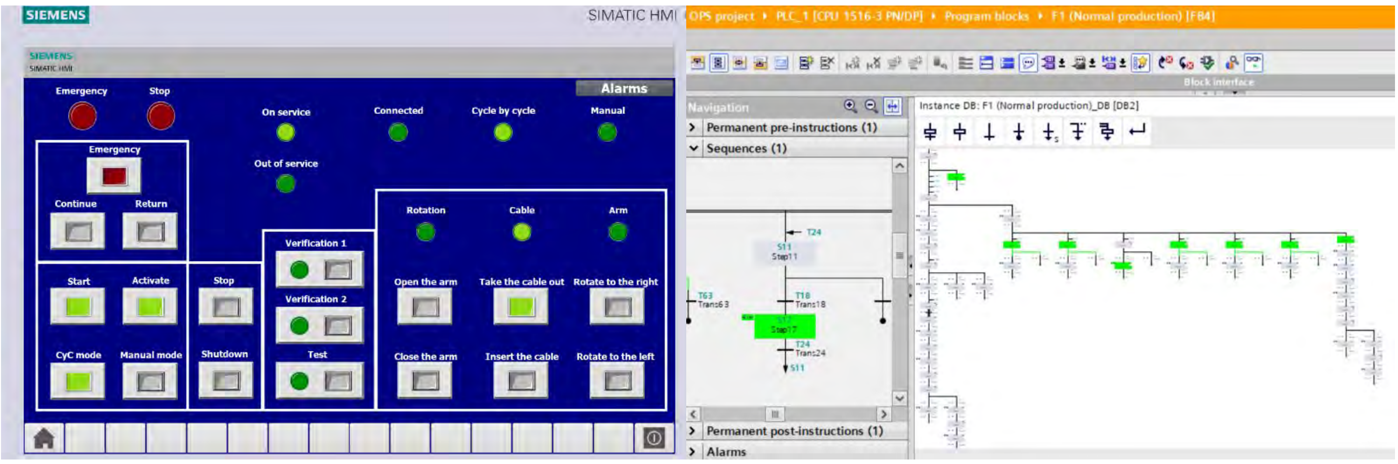


(a) (b)

(c)

Figure 6.20: The program is placed at the normal production mode (F1) of GEMMA, cycle by cycle mode while close the arm is activated. (a) the screen, (b) the program, (c) the crane

Additionally, the operator can open the cable as much as needed in order to reach the socket, even when the crane is located in its initial state. The figure below describes this situation. It shows the operation screen while the cable is going out including the responsible motor that is activated. Also, the program at that stage, and the crane after the stage finished.

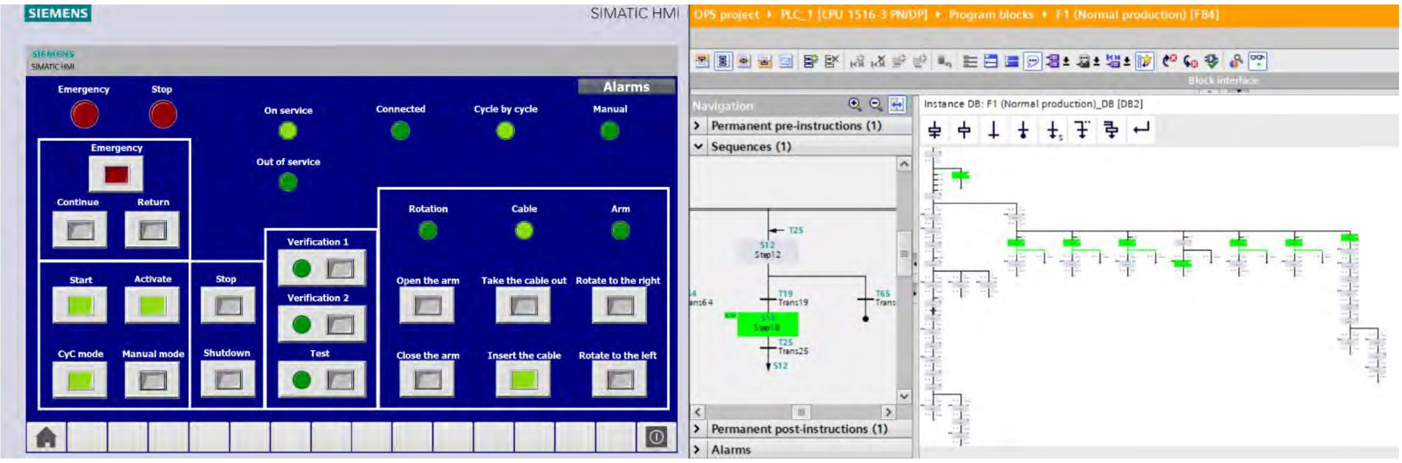


(a) (b)

(c)

Figure 6.21: The program is placed at the normal production mode (F1) of GEMMA, cycle by cycle mode while take the cable out is activated. (a) the screen, (b) the program, (c) the crane

In the same way the operator is able to insert the cable when it is necessary, and to the necessary point as it is shown in the figure below. The figure shows the operation screen at that stage including the responsible motor, the program, and the crane while that cable is inside again.

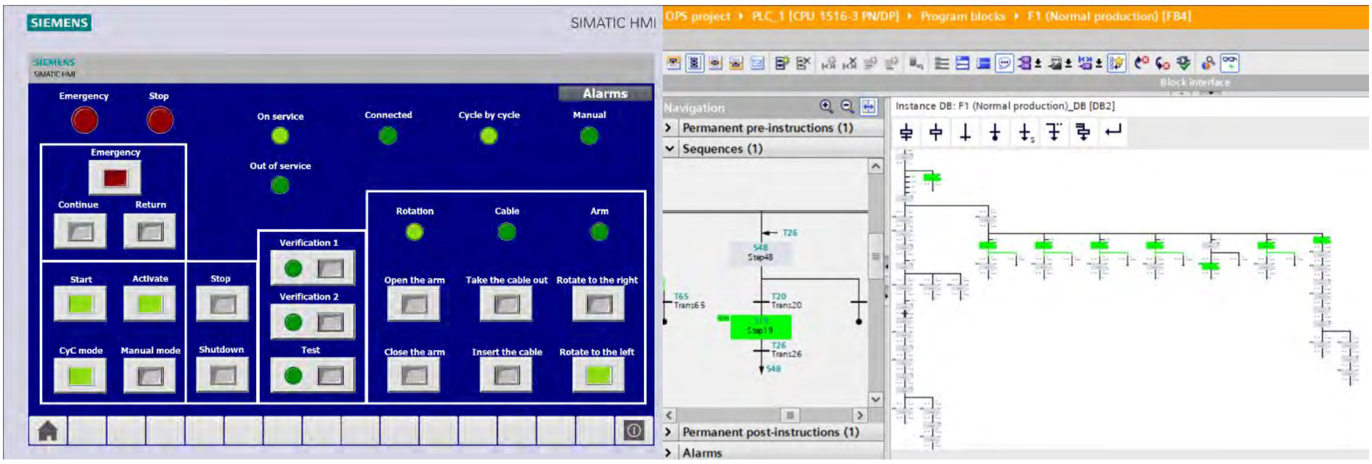


(a) (b)

(c)

Figure 6.22: The program is placed at the normal production mode (F1) of GEMMA, cycle by cycle mode while insert the cable is activated. (a) the screen, (b) the program, (c) the crane

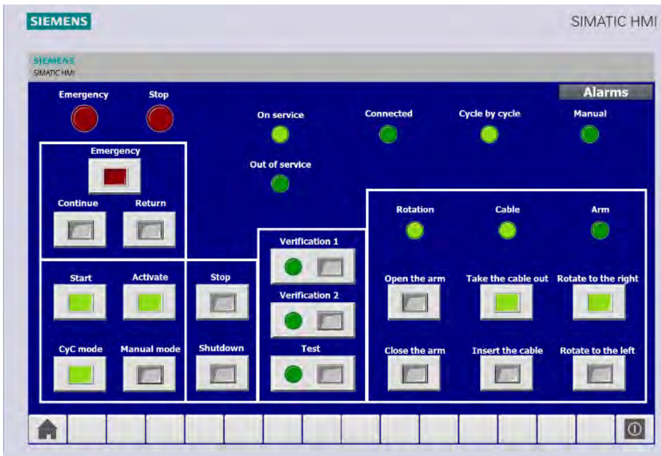
The operator also can rotate the crane at any moment to the right and left in order to reach the best position. Figures 6.23 and 6.24 show the rotation to the left and right respectively. In these figures it is possible to see the operation screen, the program, and the crane position for the certain stage. Figure 6.24 describes a situation that the operator activates both the rotation to the right and also take the cable out. It shows that the operator is able to activate two different parts of the crane at the same time.



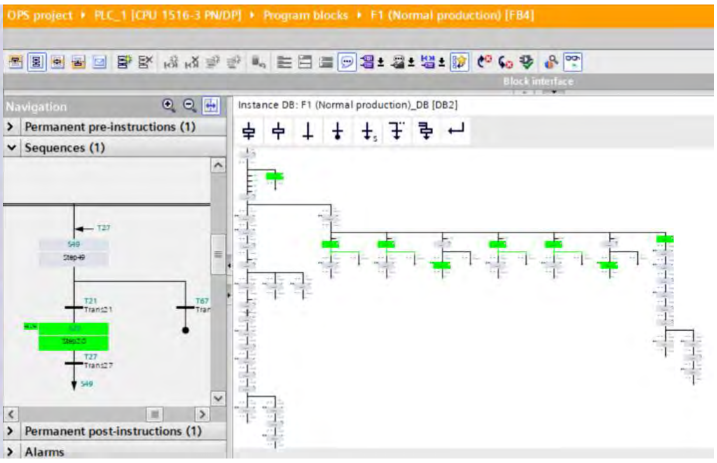
(a) (b)

(c)

Figure 6.23: The program is placed at the normal production mode (F1) of GEMMA, cycle by cycle mode while rotation to the left is activated. (a) the screen, (b) the program, (c) the crane



(a)

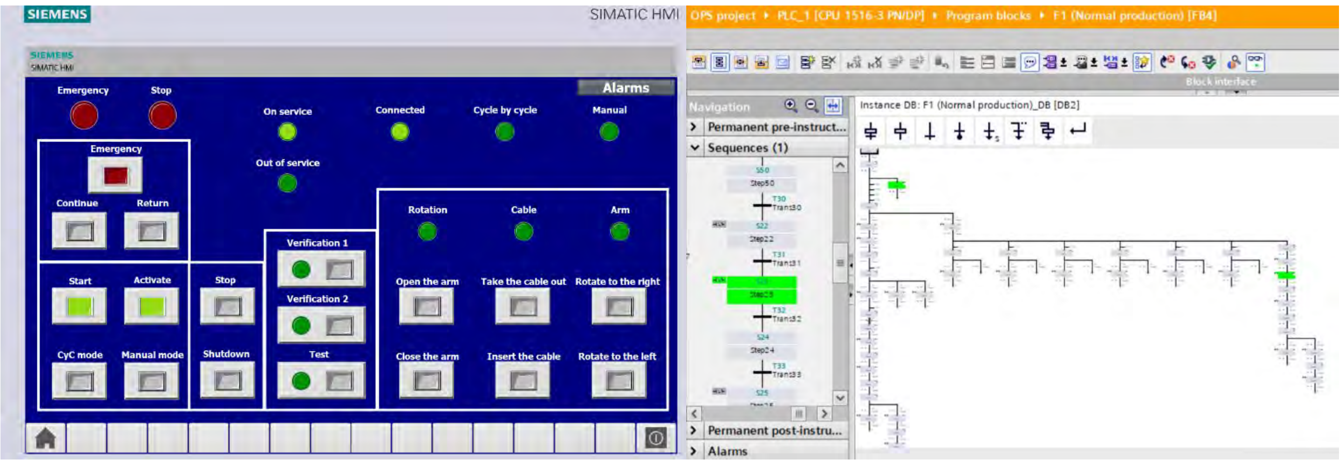


(b)

(c)

Figure 6.24: The program is placed at the normal production mode (F1) of GEMMA, cycle by cycle mode while both rotation to the right and take the cable out are activated. (a) the screen, (b) the program, (c) the crane

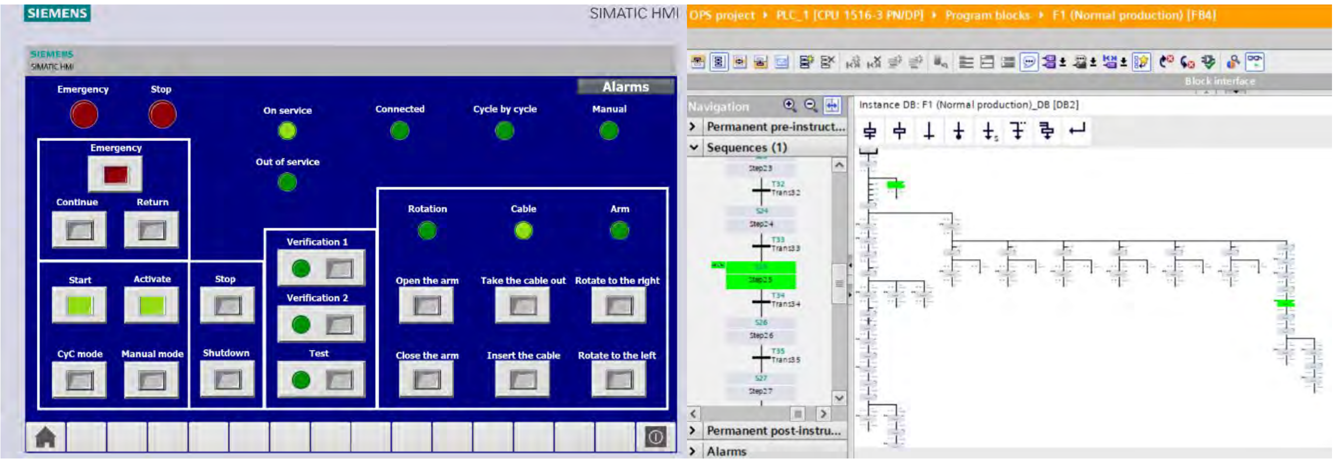
A soon as the operator has reached the task and the crane is in the correct place, it is possible to connect the plug to the socket of the ship in order to supply the electricity to the ship. Figure 6.25 describes this stage. The operation screen shows that the plug is connected, and the program of that stage.



(a) (b)

Figure 6.25: The program is placed at the normal production mode (F1) of GEMMA, while the plug of the crane is connected. (a) the screen, (b) the program

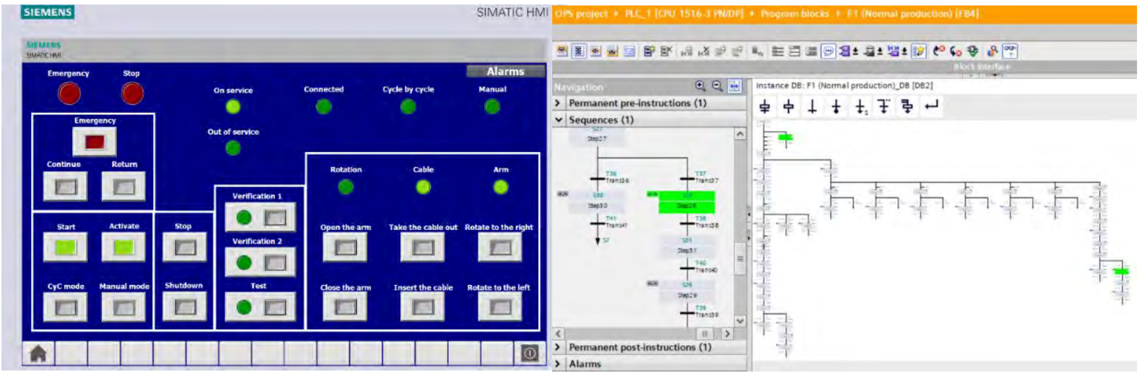
When the ship has to leave the port, the plug is disconnected. At that moment, the Cycle by Cycle mode closing process starts automatically. In the figure below it is possible to see that the plug has been disconnected, and the Cycle by Cycle closing process is started. At the first stage, the cable goes in. The figure shows the operation screen at that stage including the activation of the responsible motor, and the program.



(a) (b)

Figure 6.26: The program is placed at the normal production mode (F1) of GEMMA, while the plug of the crane is disconnected and the crane closing process is operated, cable is coming in. (a) the screen, (b) the program

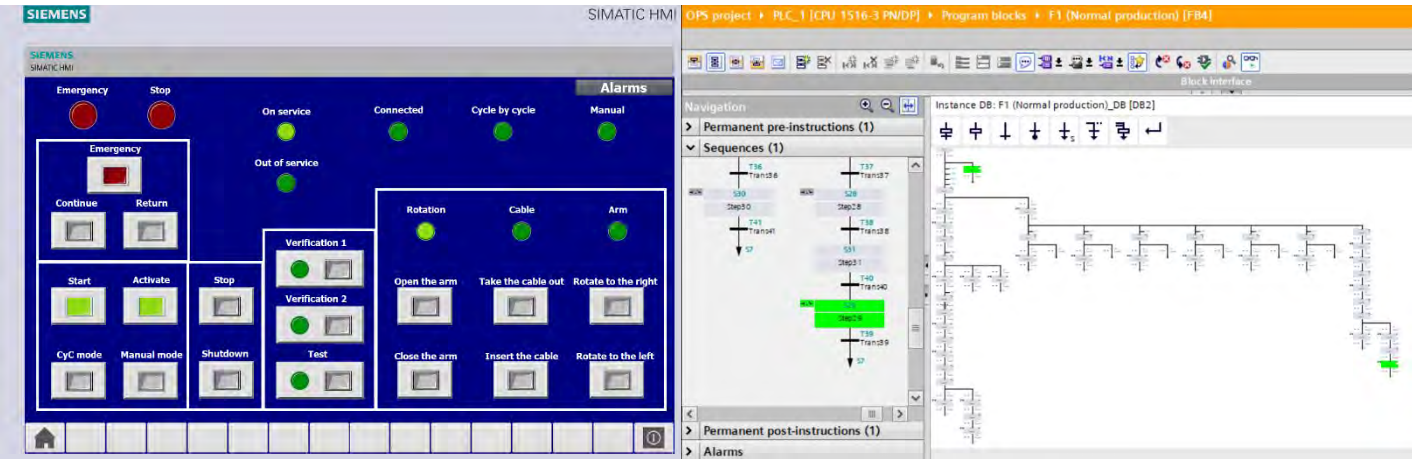
While the cable has finished to insert, the closing arm stage is started. The figure below shows the operation screen, and the program at that stage. It is possible to see that the motors of the arm and cable are activated in order to close the arm to its initial state.



(a) (b)

Figure 6.27: The program is placed at the normal production mode (F1) of GEMMA, while the plug of the crane is disconnected and the crane closing process is operated, arm is closing. (a) the screen, (b) the program

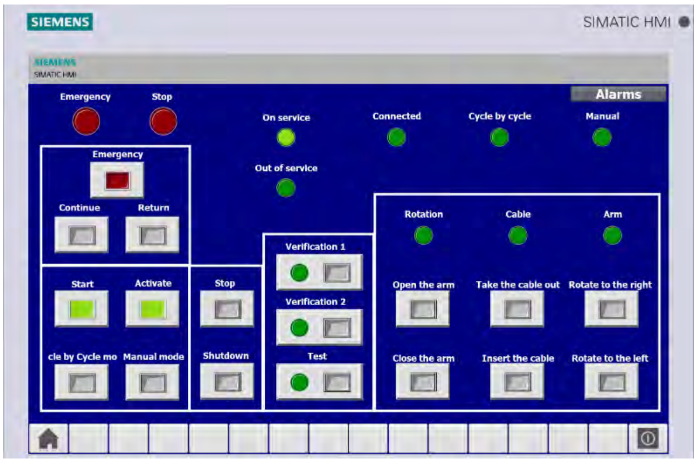
As soon as the closing the arm process has been finished, the crane is rotated to its initial state. Figure 6.28 shows the operation screen including the activation of the motor, and the program at that stage.



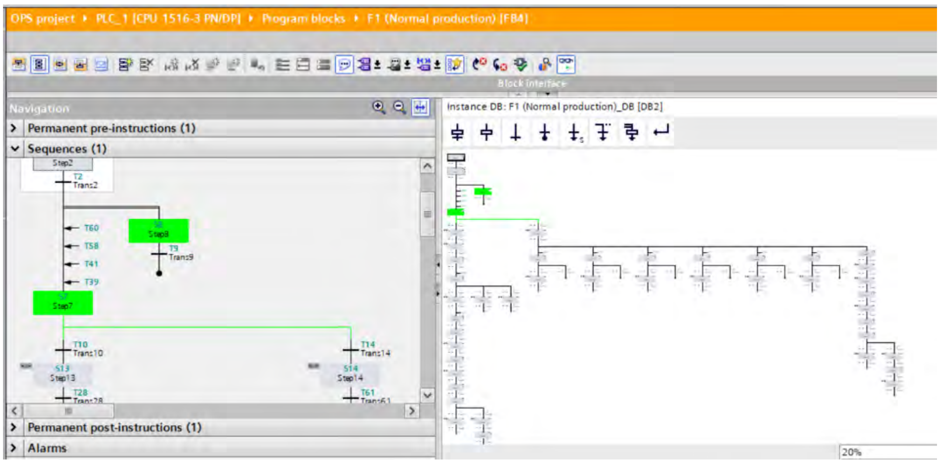
(a) (b)

Figure 6.28: The program is placed at the normal production mode (F1) of GEMMA, while the plug of the crane is disconnected and the crane closing process is operated, the crane is rotated to its initial state. (a) the screen, (b) the program

After the Cycle by Cycle closing process has been finished, the normal production mode (F1) of the crane is placed at its initial state. At that moment, it is ready for the next operation. The figure below shows that stage including the operation screen, the program, and the crane.



(a)

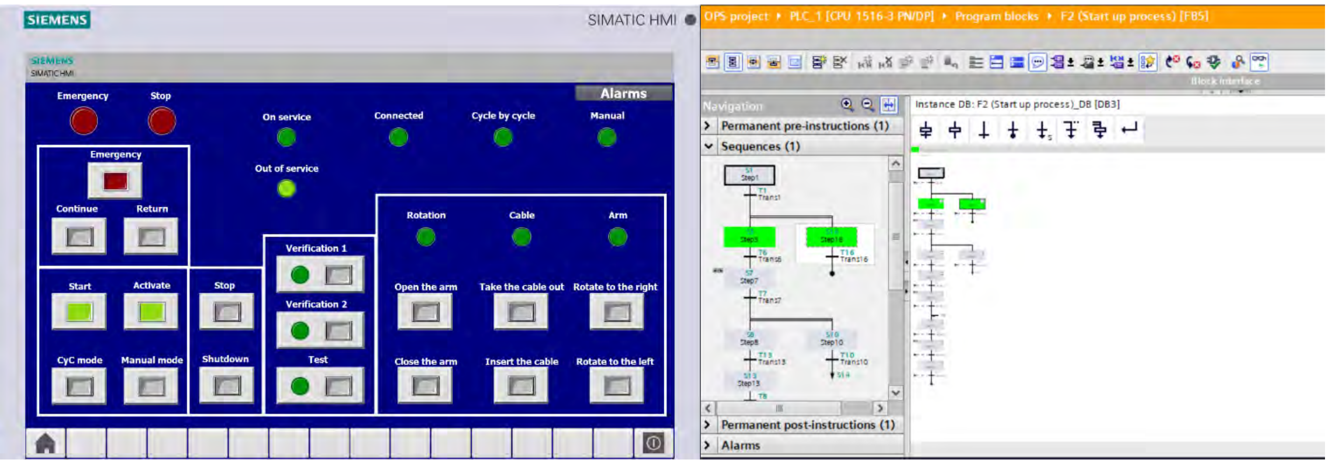


(b)

(c)

Figure 6.29: The program is placed at the normal production mode (F1) of GEMMA, after the crane closing process has been finished. (a) the screen, (b) the program, (c) the crane

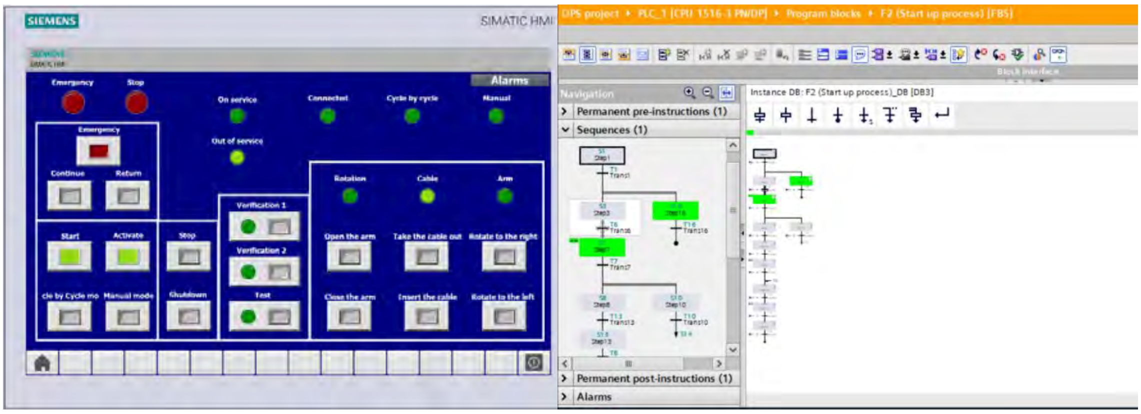
If the crane for any reason is not prepared for the operation. That is to say, the crane is not in its initial state, for example, the arm is opened, the cable is out, or the crane is rotated, and it is located in some angle. When the operator desires to start the operation of the crane, the program will be placed automatically in the startup process mode (F2) in order to prepare the crane to the operation. Figure 6.30 shows the operation screen, and the program in the initial state of the startup process mode. In the operation screen it is possible to see that at this stage the out of service led is activated, which means that the operator cannot control the crane, and he has to wait that the startup process will finish.



(a) (b)

Figure 6.30: The program is placed at the startup process mode (F2) of GEMMA. (a) the screen, (b) the program

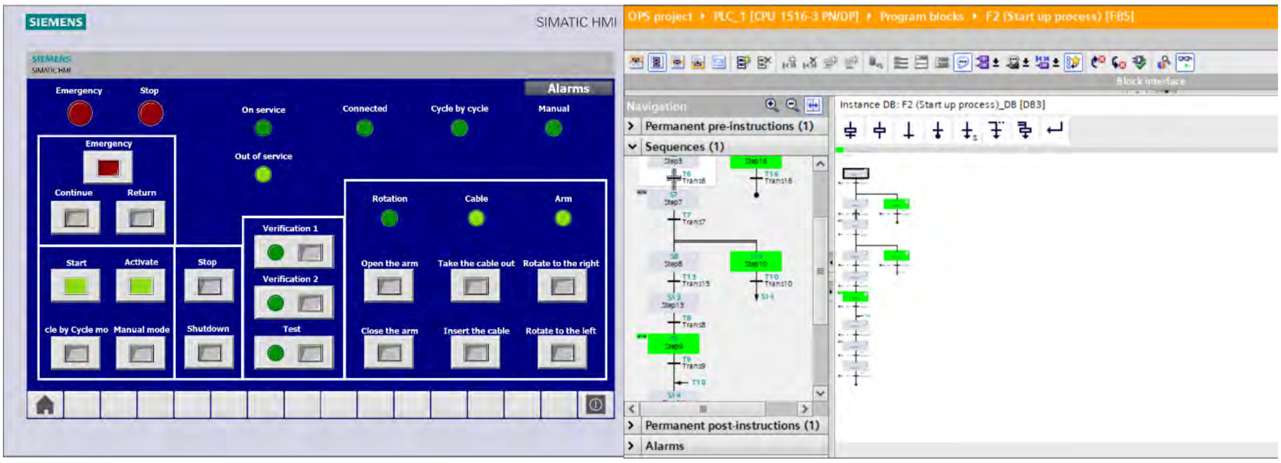
The first stage of the startup process is inserting the cable if it is necessary. In a situation that the cable is inside, the program jumps automatically to the next stage. In the figure below it is possible to see the operation screen, and the program at that stage.



(a) (b)

Figure 6.31: The program is placed at the startup process mode (F2) of GEMMA, the startup process is operated, cable goes in. (a) the screen, (b) the program

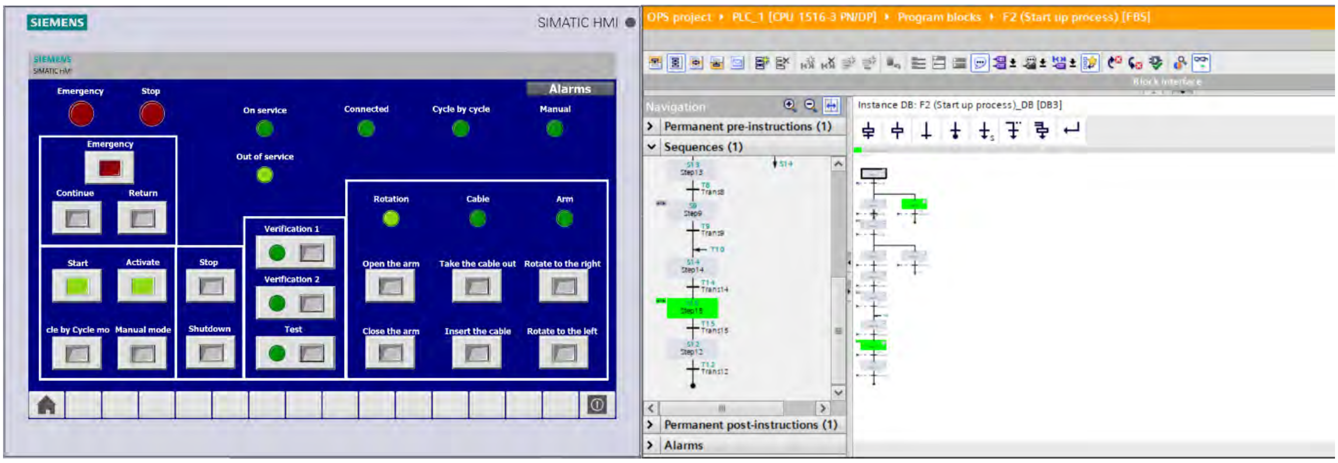
The second stage is the closing the arm process. At that stage, the arm is closing to its initial state (this stage is activated only in the case that the arm is not in its initial state). Figure 6.32 shows the operation screen and the program at that stage.



(a) (b)

Figure 6.32: The program is placed at the startup process mode (F2) of GEMMA, the startup process is operated, arm is closing. (a) the screen, (b) the program

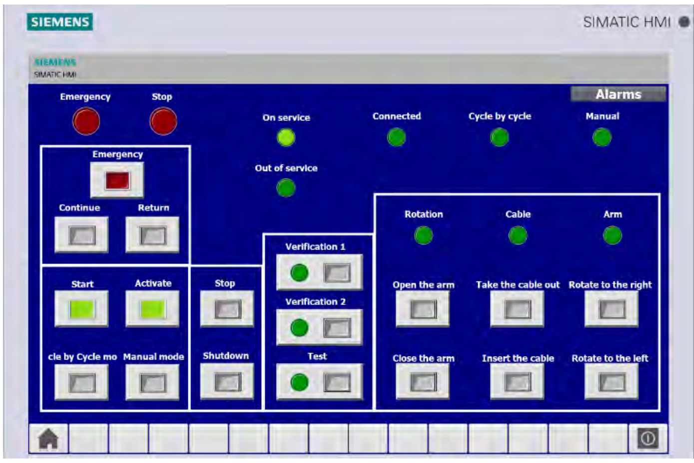
The last stage is responsible to the crane rotation. If the crane is not located in its initial angel, at this stage the crane is rotated to its initial state. The figure below shows the operation screen including the activation of the rotation motor, and the program at that stage.



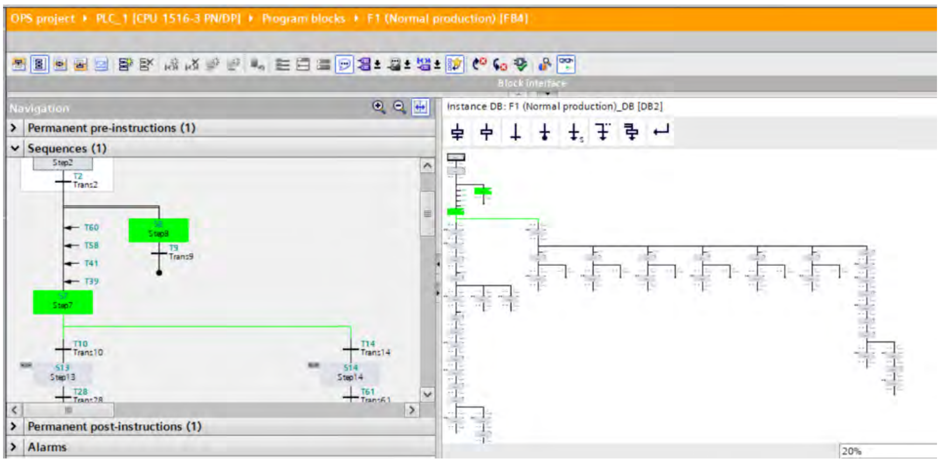
(a) (b)

Figure 6.33: The program is placed at the startup process mode (F2) of GEMMA, the startup process is operated, the crane is rotating to its initial state. (a) the screen, (b) the program

When the last stage has been finished and the crane is prepared for the operation, the startup process mode (F2) will be disactivated and the program will be placed at the normal production mode (F1) in order to allow the operation. The figure below shows the operation screen, and the program after the startup process has been finished. It is possible to see that the program is placed at the normal production mode (F1) and it is ready for the operation.



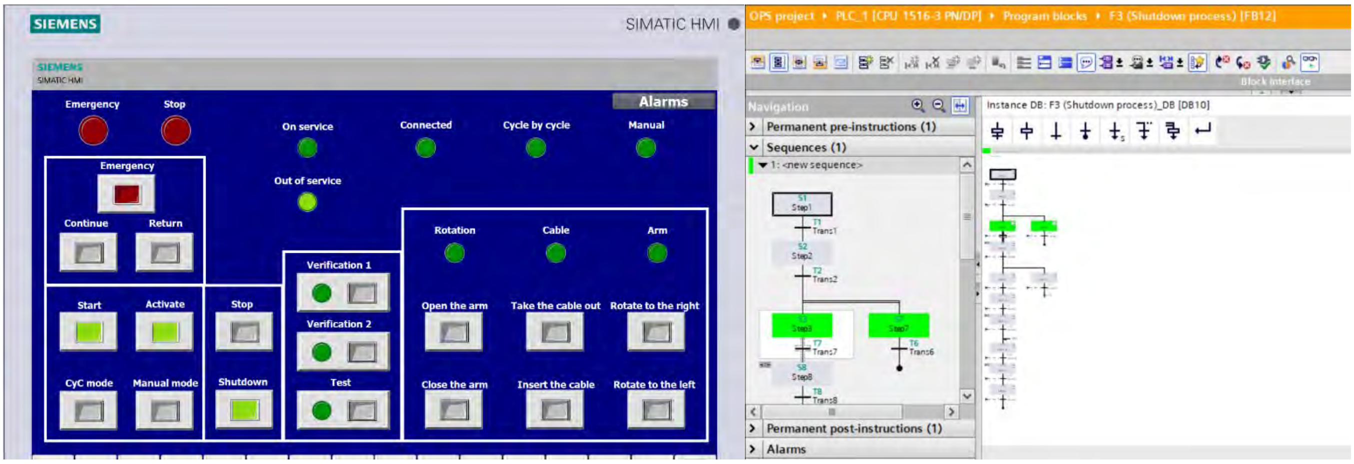
(a)



(b)

Figure 6.34: The program is placed at the normal production mode (F1) of GEMMA, after the crane closing process has been finished. (a) the screen, (b) the program

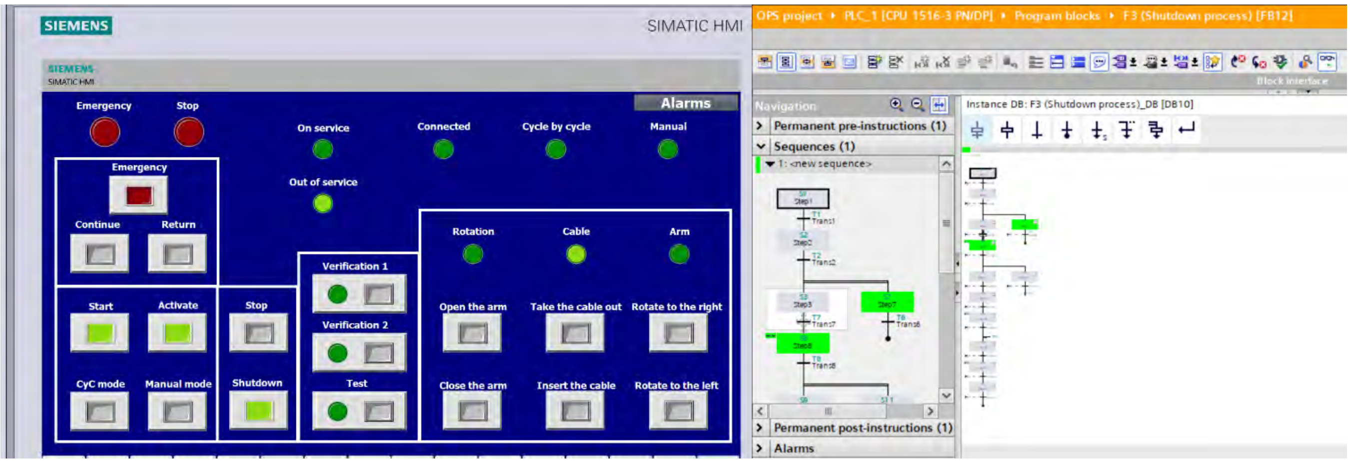
In a similar way, the shutdown process is working. In other words, in a situation that the closing process did not finish correctly for some reason, and the operator desires to shut down the program. At this situation, the program will be placed first in the shutdown process mode (F3) in order to shut down the crane correctly and to prepare it for the next operation. Figure 6.35 shows this situation, which the operator has pressed the shutdown button and the program is placed at the shutdown process mode for the preparation. In the figure it is possible to see the operation screen including the out of service led, and the program.



(a) (b)

Figure 6.35: The program is placed at the shutdown process mode (F3) of GEMMA. (a) the screen, (b) the program

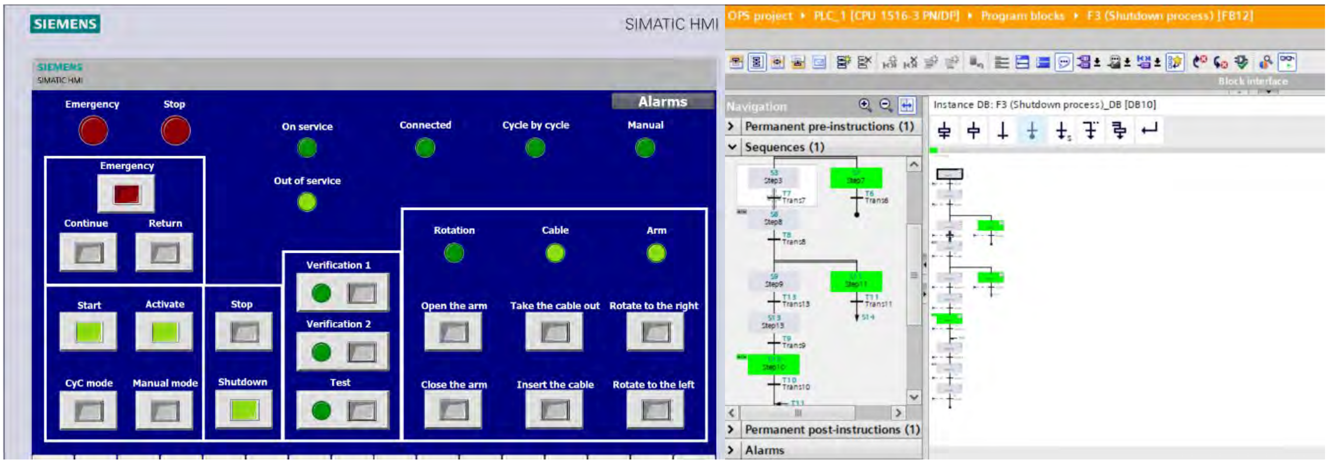
The first stage of the shutdown process is inserting the cable if it is necessary. In a situation that the cable is already inside, the program jumps automatically to the next stage. Figure 6.36 describes this stage, it is possible to see the operation screen including the activation of the responsible motor, and the program at that stage.



(a) (b)

Figure 6.36: The program is placed at the shutdown process mode (F3) of GEMMA, while the shutdown process is operated, cable goes in. (a) the screen, (b) the program

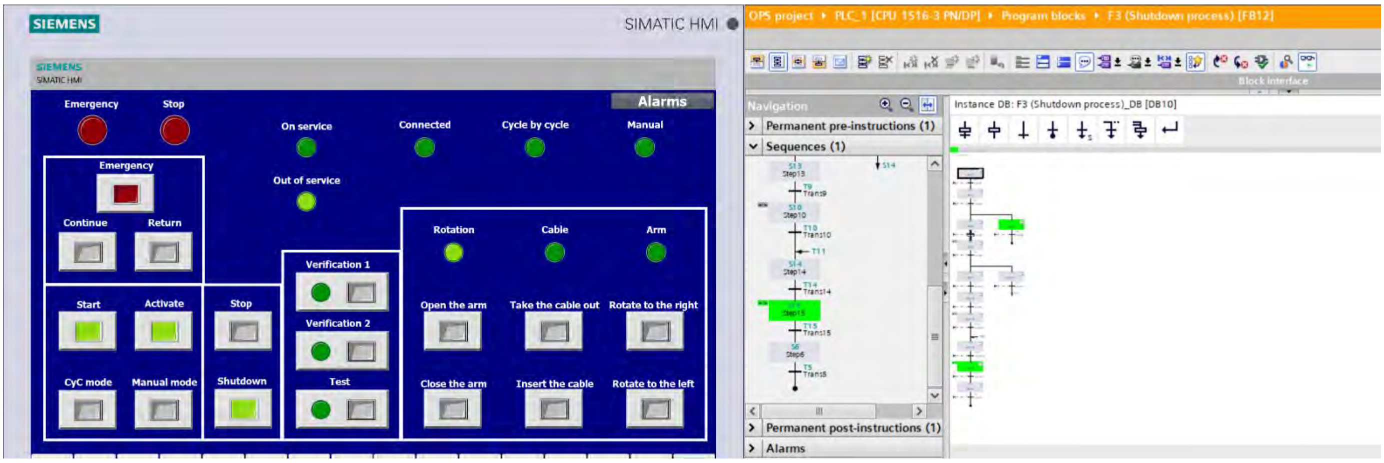
The second stage of the shutdown process is closing the arm. If the arm is not in its initial state, it will be closing at that stage. Figure 6.37 shows this stage, it includes the operation screen with the motors' activation, and the program.



(a) (b)

Figure 6.37: The program is placed at the shutdown process mode (F3) of GEMMA, while the shutdown process is operated, arm is closing. (a) the screen, (b) the program

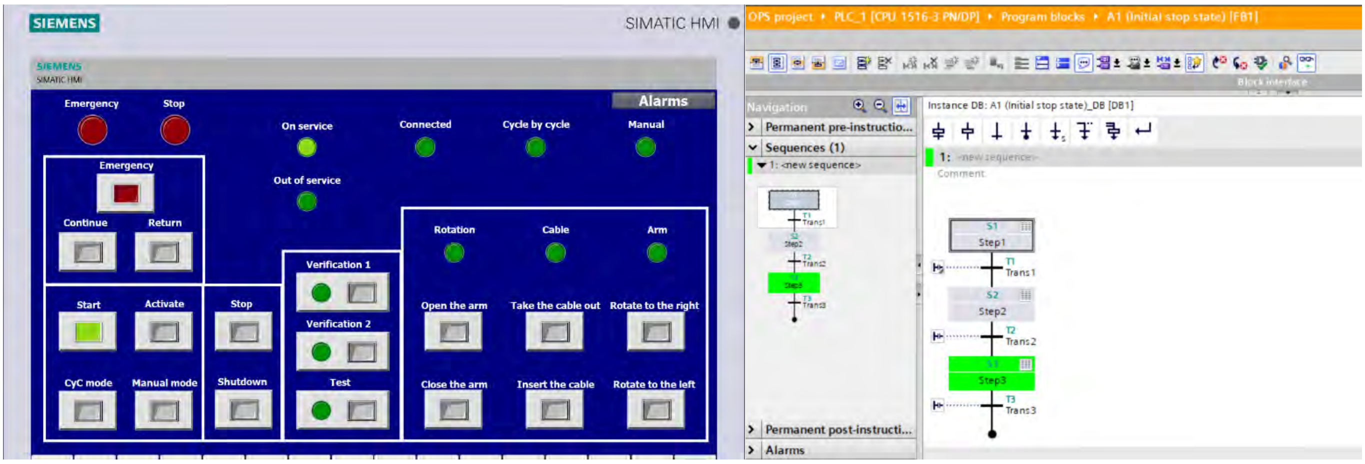
The last stage of the shutdown process is the crane's rotation. If the program detects that the crane angle is not in its initial state, the crane's rotation will be activated in order to place it in its initial state. The figure below shows the operation screen including the rotation motor activation, and the program at that stage.



(a) (b)

Figure 6.38: The program is placed at the shutdown process mode (F3) of GEMMA, while the shutdown process is operated, the crane is rotating to its initial state. (a) the screen, (b) the program

As soon as the last shutdown process stage has been finished, the shutdown process mode (F3) will be disactivated, and the program will be placed at the initial stop state (A1). The figure below shows the operation screen, and the program at that stage.



(a) (b)

Figure 6.39: The shutdown process mode (F3) of GEMMA is off, and program is placed at the initial stop state (A1) of GEMMA. (a) the screen, (b) the program

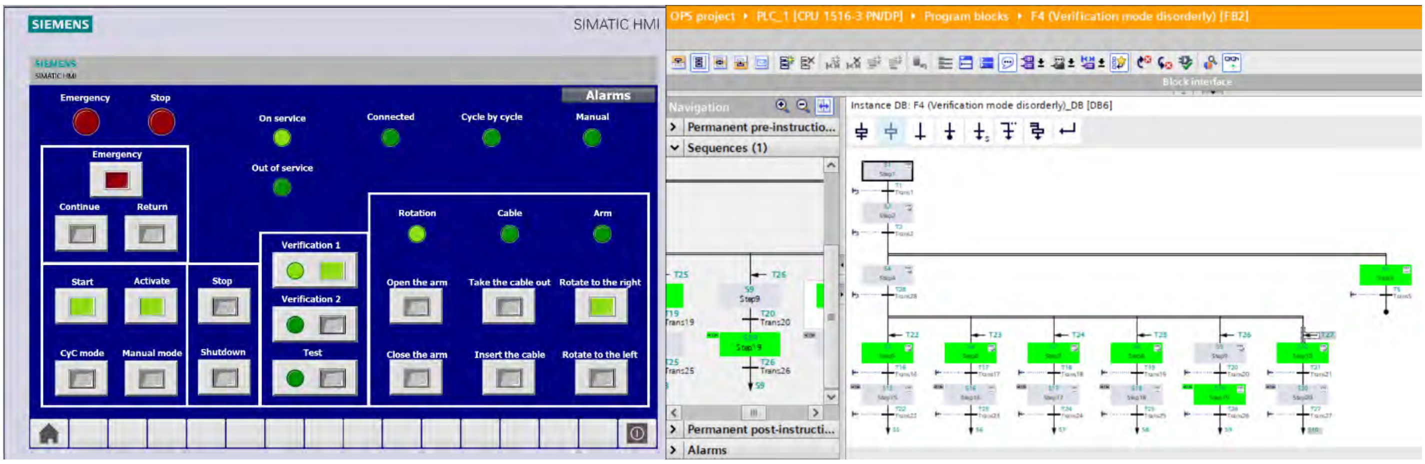
As it is explained in section 3.3.1, the GEMMA Guide Paradigm contains of two verification modes, and a test mode. The different verification and test mode can be designed according to the need of each machine. However, the running in verification mode disorderly (F4) is used to verify each part of the machine that the operator desires. Additionally, running in verification mode orderly (F5) is used to verify one cycle of the machine orderly.

The OPS crane program contains the different verification and test modes as following. The first verification mode is running in verification mode disorderly (F4) which allows the operator to activate each part of the crane without limitation, similarly to the Cycle by Cycle mode of the normal production mode (F1). Figure 6.40 describes the first verification mode including the operation screen while the verification 1 button is pressed, and verification 1 led which indicates the verification's activation. Moreover, it shows the program at that mode.

(a) (b)

Figure 6.40: The program is placed at the running in verification mode disorderly (F4) of GEMMA. (a) the screen, (b) the program

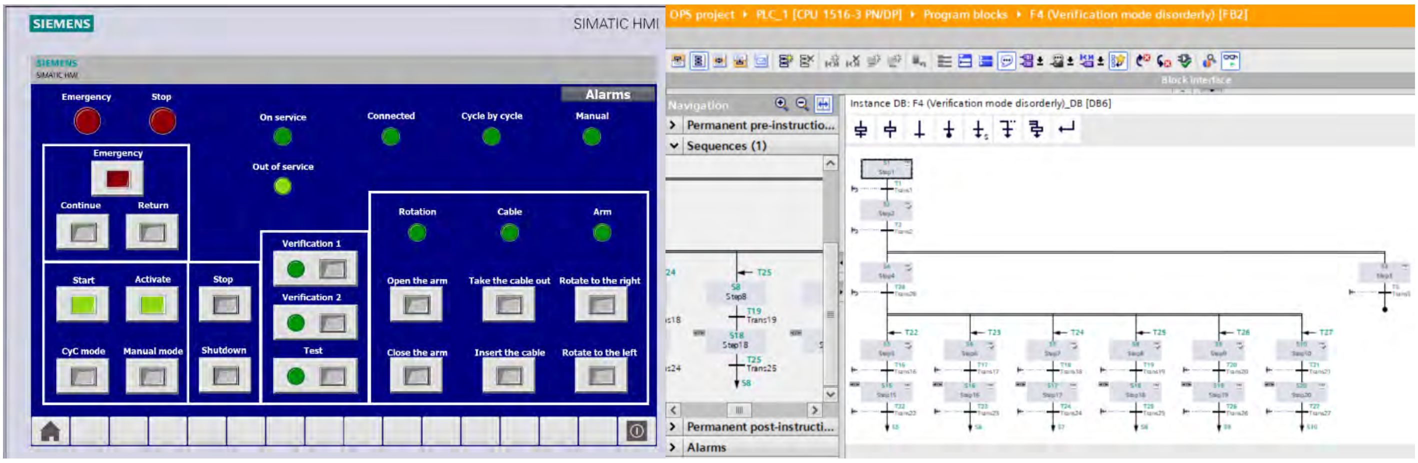
The figure below shows an operation example of the running in verification mode disorderly (F4). In this example, the operator has pressed the rotation to the right button in order to verify the rotation motor. In the figure, it is possible to see the operation screen while the rotate to the right button is activated including the rotation motor led, and the program which indicates the situation.



(a) (b)

Figure 6.41: The program is placed at the running in verification mode disorderly (F4) of GEMMA, while the rotation to the right is activated. (a) the screen, (b) the program

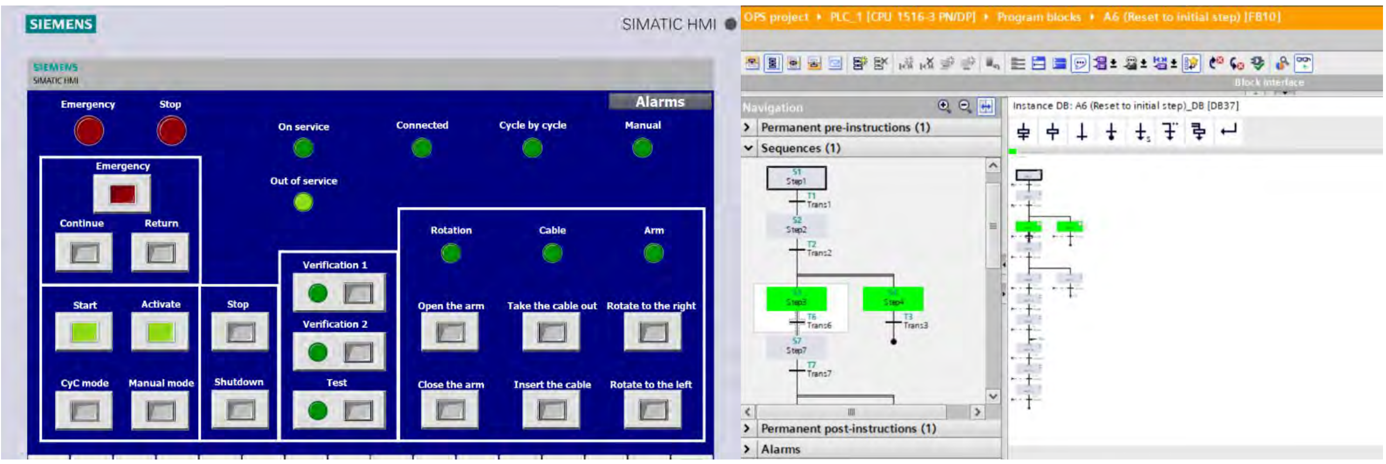
When the operator has been finished to verify the different parts of the crane, and he desires to stop the running in verification mode disorderly (F4), he has to disactivate the verification 1 button. At that moment, the program will be placed automatically in the reset to initial state mode (A6) in order to prepare the crane for the next operation. In the figure below it is possible to see that the verification button 1 is disactivated, and the running in verification mode disorderly (F4) is off. The figure illustrates the operation screen, and the program at that moment. Moreover, it is possible to notice that that out of service led is on while the reset to initial state of the program is activated.



(a) (b)

Figure 6.42: The program is placed at the reset to initial state mode (A6) of GEMMA, running in verification mode disorderly (F4) is off while the verification button 1 is released. (a) the screen, (b) the program

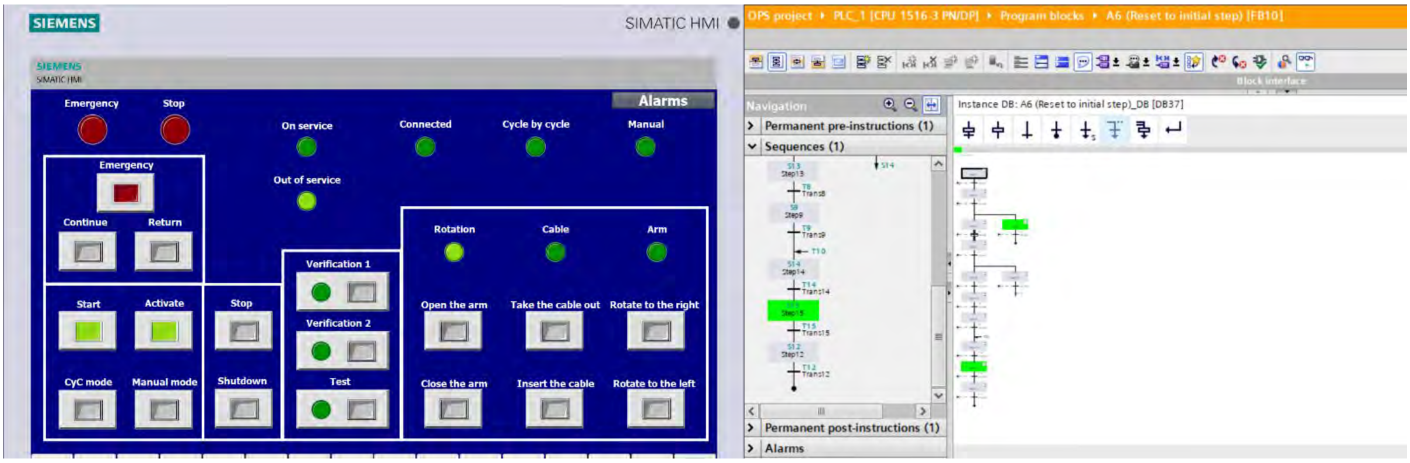
Figure 6.43 shows that when the verification button 1 is disactivated, the reset to initial state mode (A6) is on in order to start the preparation of the crane to the next operation. It is possible to see the operation screen, and the program at that stage.



(a) (b)

Figure 6.43: The program is placed at the reset to initial state mode (A6) of GEMMA, and it is ready to the reset process. (a) the screen, (b) the program

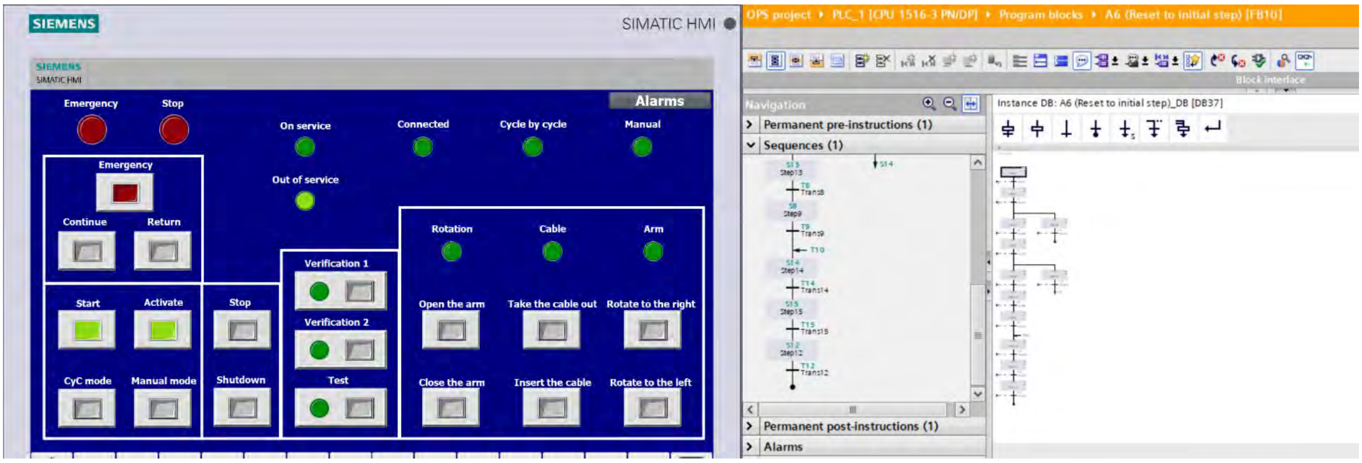
In this verification example, the operator has verified only the rotation motor of the carne. For this reason, the program detects that the rest of the parts are in their initial state, and it jumps to the last stage that is responsible for the crane rotation. At this stage, the program rotates the crane back to its initial state. In the figure below it is possible to see the operation screen including the rotation motor activation, and the program at that stage.



(a) (b)

Figure 6.44: The program is placed at the reset to initial state mode (A6) of GEMMA, the reset process is operated, and the crane is rotating to its initial state. (a) the screen, (b) the program

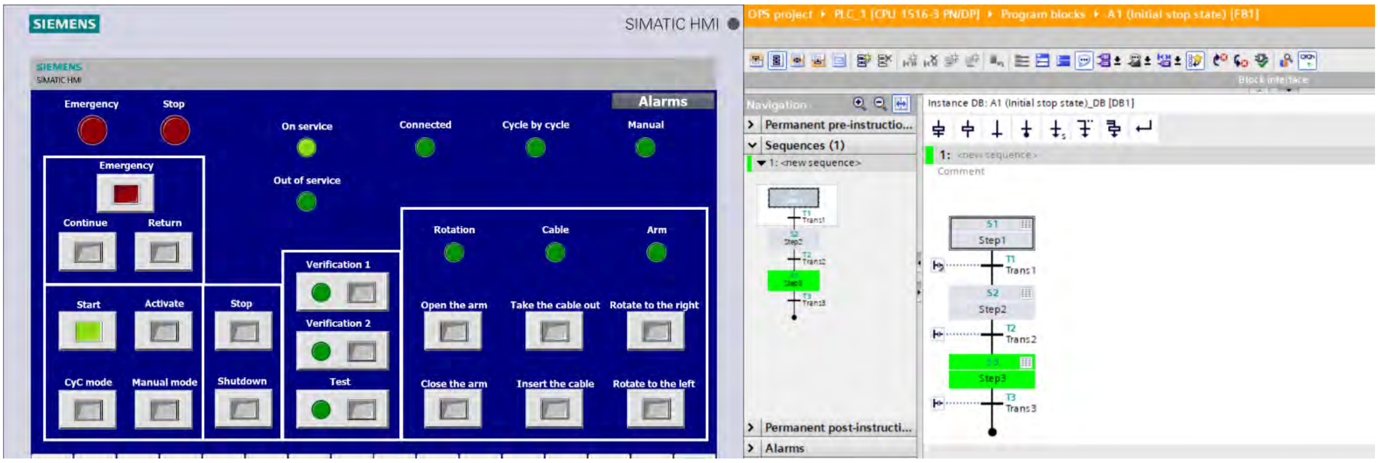
When the program has been finished the reset to initial state process, the reset to initial state mode (A6) will turn off. The figure below describes this situation of the program. It is possible to see that the program is off. Also, the operation screen shows that the program is still out of service.



(a) (b)

Figure 6.45: The reset to initial state mode (A6) of GEMMA is off, while the reset process has been finished. (a) the screen, (b) the program

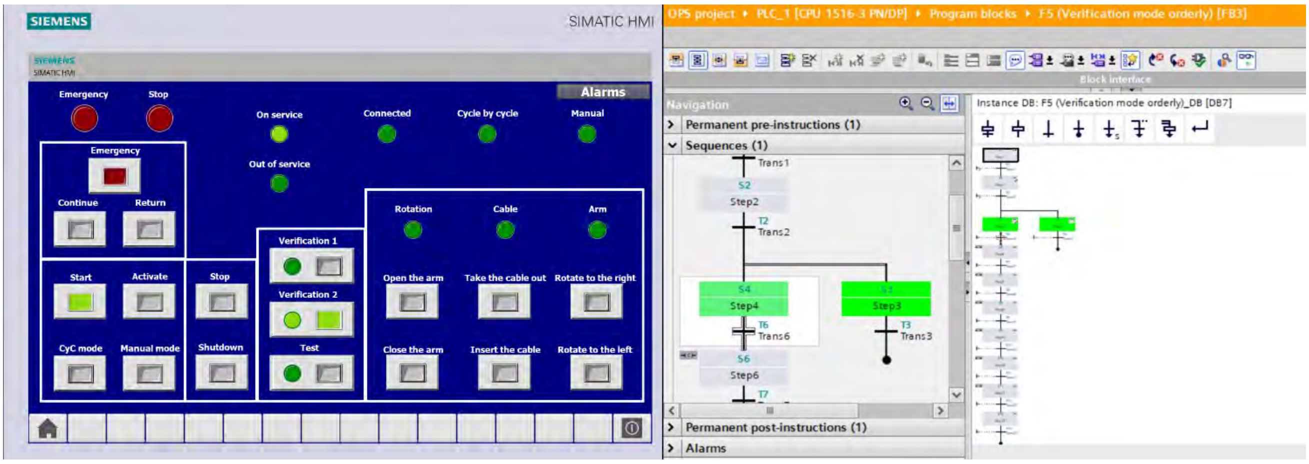
At the next moment, the program has finished its preparation and it will be placed at the initial stop state. This allows the operator to start again the operation. Figure 6.46 shows the operation screen, and the program which is ready for the operation.



(a) (b)

Figure 6.46: The program is placed at the initial stop state (A1) of GEMMA, while the reset process has been finished, and it is ready to start over. (a) the screen, (b) the program

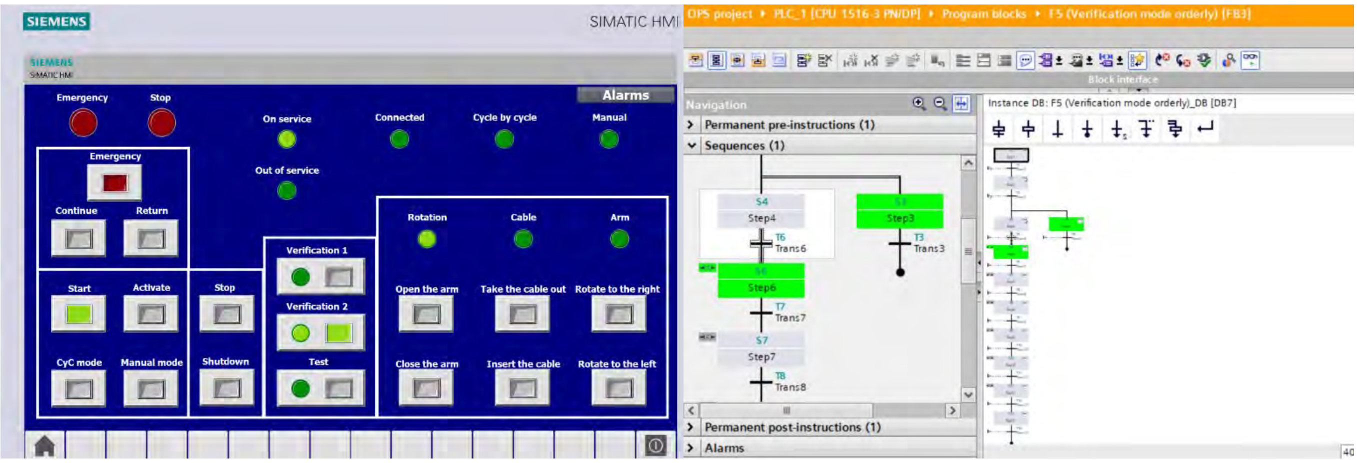
The second verification mode is the running in verification mode orderly (F5). This verification mode allows the operator to operate one cycle of the machine. In the OPS crane, this mode activates all the different parts orderly which it simulates a real situation of the crane operation. That is to say, the program first rotates the crane, then opens the crane's arm, and at last takes the cable out. When the cycle is finished, the program continues to the last stage of the running in verification mode orderly (F5). At that stage, the program reset the crane to its initial state by inserting the cable, closing the arm, and rotating back the crane. The figure below shows the program in the initial state of the running in verification mode orderly (F5). At that point, the program is ready to start the verification mode. The figure describes the operation screen, and the program at that stage.



(a) (b)

Figure 6.47: The program is placed at the running in verification mode orderly (F5) of GEMMA. (a) the screen, (b) the program

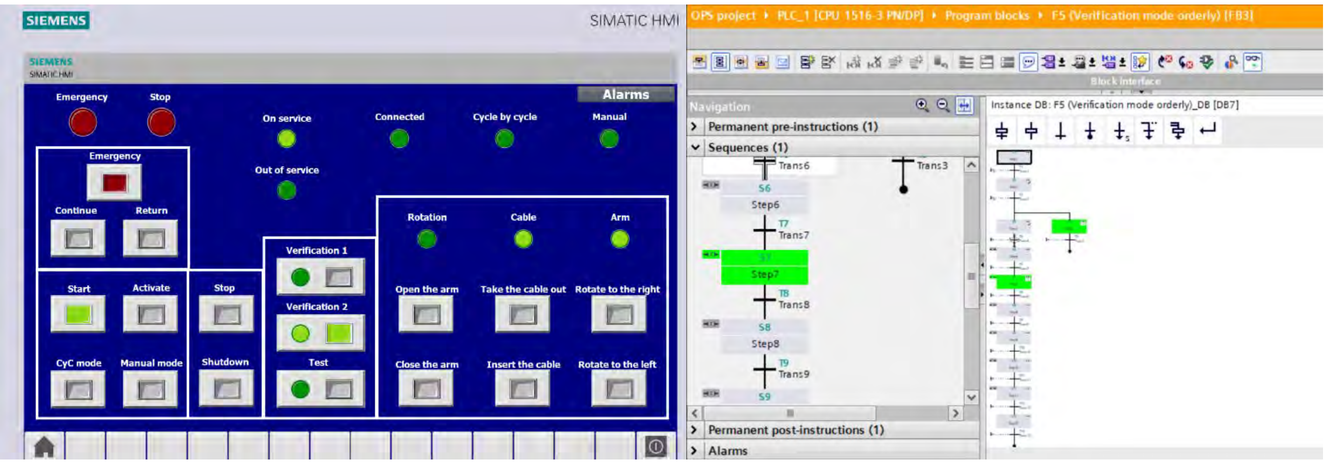
After a delay of three minutes, the process starts. First the program activates the rotation motor in order to verify the motor's rotation. Figure 6.48 shows the operation screen including the rotation motor activation, and the program while the crane is rotating.



(a) (b)

Figure 6.48: The program is placed at the running in verification mode orderly (F5) of GEMMA, the crane is rotating. (a) the screen, (b) the program

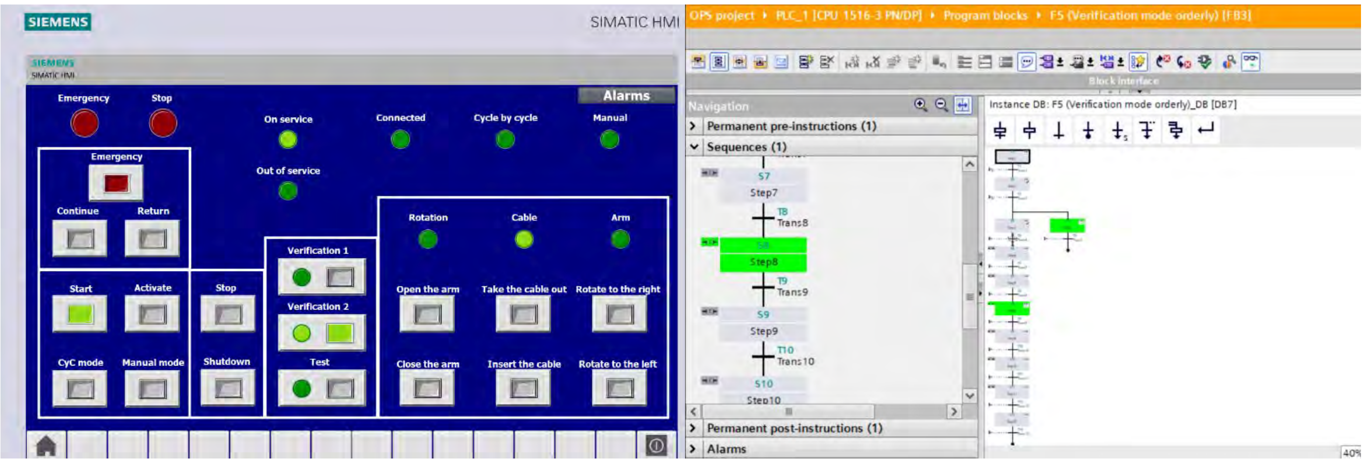
In the moment that the crane rotation has finished, the arm is opening for verifying the arm's motor. In the figure below it is possible to see the operation screen including the arm motor activation, and the program.



(a) (b)

Figure 6.49: The program is placed at the running in verification mode orderly (F5) of GEMMA, the arm is opening. (a) the screen, (b) the program

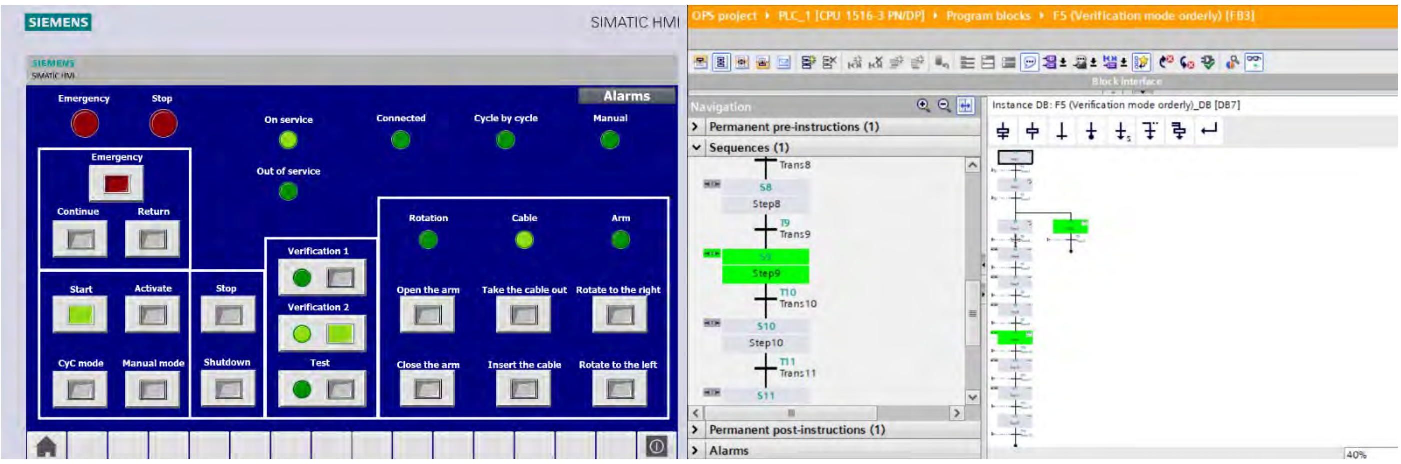
The last verification is the cable motor. After the crane has rotated, and the arm has opened, the cable goes out in order to verify the cable motor. The figure below describes the program while the program verifies the cable's motor, and the operation screen at that time.



(a) (b)

Figure 6.50: The program is placed at the running in verification mode orderly (F5) of GEMMA, the cable is going out. (a) the screen, (b) the program

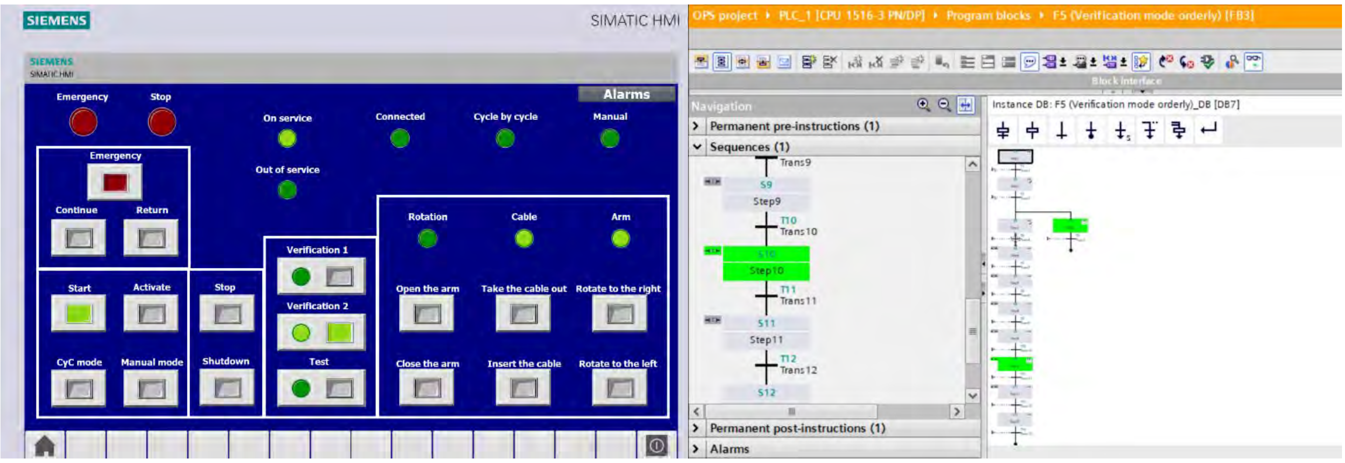
When the verification process has been finished, the program has a delay of five minutes. Afterwards, the reset to initial state of the running in verification mode orderly (F5) starts. That is to say, the program returns the crane to its initial state in order to prepare it to the next operation. First, the cable goes in, then the arm closes, and last the crane rotates to its initial state. Figure 6.51 shows the first stage which the cable motor is activated in order to insert the cable.



(a) (b)

Figure 6.51: The program is placed at the running in verification mode orderly (F5) of GEMMA, the cable goes in. (a) the screen, (b) the program

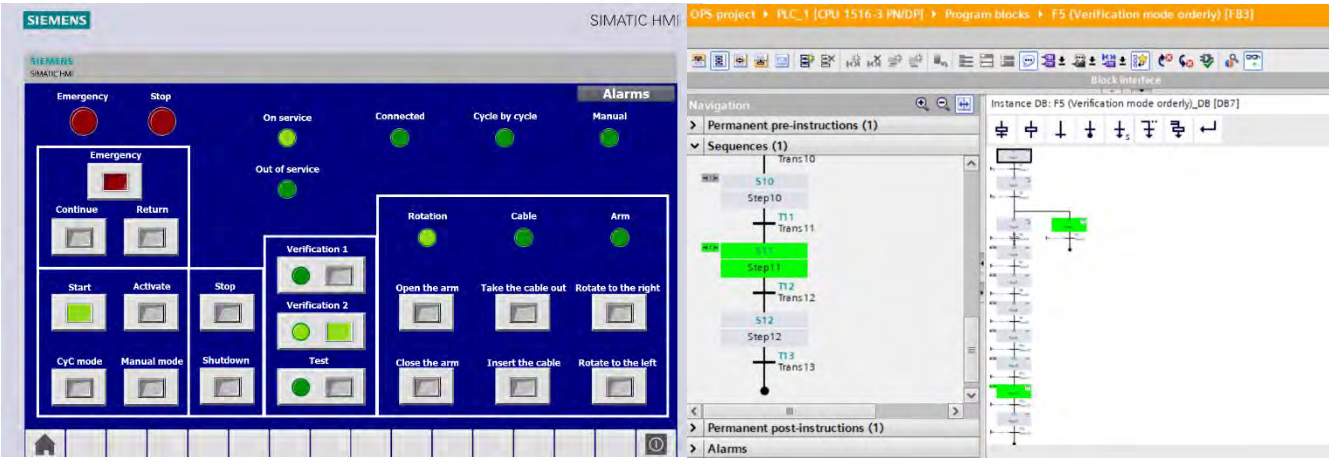
As soon as the cable is inside, the program continues to the next stage. At that stage, the arm is closing to its initial state. The figure below describes this situation of the reset process. It is possible to see the operation screen including the arm's motor activation, and the program at that stage.



(a) (b)

Figure 6.52: The program is placed at the running in verification mode orderly (F5) of GEMMA, the arm is closing. (a) the screen, (b) the program

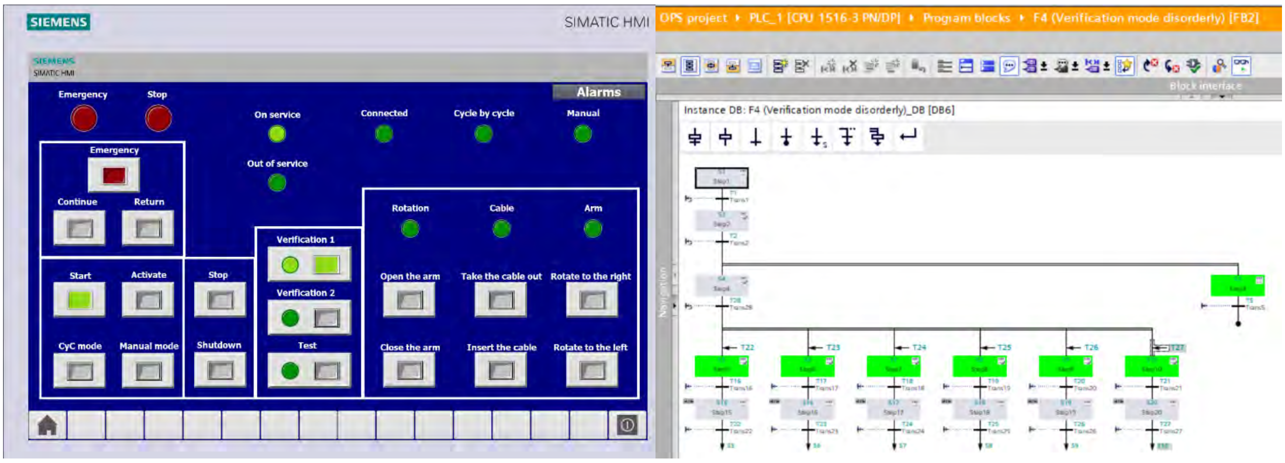
The last stage of the reset process is the crane rotation. At that stage, the crane rotates to its initial state. Figure 6.53 shows this stage including the operation screen, and the program.



(a) (b)

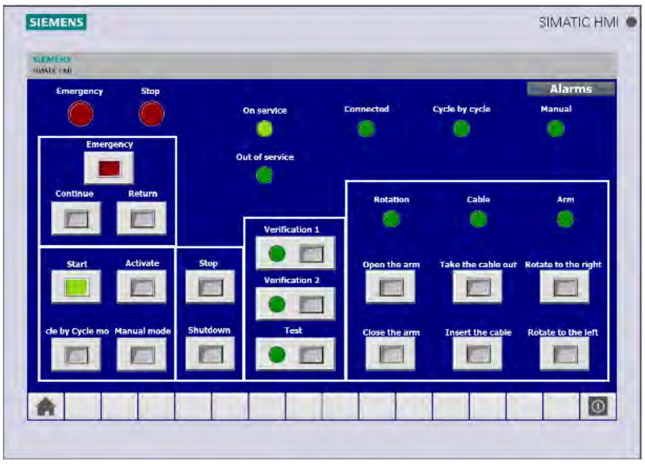
Figure 6.53: The program is placed at the running in verification mode orderly (F5) of GEMMA, the crane is rotating to its initial state. (a) the screen, (b) the program

When the reset process has been finished, the operator is able to place the program in the running in verification mode disorderly (F4) by pressing the verification 1 button as it is shown in figure 6.54. Moreover, if he desires to return the program to the normal production mode (F1), he is able to do it by release the verification button 2 as it is shown in figure 6.55. It allows the operator the flexibility of either operating the crane again or verifying the crane disorderly. In a situation that the operator chooses to place the program in the running in verification mode disorderly (F4), he is able also to place the program in the initial stop state (A1) by the deactivation of the verification 1 button.

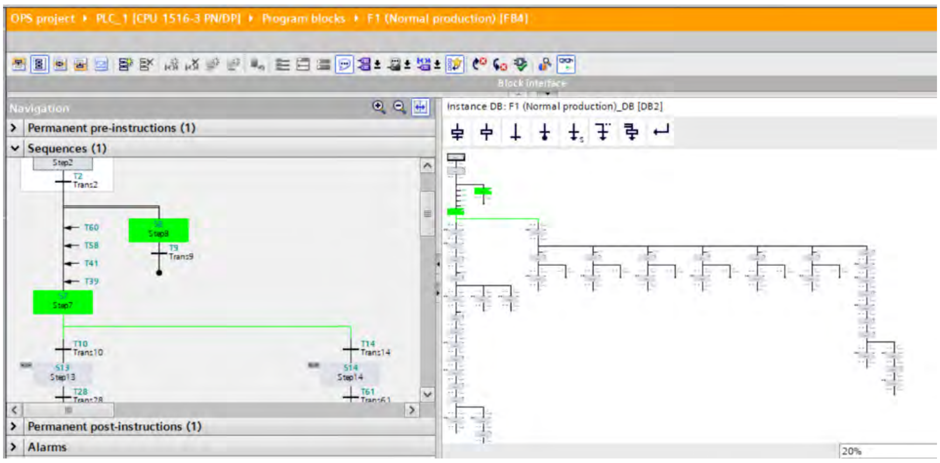


(a) (b)

Figure 6.54: The program is placed at the running in verification mode disorderly (F4) of GEMMA, while the verification button 1 is pressed. (a) the screen, (b) the program



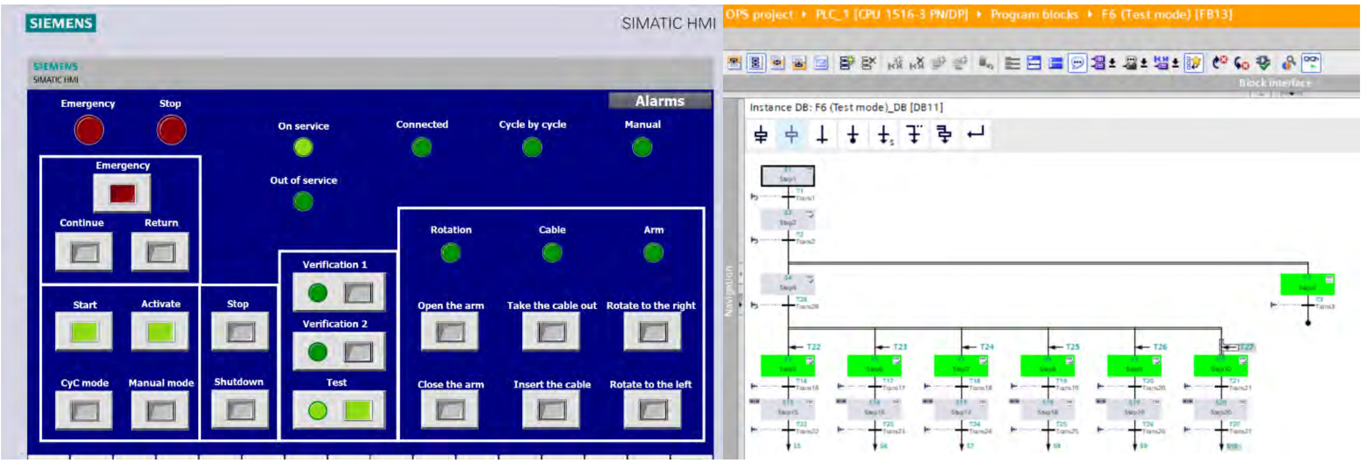
(a)



(b)

Figure 6.55: The program is placed at the normal production mode (F1) of GEMMA, while the verification button 2 is released. (a) the screen, (b) the program

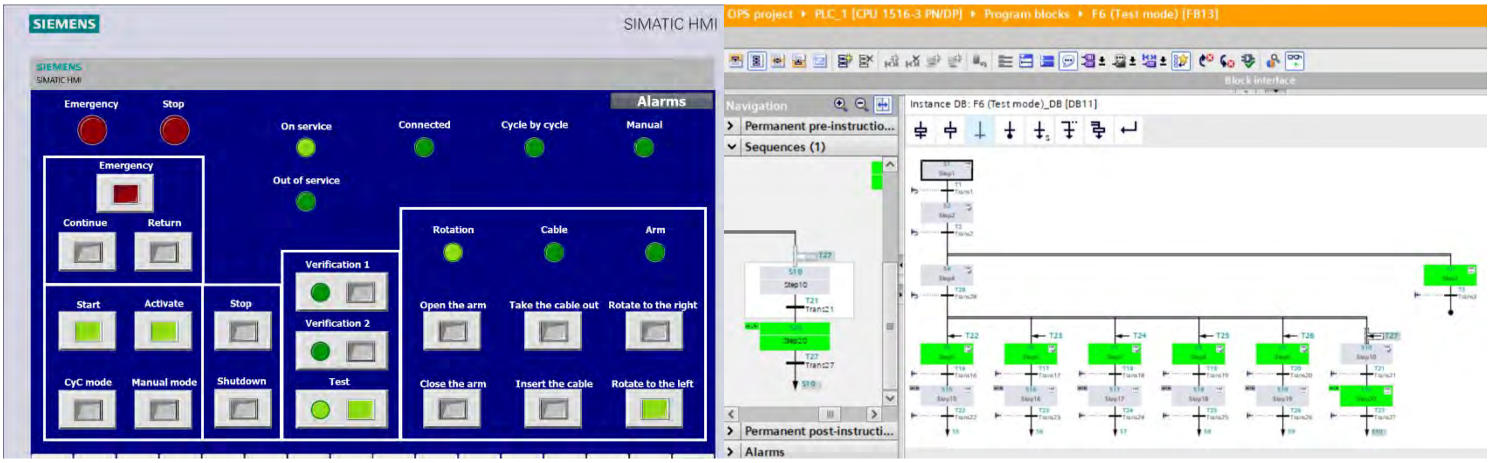
The last mode for the crane's verification is the test mode (F6). This mode allows the operator to verify each part of the crane disorderly similarly to the running in verification mode disorderly (F4). The difference between these two modes is the transitions. In other words, the operator is able to place the program in F4 from the initial stop state (A1), and also from the normal production mode. However, after he finished to verify the crane, he is able only to restart the crane. Differently, in order to place the program in the test mode, it is possible from the normal production mode. Additionally, after he finished to verify the crane in the test mode, he can return to the normal production mode and continue the operation. This mode is very useful while the operator desires to verify the crane at some point of the operation, and then to continue the operation after the verification. Figure 6.56 shows thew program at this mode, and the operation screen.



(a) (b)

Figure 6.56: The program is placed at the test mode (F6) of GEMMA, the normal production mode (F1) is off while the test button is pressed, and it is ready to the different test actions. (a) the screen, (b) the program

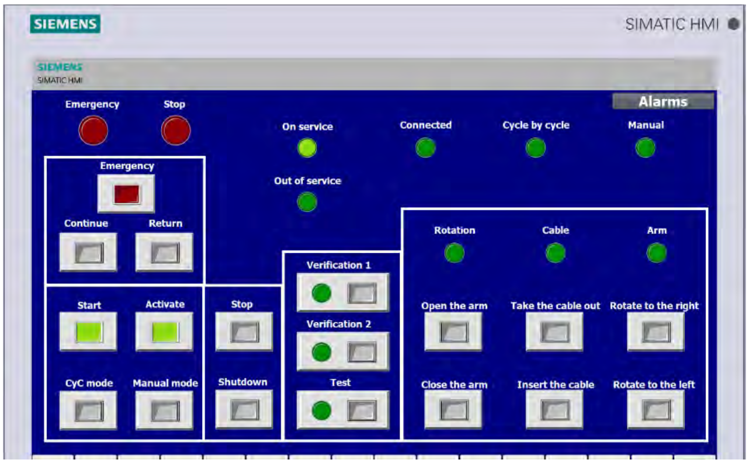
While the operator places the program in this mode, he is able to verify the desired part or parts of the crane. In the figure below it is possible to see an example of the verification. In this example, the operator verifies the rotation's motor of the crane. The figure presents the operation screen, and the program of this verification.



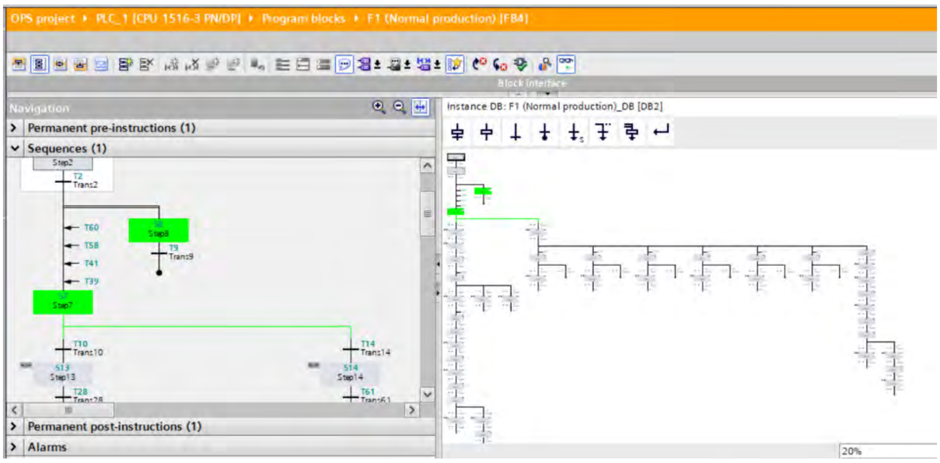
(a) (b)

Figure 6.57: The program is placed at the test mode (F6) of GEMMA, while the rotation to the left is activated. (a) the screen, (b) the program

When the operator has finished the desired verifications, he can continue the normal operation of the crane. He is able to place the program back at the normal production mode by disactivating the test button. Figure 6.58 shows the operation screen, and the program in the normal production mode (F1) while the test button is disactivated.



(a)



(b)

Figure 6.58: The program is placed at the normal production mode (F1) of GEMMA, the test mode is off while the test button is disactivated. (a) the screen, (b) the program

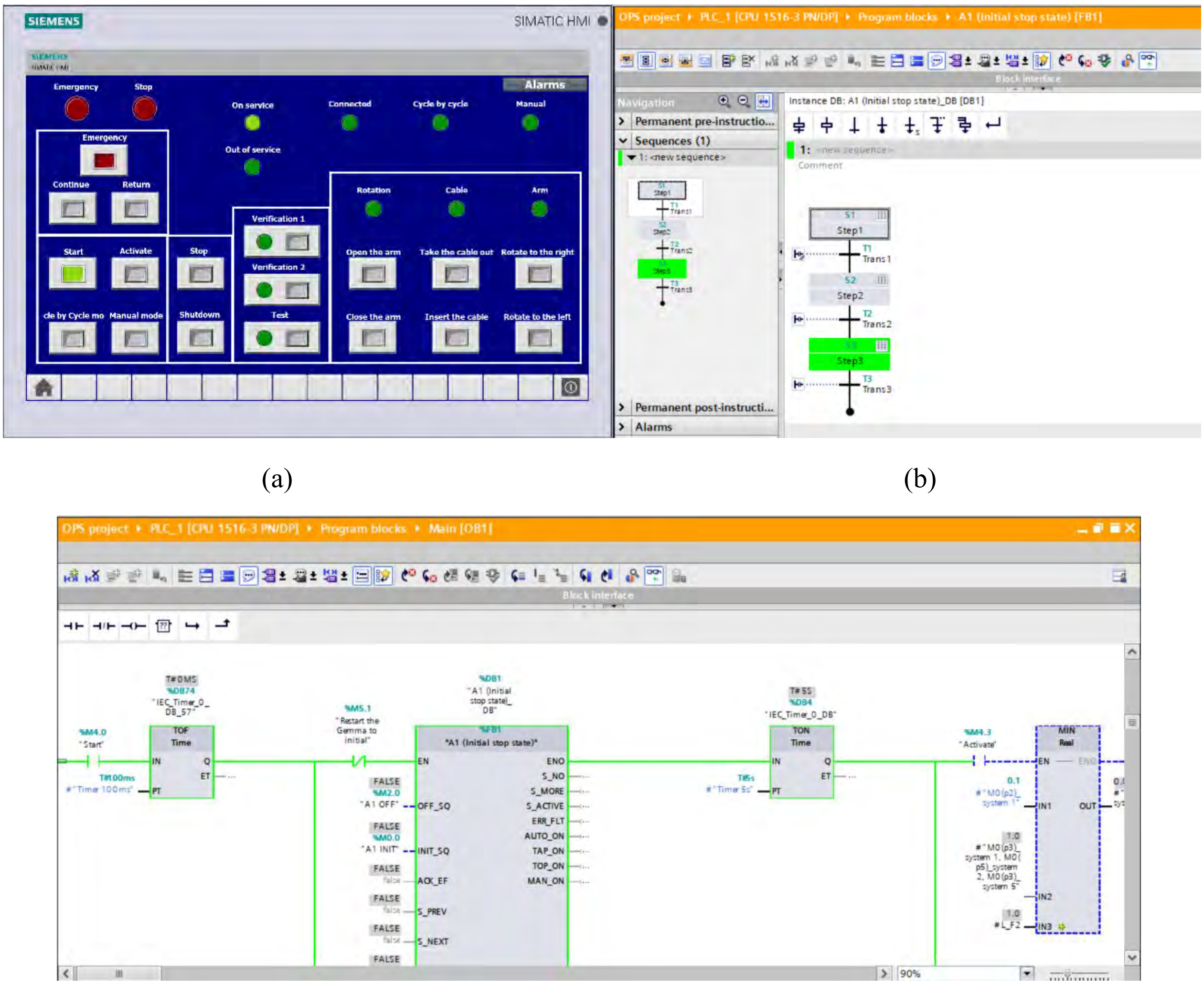
6.1.4. Implementation of the Algorithms

The different algorithms for the transitions of the GEMMA Guide Paradigm are proved mathematically and explained in Chapter 4. In this subsection of the thesis, the experiments of these algorithms on the crane are presented. The main propose of this subsection is to validate that the algorithms for the transitions are working properly for operating the OPS (On shore power supply) crane and providing an intelligent control and good decision-making system. In the next subsections it is possible to see the experiments of each algorithm on the OPS crane operation, and their results.

6.1.4.1. Stop Procedure to Operation Procedure

The stop procedure to operation procedure transitions are very important to the crane operation as it is explained in section 4.2. This transits the program from the initial state mode (A1) to the appropriate mode regarding to the requirements and conditions. That is to say, it is responsible for the transitions to either normal production mode (F1) or startup process mode (F2), and also to the different verification modes.

Figure 6.59 presents the first stage while the program is placed at the initial state mode. In the figure, it is possible to see the operation screen, the program, and that Fuzzy Petri Nets intelligent algorithm at that stage.

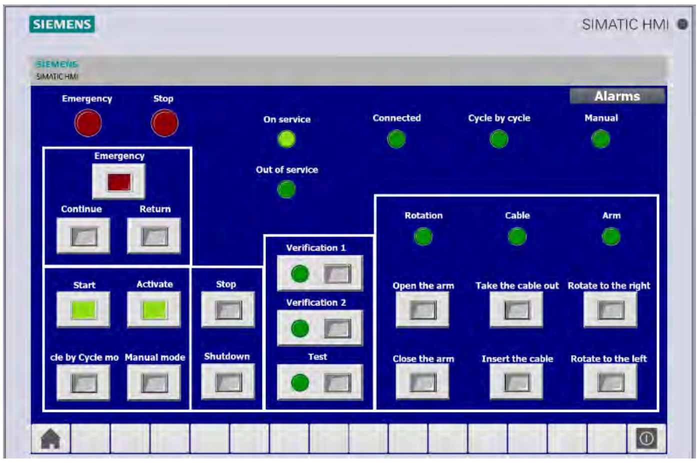


(a) (b)

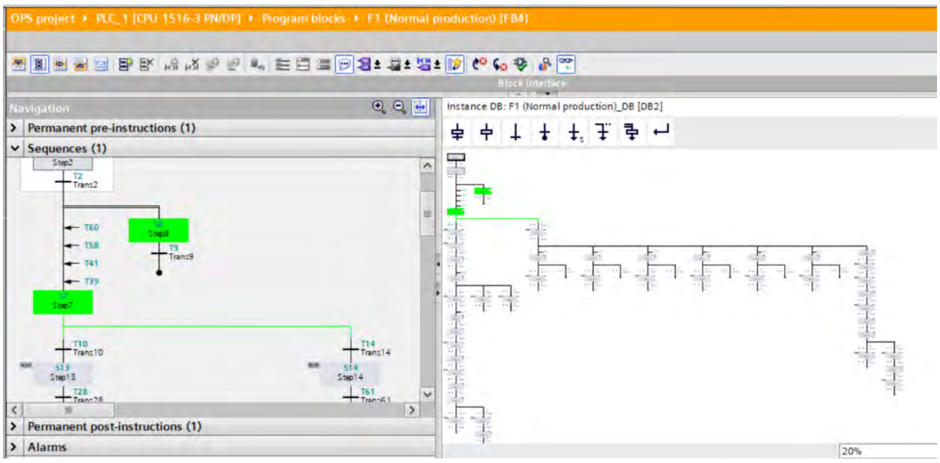
(c)

Figure 6.59: The program is placed at the initial stop state (A1) of GEMMA. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

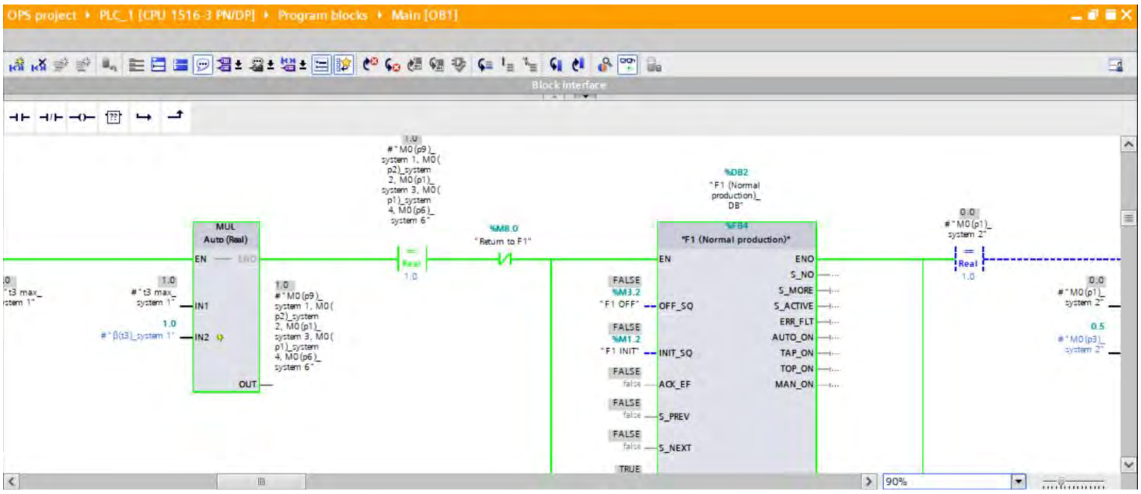
When the operator desires to start the crane's operation, he presses the activation button. At that moment, the algorithm receives the order, and places the program in the correct mode regarding to the conditions. In other words, if the initial sensors are activated the program will be placed at the normal production mode (F1). Otherwise, the algorithm will place the program in the startup process mode (F2) in order to prepare the crane to the operation. In each machine, there are different sensors that are used as initial sensors in order to indicate the machine situation. The sensors that are used as initial sensor in the crane are the closed arm, cable in its initial state, and the rotation. By theses sensors the algorithm is able to notice the crane situation. Figure 6.60 presents the moment that the operator presses the activation button while the crane is in its initial state. At that situation, the algorithm places the program in the normal production mode for starting the operation. The figure shows the operation screen, the program, and the Fuzzy Petri Nets intelligent algorithm.



(a)



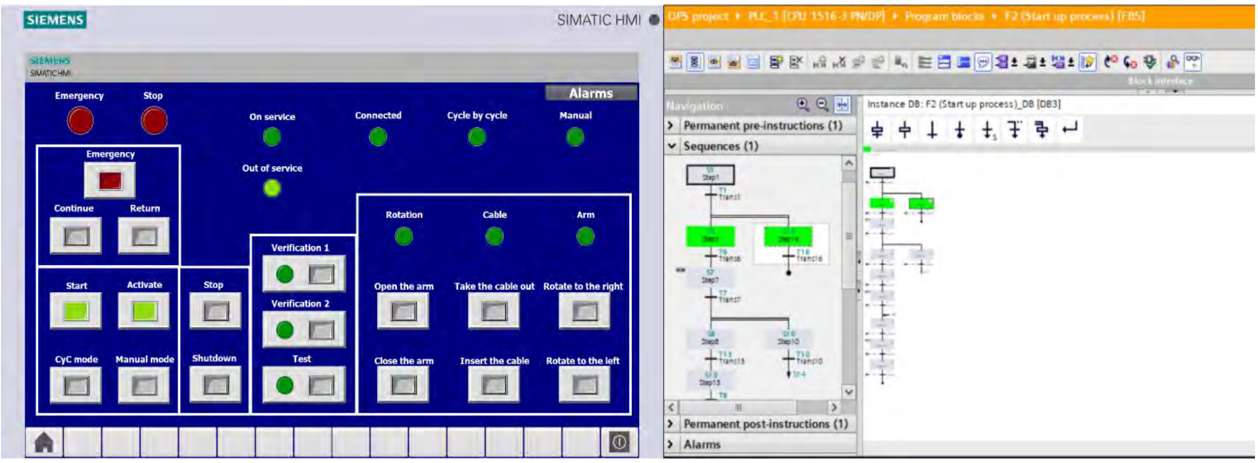
(b)



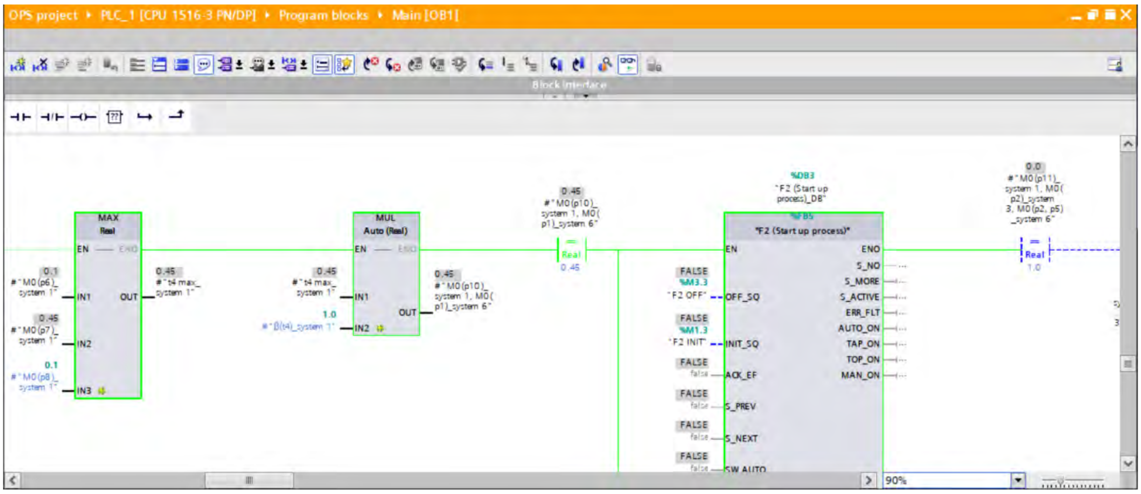
(c)

Figure 6.60: The program is placed at the normal production mode (F1) of GEMMA, while the activation button is pressed. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

When the operator desires to start the operation and the crane is not in its initial state, the algorithm places the program in the startup process in order to prepare the crane for the operation. The figure below presents the operation screen, the program, and the Fuzzy Petri Nets intelligent algorithm for this situation.



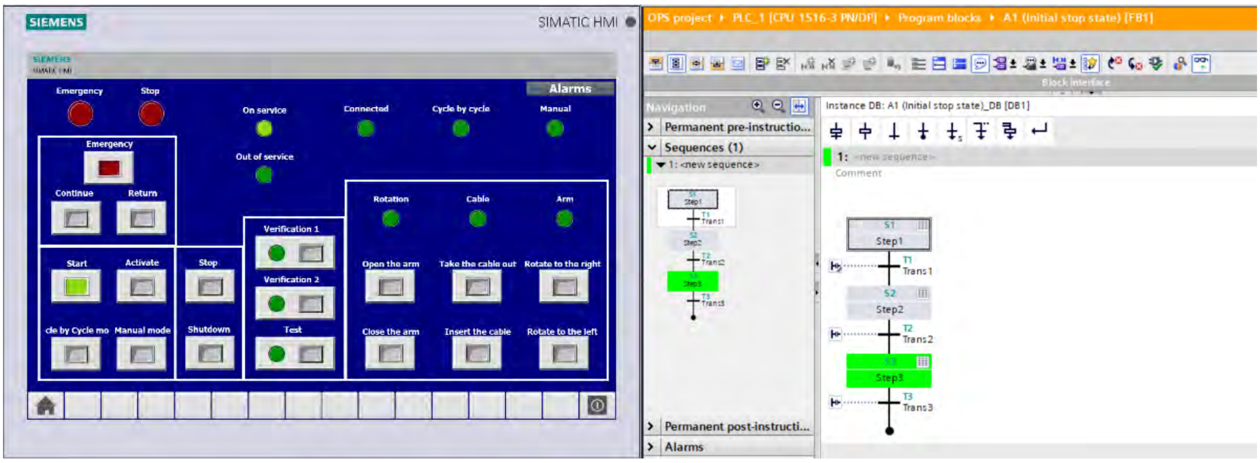
(a) (b)



(c)

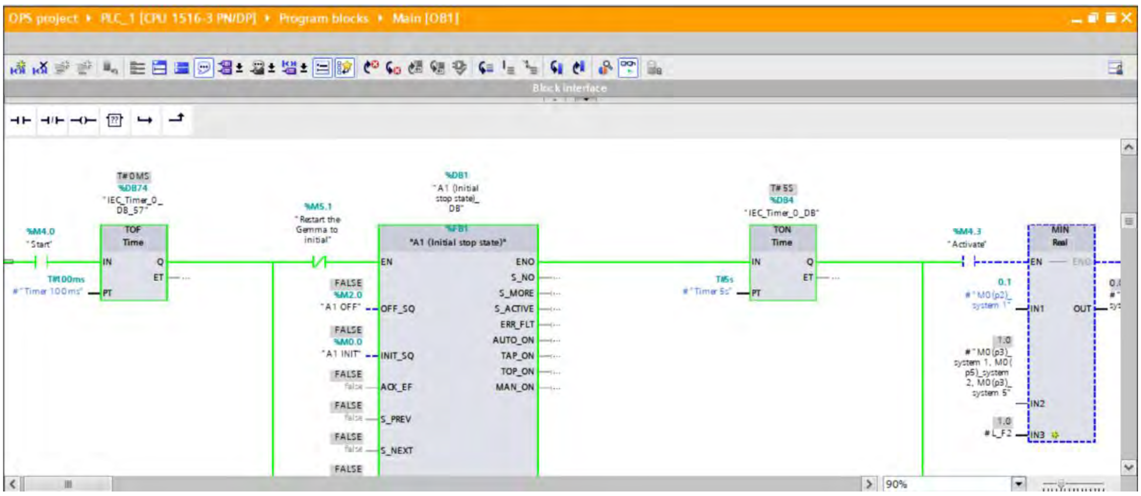
Figure 6.61: The program is placed at the startup process mode (F2) of GEMMA, while the activation button is pressed. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

This algorithm is also responsible for the transitions between the stop initial state (A1) and the running in verification mode disorderly (F4)/running in verification mode orderly (F5) as it is explained in the beginning of this section. As soon as the operator wants to verify the different parts of the crane either disorderly (F4) or orderly (F5), he is able do to it by the appropriate button. While one of the verification buttons is pressed, the algorithm placed the program in the desired mode. Moreover, the algorithm places the program as well in the necessary mode after the verification mode finishes. In the figure below it is possible to see the operation screen, program, and Fuzzy Petri Nets intelligent algorithm while the program is placed at the stop initial state (A1).



(a)

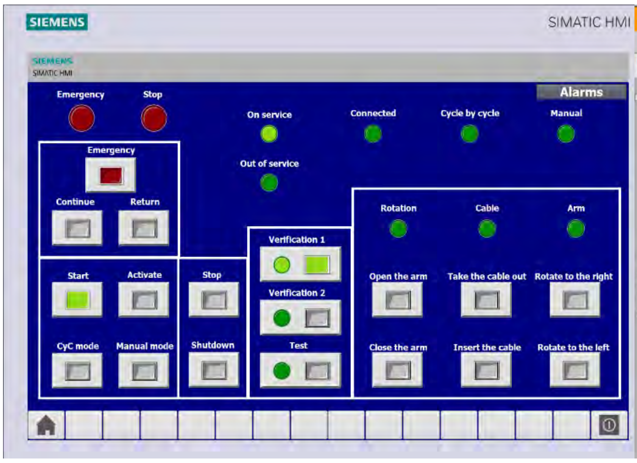
(b)

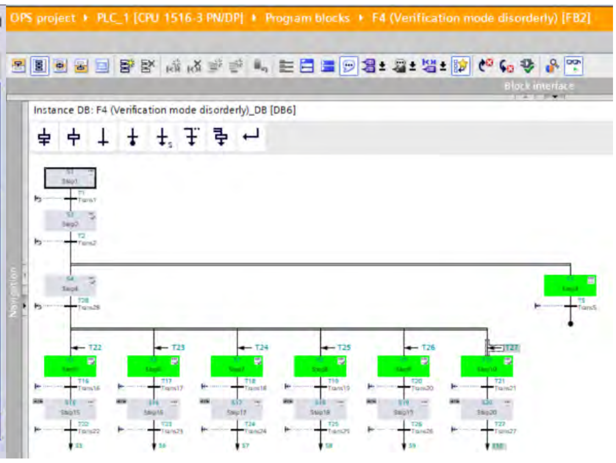


(c)

Figure 6.62: The program is placed at the initial stop state (A1) of GEMMA. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

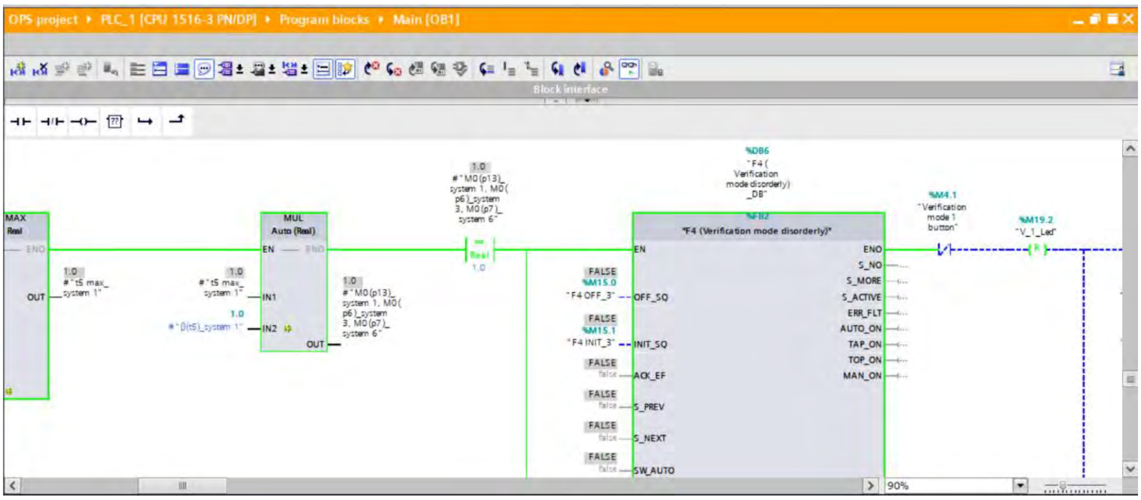
As soon as the operator desires to start the disorderly verification mode, he presses the verification 1 button. At that moment, the algorithm notices that the verification 1 button is pressed, and it places the program in the running in verification mode disorderly (F4). Moreover, the algorithm switches off the initial stop state (A1) at that moment.





(a)

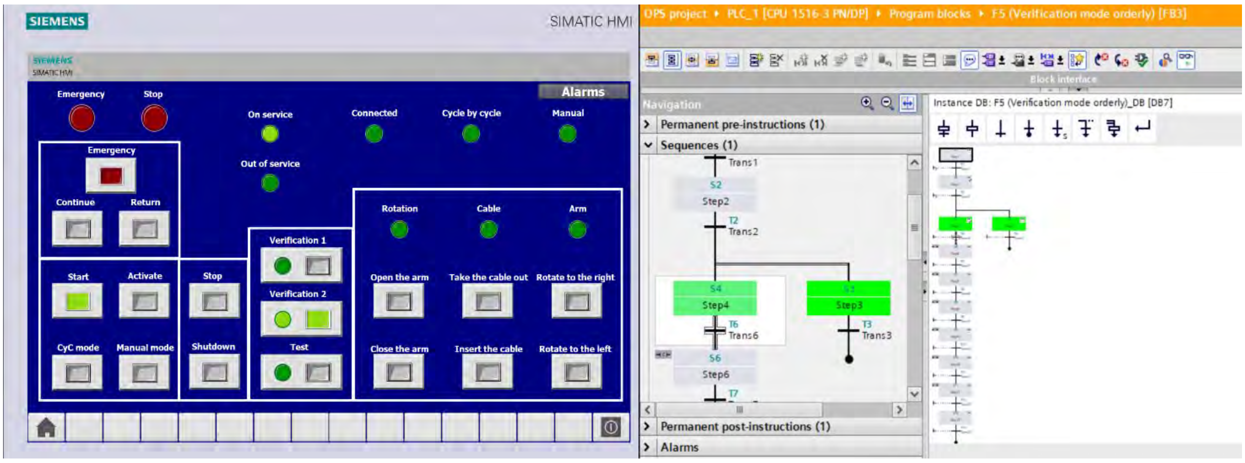
(b)



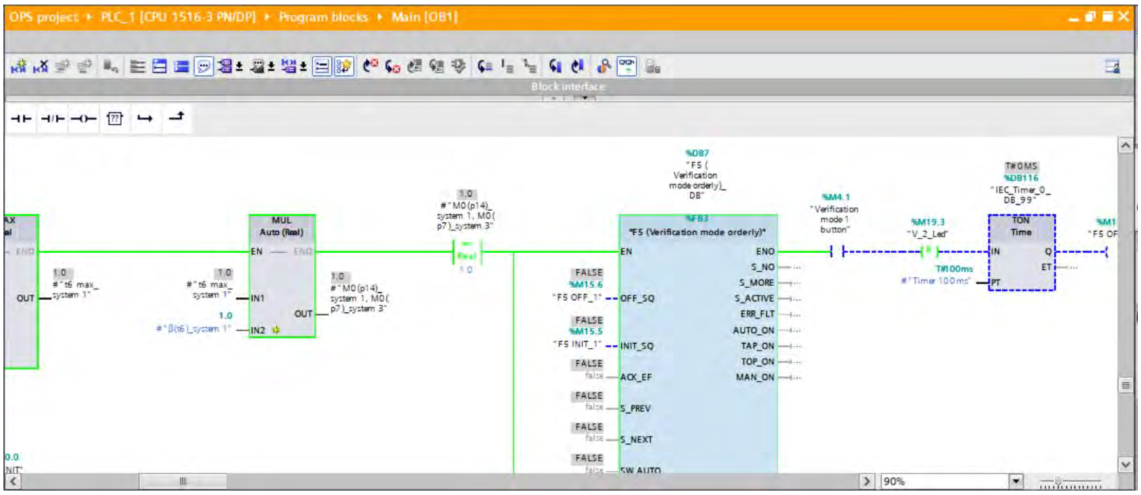
(c)

Figure 6.63: The program is placed at the running in verification mode disorderly (F4) of GEMMA, and the initial stop state is off while the verification button 1 is pressed. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

In the same way, if the operator desires to start the orderly verification mode, the algorithm allows him to do it by pressing the verification 2 button. In the moment that the operator presses the verification 2 mode, the algorithm switches off the initial stop state (A1) and places the program in the verification mode orderly (F5). In the figure below it is possible to see the operation screen, the program, and the Fuzzy Petri Nets intelligent algorithm while the operator has pressed the verification 2 button.



(a) (b)



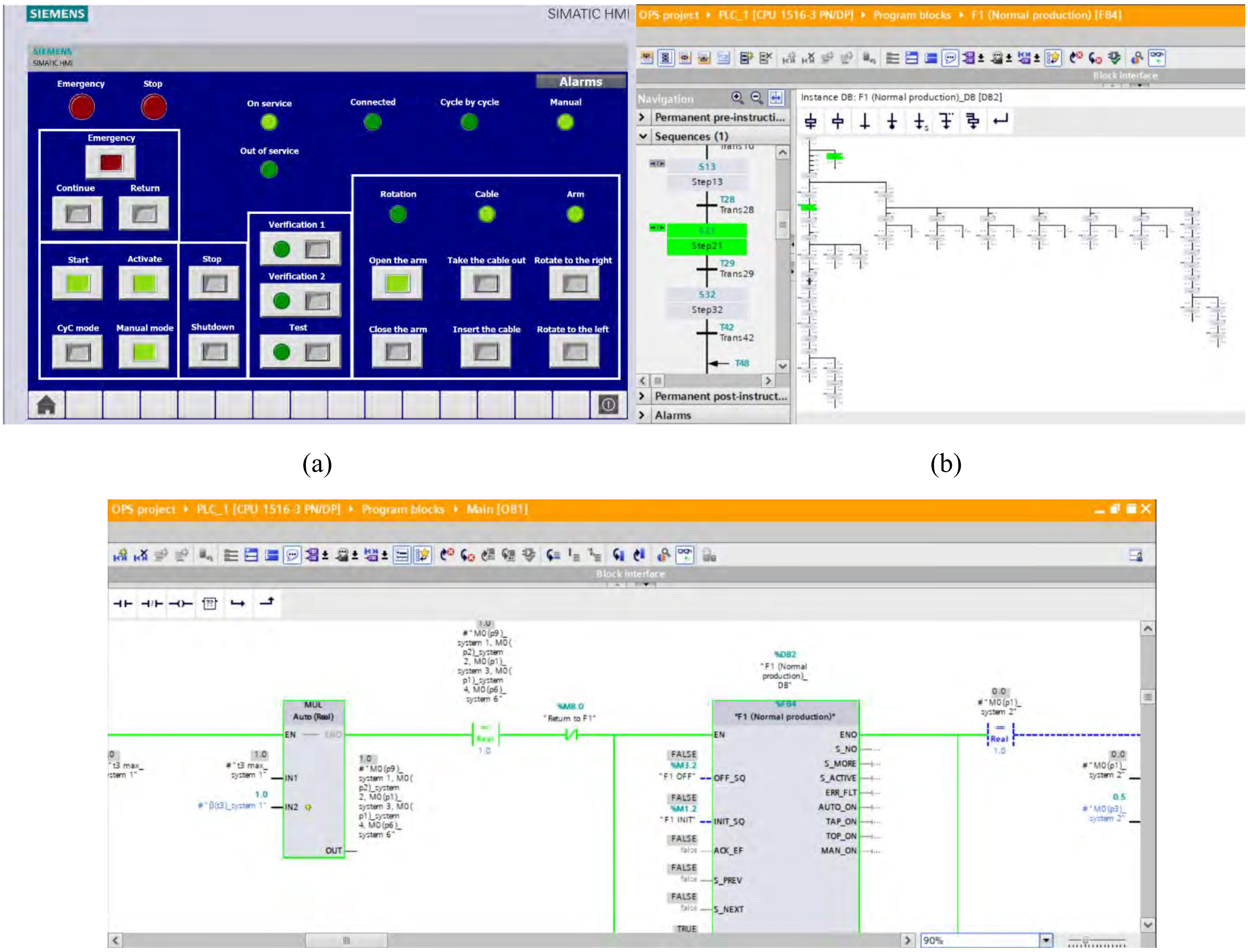
(c)

Figure 6.64: The program is placed at the running in verification mode orderly (F5) of GEMMA, and the initial stop state is of while the verification button 2 is pressed. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

6.1.4.2. Operation Procedure

The operation procedure transitions of the GEMMA Guide are very important for the machine operations as it is explained in Subsection 4.3. They are responsible for the transitions between the normal production (F1) and the different verification and test modes of the GEMMA Guide Paradigm. While the program is placed at the normal production mode (F1), the operator is able to verify the crane in one of the modes regarding to his needs. The first verification mode that is presented is the running in verification mode disorderly (F4).

In the figure below it is possible to see that the program is placed at the normal production mode, in manual mode while open the arm is activated. This situation shows that the operator is able to start the verification mode at any point of the operation. In this case, the algorithm will stop the operation, switch off the normal production mode (F1), and place it in the chosen verification mode.

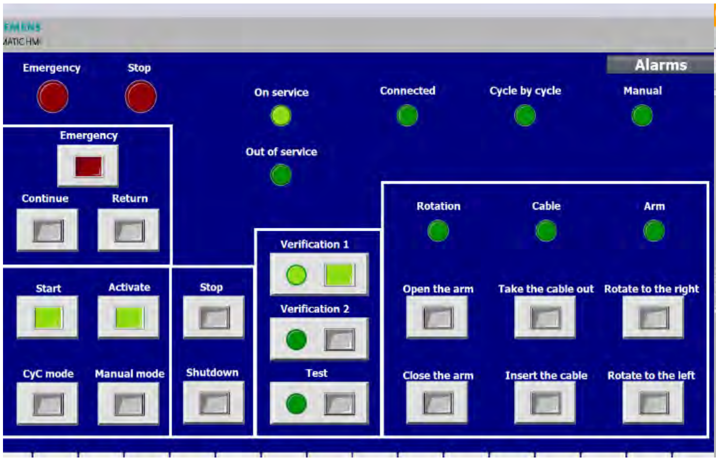


(a) (b)

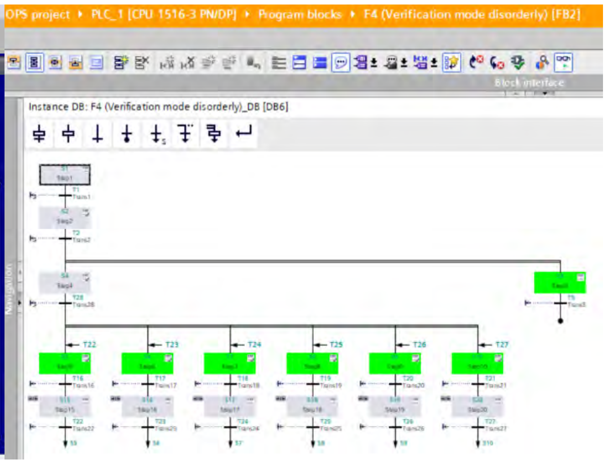
(c)

Figure 6.65: The program is placed at the normal production mode (F1) of GEMMA, manual mode, while open the arm is activated. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

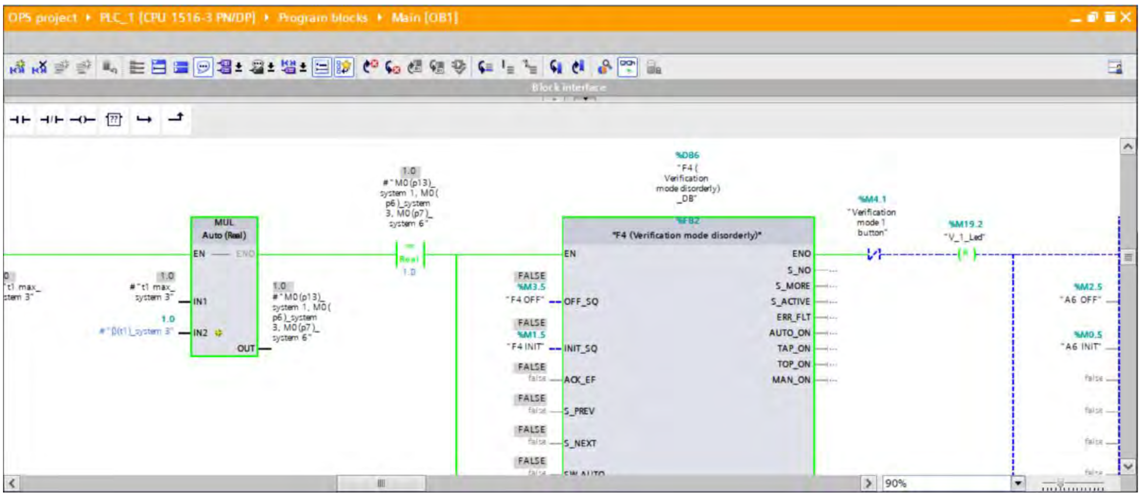
When the operator is pressing the verification 1 button, the algorithm places the program in the running in verification mode disorderly (F4). The figure below presents the operation screen, the program, and the Fuzzy Petri Nets intelligent algorithm while the algorithm is placed the program in this mode. It is possible to see that in the moment that the operator has pressed the verification 1 button, the motors that were activated during the operation have stopped automatically.



(a)



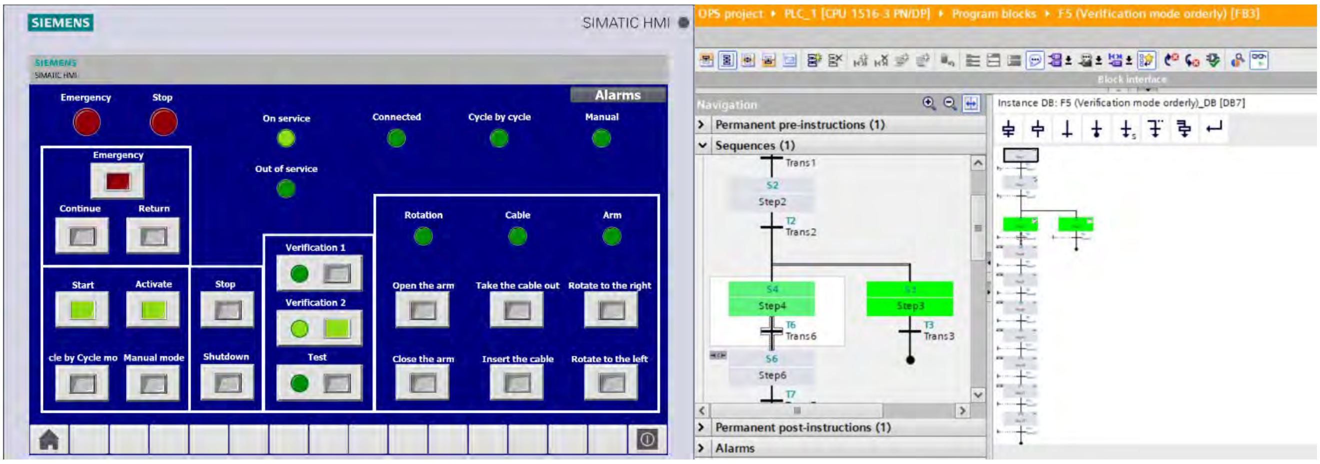
(b)



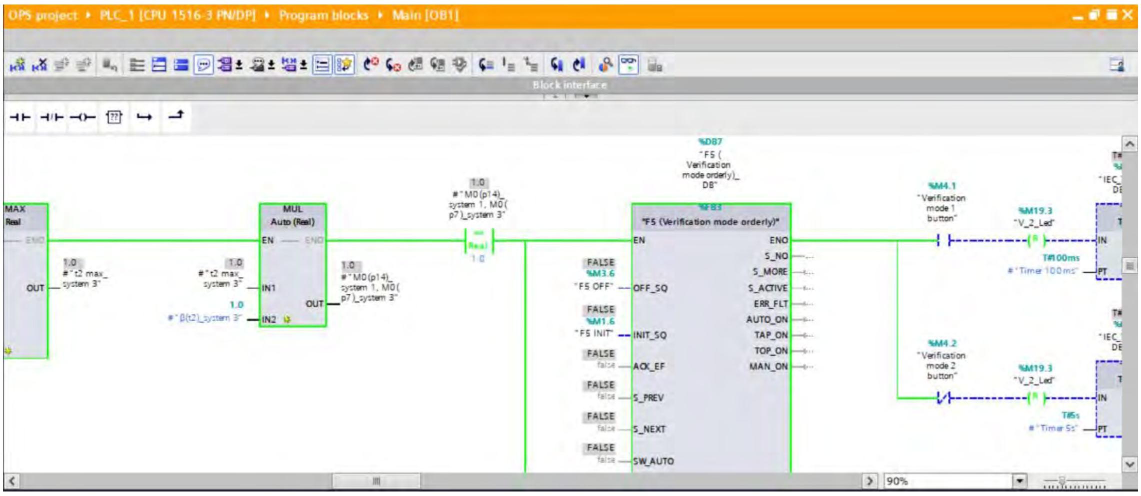
(c)

Figure 6.66: The program is placed at the running in verification mode disorderly (F4) of GEMMA, while the verification button 1 is pressed. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

Similarly, when the operator desires to start the verification mode orderly (F5), he is able to do it by pressing the verification 2 button. As soon as the operator presses the button, the algorithm places the program in the F5 mode. Figure 6.67 shows the program in the initial state of the verification mode orderly (F5), the verification of a one cycle is automatically activated as it is explained in section 4.3. Moreover, it shows the operation screen, the program, and the Fuzzy Petri Nets intelligent algorithm. It is possible to notice that the motors that were activated during the normal production are disactivated automatically by the algorithm.



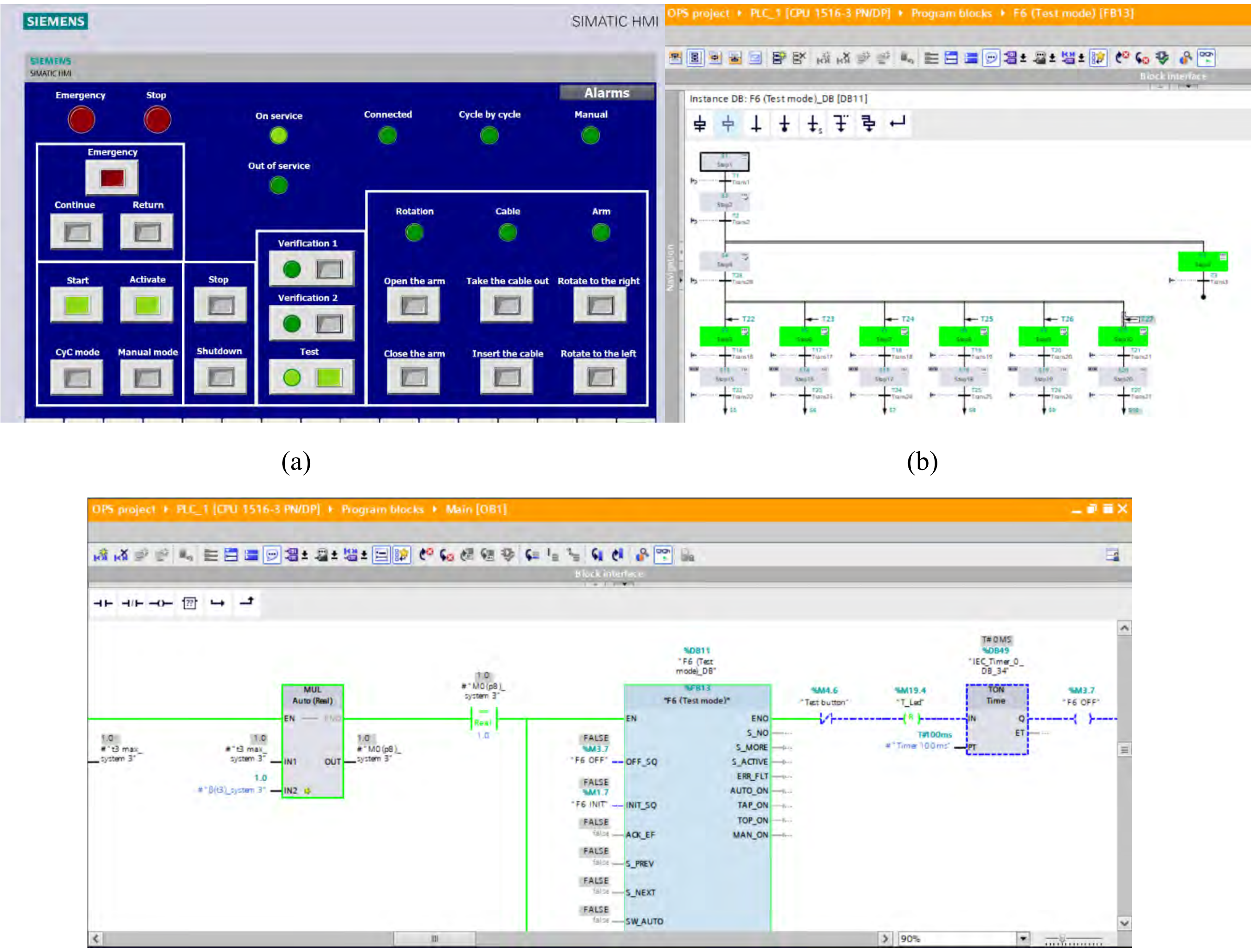
(a) (b)



(c)

Figure 6.67: The program is placed at the running in verification mode orderly (F5) of GEMMA, while the verification button 2 in pressed and it is ready to the verification process. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

The last transition of the operation procedure is the transition between the normal production mode (F1) and the test mode (F6) of the GEMMA Guide Paradigm. The transition works in a similar way as the previous transitions. At any moment of the operation, the operator is able to start the test mode. The figure below presents the same example of the transition as before which the program is placed at the normal production mode, in manual mode while open the arm is activated. It is possible to see that the algorithm disactivates the motors that were working and places the program in the test mode (F6). The figure shows the operation screen, the program, and the Fuzzy Petri Nets intelligent algorithm when the algorithm places the program in the test mode.



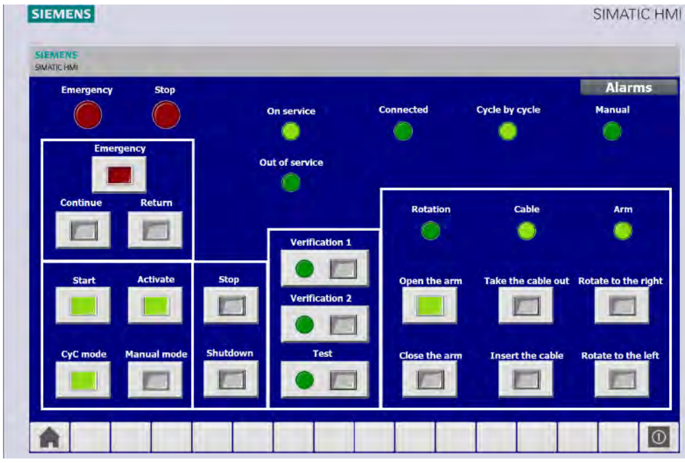
(a) (b) (c)

Figure 6.68: The program is placed at the test mode (F6) of GEMMA, the normal production mode (F1) is off while the test button is pressed, and it is ready to the different test actions. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

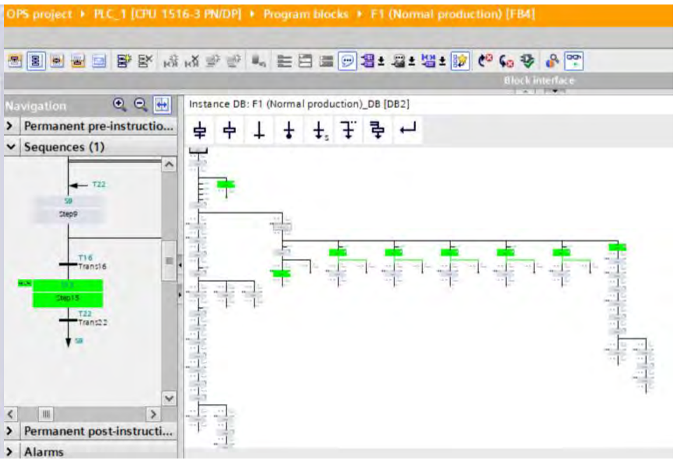
6.1.4.3. Operation Procedure to Stop Procedure

The operation procedure to stop procedure transitions are meaningful for the control of a machine as it is explained in section 4.4. Generally, it responsible for both the stop and shutdown processes transitions. That is to say, when the operation desires to stop the machine, the algorithm will place the machine automatically in either requested stop at the end of the cycle (A2) or requested stop (non-initial state) (A3) depending on the machine situation. In a similar way, when the operator desires to shut the machine down, it will be placed at either requested stop at the end of the cycle (A2) or the shutdown process mode (F3).

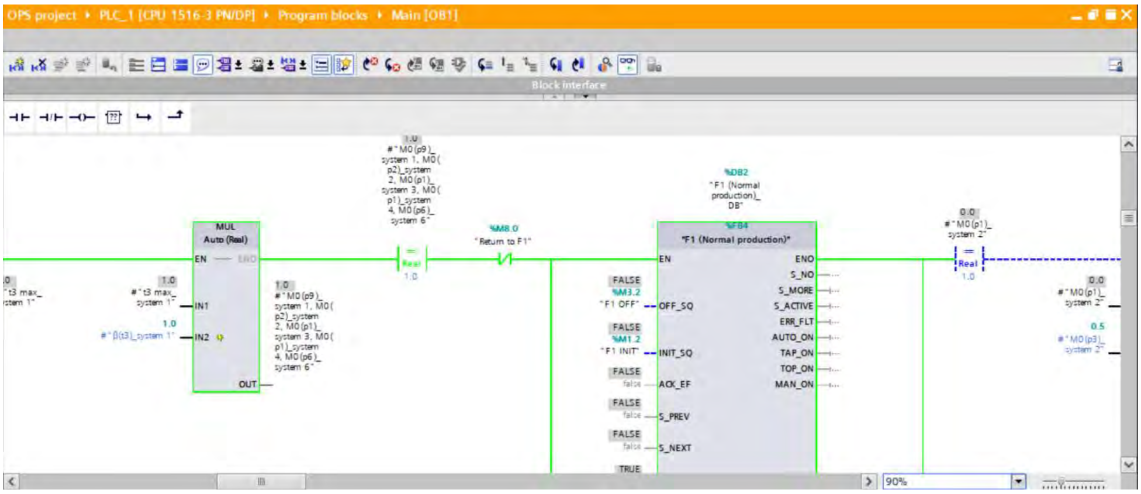
Figure 6.69 presents the program at some point of the operation, in normal production mode (F1), in Cycle by Cycle mode, at the moment that the arm is opening. The figure shows the operation screen, the program, and the Fuzzy Petri Nets algorithm at this operation moment.



(a)



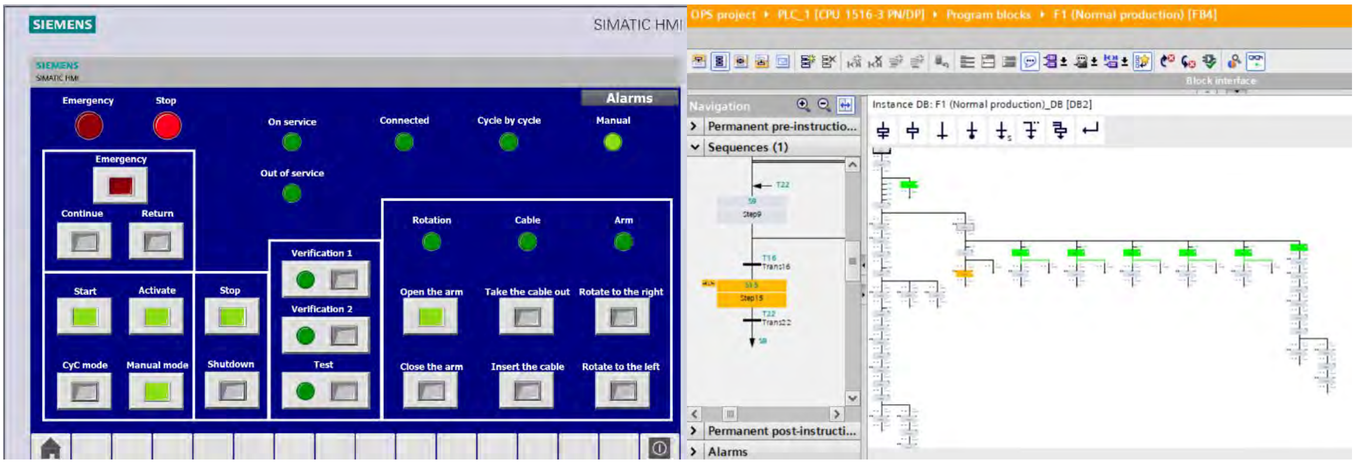
(b)



(c)

Figure 6.69: The program is placed at the normal production mode (F1) of GEMMA, cycle by cycle mode, while open the arm is activated. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

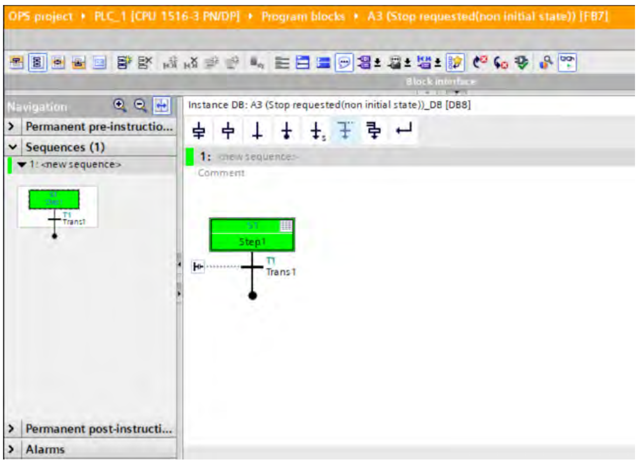
As soon as the operator desires to stop the crane operation, the operation will stop immediately. That is to say, all the motors that are activated will stop, and the normal production mode (F1) will freeze as it is shown in the figure below. Moreover, the stop led will be activated in order to indicate that the crane has been stopped. Figure 6.70 shows the program and the operation screen while the stop button has been pressed.



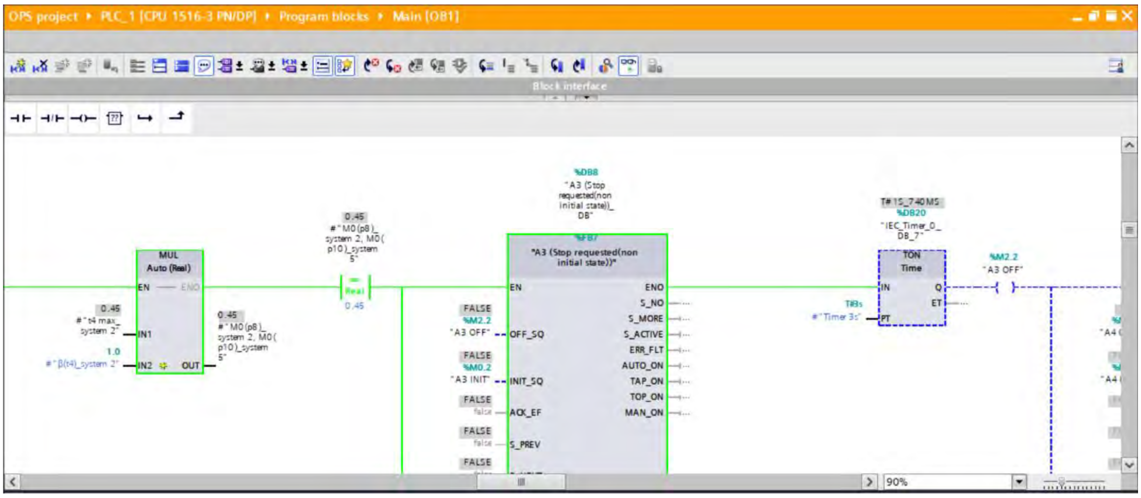
(a) (b)

Figure 6.70: The normal production mode (F1) of GEMMA is stopped, while the stop button is pressed. (a) the screen, (b) the program

After the operator has been pressed the stop button, there two modes that the algorithm has to place the program regarding to the GEMMA Guide Paradigm as it is explained in the section 3.3.1. The first one is the requested stop (non-initial state) (A3), and the second stop mode (non-initial state) (A4). Figure 6.71 shows the program placed at the first mode (A3) which memorize the requested stop of the operator. Then, figure 6.72 shows that the program is placed at the second mode (A4) which the program waits there until the stop button will disactivate in order to come back to the operation.

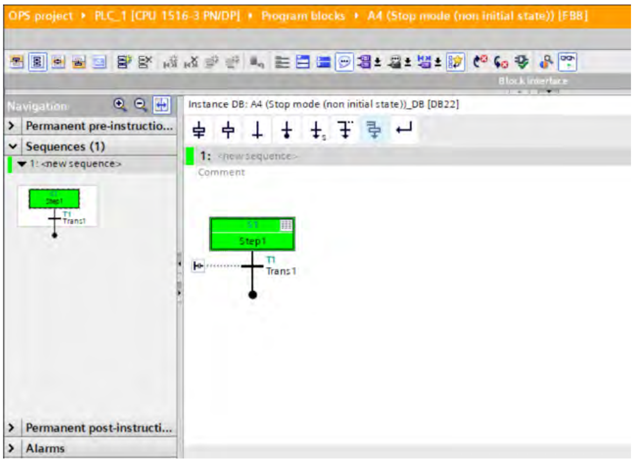


(a)

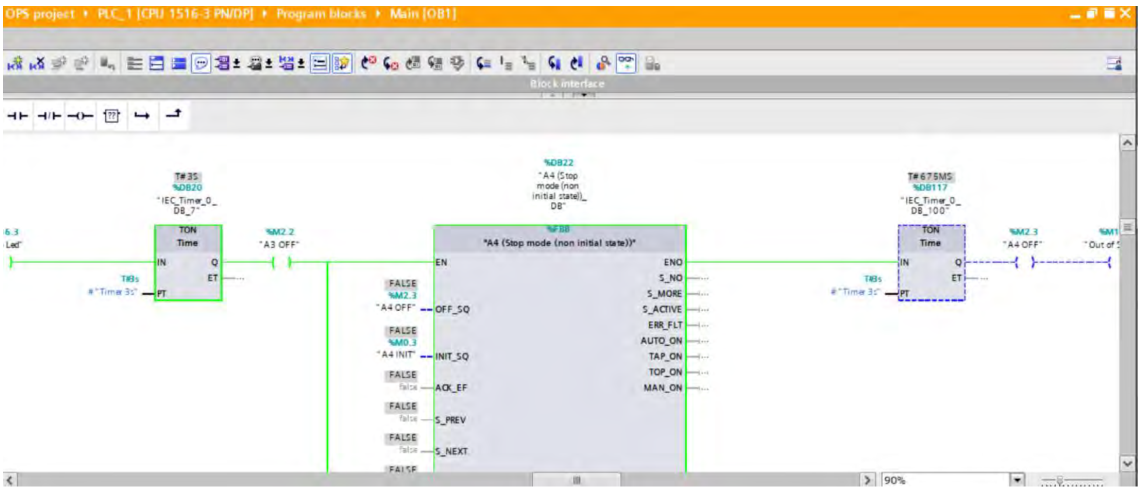


(a)

Figure 6.71: The program is placed at requested stop (non-initial state) (A3) of GEMMA. (a) the program, (b) the Fuzzy Petri Nets intelligent algorithm



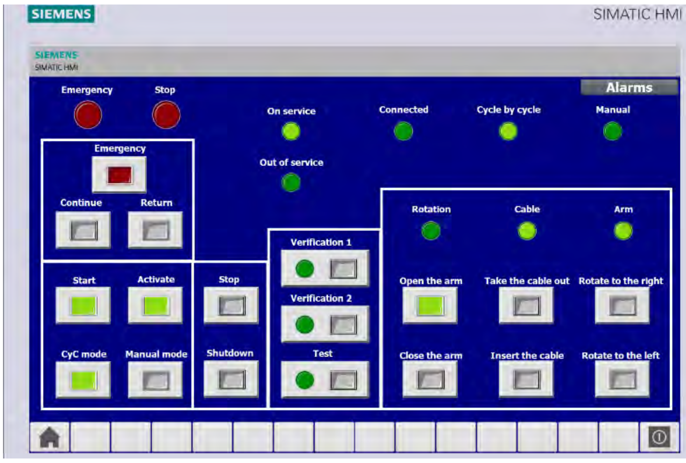
(a)



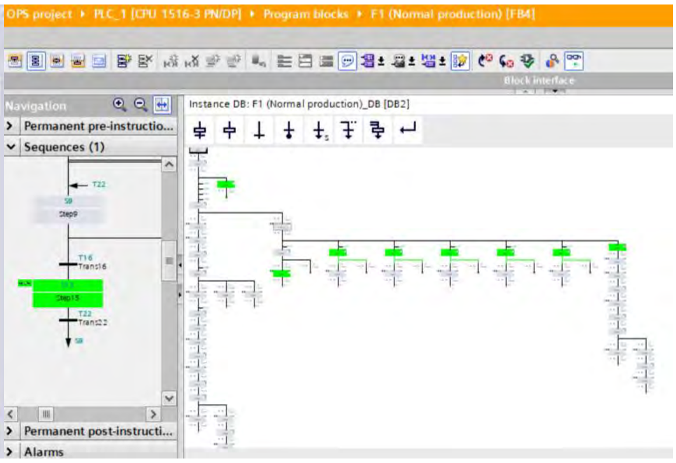
(b)

Figure 6.72: The program is placed at stop mode (non-initial state) (A4) of GEMMA. (a) the program, (b) the Fuzzy Petri Nets intelligent algorithm

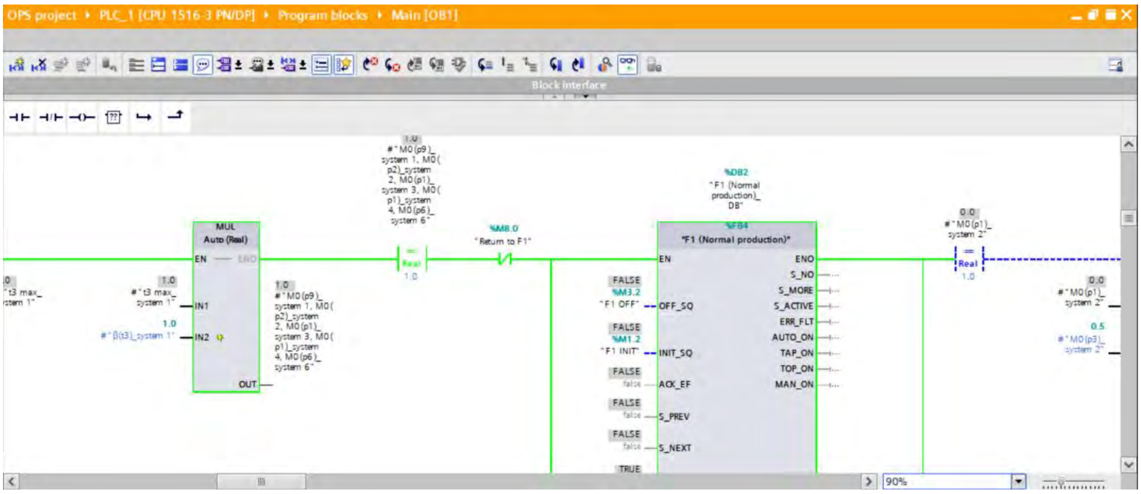
As soon as the operator desires to return the crane to the operation, he is able to do it by deactivating the stop button. At that moment, the algorithm will place the program back in the normal production mode (F1). Moreover, in the same point of the operation that it was before the button was pressed. In the figure below it is possible to see that the program is placed at the exact place of the operation as before, Cycle by Cycle mode, open the arm. The figure shows the operation screen, the program, and the Fuzzy Petri Nets intelligent algorithm.



(a)



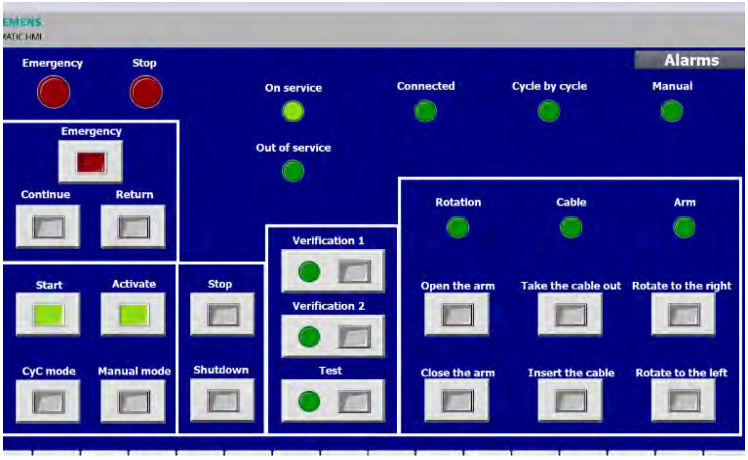
(b)



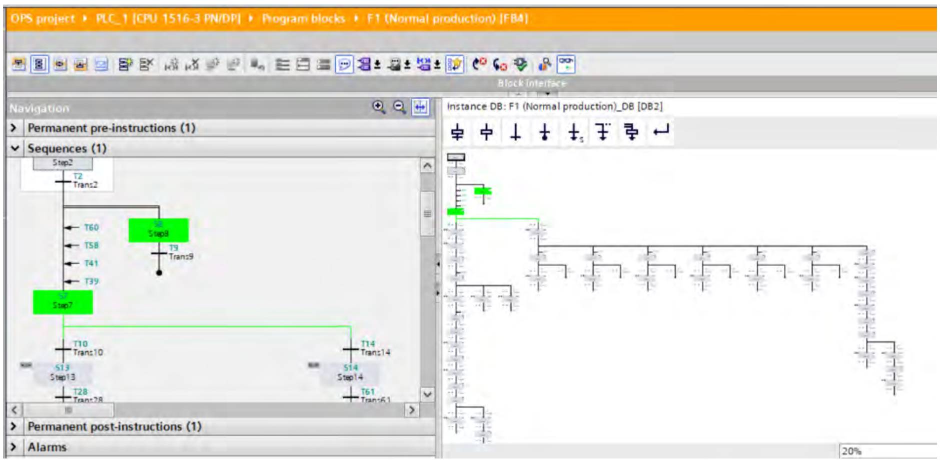
(c)

Figure 6.73: The program is placed at the normal production mode (F1) of GEMMA, cycle by cycle mode, while open the arm is activated. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

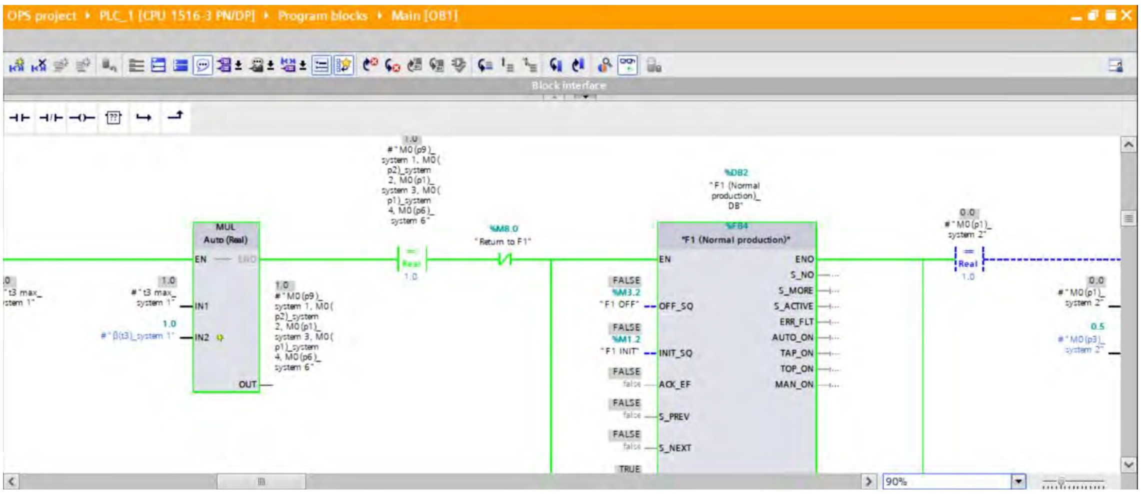
Another case of stopping the crane is while the crane is placed at its initial state. At that case, the algorithm detects that the crane in placed at its initial state, and it places the program in the requested stop at the end of the cycle (A2) in order to start over the program. After this mode, the program will be placed at the initial stop state (A1). The figure below presents the program in the initial state of the normal production mode (F1), the operation screen, and the Fuzzy Petri Nets intelligent algorithm in this stage.



(a)



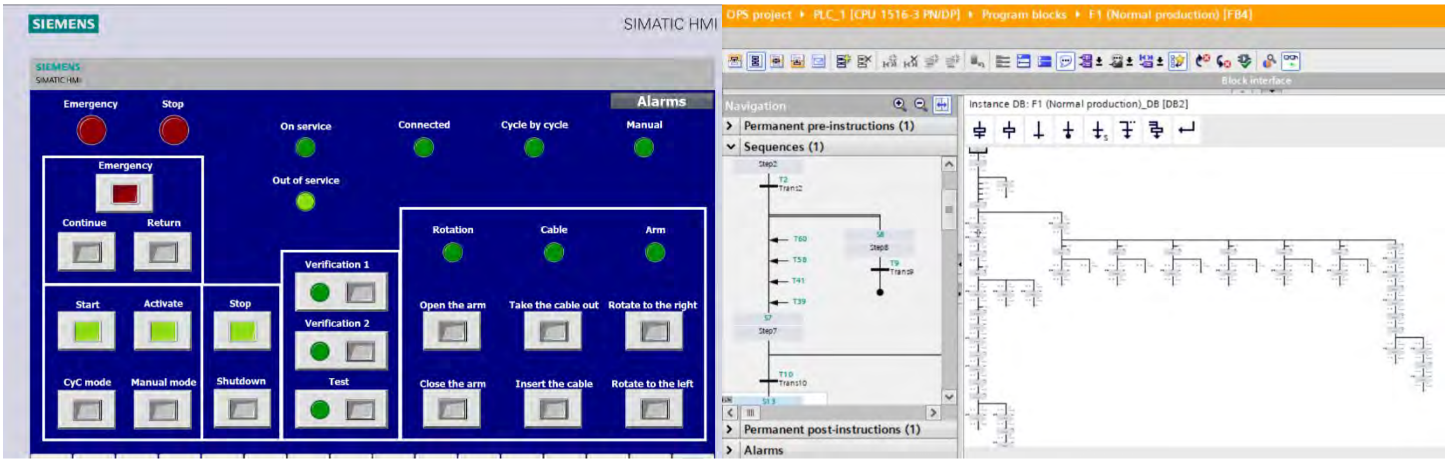
(b)



(c)

Figure 6.74: The program is placed at the normal production mode (F1) of GEMMA. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

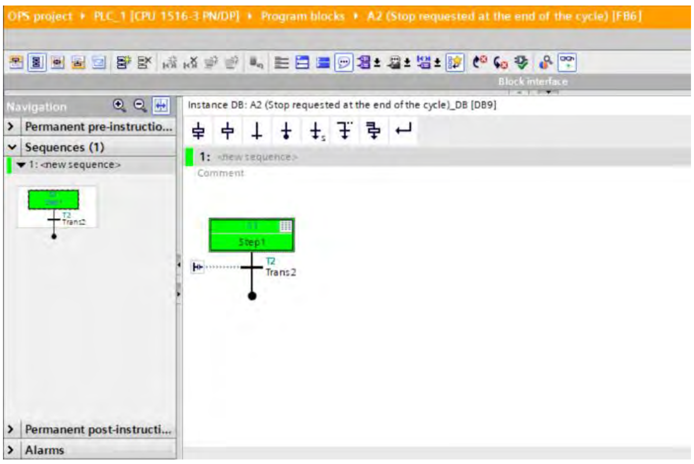
As soon as the operator presses the stop button while the crane is placed at its initial state, the algorithm switches off the normal production mode (F1). Figure 6.75 shows the operation screen while the stop button is pressed, and the program.



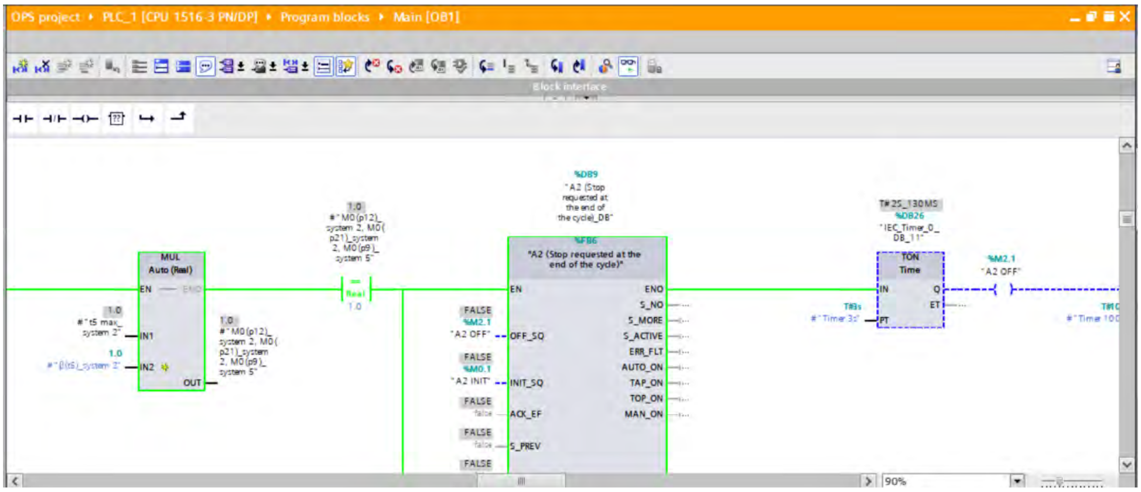
(a) (b)

Figure 6.75: The normal production mode (F1) of GEMMA is off, while the stop button is pressed. (a) the screen, (b) the program

At the same moment, the algorithm places the program in the requested stop at the end of the cycle (A2). This is a temporal mode until the program arrives to the initial stop state (A1) as it is explained in section 3.3.1. The figure below shows the program, and the Fuzzy Petri Nets intelligent algorithm in the A2 mode.



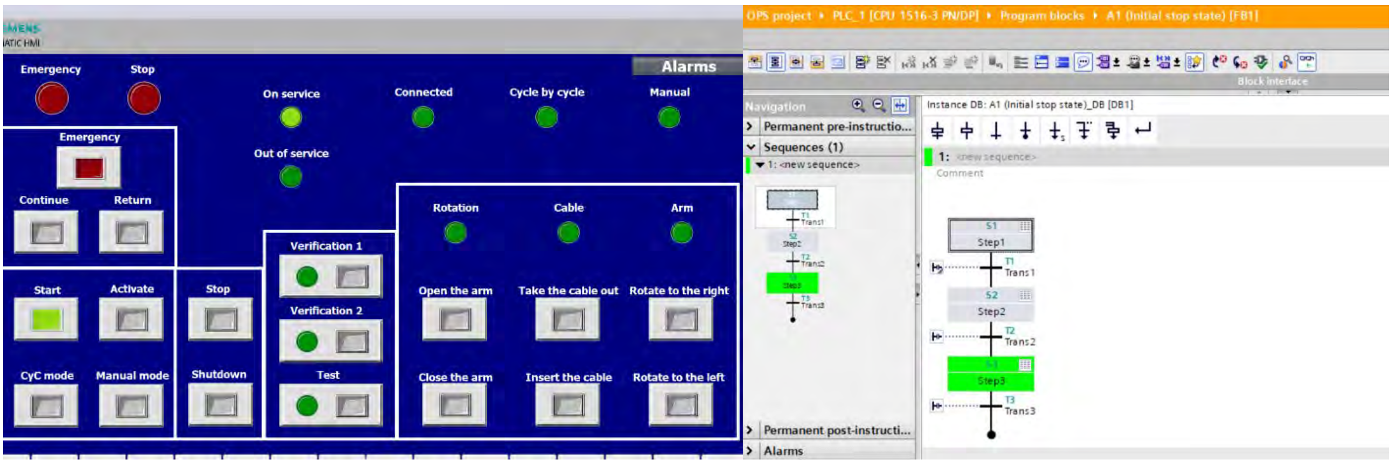
(a)



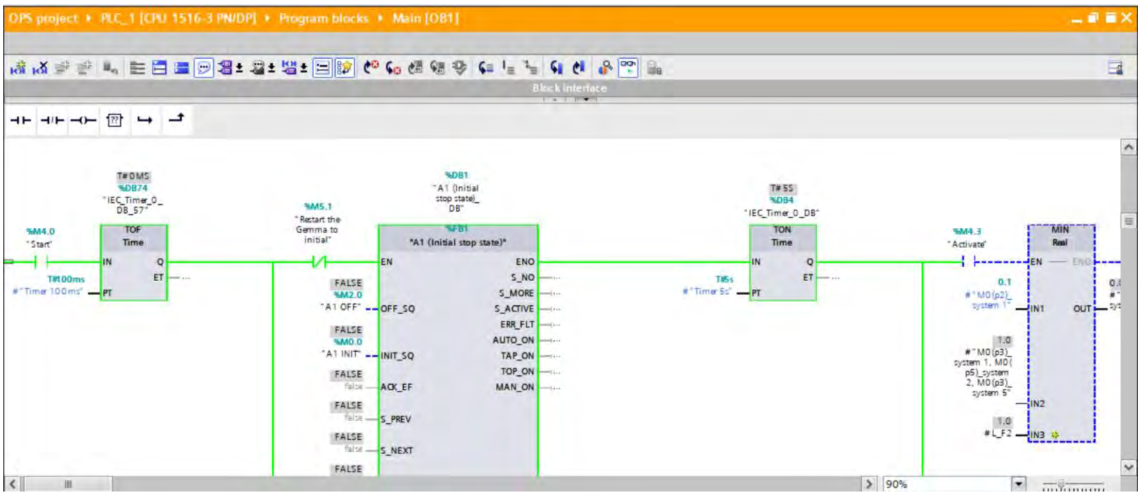
(b)

Figure 6.76: The program is placed at the requested stop at the end of the cycle (A2) of GEMMA. (a) the program, (b) the Fuzzy Petri Nets intelligent algorithm

As soon as the temporal mode (A2) has been finished, the algorithm places the program in the initial stop state (A1). This mode is the first mode of the GEMMA which allows the operator to do the next desired action. Figure 6.77 shows the operation screen, the program, and the Fuzzy petri Nets intelligent algorithm while the program has arrived at this mode.



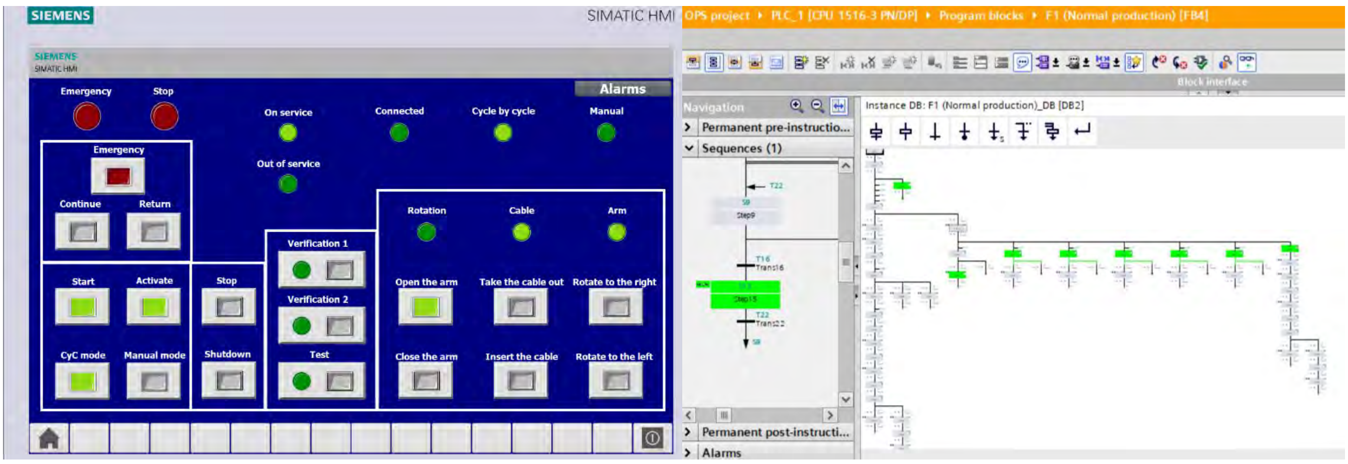
(a) (b)



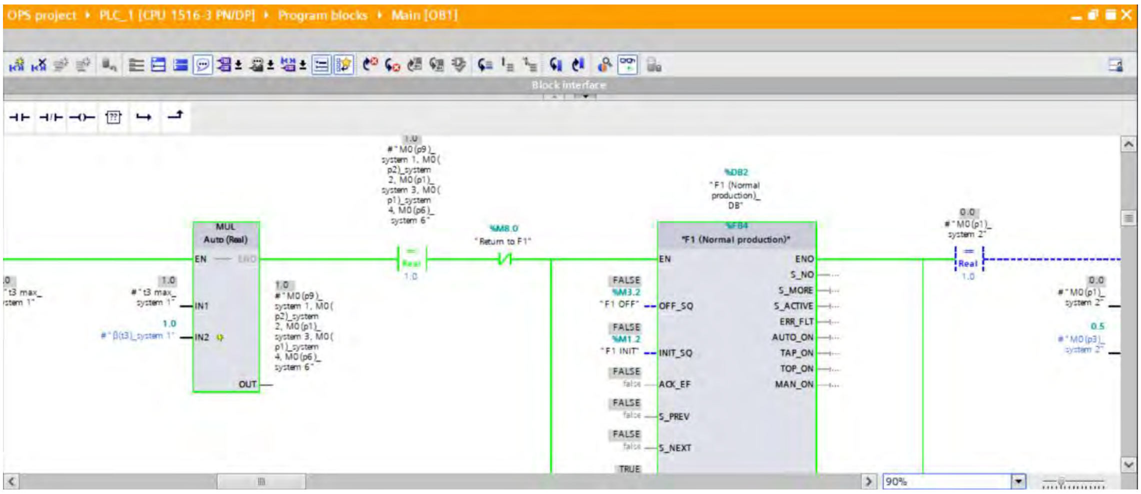
(c)

Figure 6.77: The program is placed at the initial stop state (A1) of GEMMA. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

The next two transitions of the operation to stop procedure are responsible for the crane shutdown. The shutdown of the GEMMA is divided into two cases; the crane requires the shutdown process, and the second one is the case that the crane is placed at its initial state similarly to the last stop transition. The first case is more common due to the reason that the operator normally operates some parts while the program is placed at the normal production mode (F1). The figure below presents the first case while the program is placed at the normal production mode (F1), Cycle by Cycle mode, open the arm. This example presents that the crane it not in its initial state, and even when the operator has the need to shut down the crane at any point of the operation, he is able to do it. In this case, the operator shut the crane down while the arm motor is activated. Figure 6.78 presents the operation screen including the activation of the arm's motor, the program, and the Fuzzy Petri Nets intelligent algorithm.



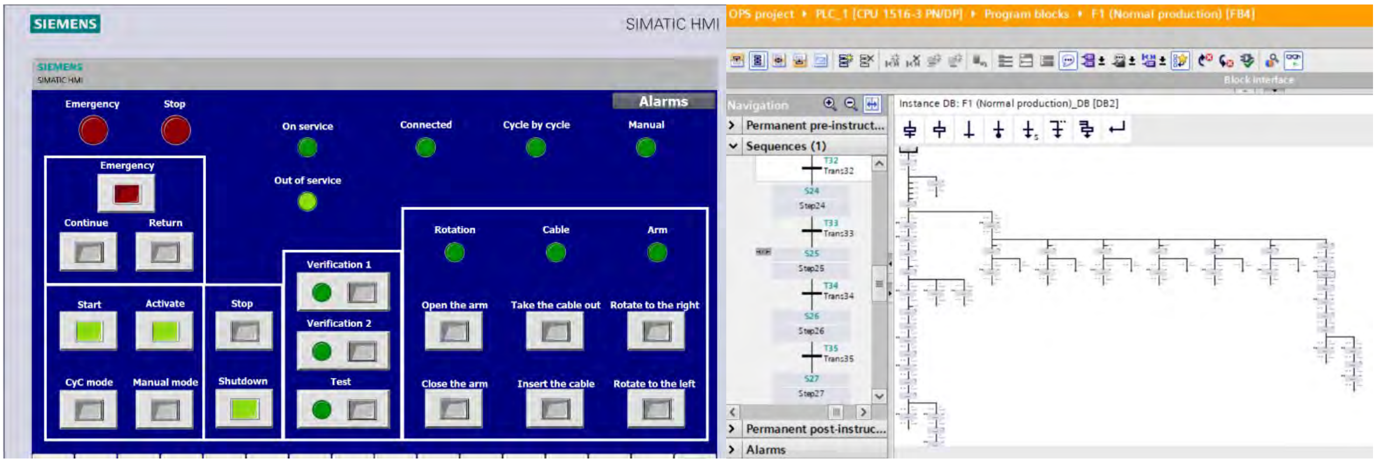
(a) (b)



(a)

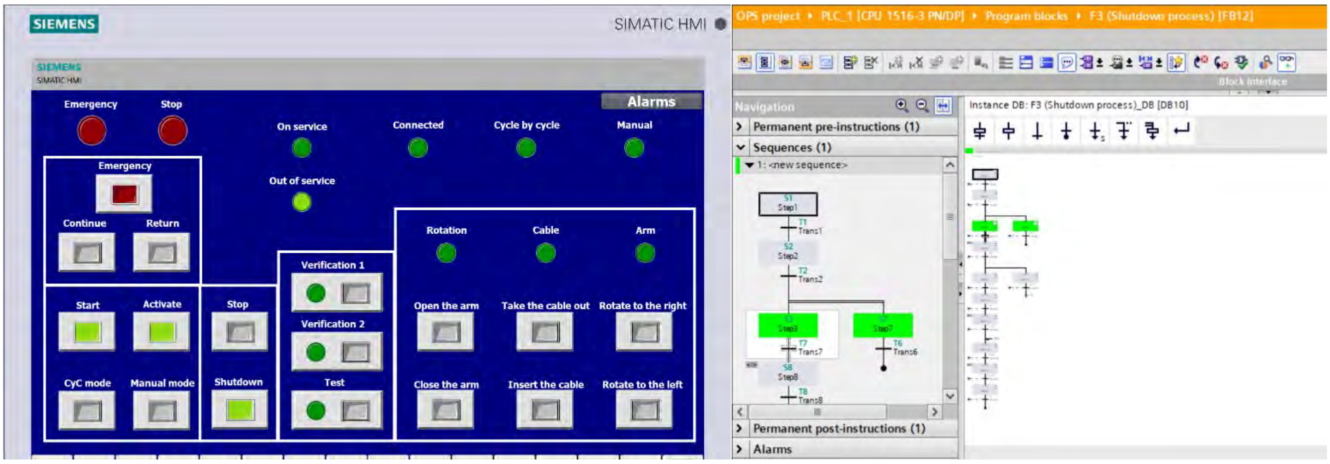
Figure 6.78: The program is placed at the normal production mode (F1) of GEMMA, in Cycle by Cycle mode, while open the arm is activated. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

As soon as the operator presses the shutdown button, the algorithm switches off the normal production mode (F1), and the deactivates the motors that are working. Moreover, it places the program in the shutdown process mode (F3) in order to prepare the crane to the initial stop state (A1). It is possible to see this in figure 6.79 that the normal production mode (F1) is off, and the motors are deactivated. Additionally, figure 6.80 presents the activation of the shutdown process mode (F3) at the same moment. The figures present the operation screen, the program, and the Fuzzy petri Nets intelligent algorithm.

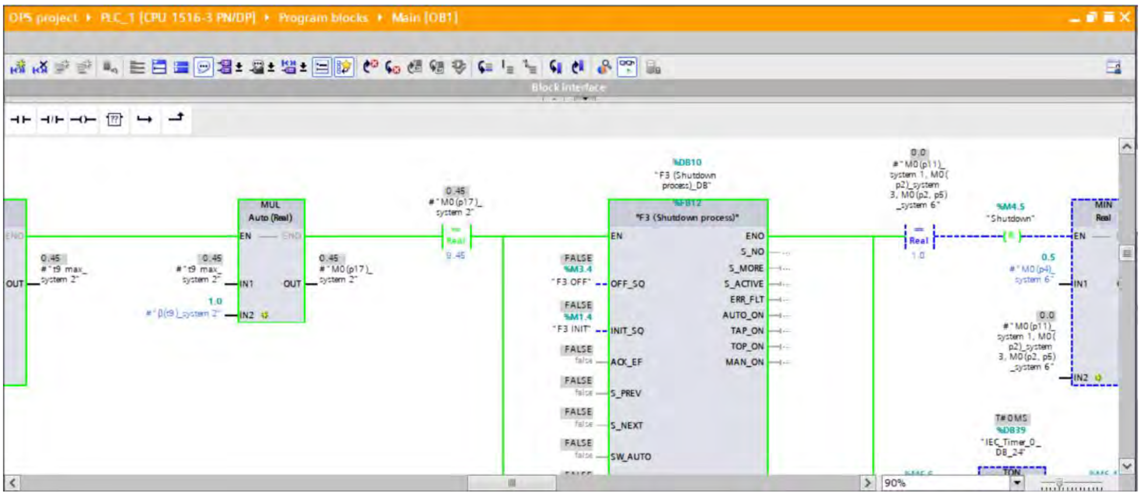


(a) (b)

Figure 6.79: The normal production mode (F1) of GEMMA is off, while the shutdown button is pressed. (a) the screen, (b) the program



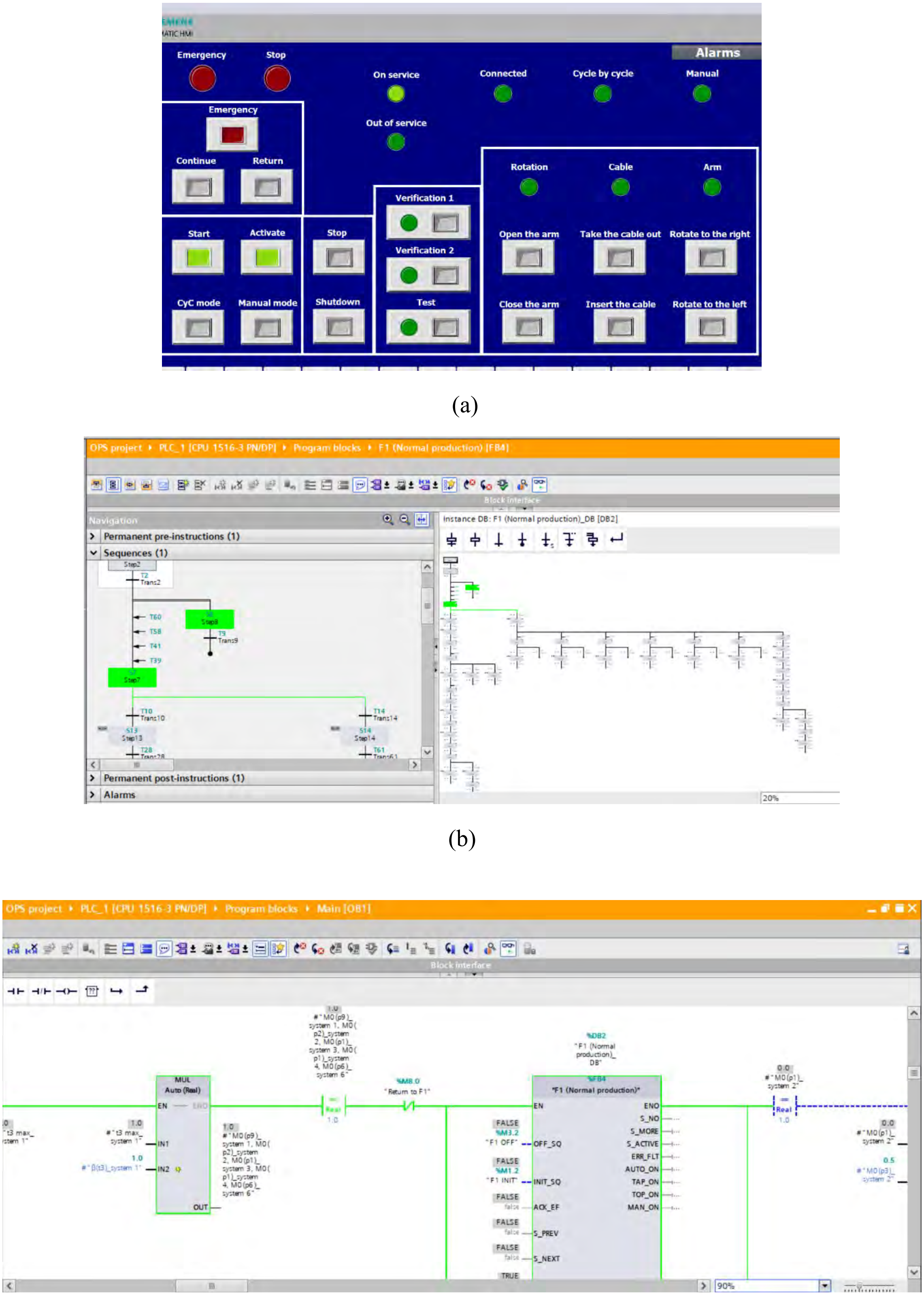
(a) (b)



(c)

Figure 6.80: The program is placed at the shutdown process mode (F3) of GEMMA. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent transitions

The second case of the shutdown transition is less useful, but it may be necessary as well. At that case, the crane is placed at its initial state, and the operator desires to shut down the program. In this situation the shutdown process is not needed, and the program has to return to the initial stop state. In order to arrive there, it has to pass the requested stop at the end of the cycle (A2) according to the GEMMA rules as it is explained before. In figure 6.81, it is possible to see that the program is placed at the initial state of the normal production mode (F1), which means that the operator did not activate any part of the crane.



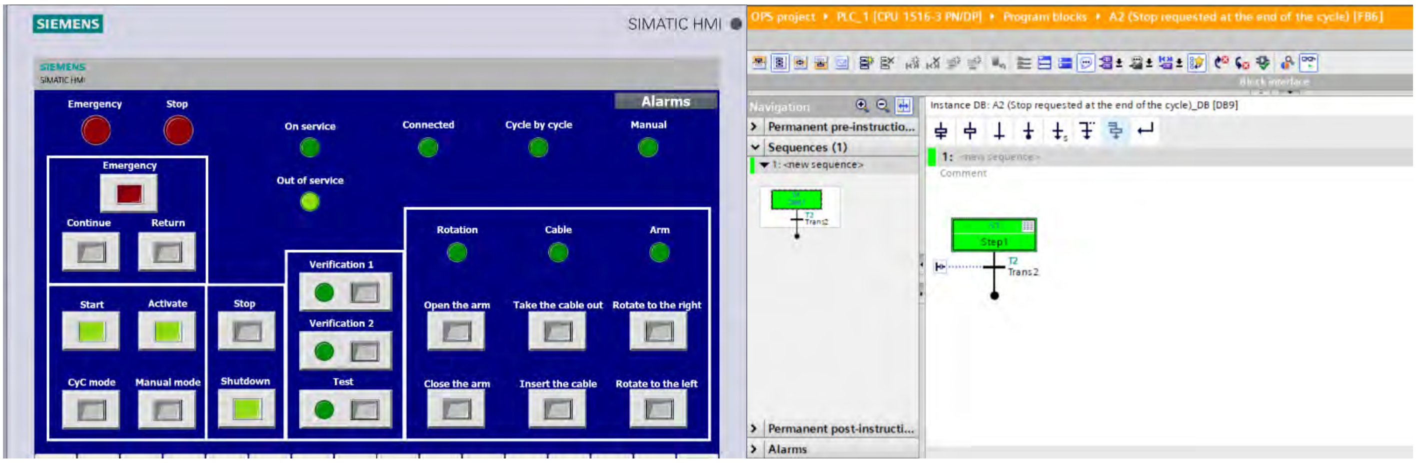
(a)

(b)

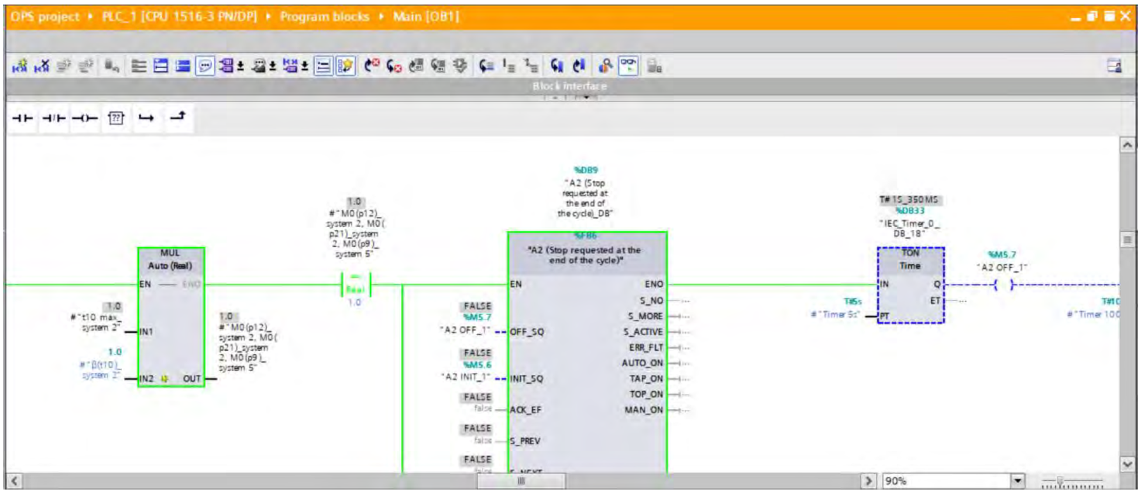
(c)

Figure 6.81: The program is placed at the normal production mode (F1) of GEMMA. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

When the shutdown button is pressed, the algorithm places the program in the requested stop at the end of the cycle (A2) in order to start over the program. The figure below shows this stage including the operation screen which indicates the situation.



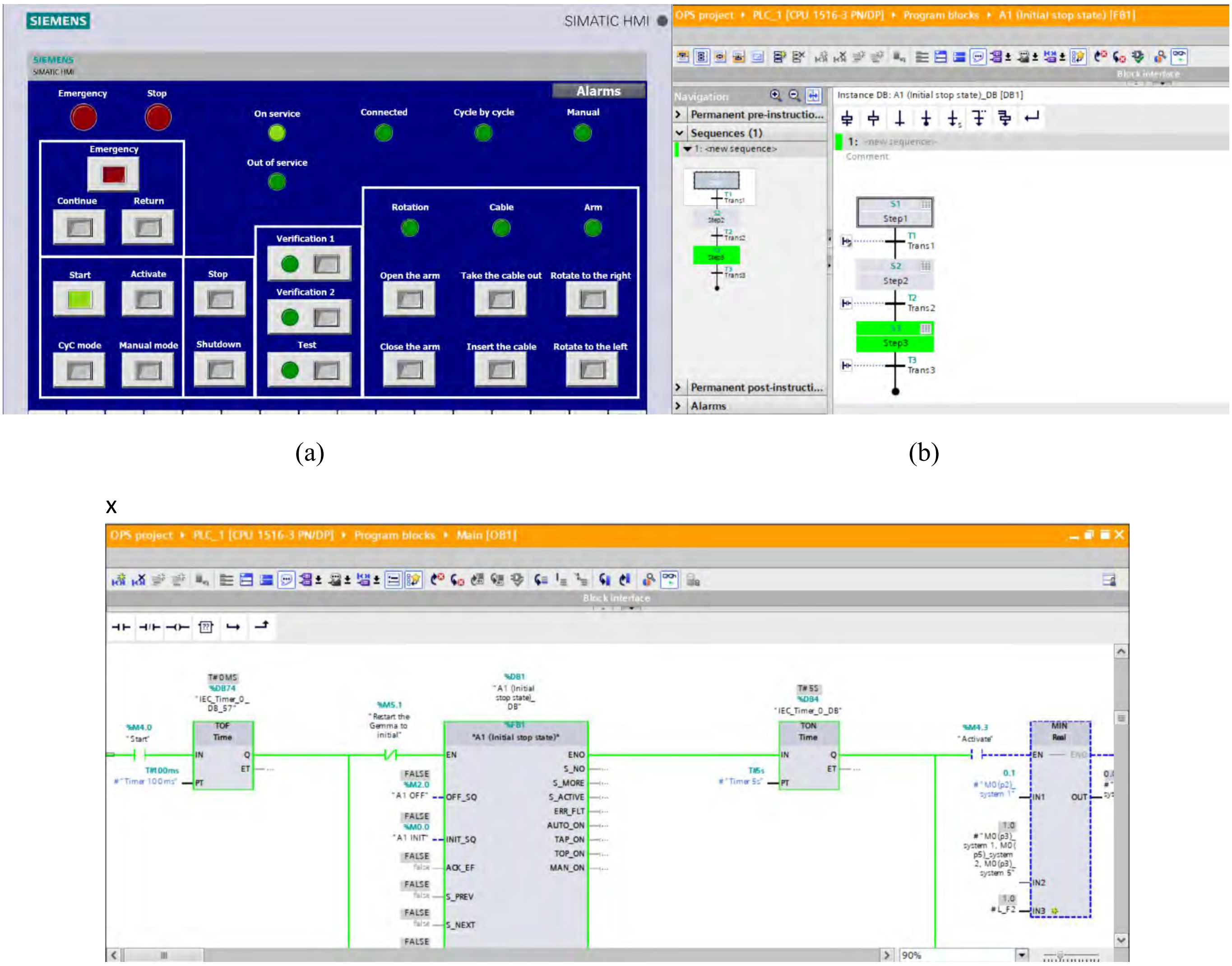
(a) (b)



(c)

Figure 6.82: The program is placed at the requested stop at the end of the cycle (A2) of GEMMA, the normal production mode is off while the shutdown button is pressed. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

As soon as the requested stop at the end of the cycle (A2) has been finished, the algorithm places the program in the initial stop state as it is shown in the figure below.



(a) (b)

(c)

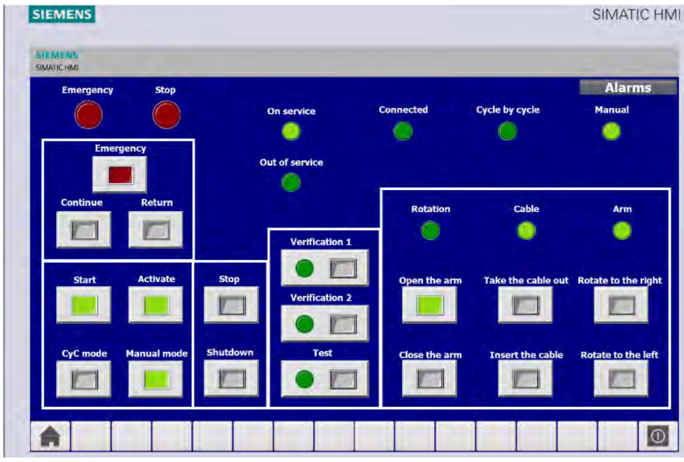
Figure 6.83: The program is placed at the initial stop state (A1) of GEMMA. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

6.1.4.4. Operation Procedure to Failure Procedure

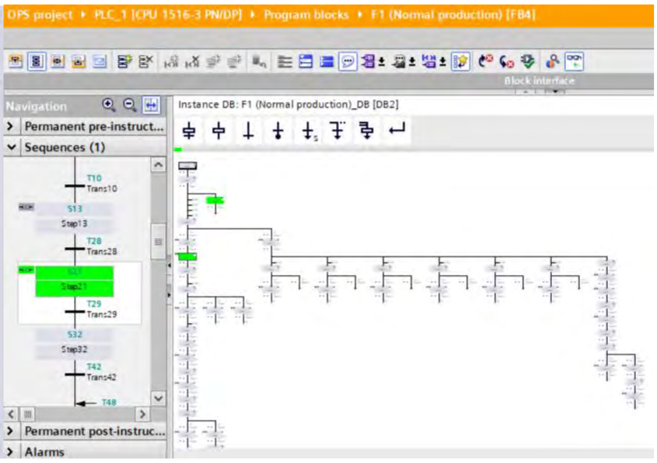
The operation procedure to failure procedure transitions are the most critical and important. It is responsible for stopping the machine while either some failure occurs or at the moment that the operator has this need and presses the emergency button. These transitions save the human life while there is some danger which is caused from the failure. Moreover, the protect the machine from a damage that may occur due to the failure. The operation procedure to failure procedure is explained deeply in the section 4.5. including the algorithm explanations.

In this section, the examination of the intelligent algorithm on the OPS crane is presented. The transitions of the intelligent algorithm are divided into two parts;

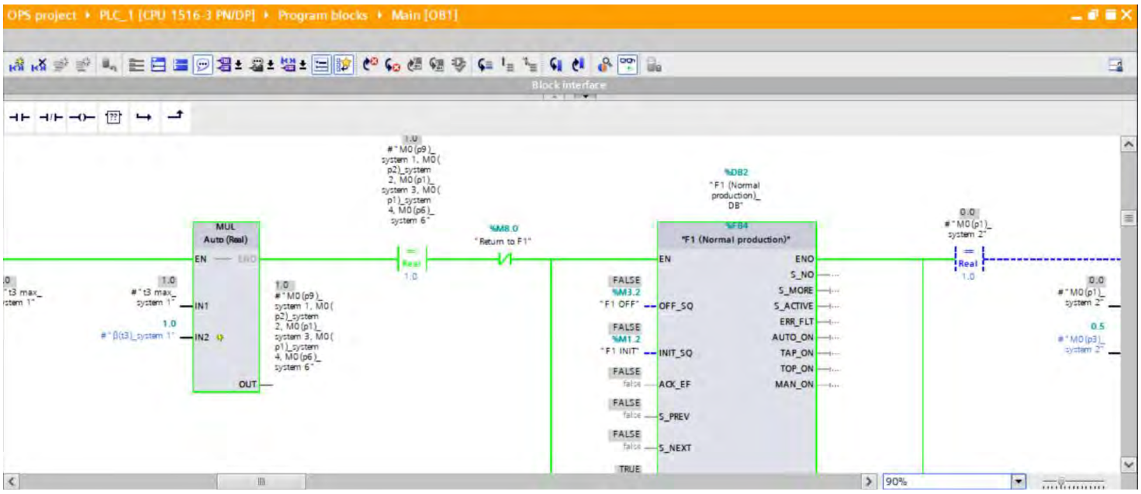
emergency button, and automatically stop while some failure occurs. The transition of the first part happens while the operator detects that some failure may occur, and he presses the emergency button. At that moment, the algorithm immediately stops the crane operation and places the program in the emergency stop mode (D1). As soon as the failure has been fixed, the operator is able to choose either continue the operation or start over the program. It provides the operator a safe operation and the flexibility to choose the next step. In the figure below it is possible to see the program while the crane is in the normal operation mode, Manual mode, while the arm is opening. The figure presents the operation screen, the program, and the Fuzzy Petri Nets intelligent program at this situation.



(a)



(b)



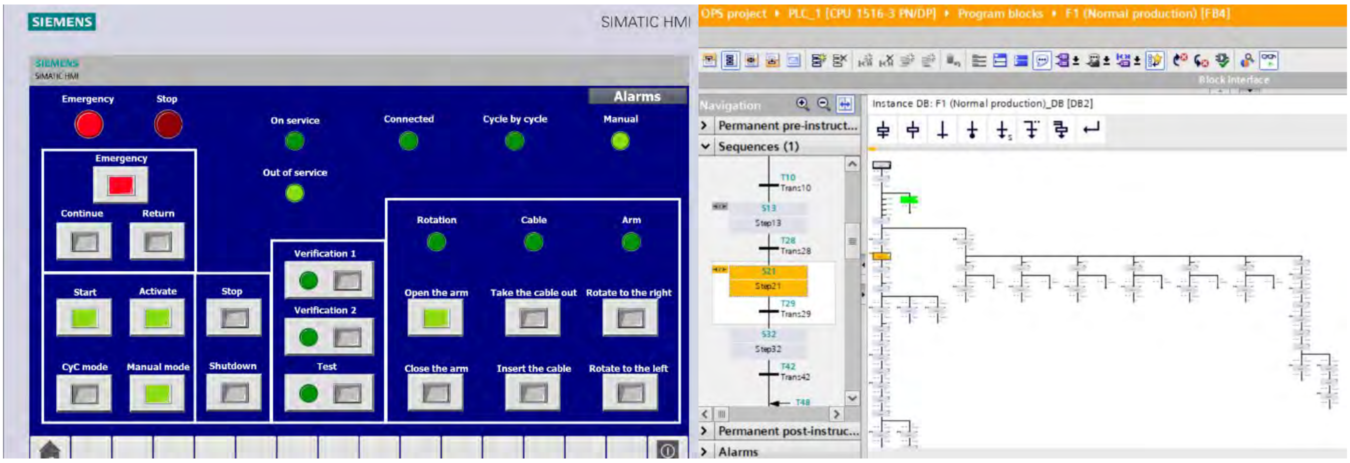
(c)

Figure 6.84: The program is placed at the normal production mode (F1) of GEMMA, in manual mode, while open the arm is activated. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

The operation screen includes an alarm screen that detects at any moment the failures that occur. At that moment, the crane operation is working properly, and there is no failure. Figure 6.85 shows the alarms screen at that moment when there is no failure at any part of the crane. It is possible to see that the alarms screen is empty and does not detect any failure.

Figure 6.85: The alarm screen, while there is no failure

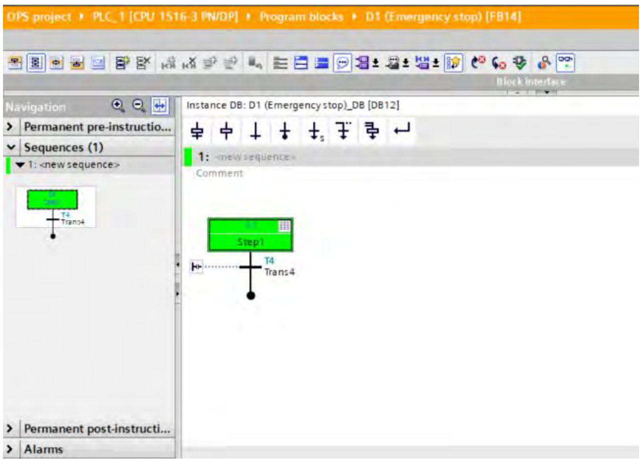
When the operator detects that some failure may occur, he is able to prevent it before it happens by pressing the emergency button. As soon as the operator presses the button, the algorithm freezes the program immediately, and deactivates the motors that were operating. The figure below shows this situation while the emergency button has been pressed. It is possible to notice that the normal production mode (F1) is frozen (the step color that was activating has changed to orange). Moreover, the program is in out of service, and the motors are deactivated as it is shown in the operation screen.



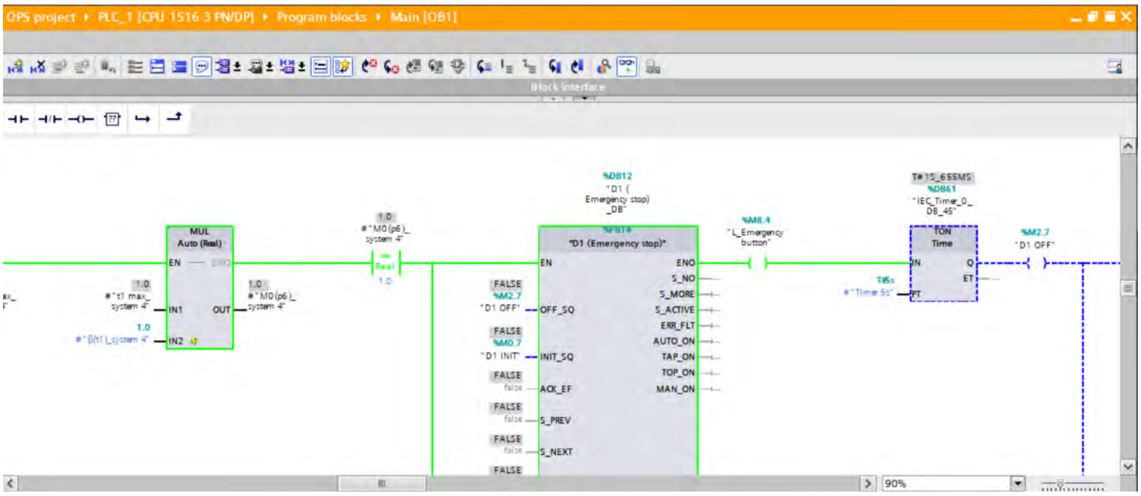
(a) (b)

Figure 6.86: The normal production mode (F1) of GEMMA is frozen, while the emergency button is pressed. (a) the screen, (b) the program

At that moment, the algorithm places the program in the emergency stop mode (D1). The program will be in this mode until the failure will be fixed. In the figure below it is possible to see that the program is placed at this mode while there is a failure. The figure presents the program, and the Fuzzy Petri Nets intelligent algorithm.



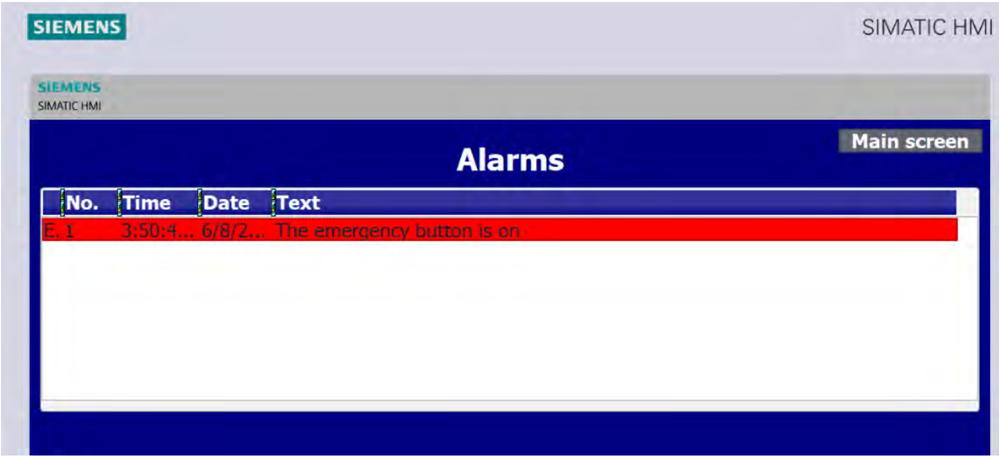
(a)



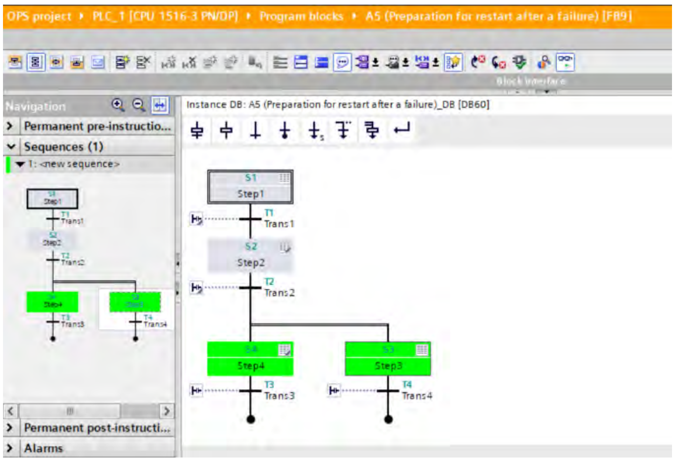
(b)

Figure 6.87: The program is placed at the emergency stop mode (D1) of GEMMA. (a) the screen, (b) the Fuzzy Petri Nets intelligent algorithm

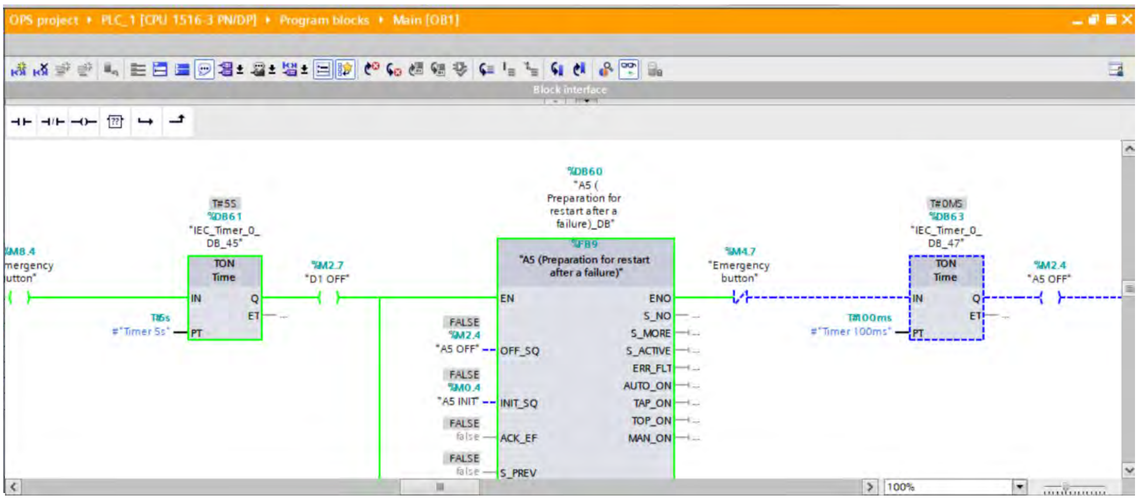
After the crane operation has been stopped, the algorithm continues to the next emergency stage and places the program in the preparation for startup after a failure (A5). In this mode, the alarm screen shows the failure, and allows the maintenance workers to fix the failure. The screen shows the failure that occurs, in this case, the program detects that the emergency stop button is pressed. The alarm screen will present it until the operator will release the emergency stop button. Figure 6.88 shows the alarm screen while the emergency button is pressed. The alarm line includes the time and date that the failure has occurred, and description of the failure. Moreover, it presents the program, and the Fuzzy Petri Nets intelligent algorithm during this situation.



(a)



(b)

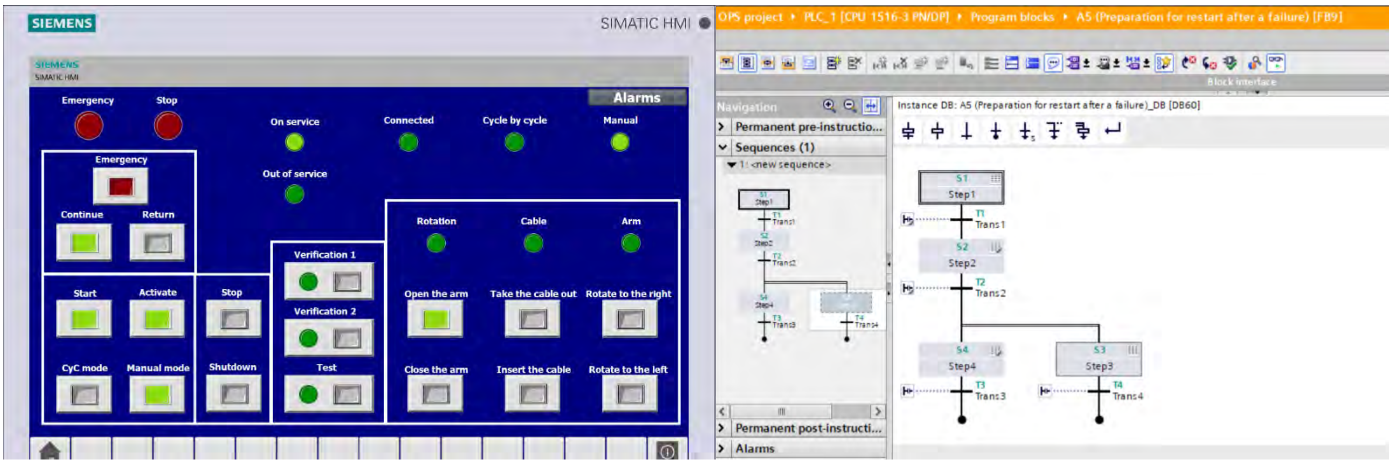


(c)

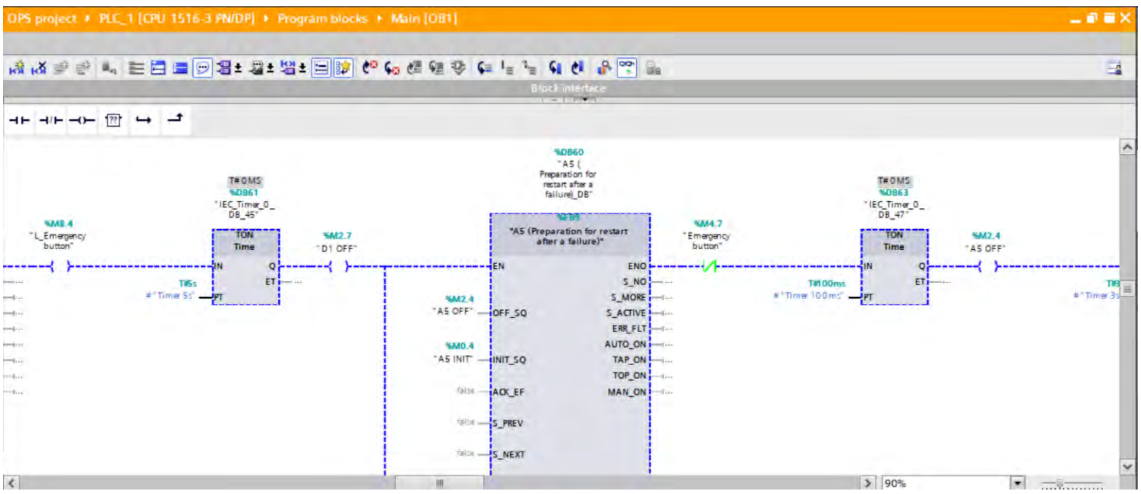
Figure 6.88: The program is placed at preparation for startup after a failure mode (A5) of GEMMA. (a) alarm screen including the failure presentation, (b) program, (c) the Fuzzy Petri Nets intelligent algorithm

As soon as the failure has been fixed, the operator has two alternatives. The first one is to continue the operation at the same point that it has stopped when the failure occurred. The second alternative allows the operator to return the crane to its initial state and start over the program for placing it at the initial stop state (A1).

In a case that the operator desires to continue the crane operation after the failure has been fixed, he is able to do it by pressing the continue button. At that moment, the algorithm switches off the preparation for startup after a failure (F5), and will place the program in the normal production mode (F1) at the same point of the operation that it was before the operator pressed the emergency button. The figure below presents this case, while the operator has pressed the continue button, and the F5 mode is off.



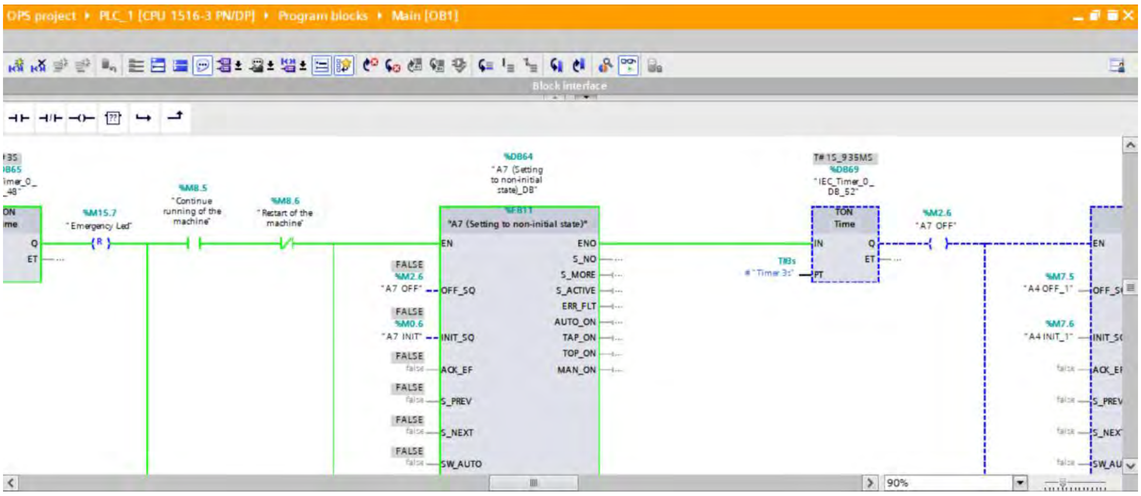
(a) (b)



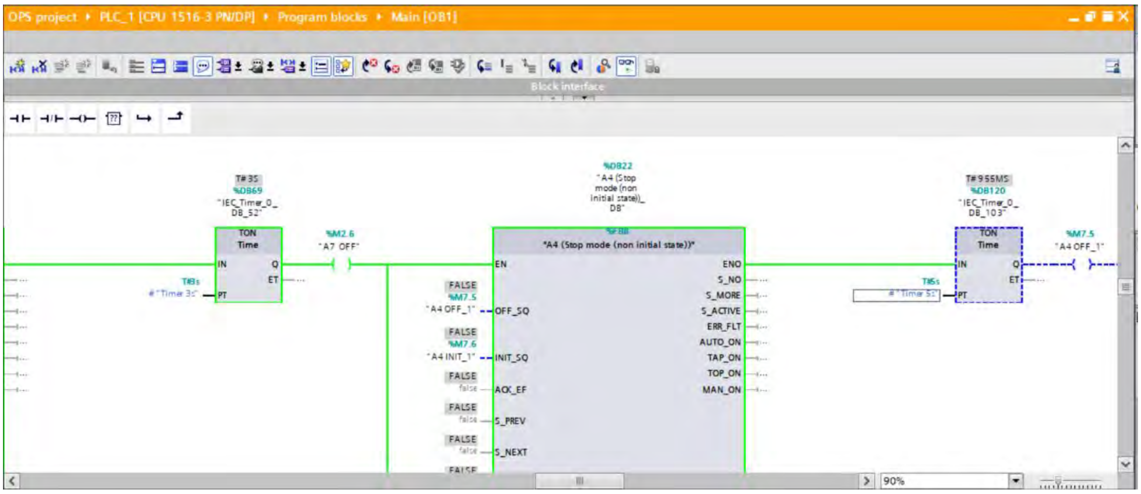
(c)

Figure 6.89: The preparation for startup after a failure mode (A5) of GEMMA is off, while the continue button is pressed. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

At the moment that the operator has pressed the continue button, the algorithm will place the program in the temporal mode setting to non-initial state (A7). In this mode, the program prepares itself to the same point of operation that it was before the emergency button pressed. Afterwards, the algorithm places the program in the stop mode (non-initial state) (A4) in order to allow the operator to continue the operation. Figure 6.90 presents the Fuzzy Petri Nets intelligent algorithm at these modes.



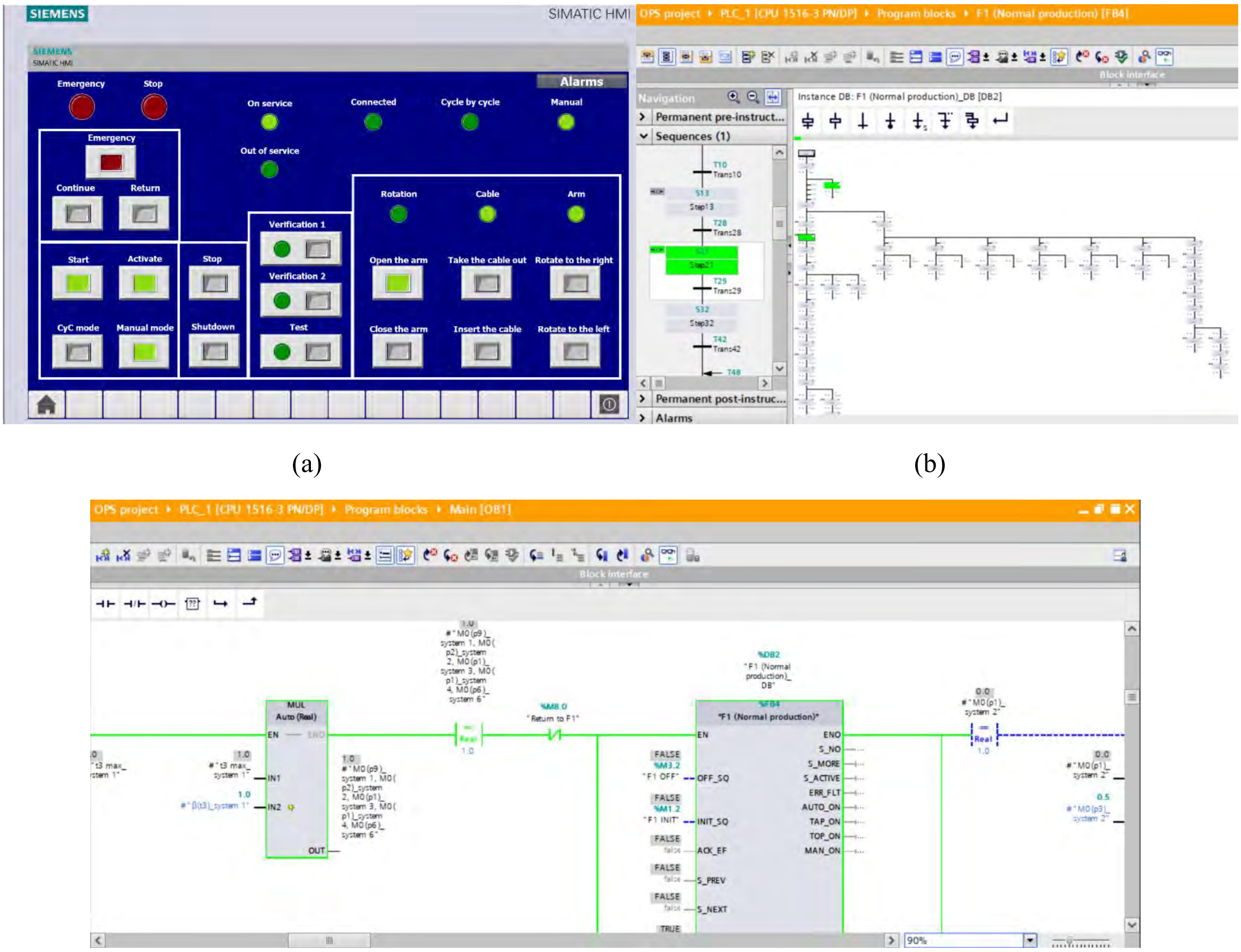
(a)



(b)

Figure 6.90: The preparation for startup after a failure mode, the Fuzzy Petri Nets intelligent transitions. (a) setting to noninitial state (A7), (b) stop mode (non-initial state) (A4)

At last, the algorithm places the program at the normal production mode (F1) as it is shown in the figure below. As it is possible to see, the program is placed at the exact point of operation that it was before the emergency button was pressed. The operation is in Manual mode in the open the arm stage. The figure presents the operation screen, the program, and the Fuzzy Petri Nets intelligent algorithm.

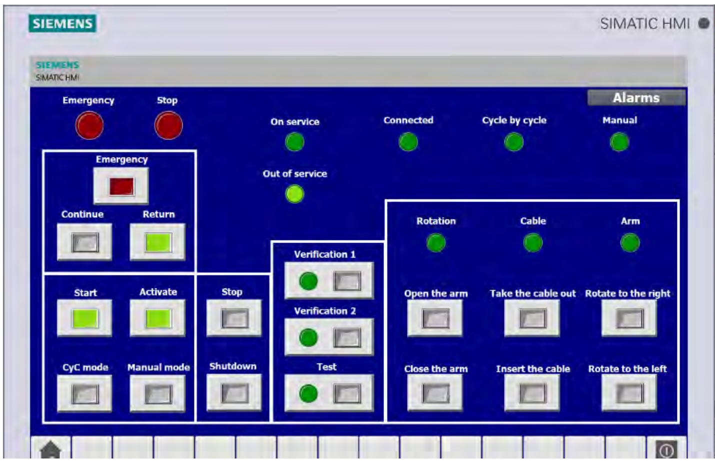


(a) (b)

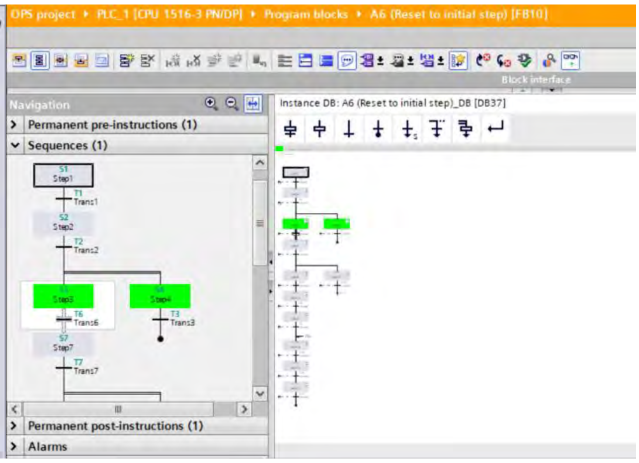
(c)

Figure 6.91: The program is placed at normal production mode (F1) of GEMMA, manual mode, while the open the arm is activated. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

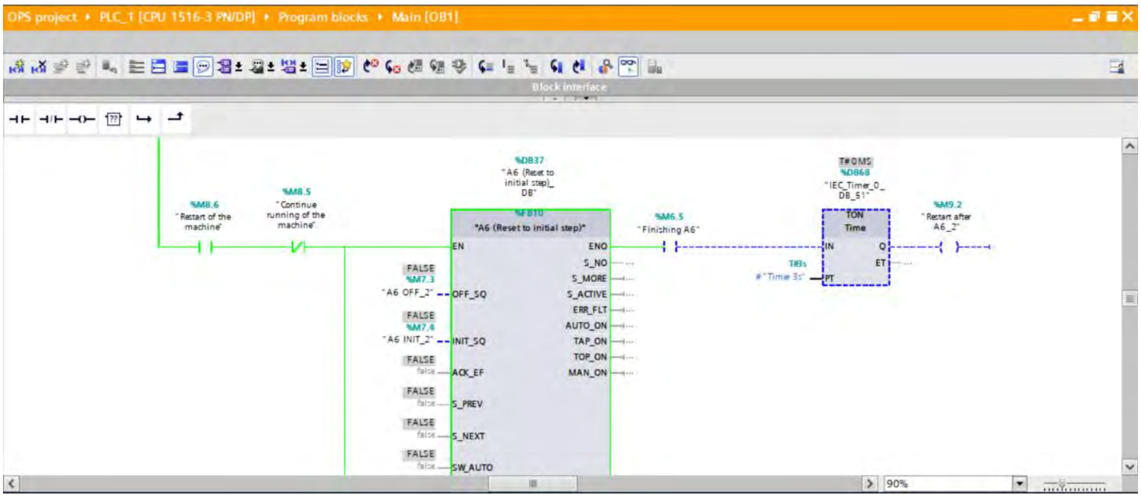
Differently, in the second alternative, the operator is able to return the crane to its initial state and start over the program after the failure has been fixed. In order to do it, the operator presses the return button. At that moment, the algorithm will place the program at the reset to initial state mode (A6). This mode will reset the crane similarly to the shutdown process in order to prepare it to the next operation. The figure below presents the program in this mode while the operator has pressed the return button. Moreover, it is possible to see the operation screen, and the Fuzzy Petri Nets intelligent algorithm. Additionally, the algorithm switches off the normal production mode (F1) that was frozen due to the activation of the emergency button as it is shown in figure 6.93.



(a)



(b)



(c)

Figure 6.92: The program is placed at reset to initial state mode (A6) of GEMMA, the preparation for startup after a failure mode (A5) of GEMMA is off, while the return button is pressed. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

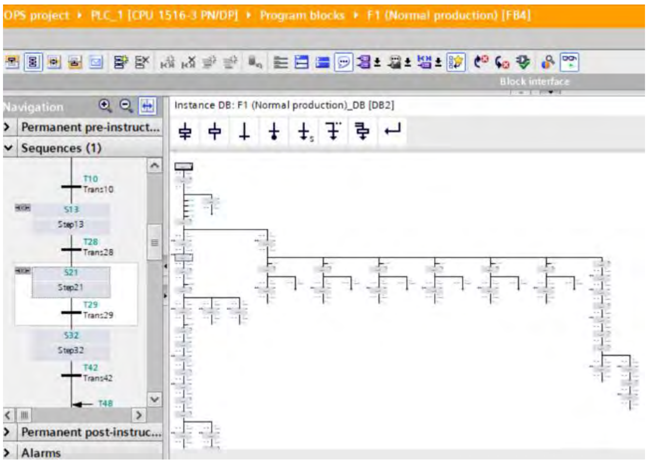
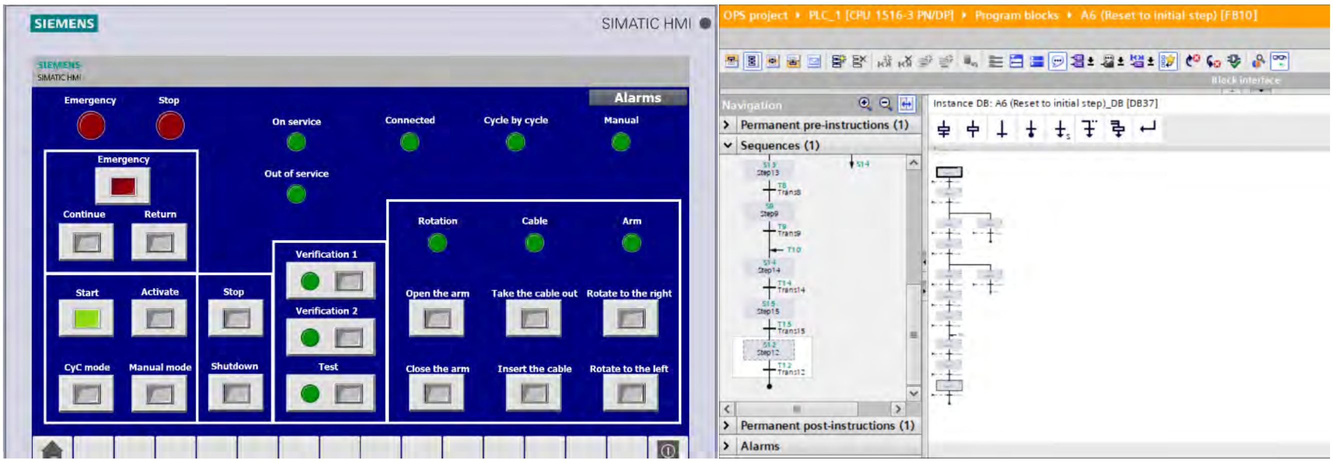
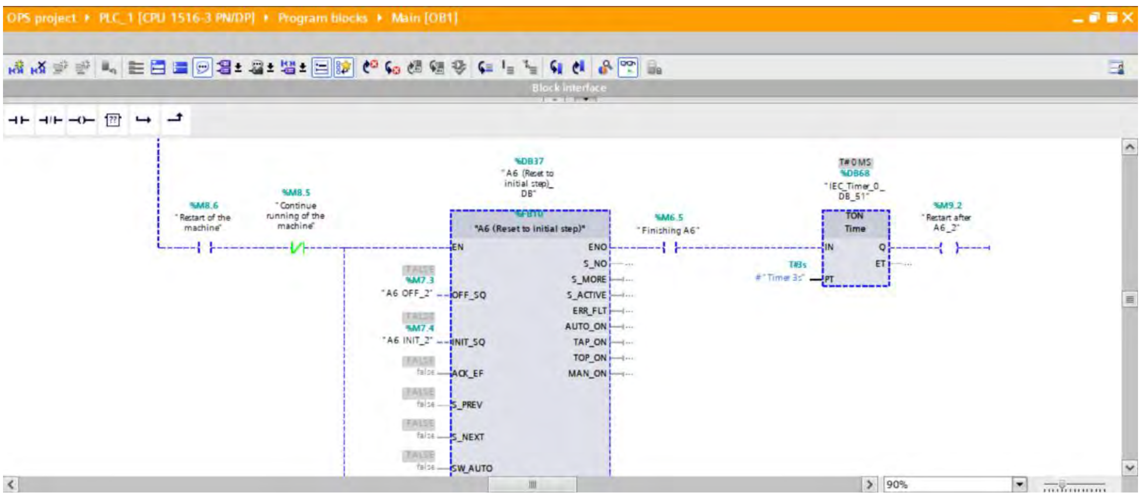


Figure 6.93: The normal production mode (F1) of GEMMA is off

As soon as the closing process of the crane has been finished, the algorithm will switch off the reset to initial state mode (A6). It is possible to see in the figure below that the A6 mode is off. The figure shows the operation screen, the program, and the Fuzzy Petri Nets intelligent algorithm.



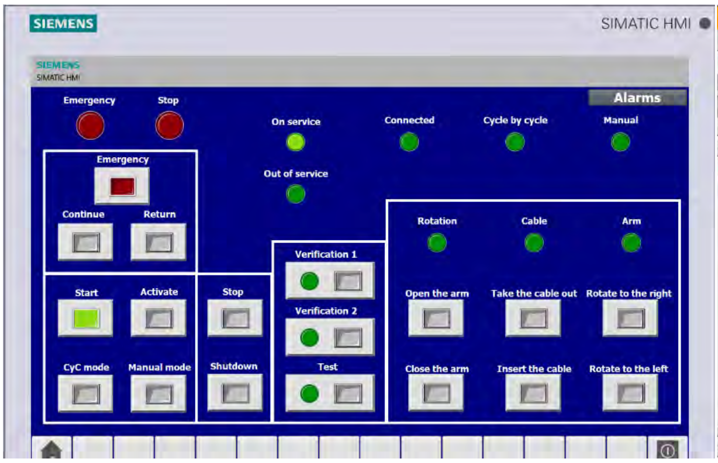
(a) (b)



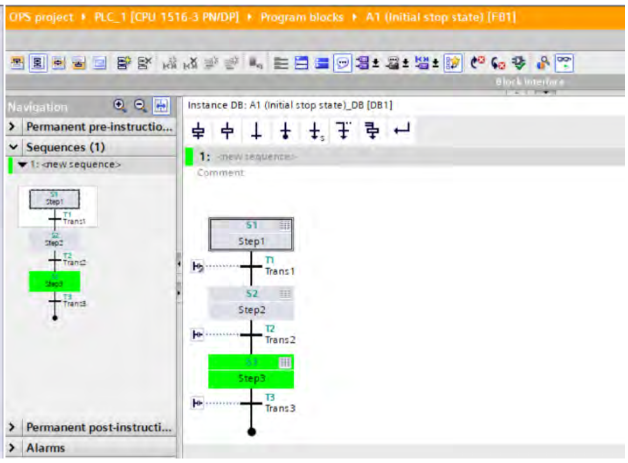
(c)

Figure 6.94: The reset to initial state mode (A6) of GEMMA is off, while the reset to initial state process has been finished. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent transition

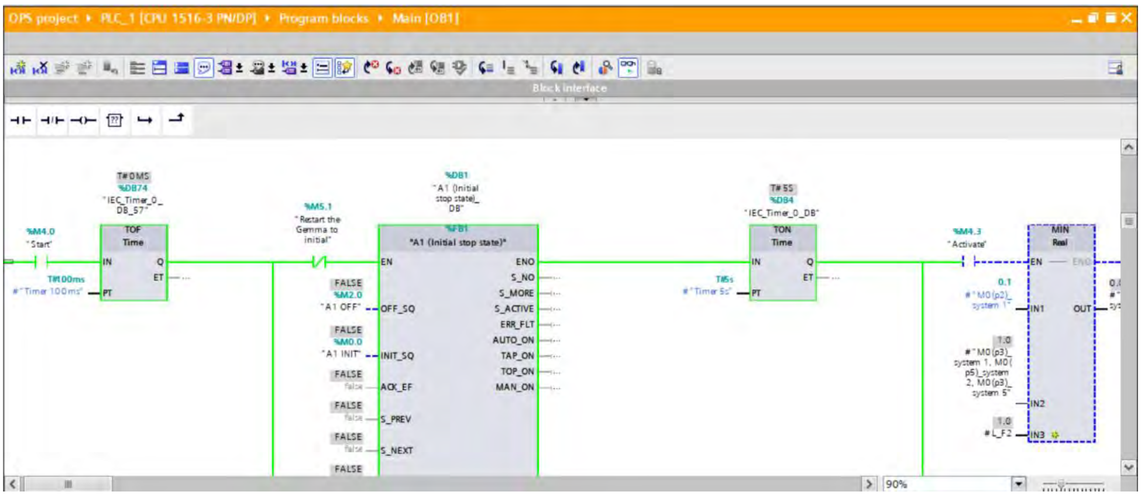
At that moment, the algorithm places the program in the initial stop state (A1). It allows the operator to either start the operation or do another desired action. Figure 6.95 presents the program in the A1 mode. It is possible to see that the program is on service and it is ready for the next desired step of the operator.



(a)



(b)



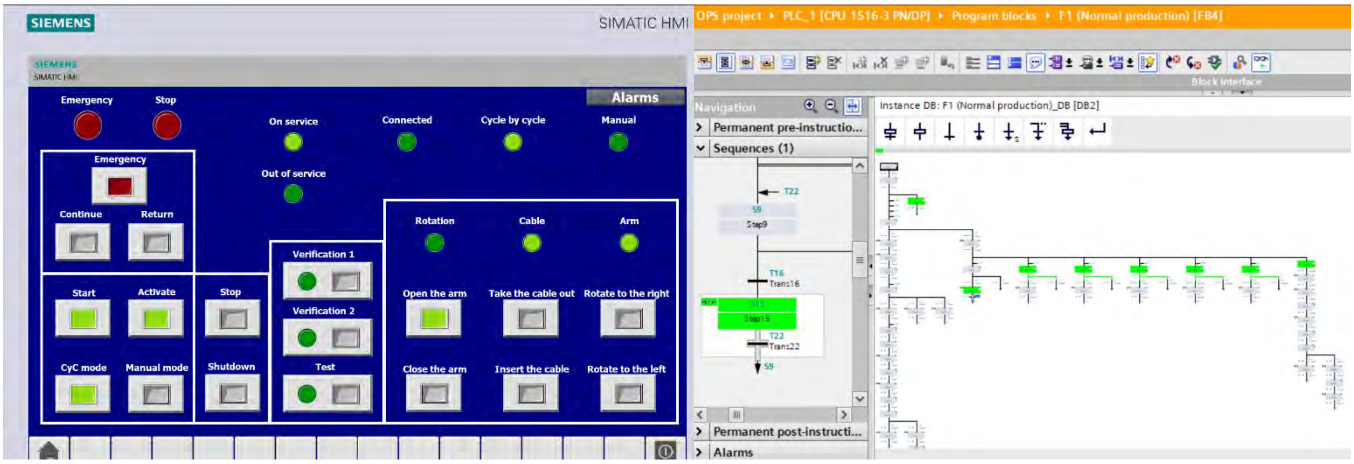
(c)

Figure 6.95: The program is placed at the initial stop state (A1) of GEMMA. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent transition

The second part of the operation procedure to failure procedure transitions is related to different failures that the program detects automatically and stops the crane. This part is divided into three parts of failures according to the failure level. That is to say, each failure’s level that is detected by the program is treated in a different way in order to provide safety to the operator, and the crane. The three levels of the failure are critical failure, medium, and noncritical.

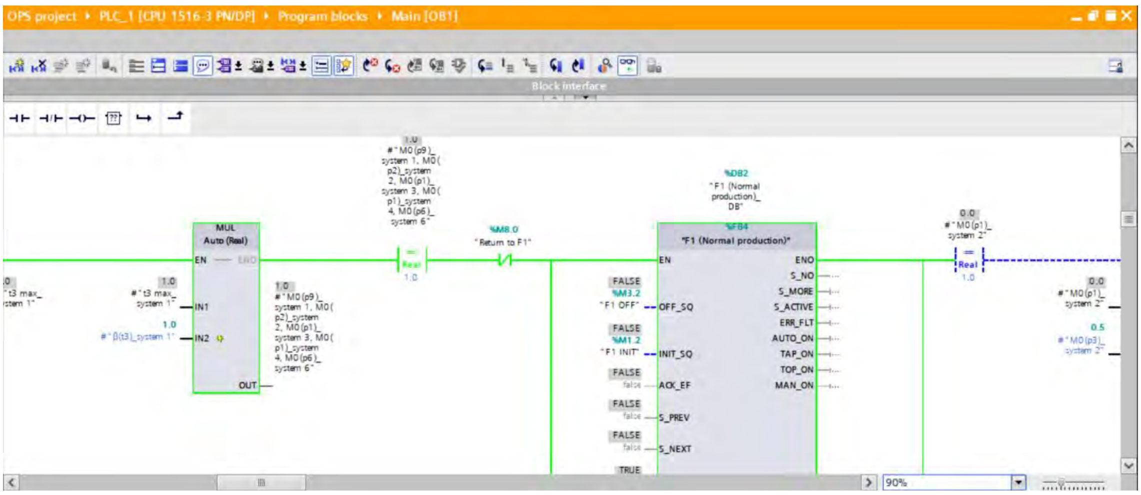
The critical failure is a failure that can cause danger for the operator, and damage to the crane. In this case the algorithm will immediately stop the crane operation and will place the program in the emergency stop mode (D1). At the next stage, the program will be placed at the preparation for startup after a failure (A5) in order to detect the failure which may help the maintenance workers to know where the failure is. As soon as the failure has been fixed, the operator is able to choose either to continue the operation or restart the crane and start over the program.

The figure below shows the normal operation of the crane when there is no failure. At this moment, the program is placed at the normal production mode (F1), Cycle by Cycle mode, while the arm is opening.



(a)

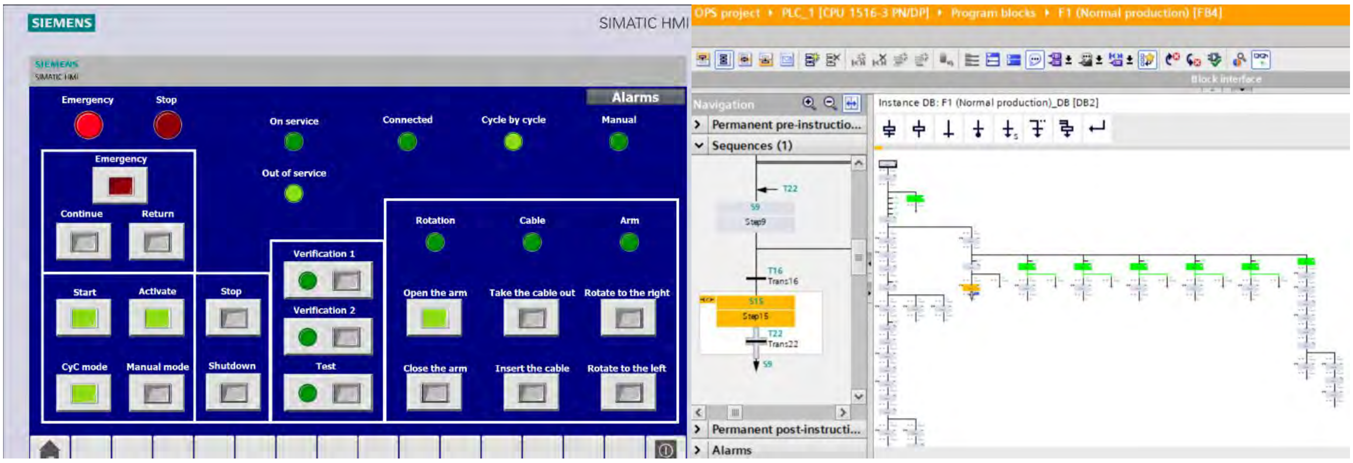
(b)



(c)

Figure 6.96: The program is placed at the normal production mode (F1) of GEMMA, Cycle by Cycle mode, open the arm is activated. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

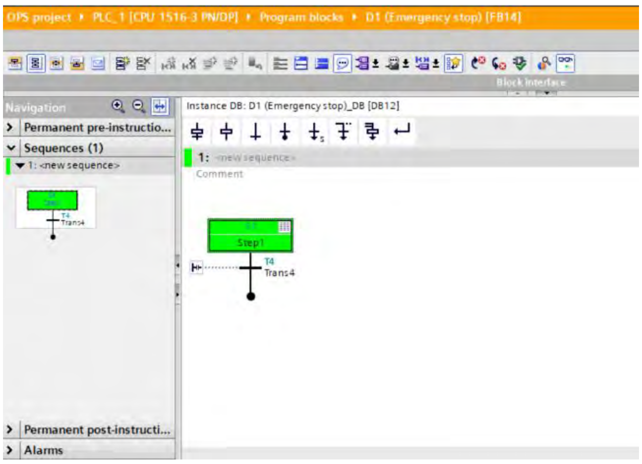
As soon as the critical failure is detected, the algorithm stops immediately all the activated motors, and freezes the normal production mode (F1) (the activated step will change its color from green to orange). Figure 6.97 presents the operation screen and program while the failure occurs. Moreover, the operation screen indicates to the leds that the program is out of service and in emergency.



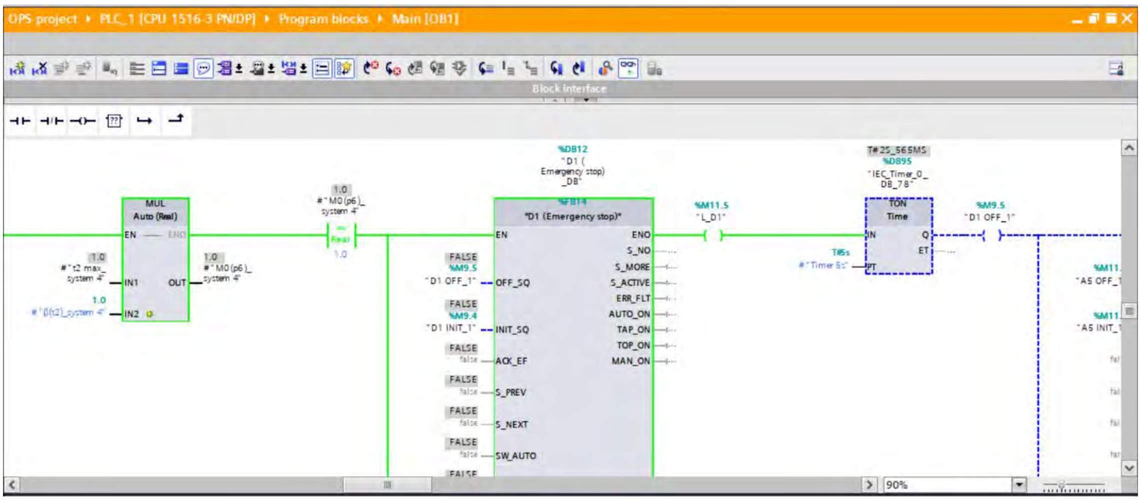
(a) (b)

Figure 6.97: The normal production mode (F1) of GEMMA is frozen while a critical failure is detected. (a) the screen, (b) the program

At that moment, the algorithm places the program in the emergency stop mode (D1) as it is shown in figure 6.98. This mode helps to memorize the last state of the operation. Moreover, it places both the crane and operator in safety. The figure presents the program, and the Fuzzy Petri Nets intelligent algorithm.



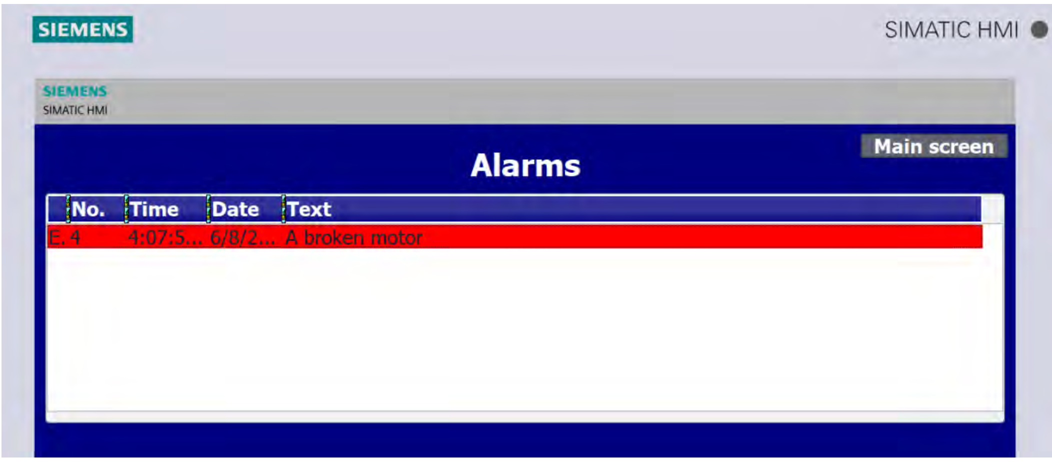
(a)



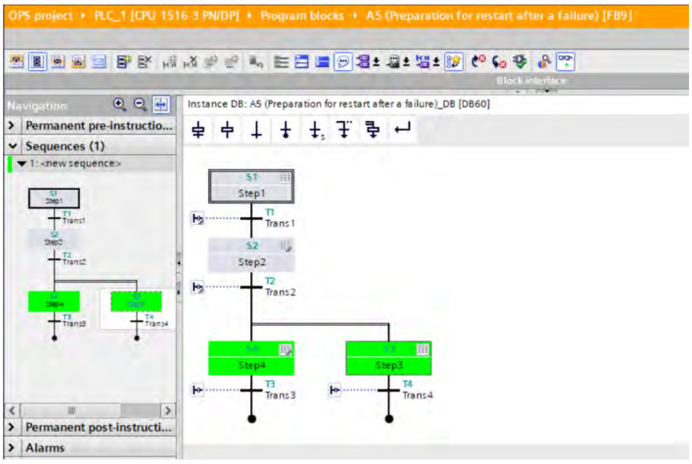
(b)

Figure 6.98: The program is placed at the emergency stop mode (D1) of GEMMA, (a) the program, (b) the Fuzzy Petri Nets intelligent algorithm

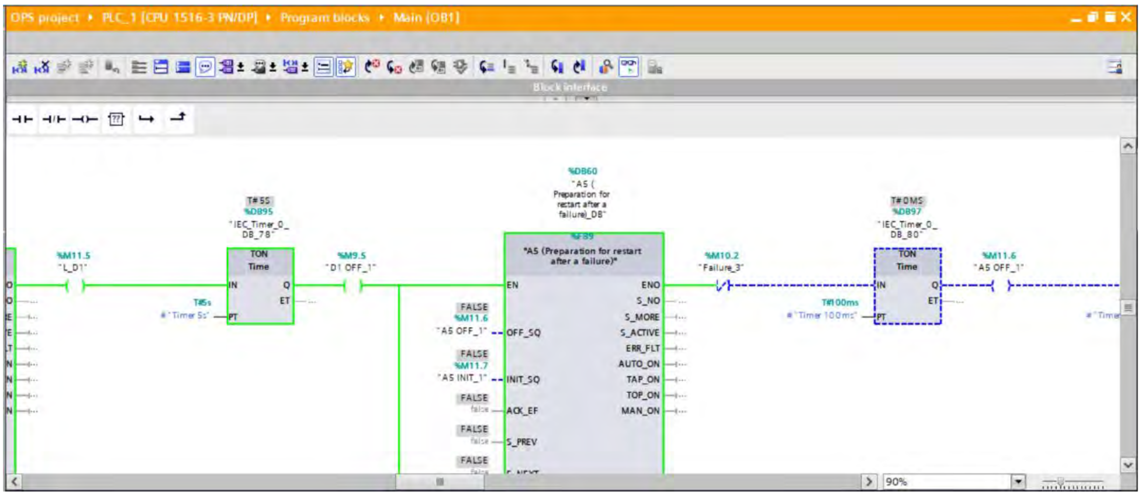
After the algorithm has stopped the crane and placed it in the safety mode (D1), the algorithm places the program in the preparation for startup after a failure (A5). In this mode the program detects the failure and describes it in the alarm screen. It helps the maintenance workers to save time and to solve the problem faster. In this example there is a problem with one of the crane's motors. In the figure below, it is possible to see the alarm screen with the detected failure which it shows the message ”A broken motor” in red which means that this is a critical failure. Moreover, the figure presents the program, and the Fuzzy Petri Nets intelligent algorithm while the program is placed at this mode.



(a)



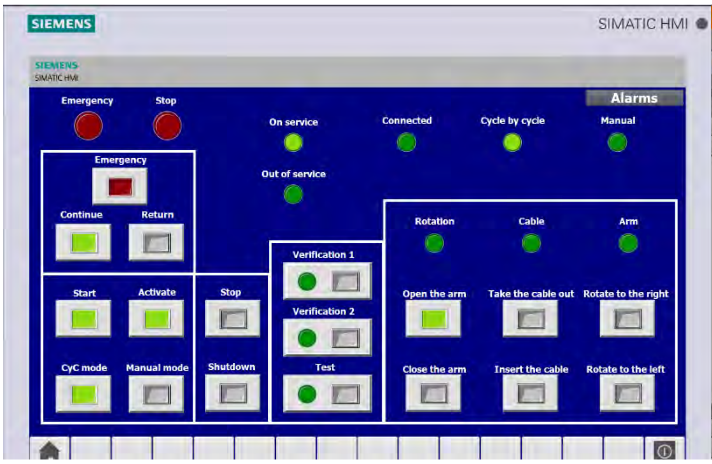
(b)

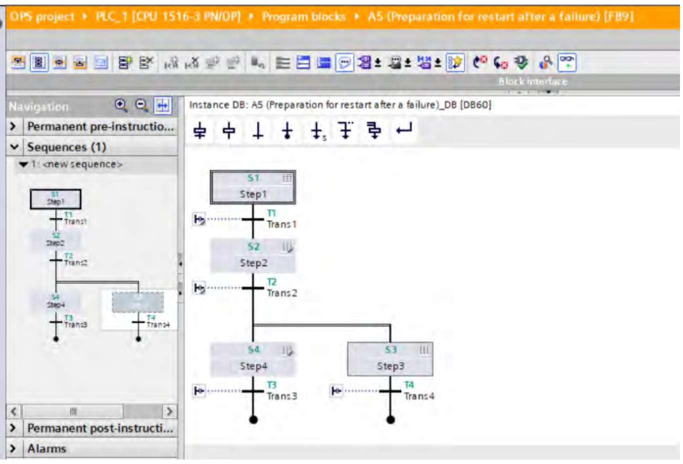


(c)

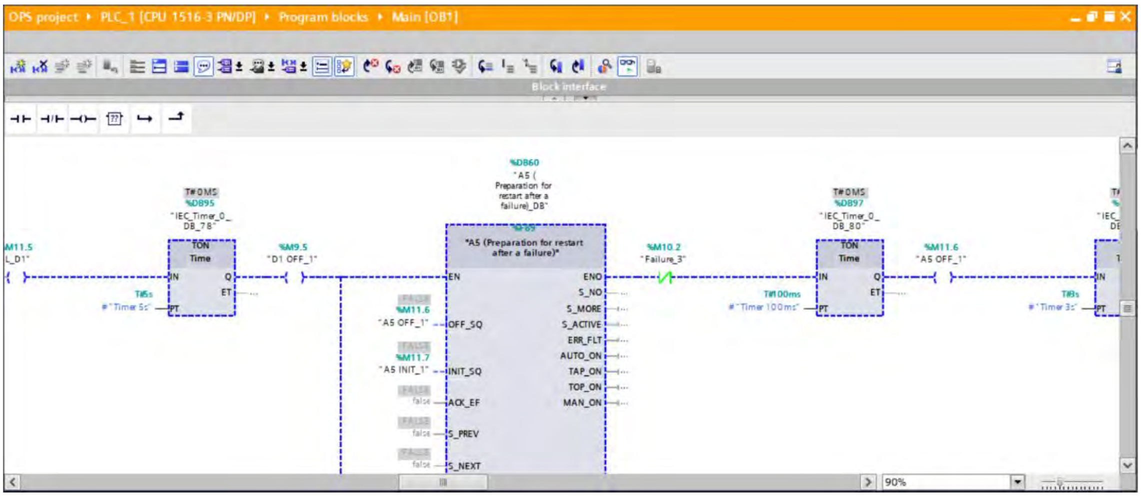
Figure 6.99: The program is placed at preparation for startup after a failure mode (A5) of GEMMA. (a) alarm screen including the failure presentation, (b) program, (c) the Fuzzy Petri Nets intelligent algorithm

As soon as the failure has been fixed, the operator has two alternatives. To continue the operation at the exact point that it was before the failure occurred or restart the crane to its initial state and start over the program. The first alternative that it is shown is the case the operator desires to continue the operation. In order to it, the operator presses the continue button, and the algorithm receives this order and switches off the preparation for startup after a failure (A5). Figure 6.100 presents this stage, it is possible to notice that the continue button has pressed, and the A5 mode is off.





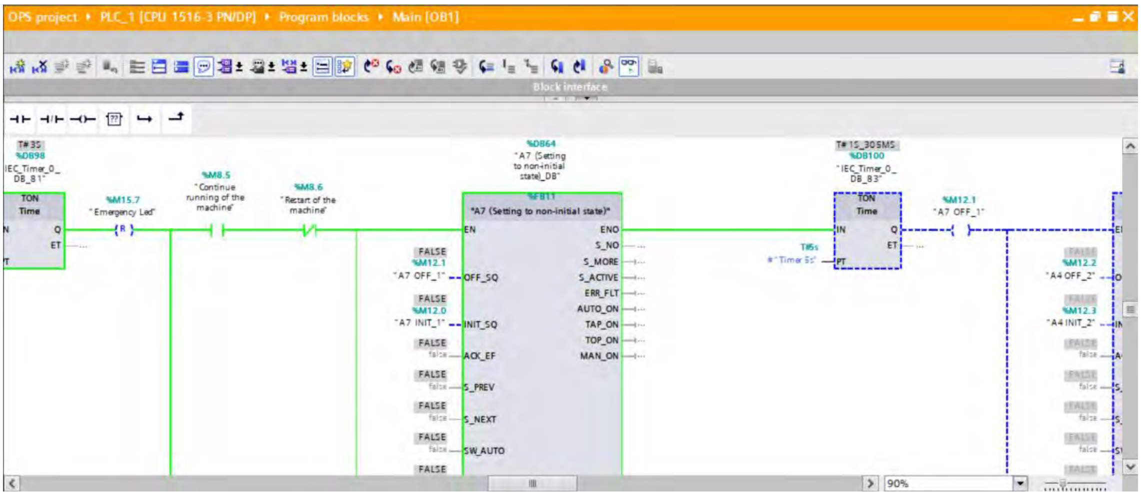
(a) (b)



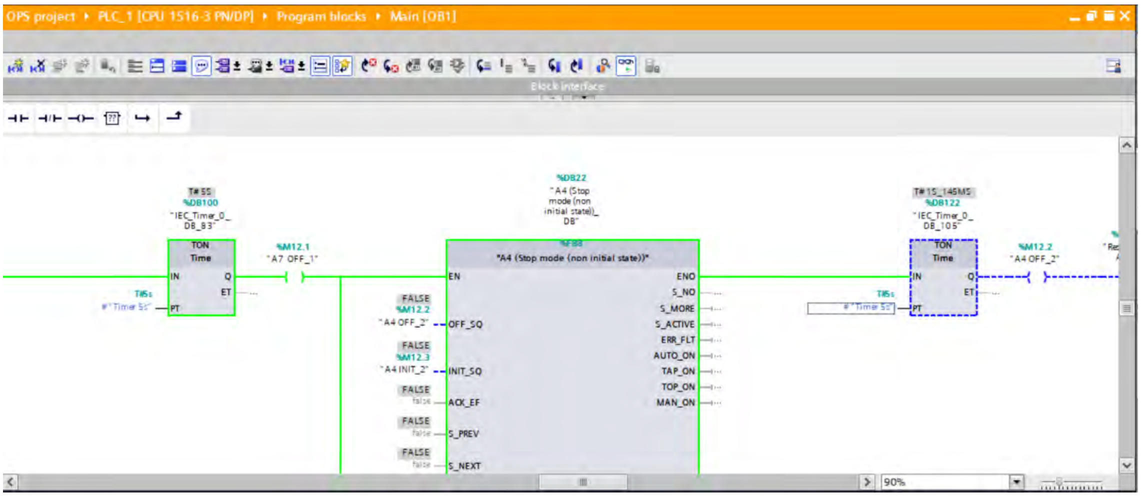
(c)

Figure 6.100: The preparation for startup after a failure mode (A5) of GEMMA is off, while the continue button is pressed. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

When the operator has pressed the continue button, the program has to prepare for returning to the operation. In other words, to be placed at the exact point of the operation that it was before the failure occurred. The algorithm places the program first in the temporal mode setting to non-initial state (A7) in order to prepare the program for returning to the same point of the operation. At the moment that the program is prepared, the algorithm places the program at the stop mode (non-initial state) (A4) which it is similar to the initial stop mode (A1). At this mode, the program is waiting for starting the operation again. Figure 6.101 presents the Fuzzy petri Nets intelligent algorithm of the transitions of these modes.



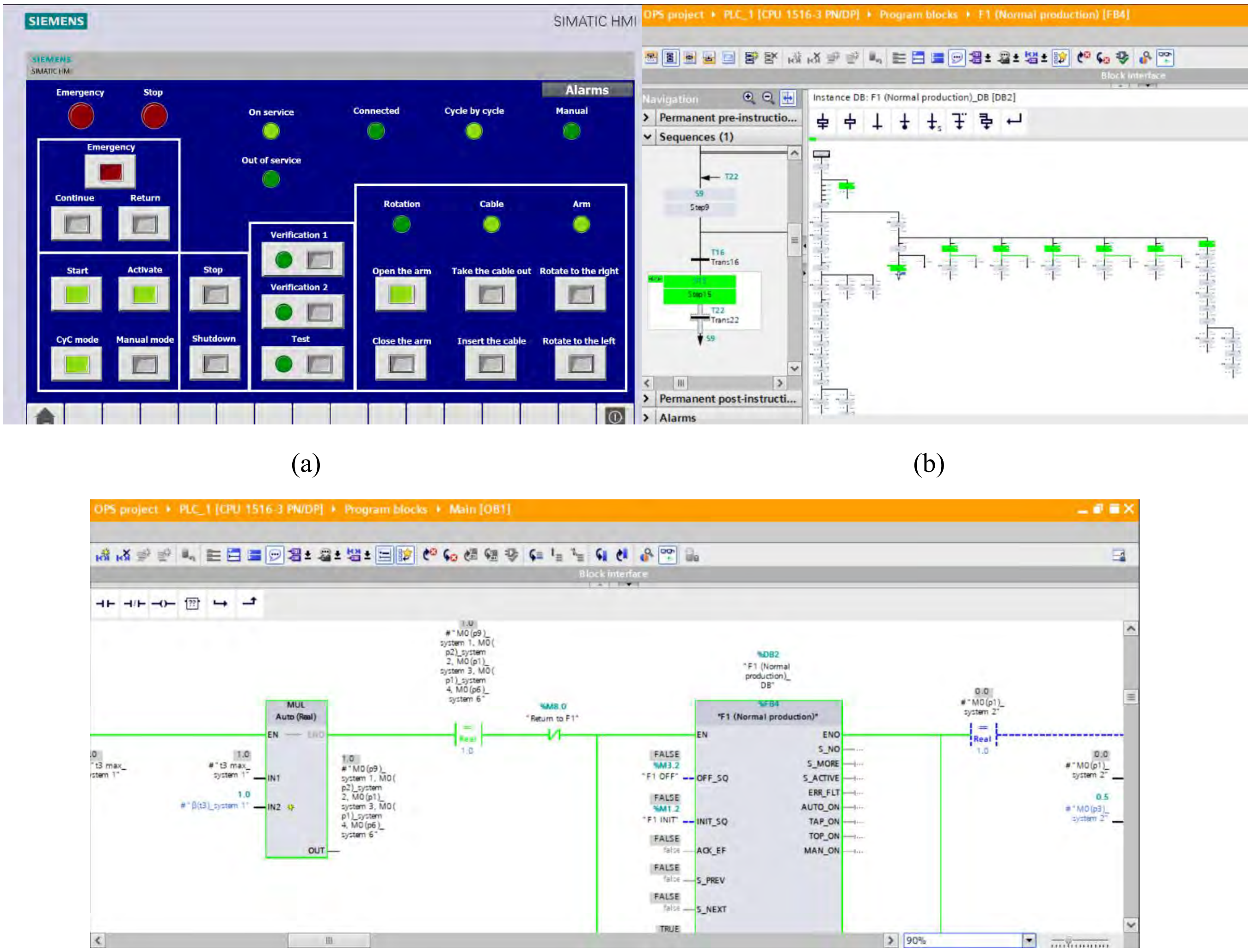
(a)



(b)

Figure 6.101: The preparation for startup after a failure mode, the Fuzzy Petri Nets intelligent transitions. (a) setting to noninitial state (A7), (b) stop mode (non-initial state) (A4)

As soon as the program is ready for starting the operation at the necessary operation point, the algorithm places the program back in the normal production mode (F1). The figure below shows the operation screen, the program, and the Fuzzy Petri Nets intelligent algorithm. It is possible to notice that the operation continues from the exact place that it was before, Cycle by Cycle mode, and the arm is opening. The figure shows that the activation motor step color of the program is again green which means that the motor is activated.

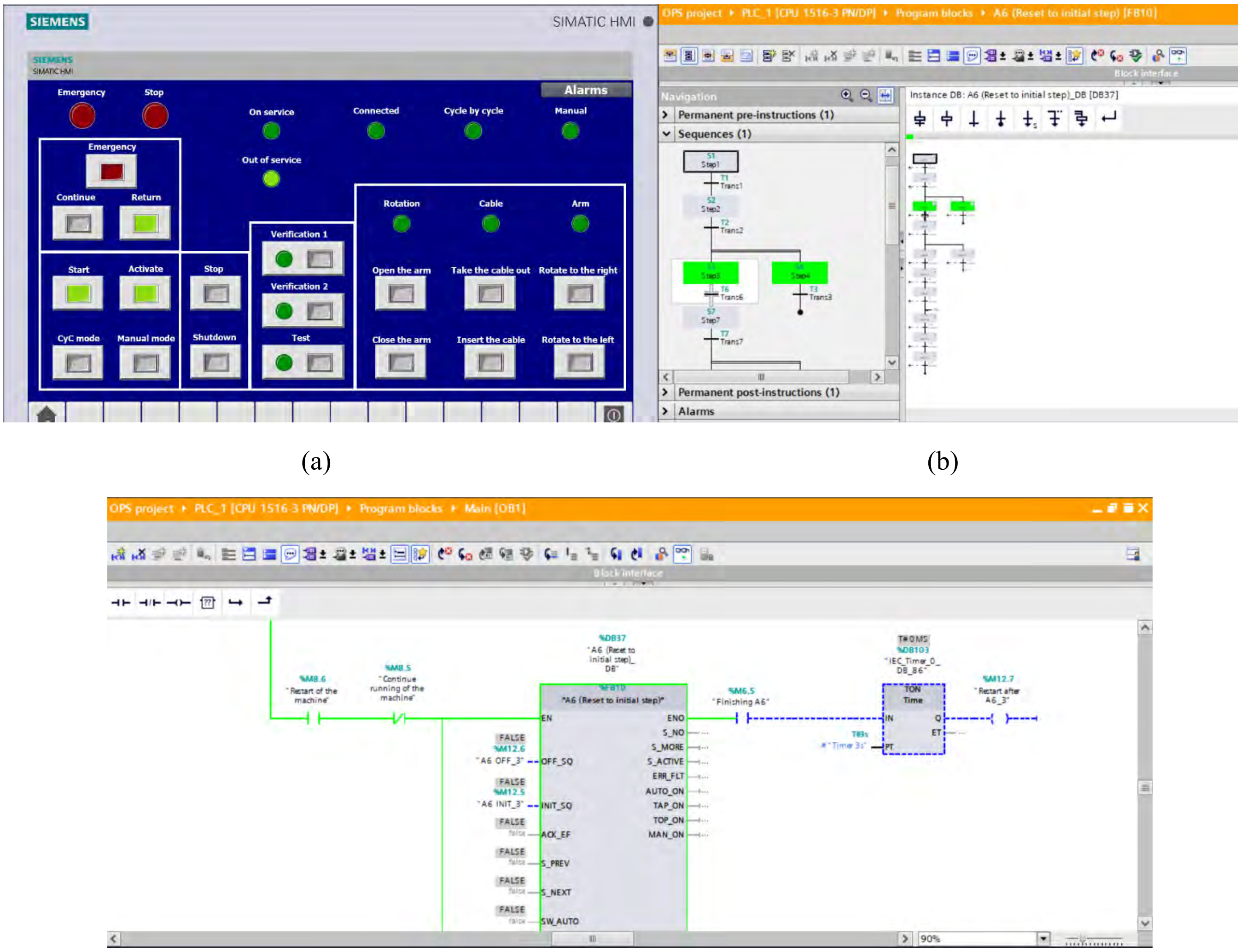


(a) (b)

(c)

Figure 6.102: The program is placed at normal production mode (F1) of GEMMA, cycle by cycle mode, while the open the arm is activated. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

The second alternative that the operator has after the failure has been fixed is to restart the crane to its initial state and start over the program as it is explained earlier in this section. The operator is able to do it by pressing the return button in order to prepare the crane for the initial stop state. When the return button is pressed, the algorithm places the program in the reset to initial state (A6). In this mode the program detects which parts of the crane are not in their initial state in order to reset the crane. Figure 6.103 shows the operation screen while the return button has pressed. It is possible to notice that the program is still out of service. Also, the figure presents the program, and the Fuzzy Petri Nets intelligent algorithm while the program is placed at this mode. Moreover, at that moment, the algorithm switches off the normal production mode (F1) due to the operator choice as it is shown in figure 6.104.



(a) (b)

(c)

Figure 6.103: The program is placed at reset to initial state mode (A6) of GEMMA, while the return button is pressed. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

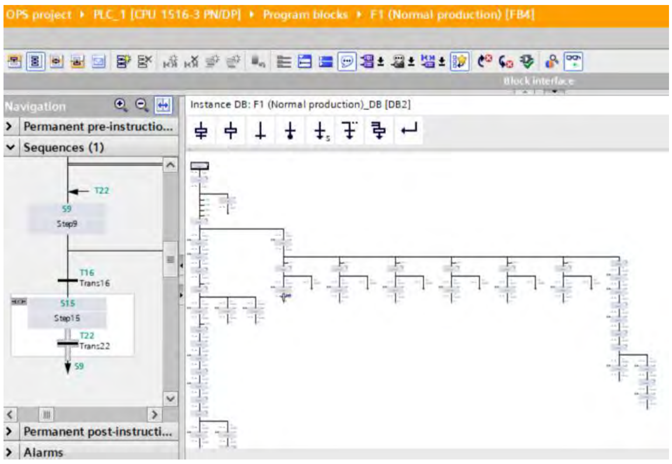
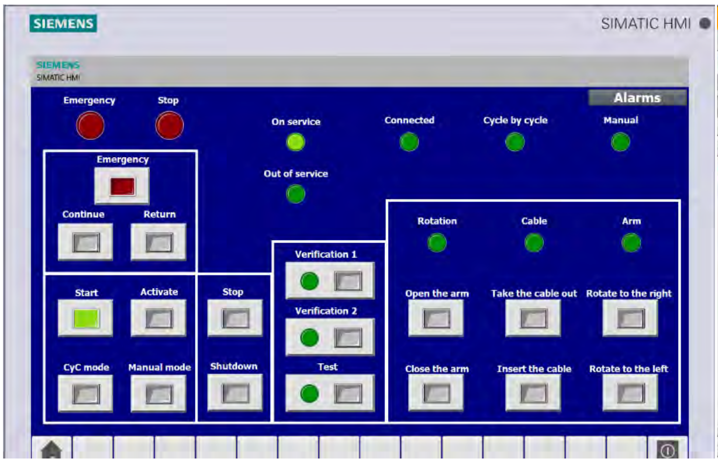
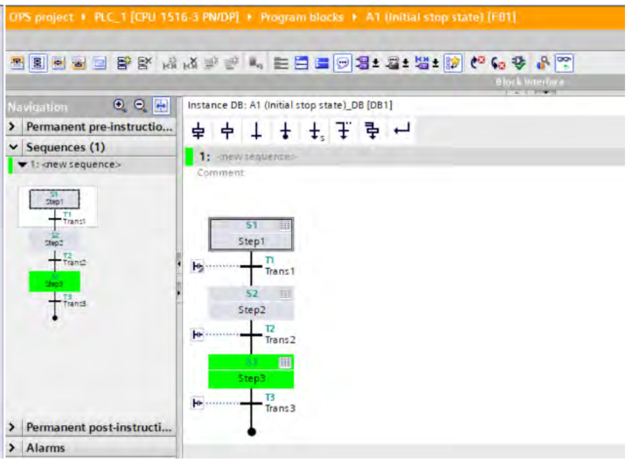


Figure 6.104: The normal production mode (F1) of GEMMA is off

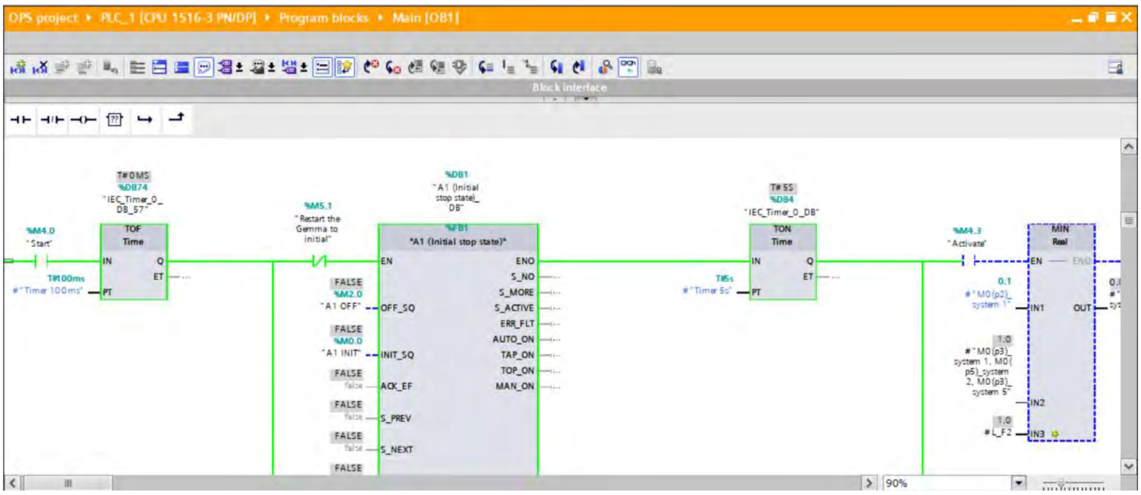
As soon as the closing process of the crane has been finished, the algorithm places the program in the initial stop state (A1) as it is shown in figure 6.105. At this mode, the program is placed at its initial state, and it is ready for the next action of the operator.



(a)



(b)

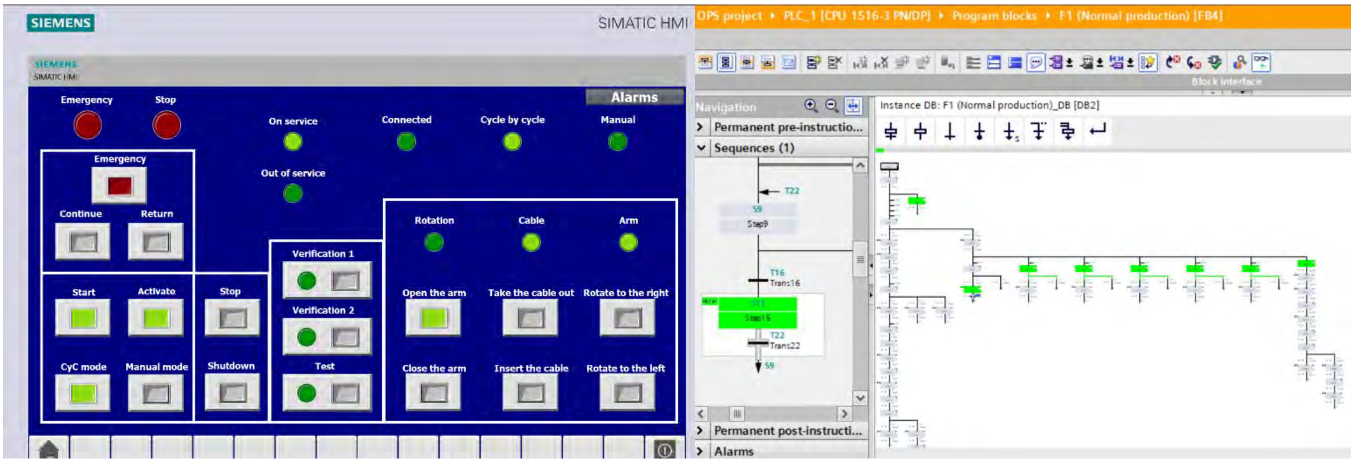


(c)

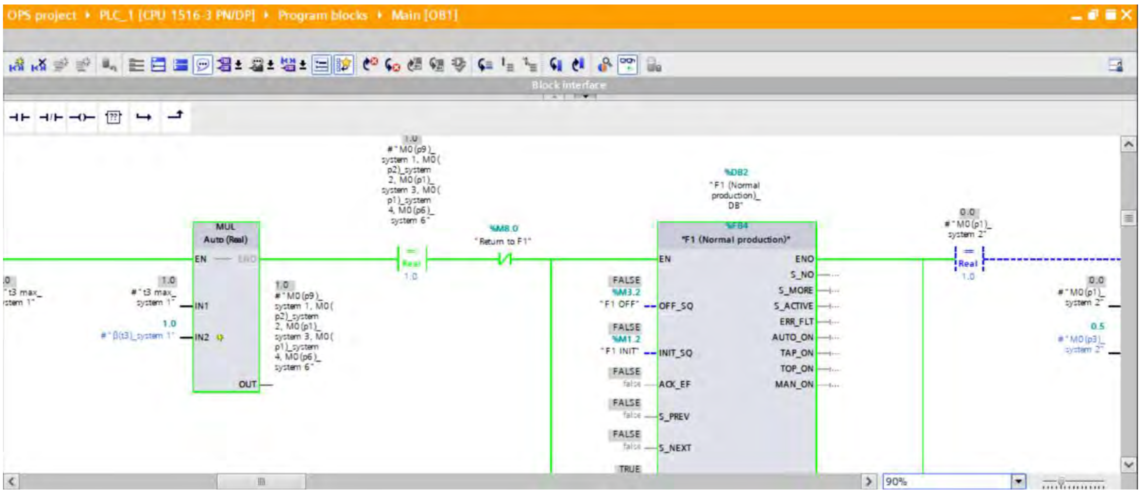
Figure 6.105: The program is placed at the initial stop state (A1) of GEMMA. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

The second failure level is medium critical failure, this level of failure also may put the operator in danger and may damage the machine as well. However, the algorithm treats this level of failure in a different way due to the GEMMA rules. In the following example, the program notices a mechanical problem. The algorithm detects this failure as a medium critical failure and treats the failure in the following way. First of all, the algorithm stops all the activated motors of the crane immediately and freezes the normal production mode (F1), similarly to any emergency situation. Then, the algorithm places the program at diagnosis and/or treatment of the failure (D2) in order to guide the operator to the failure that has occurred as is it explained in Section 3.3.1. When the failure has been fixed, the operator is able to either continue the operation or restart the crane to its initial state, similarly to the order after the emergency stop mode (D1). The difference between the critical and the medium critical failure is the failure diagnosis. In other words, in this level the program is able to detect the problem more specifically in order to help the maintenance workers to fix it due to the different failure type.

The figure below presents the program while it is operated normally without any failure. Alike to the last example, the program is placed at the normal production mode (F1), in Cycle by Cycle mode, while the arm is opening.



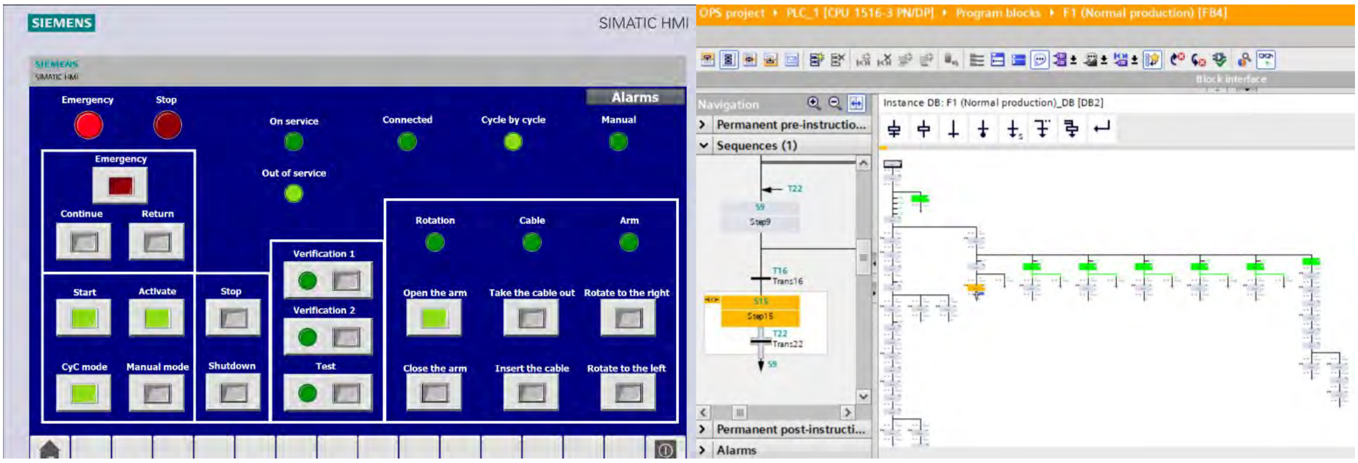
(a) (b)



(c)

Figure 6.106: The program is placed at normal production mode (F1) of GEMMA, cycle by cycle mode, while the open the arm is activated. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

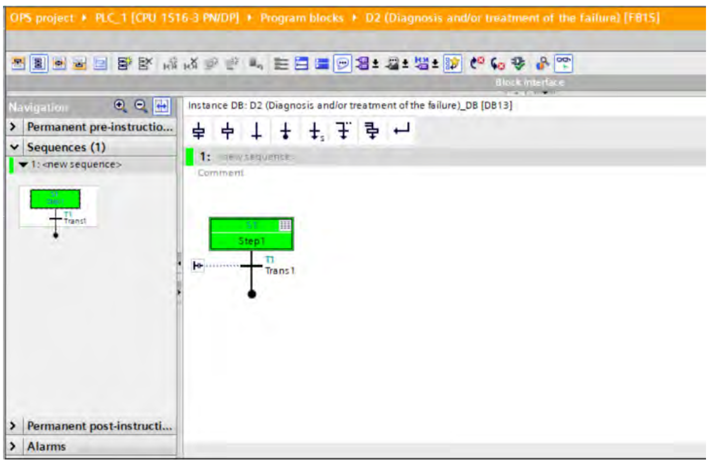
When the medium failure occurs, the program detects it, and the algorithm stops all the activated motors, and freezes the normal production mode (F1) as it is explained before. Figure 6.107 presents this situation, it is possible to see in the operation screen that all the motors are deactivated, the program is in out of service, and the emergency led is activated. Moreover, the step that activates the motor is frozen (its color has changed to orange).



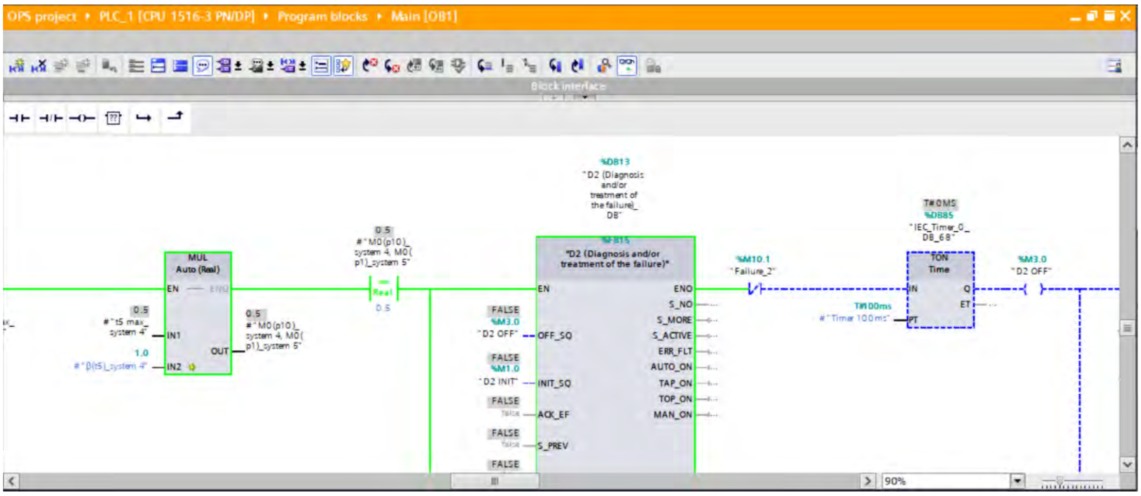
(a) (b)

Figure 6.107: The normal production mode (F1) of GEMMA is frozen while a medio critical failure is detected. (a) the screen, (b) the program

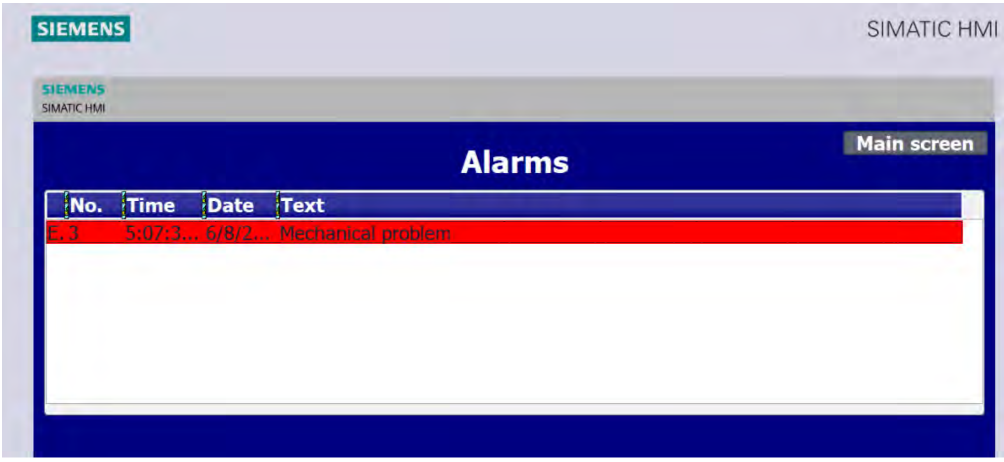
At that moment, the algorithm places the program at the diagnosis and/or treatment of the failure (D2). This mode diagnosis the failure in order to guide the maintenance workers. As it is shown in figure 6.108 the alarm screen presents the failure, and there is a mechanical problem at this case. Due to this information, the maintenance workers know that they have to check the crane mechanically. The figure also shows the program, and the Fuzzy Petri Nets intelligent algorithm while the program is placed at this mode.



(a)



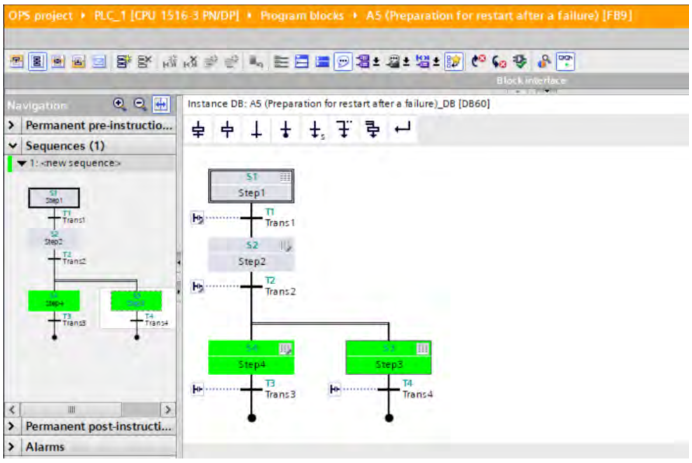
(b)



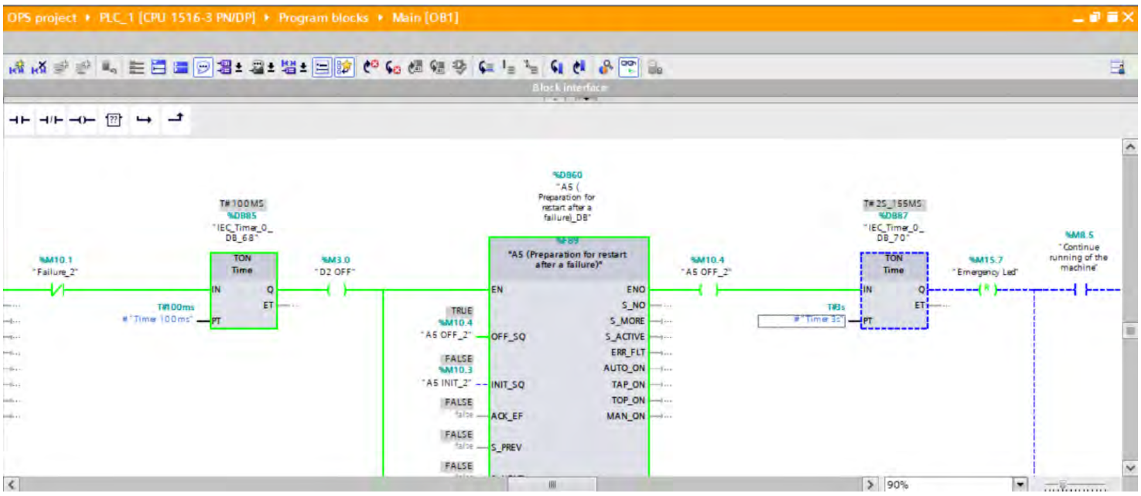
(c)

Figure 6.108: The program is placed at the diagnosis and/or treatment of the failure mode (D2) of GEMMA. (a) the screen, (b) the Fuzzy Petri Nets intelligent algorithm, (c) the alarm screen including the failure presentation

As soon as the failure has been detected, the algorithm places the program in the preparation for startup after a failure (A5). In this mode, the maintenance workers are able to fix the failure and have time without any risk to make sure that everything is properly. Figure 6.109 presents the program and the Fuzzy Petri Nets intelligent algorithm at this mode.



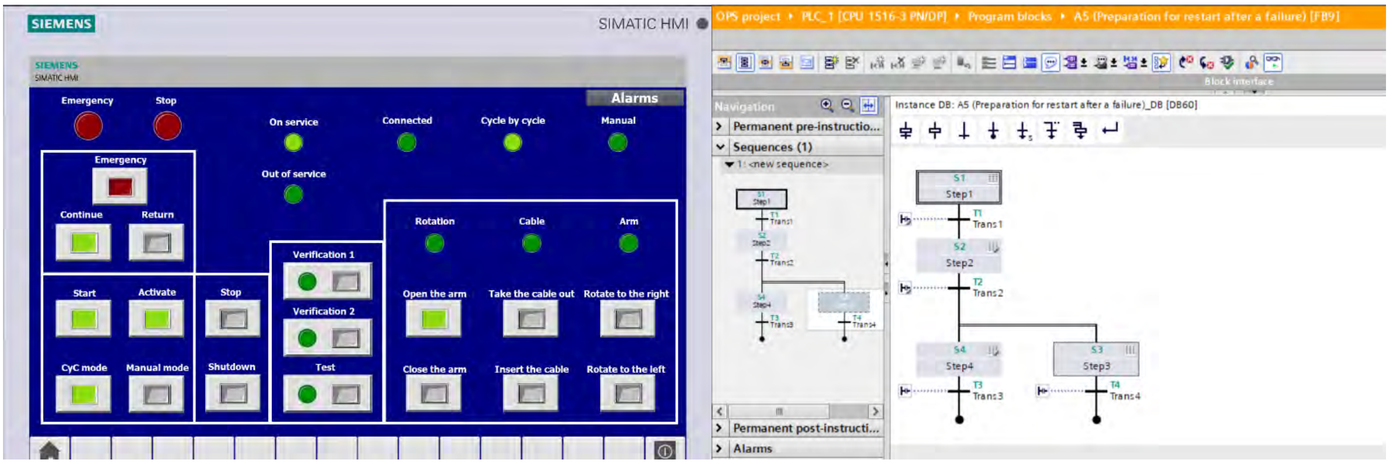
(a)



(b)

Figure 6.109: The program is placed at preparation for startup after a failure mode (A5) of GEMMA, (a) program, (b) the Fuzzy Petri Nets intelligent algorithm

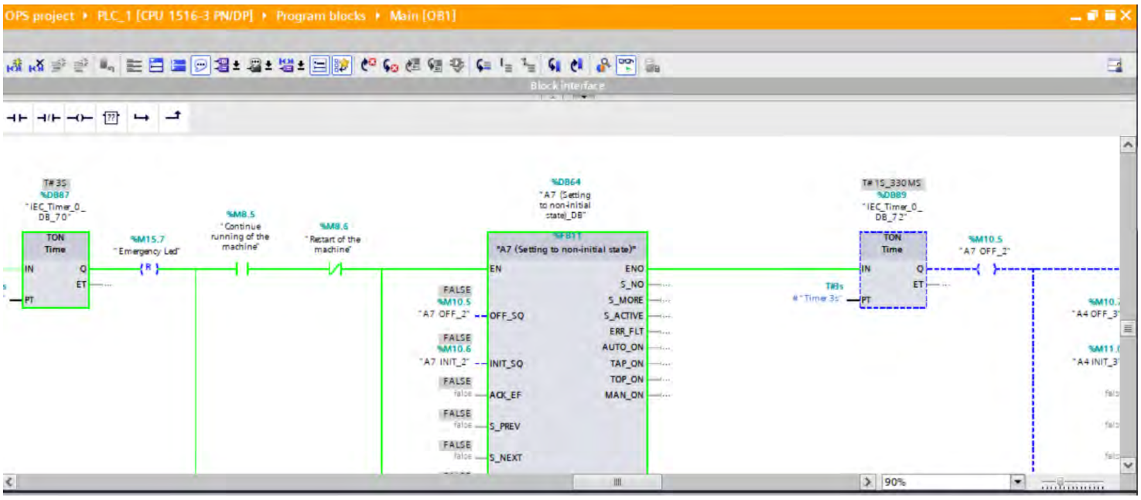
When the failure has been fixed, and the maintenance workers have verified that everything is properly, the operator has two alternatives similarly to last failure cases that has been presented until now. He is able to either continue the operation from the same moment that it stopped when the failure occurred or to reset the crane to its initial state and start over the program. The first case presents the alternative that the operator desires to continue the operation. In this case, the operator presses the continue button, and the algorithm switches off the preparation for startup after a failure (A5) as it is shown in the figure below.



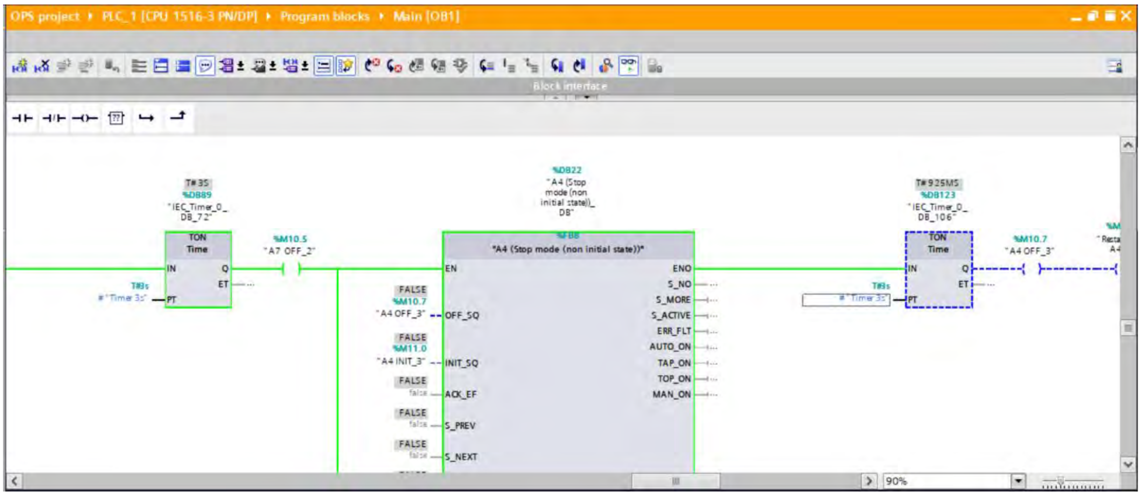
(a) (b)

Figure 6.110: The preparation for startup after a failure mode (A5) of GEMMA is off, while the continue button is pressed. (a) the screen, (b) the program

At that moment, the algorithm places the machine in the setting to non-initial state (A7) in order to prepare the program for the operation. That is to say, in this mode the program uses the memory in order to place the operation back in the exact point of the operation that it sopped when the failure occurred. In the moment that the preparation process has been finished, the algorithm places the program in the stop mode (non-initial state) (A4). In this mode, the program is ready for the operation and waiting to for starting the operation again. Figure 6.111 shows the Fuzzy Petri Nets intelligent algorithm of these two transitions that are explained.



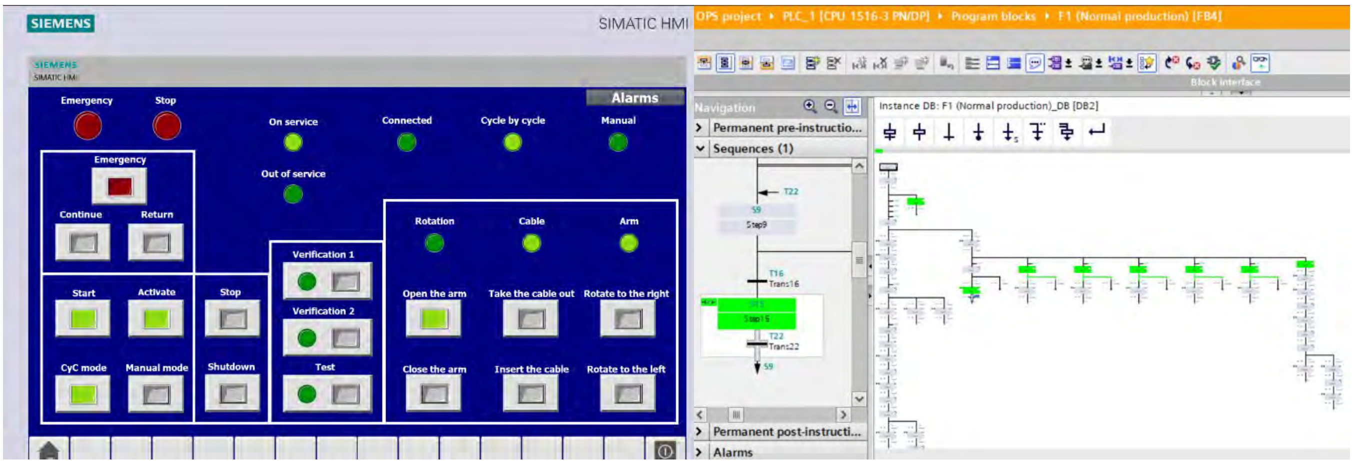
(a)



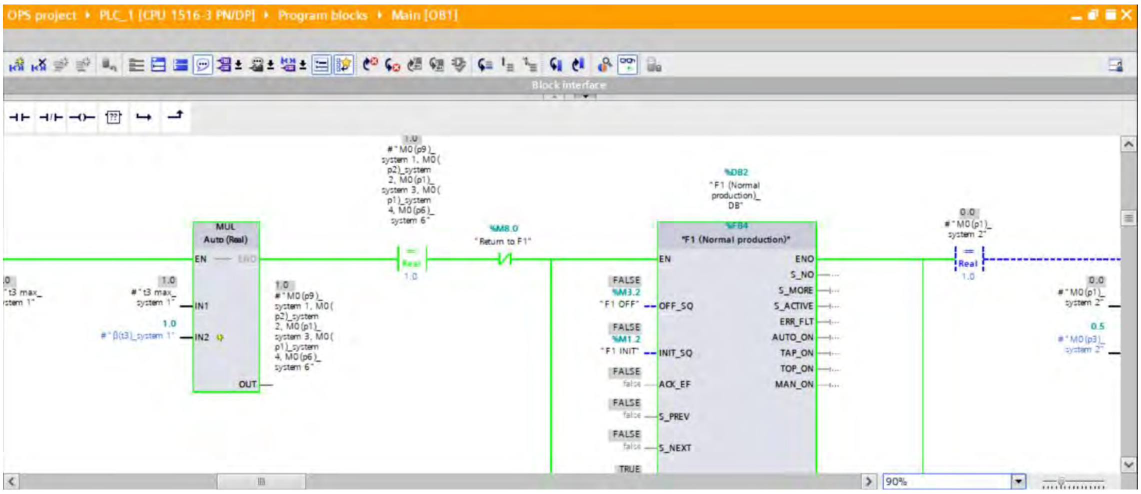
(b)

Figure 6.111: The preparation for startup after a failure mode, the Fuzzy Petri Nets intelligent transitions. (a) setting to noninitial state (A7), (b) stop mode (non-initial state) (A4)

In the next stage, the algorithm places the program in the normal production mode (F1) in the exact point that it stopped when the failure occurred. In the figure below it is possible to notice that the program is placed at the normal production mode (F1), Cycle by Cycle mode, open the arm. The figure presents the operation screen, the program, and the Fuzzy Petri Nets while the program is in the normal operation.



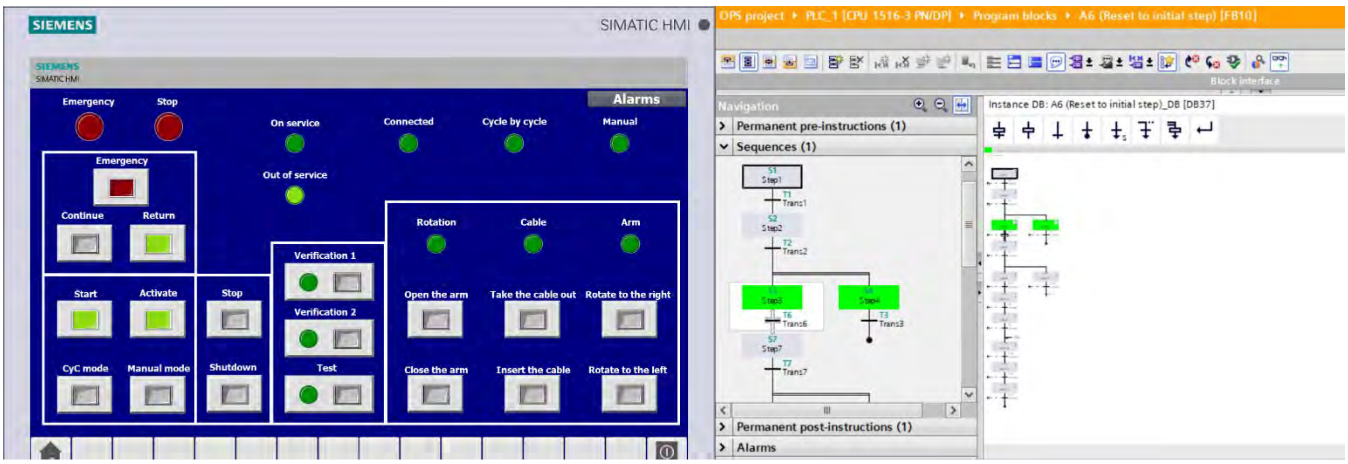
(a) (b)



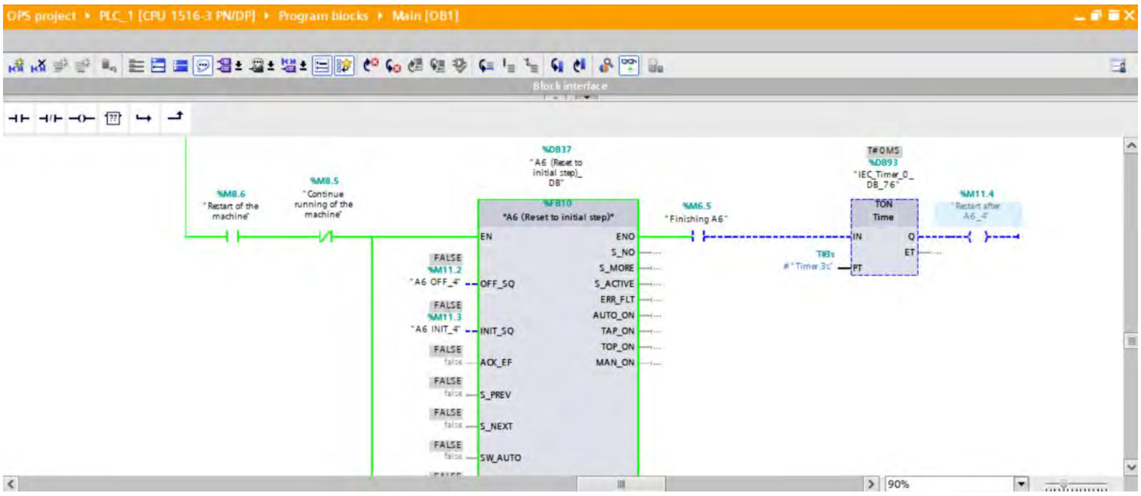
(c)

Figure 6.112: The program is placed at normal production mode (F1) of GEMMA, cycle by cycle mode, while the open the arm is activated. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

The second alternative allows the operator to reset the crane to its initial state, and to start over the program while the operator has this need. At the moment that the failure has been fixed, the operator presses the return button in order to start the reset process. At that moment, the algorithm places the program at the reset to initial state (A6) in order to start the closing process of the crane. Figure 6.113 shows the operation screen while the return button has pressed and indicates that the program is out of service. Also, it is possible to see the program, and the Fuzzy Petri Nets intelligent algorithm at this mode. Additionally, the algorithm switches off the normal production mode that was frozen as it is shown in figure 6.114 due to the reason that this mode is not necessary for this alternative.



(a) (b)



(c)

Figure 6.113: The program is placed at reset to initial state mode (A6) of GEMMA, while the return button is pressed. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

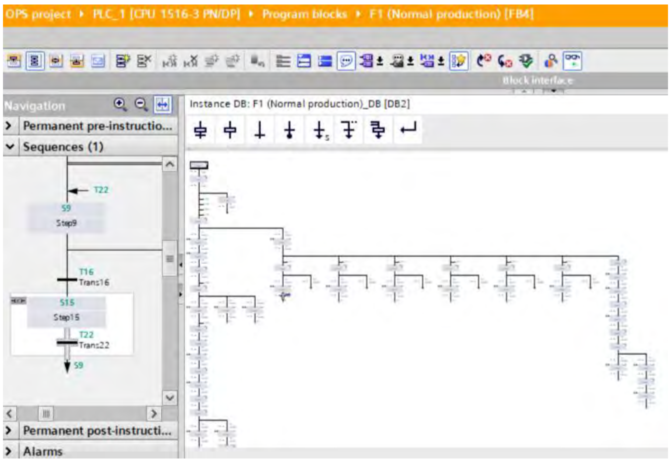
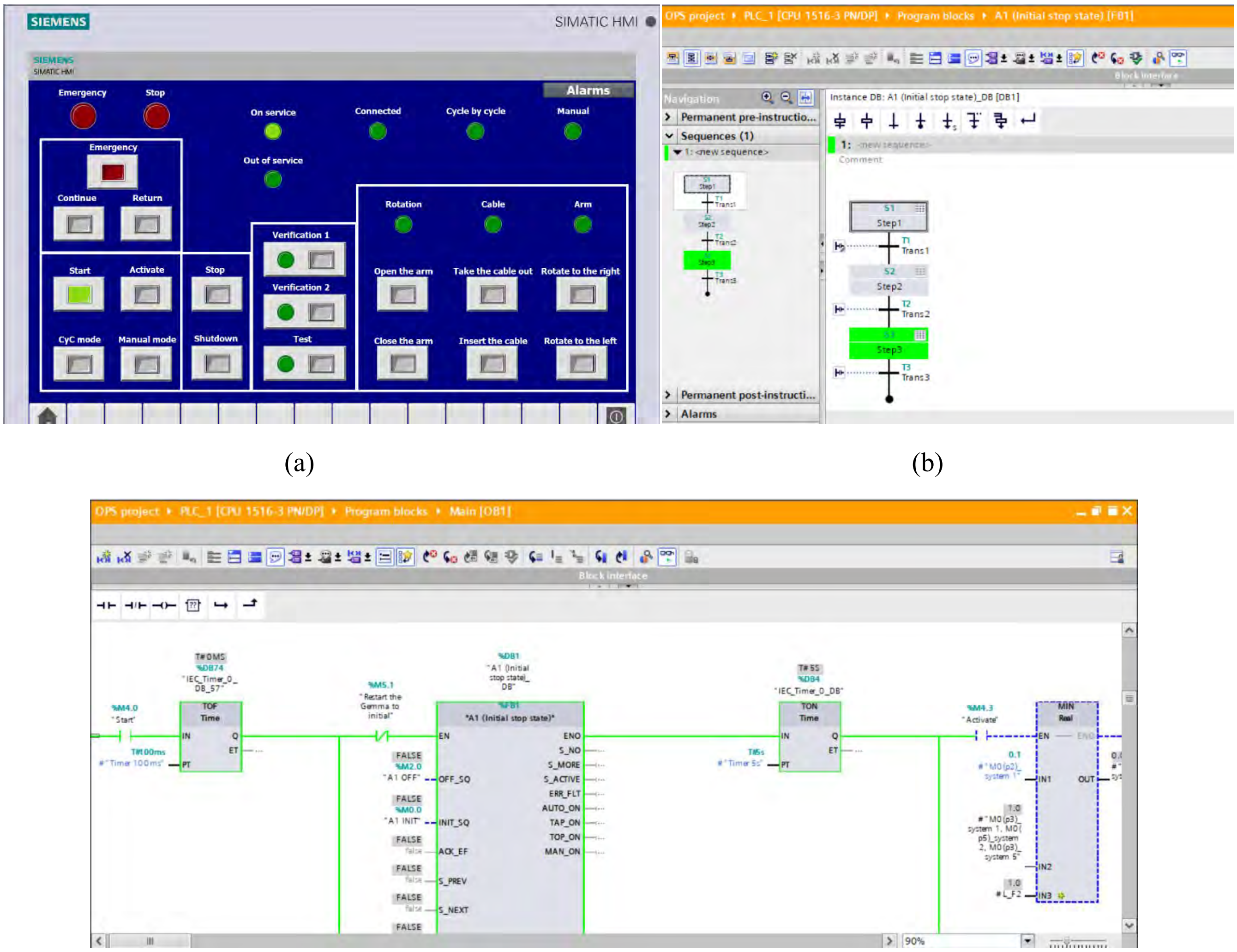


Figure 6.114: The normal production mode (F1) of GEMMA is off

As soon as the closing process of the crane has been finished, the algorithm places the program at the initial stop state (A1) in order to be ready for the next desired action. The figure below shows the operation screen, the program, and the Fuzzy Petri Nets intelligent algorithm while the program is placed at this mode and ready for the next operation.

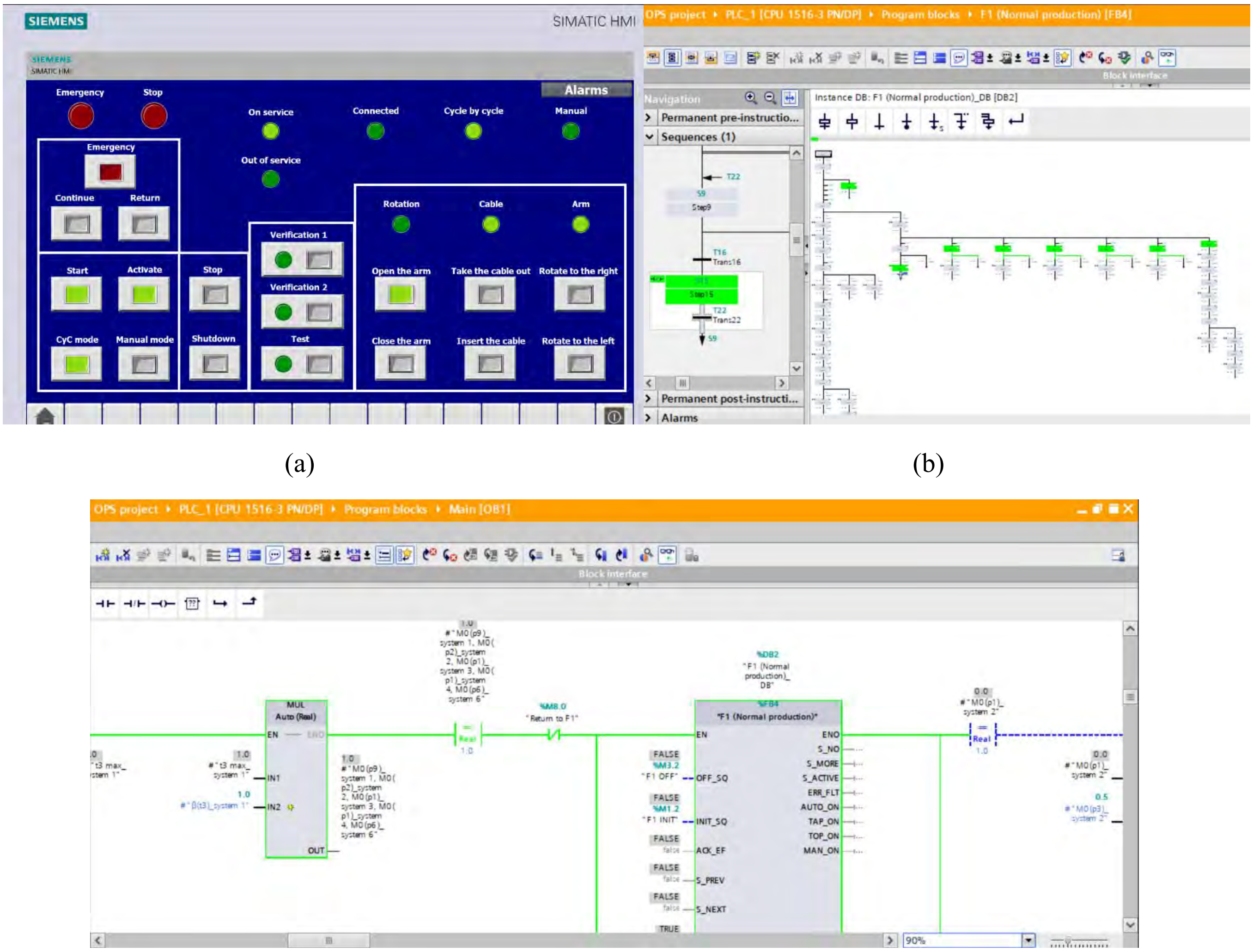


(a) (b)

(c)

Figure 6.115: The program is placed at the initial stop state (A1) of GEMMA. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

The last level of failure is the noncritical failure, this failure is not dangerous to the operator, and will not damage the crane. However, the operator must know about the failure and has to operate the crane carefully according to the failure that has occurred. The figure below presents the same example while the crane is at the normal operation, Cycle by Cycle mode, while the arm is opening. At that moment, there is no failure, and the operation is working properly. The figure presents the operation screen, the program, and the Fuzzy Petri Nets intelligent algorithm.

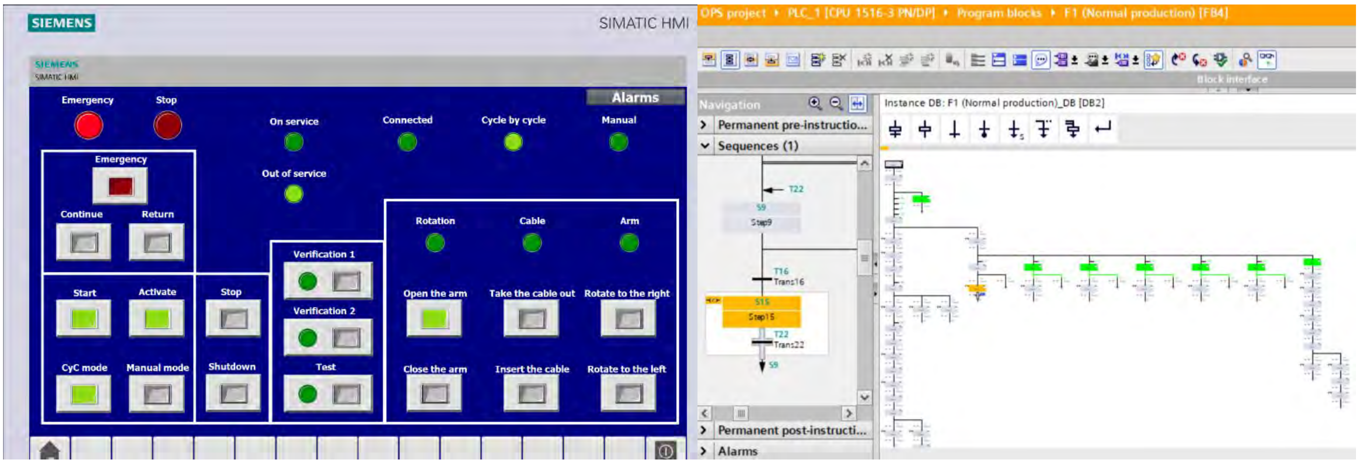


(a) (b)

(c)

Figure 6.116: The program is placed at normal production mode (F1) of GEMMA, cycle by cycle mode, while the open the arm is activated. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

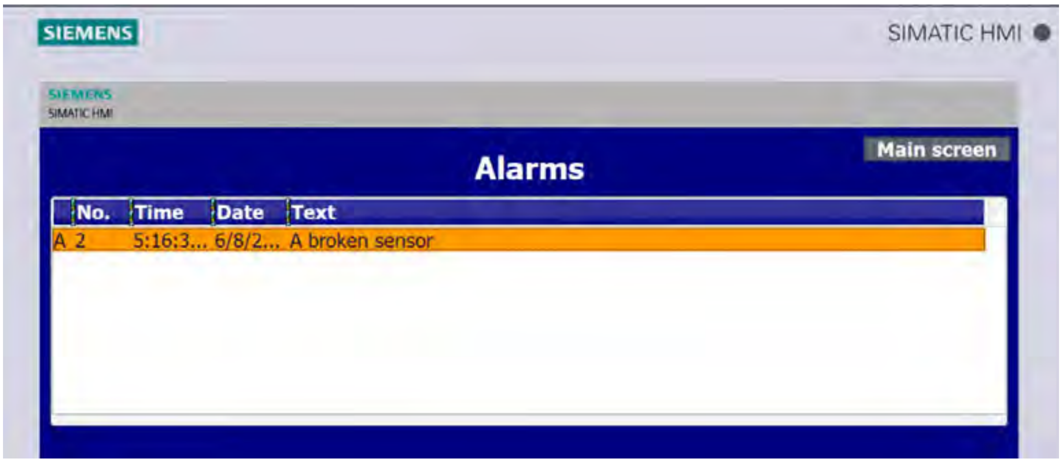
At the moment that the failure occurs, the algorithm stops immediately the motors that are working, and freezes the normal production mode (F1) in the same way as any emergency situation. The figure below shows this situation, it is possible to see the operation screen, and the program while it is frozen.



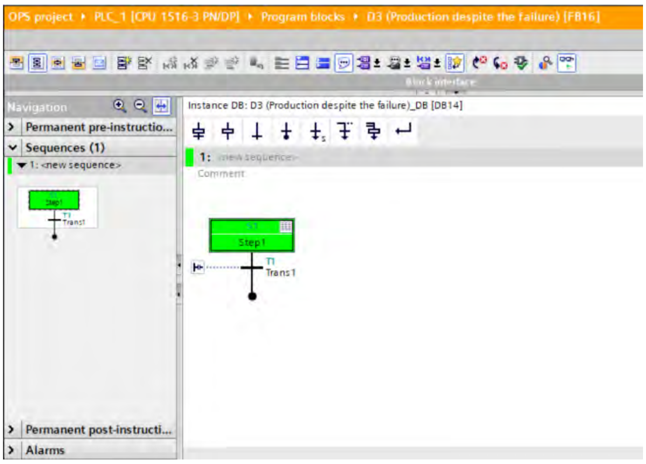
(a) (b)

Figure 6.117: The normal production mode (F1) of GEMMA is stopped while a noncritical failure is detected. (a) the screen, (b) the program

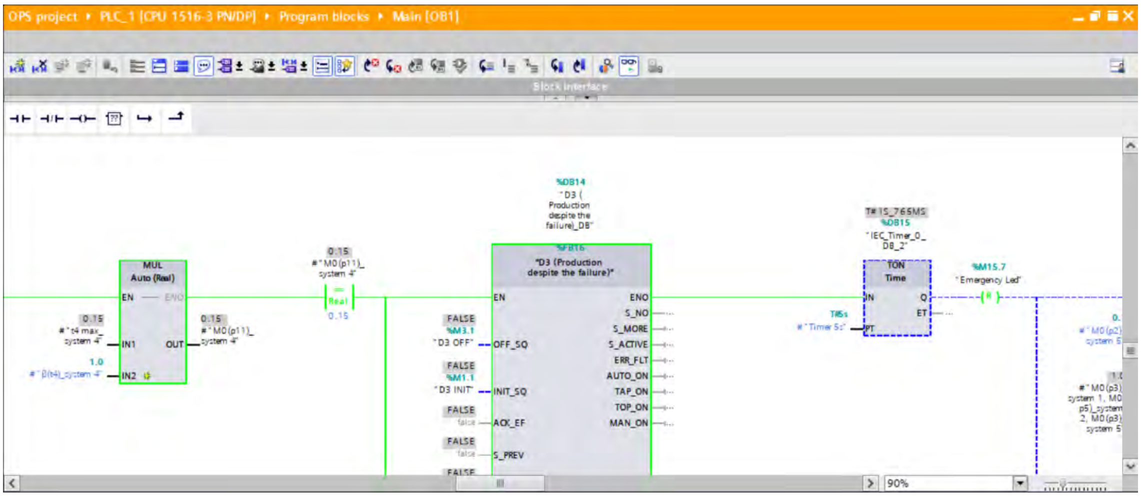
At the same time, the algorithm places the program in the production despite the failure (D3). This mode allows the operator to continue the operation despite the failure. Moreover, the failure description is appeared on the alarm screen in order to inform the operator about the failure. Figure 6.118 shows the alarm screen including the failure description, one of the crane sensors are broken in this case. This information allows the operator to operate the crane carefully and to not depend on the sensors. The figure also shows the program, and the Fuzzy Petri Nets intelligent algorithm while the program is placed at this mode.



(a)



(b)



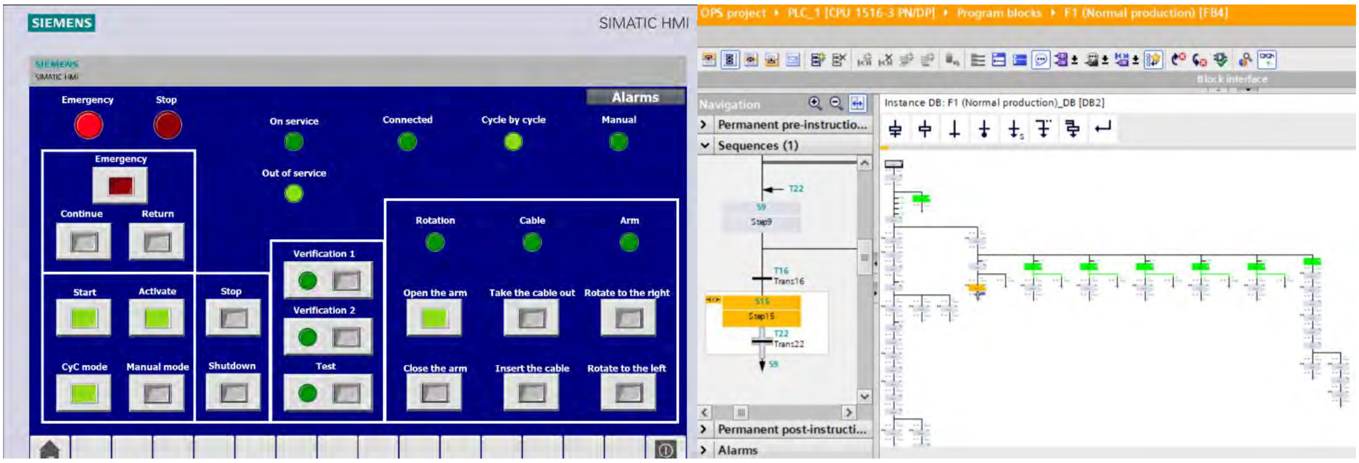
(c)

Figure 6.118: The program is placed production despite the failure mode (D3) of GEMMA. (a) alarm screen including the failure presentation, (b) program, (c) the Fuzzy Petri Nets intelligent algorithm

6.1.4.5. Failure Procedure to Stop Procedure

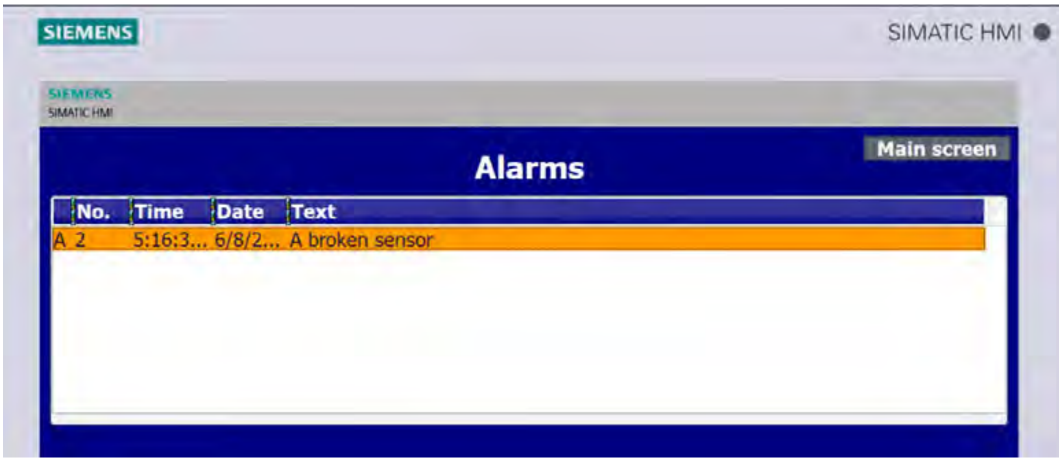
The failure procedure to stop procedure transitions are very important for the proper operation of the control system as it is explained deeply in Section 4.6. These transitions of the intelligent algorithm place the program automatically in the suitable mode according the crane situation. In other words, while there is a noncritical failure in the crane as it is sown in Subsection 6.1.4.4, the algorithm will automatically place the program in requested stop (non-initial state) (A3) in order to continue the operation. Moreover, if the failure occurred at some point that the crane is still in its initial state, the algorithm will place the program in requested stop at the end of the cycle (A2) in order to start over the program.

Figure 6.119 presents the program in emergency situation while all the motors are deactivated, and the normal production mode (F1) is frozen. This situation shows that the crane was in the middle of the operation, Cycle by Cycle mode, while the arm is opening. The following example is the continuous process of the operation procedure to failure procedure transition for the noncritical failure that was shown in the last subsection. Moreover, figure 6.120 shows the alarm screen, the program, and the Fuzzy Petri Nets intelligent algorithm while the program is placed at this mode.

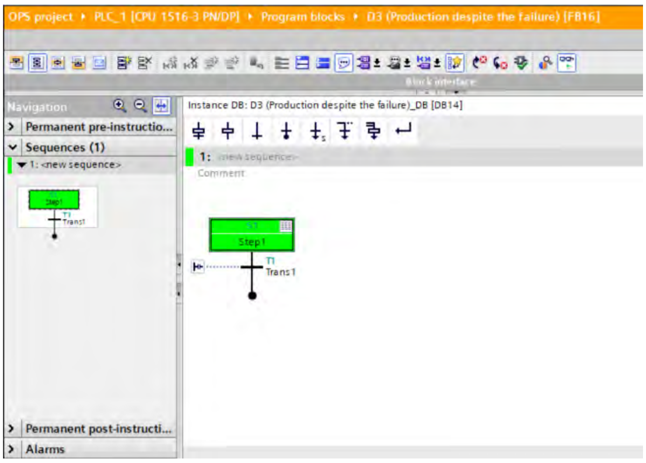


(a) (b)

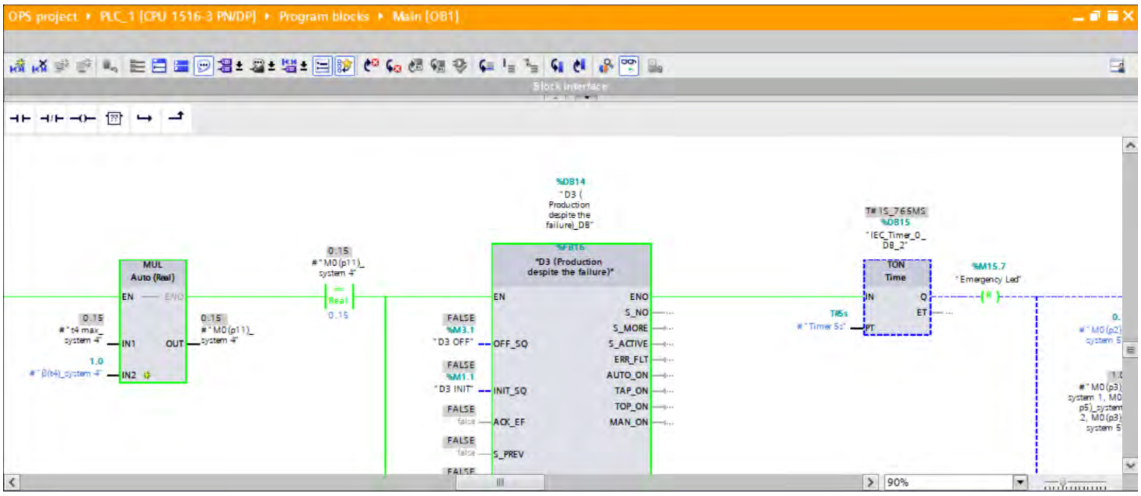
Figure 6.119: The normal production mode (F1) of GEMMA is frozen in a failure. (a) the screen, (b) the program



(a)



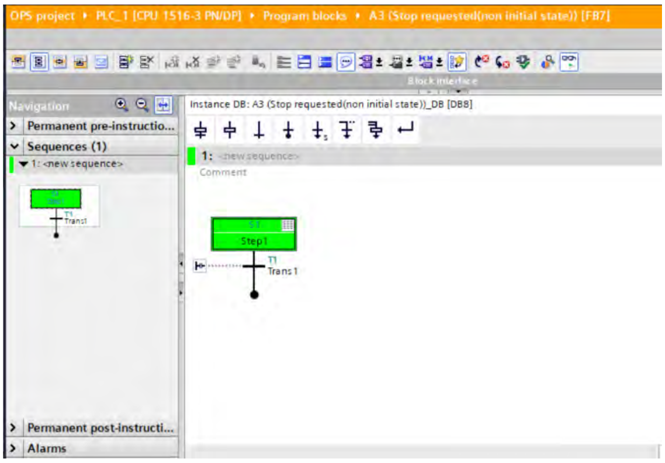
(b)



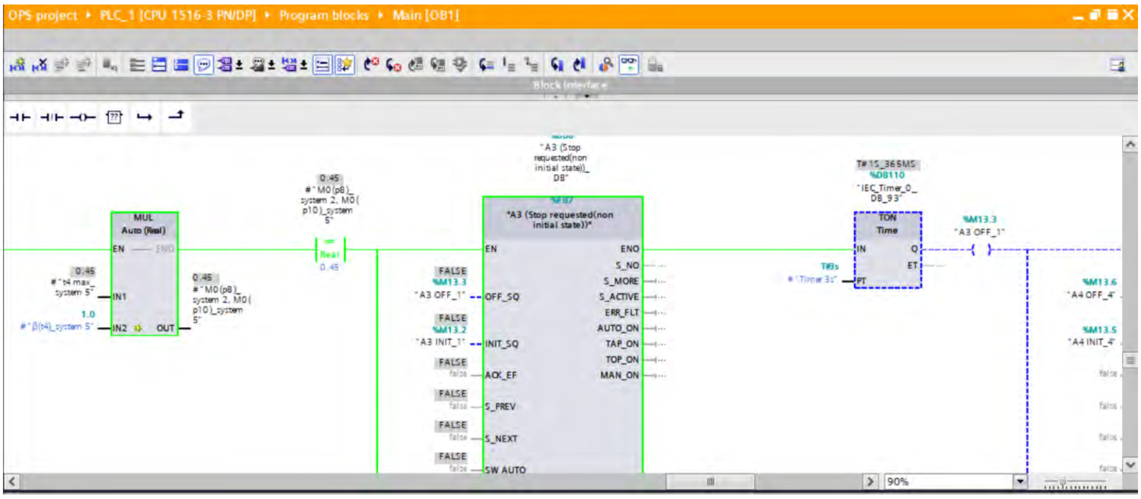
(c)

Figure 6.120: The program is placed production despite the failure mode (D3) of GEMMA. (a) alarm screen including the failure presentation, (b) program, (c) the Fuzzy Petri Nets intelligent algorithm

As it is explained before, the transitions for the failure procedure to stop procedure are divided into two cases. The first case is activated while the crane was at some point of the operation, and the second case is activated while the operation was in the initial state, and the crane is still placed at its initial state. In this example the crane was at Cycle by Cycle mode, the arm was opening as it is possible to see in figure 6.119. For this reason, the first case is appropriate for this example. As it is explained, when the noncritical failure occurred at some point of the operation, the algorithm will place the program at the requested stop (non-initial state) (A3). This mode allows to continue the operation in the exact point of the operation that it was stopped when the failure occurred. Figure 6.121 presents this transition, while the program is placed at the A3 mode. The figure shows the program, and the Fuzzy Petri Nets intelligent algorithm while the program is at this mode.



(a)



(b)

Figure 6.121: The program is placed at the requested stop (non-initial state) mode (A3) of GEMMA. (a) program, (b) the Fuzzy Petri Nets intelligent algorithm

Afterwards, the program is already prepared for the operation, and has memorized the exact operation point. At that moment, the algorithm places the program in the stop mode (non-initial state) (A4) for returning to the operation. The figure below shows the Fuzzy Petri Nets intelligent algorithm while the program is placed at this mode.

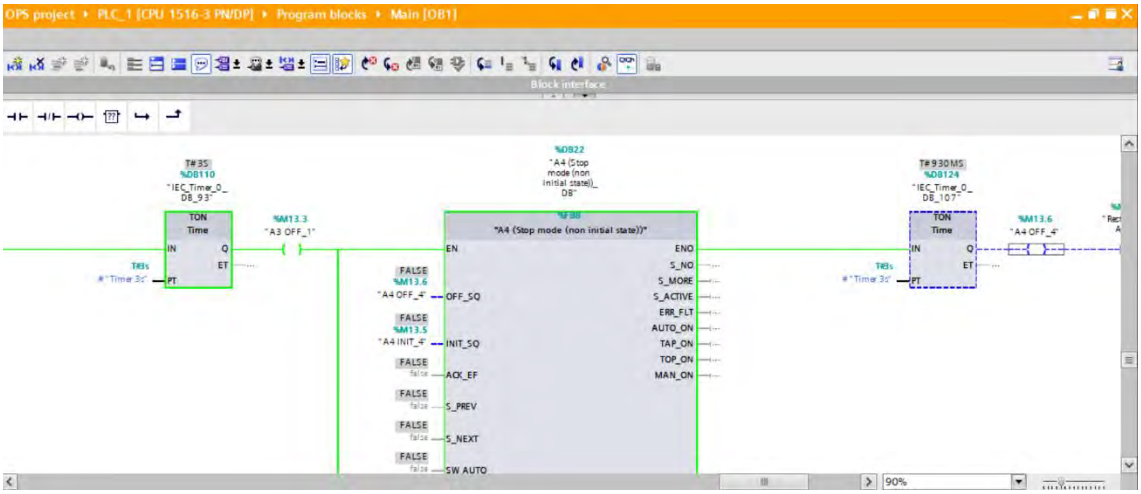
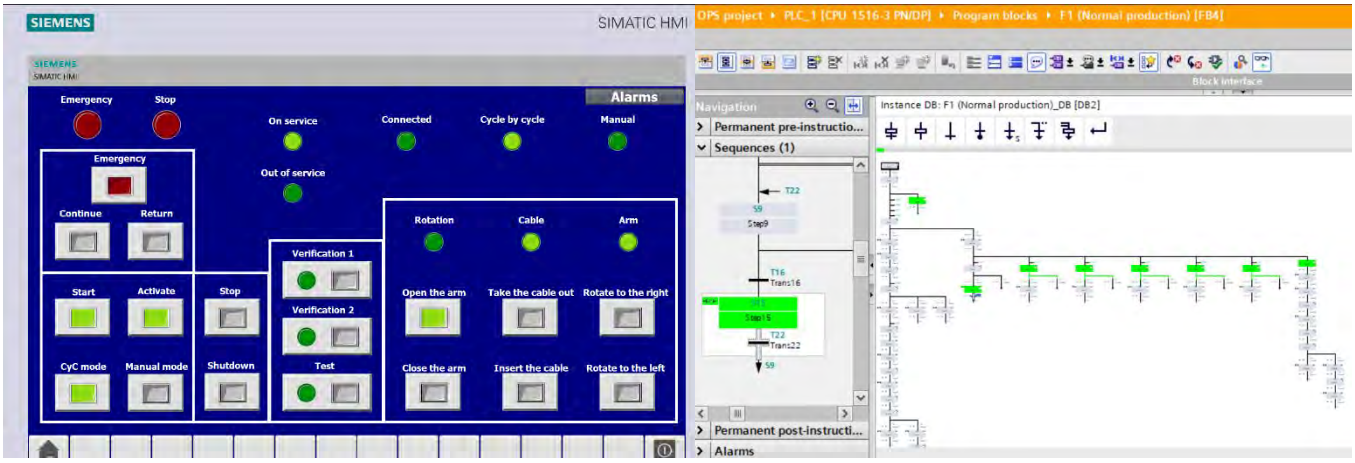
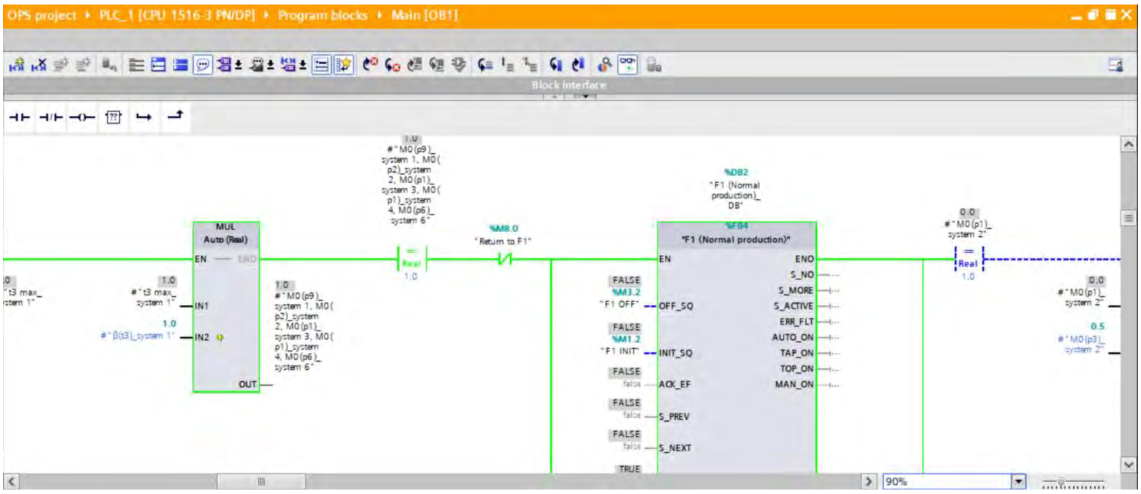


Figure 6.122: The program is placed at stop mode (non-initial state) (A4), the Fuzzy Petri Nets intelligent algorithm

At the moment that the program is placed at the stop mode (non-initial state) (A4), it is ready for returning to the operation. Figure 6.123 presents the operation screen, the program, and the Fuzzy Petri Nets intelligent algorithm while the program has returned to the normal production mode (F1). It is possible to notice that the operation continues in the exact place that it stopped when the noncritical failure occurred.



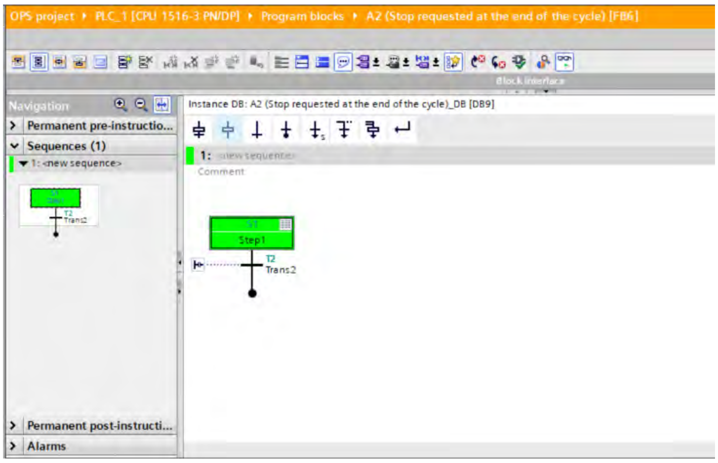
(a) (b)



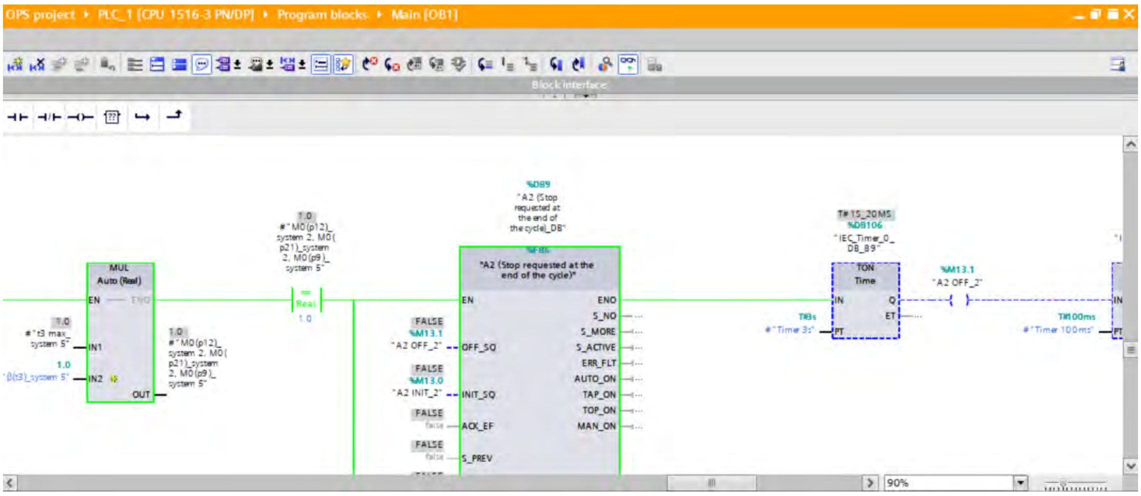
(c)

Figure 6.123: The program is placed at normal production mode (F1) of GEMMA, cycle by cycle mode, while the open the arm is activated. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

In the second case, the crane was in its initial state while the failure occurred. In this situation, the algorithm will place the program automatically at the temporal mode requested stop at the end of the cycle (A2) in order to start over the program. In the figure below it is possible to see the program, and the Fuzzy Petri Nets intelligent algorithm while the program is placed at the A2 mode.



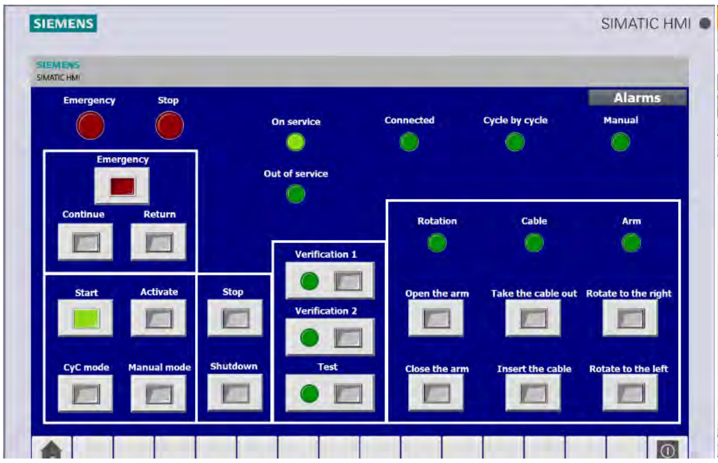
(a)

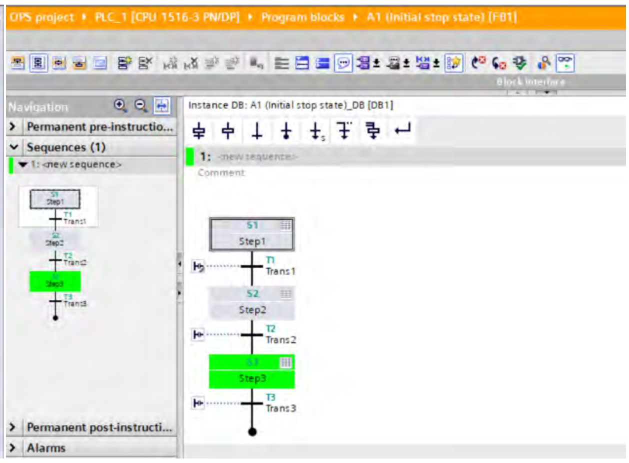


(b)

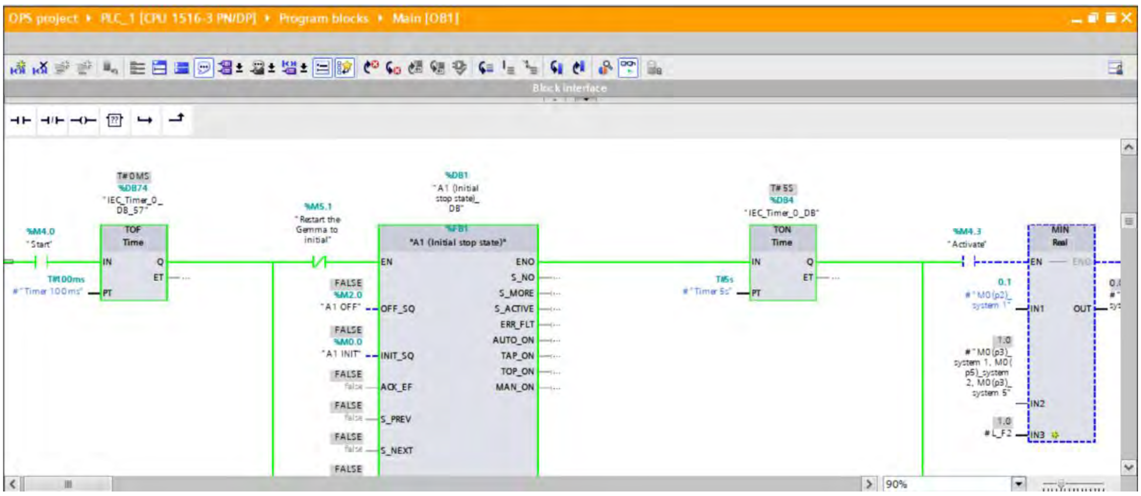
Figure 6.124: The program is placed at the requested stop at the end of the cycle mode (A2) of GEMMA, (a) the program, (b) the Fuzzy Petri Nets intelligent transition

At the next stage, the algorithm places the program at the initial stop state (A1) as it is shown in the figure below. At that moment, the program is ready for the next operation, and also the maintenance workers can fix the failure that occurs in order to operate properly the crane.





(a) (b)



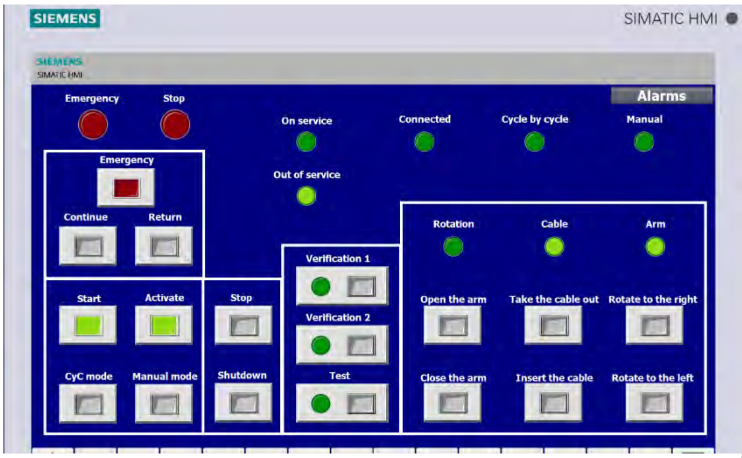
(c)

Figure 6.125: The program is placed at the initial stop state (A1) of GEMMA. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

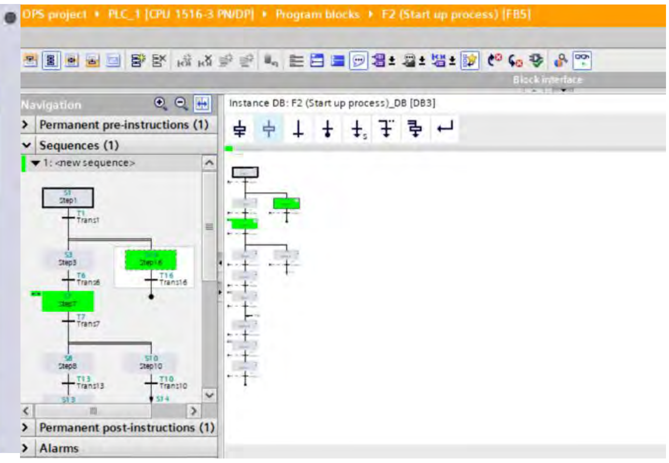
6.1.4.6. The Intelligent Algorithm for Scenario A

The intelligent algorithm for scenario A allows the operator to do the desired action while the crane is at any point of the startup process. In other words, this algorithm provides the option to place the program at the running in verification mode disorderly (F4) at any point of the startup process. This transition is very important and useful for the control system as it is explained in Section 5.2. When the program is placed at the startup process mode (F2) and the operator has the need to do some action in the crane, he is able to do it by pressing the verification 1 button. At that moment, the algorithm will place the program back in the normal production mode, and at last at the running in verification mode disorderly (F4) according to the GEMMA rules.

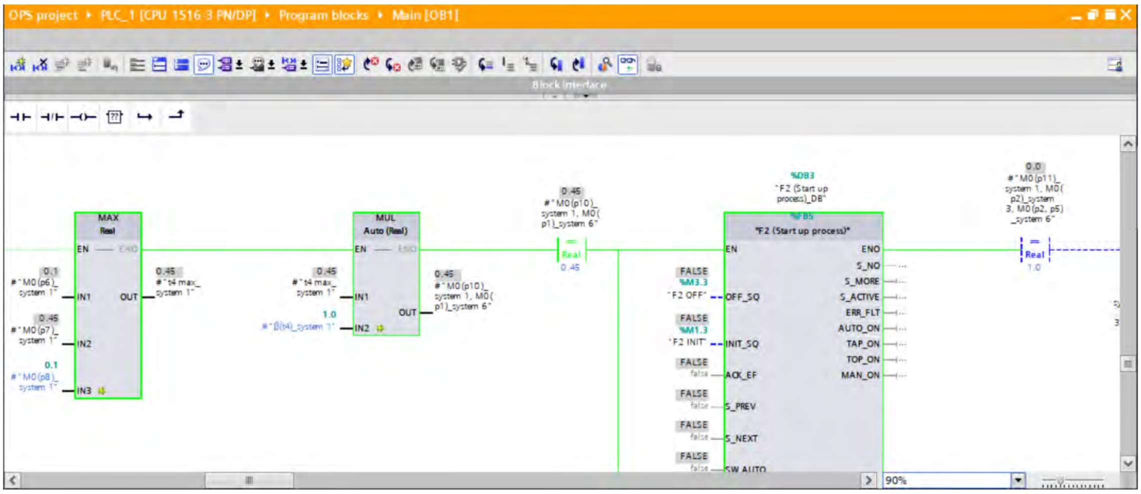
In the figure below, it is possible to see that the program is placed at the startup process mode (F2). At that moment, the crane's closing process is at the closing the arm stage. The figure presents the operation screen which indicates the situation. It is possible to see that the program is out of service, and the related motors are activated. Moreover, the program, and the Fuzzy Petri Nets intelligent algorithm are presented.



(a)



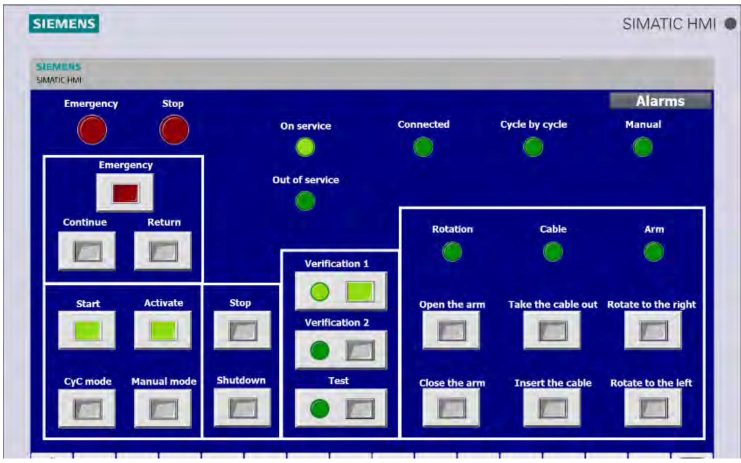
(b)

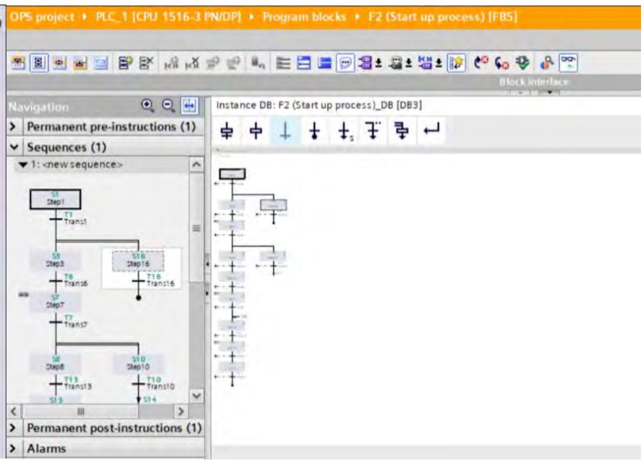


(c)

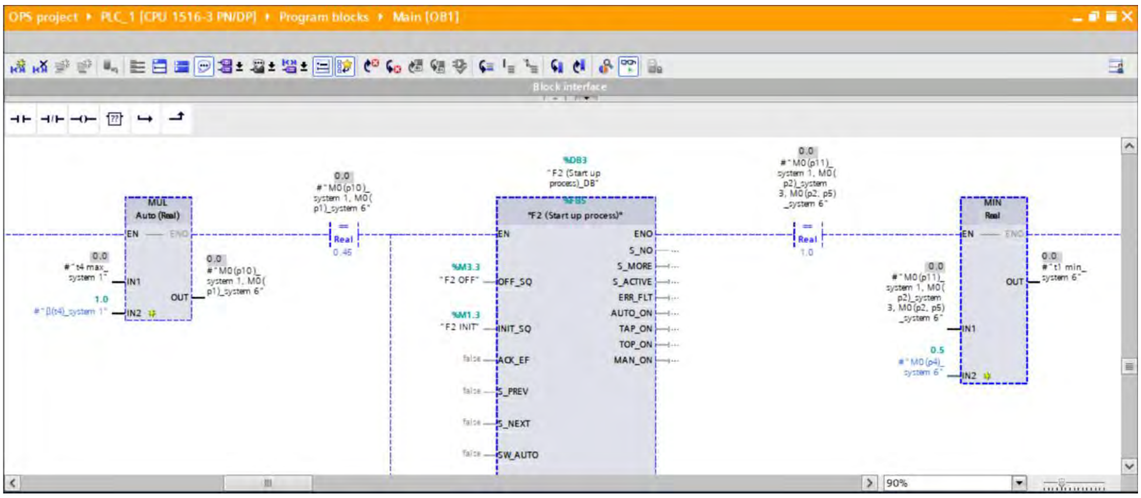
Figure 6.126: The program is placed at the startup process mode (F2) of GEMMA, while the startup process is operated, arm is closing. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

At the moment that the operator desires to stop the startup process in order to do some action in the crane, he is able to do it by pressing the verification 1 button. As soon as the operator presses the button, the algorithm deactivates the motors that are working, and switches off the startup process mode (F2). Figure 6.127 presents the operation screen, the program, and the Fuzzy Petri Nets intelligent algorithm. It is possible to notice that the verification 1 button has pressed, the motors are deactivated, and the F2 mode has switched off.





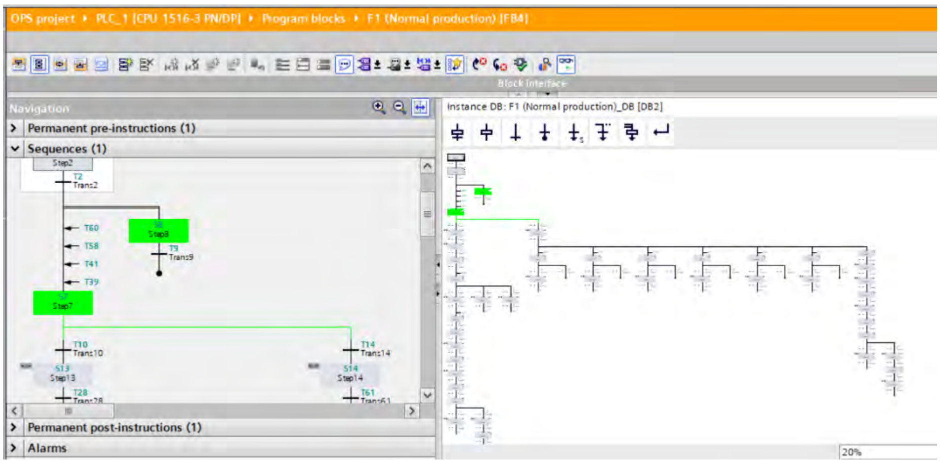
(a) (b)



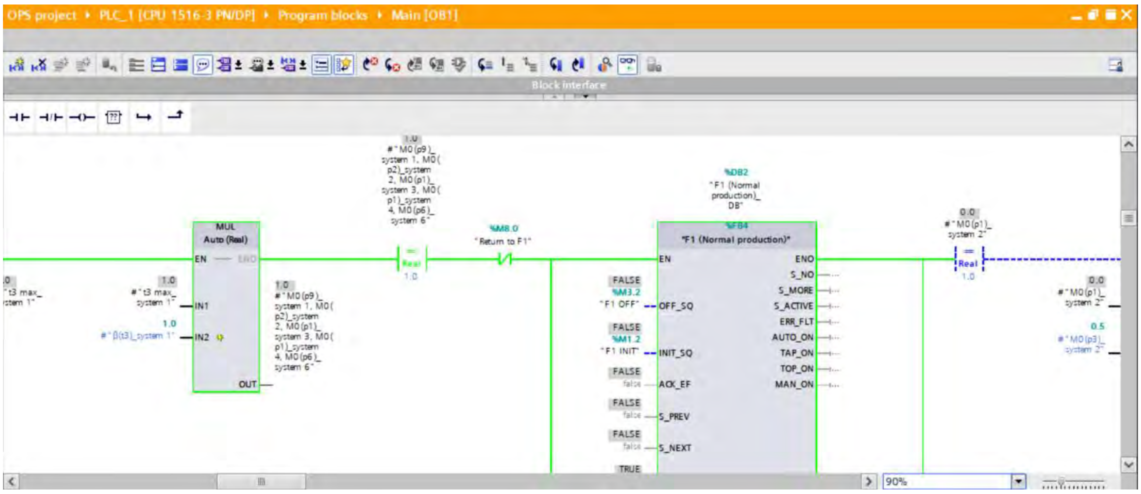
(c)

Figure 6.127: The startup process mode (F2) of GEMMA is off, while the verification button 1 has pressed. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

At that moment, the algorithm places the program at the normal production mode (F1) according to the GEMMA rules. The figure below shows the program, and the Fuzzy Petri Nets intelligent algorithm while the program is placed at the F1 mode.



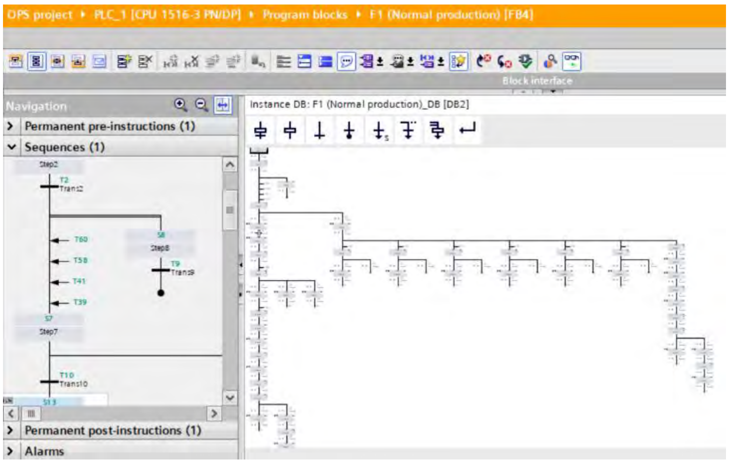
(a)



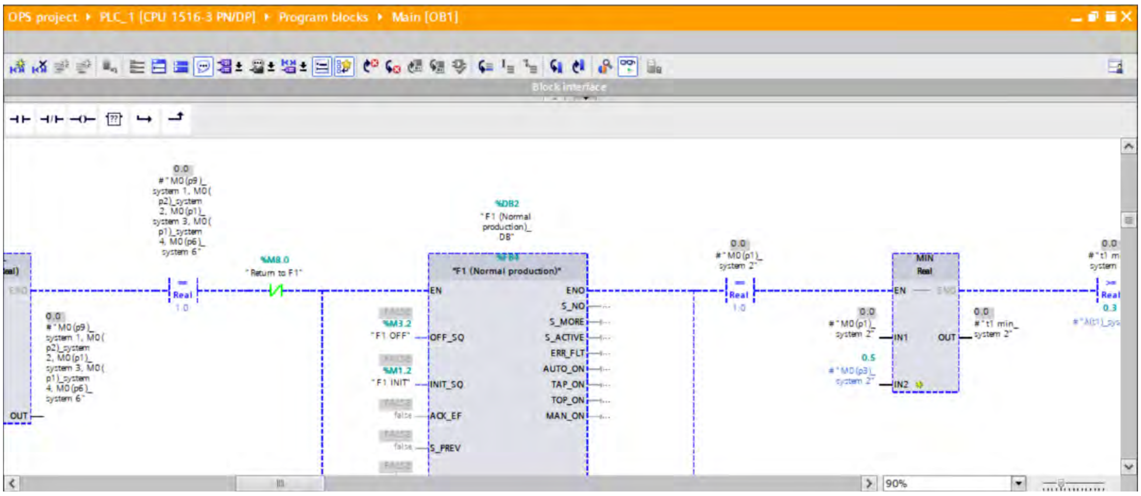
(b)

Figure 6.128: The program is placed at the normal production mode (F1) of GEMMA, after the verification button 1 has been pressed. (a) the program, (c) the Fuzzy Petri Nets intelligent algorithm

When the program is placed at the normal production mode (F1), the operator is able to disactivate the verification 1 button in order to stay at this mode and start the operation again. However, he can continue to the running in verification mode disorderly (F4) in order to do the desired action. In the situation that the button is still pressed, the algorithm will switch off the normal production mode (F1) in order to place the program at the required mode. Figure 6.129 shows this situation, it is possible to see that the normal production mode has switched off. The figure presents the program, and the Fuzzy Petri Nets intelligent algorithm.



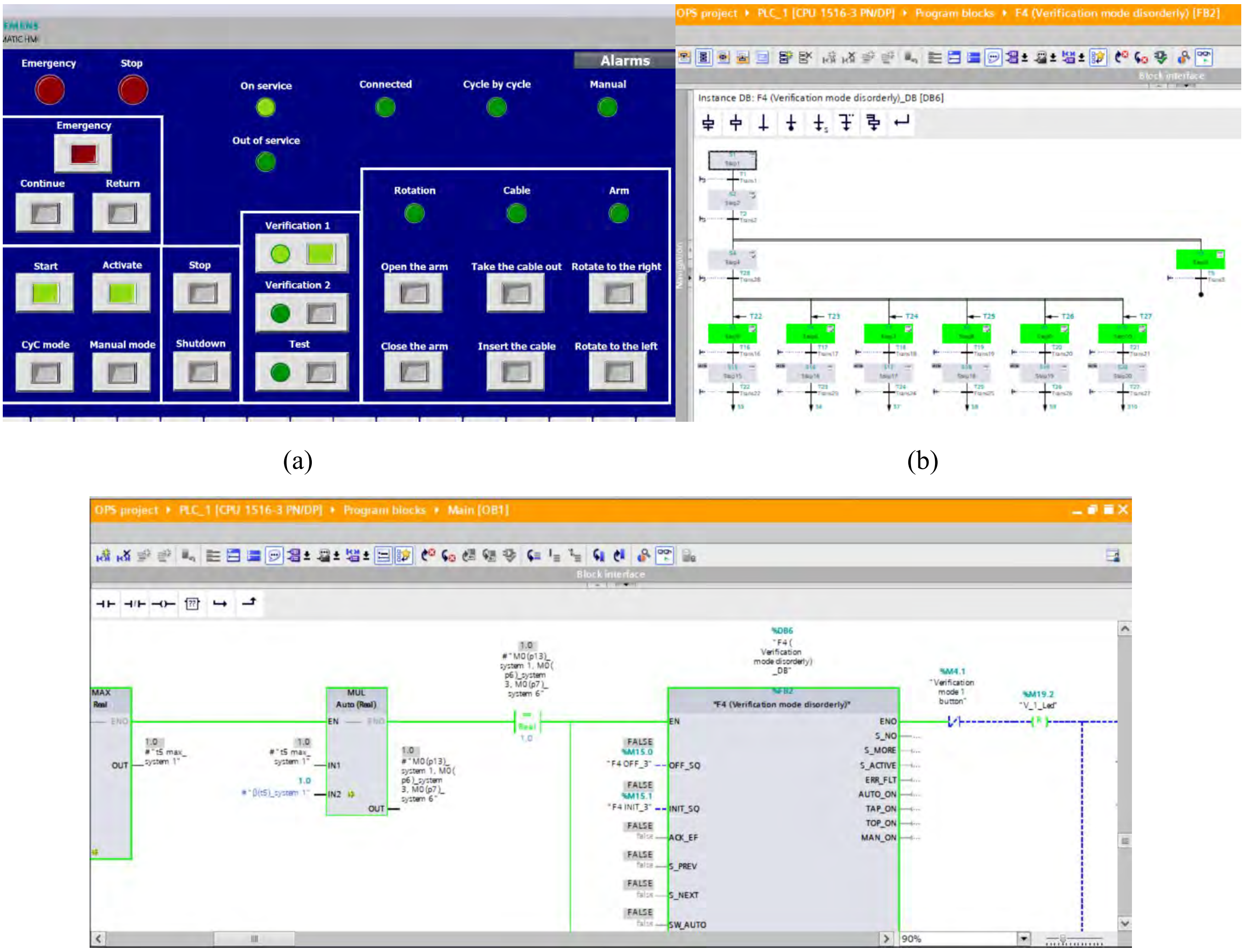
(a)



(b)

Figure 6.129: The normal production mode (F1) of GEMMA is off. (a) the program, (b) the Fuzzy Petri Nets intelligent algorithm

In this stage of the transition, the algorithm places the program at the running in verification mode disorderly (F4). The operator now is able to activate any part of the crane without limitation. The figure below presents the operation screen, the program, and the Fuzzy Petri Nets intelligent algorithm while the program is placed at the F4 mode.



(a) (b)

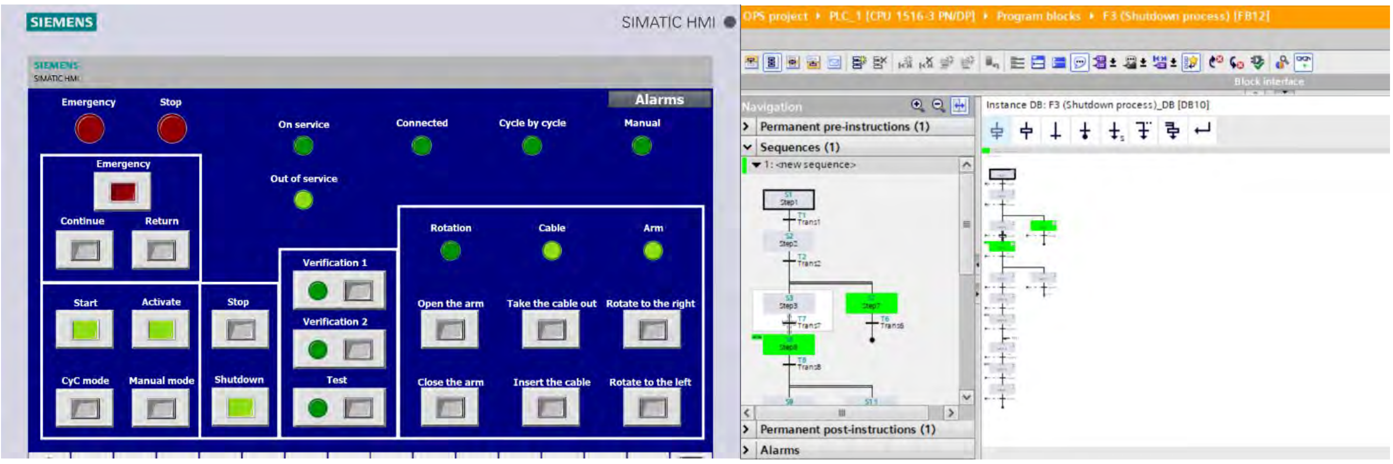
(c)

Figure 6.130: The program is placed at the running in verification mode disorderly (F4) of GEMMA, and it is ready for the different verification modes. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

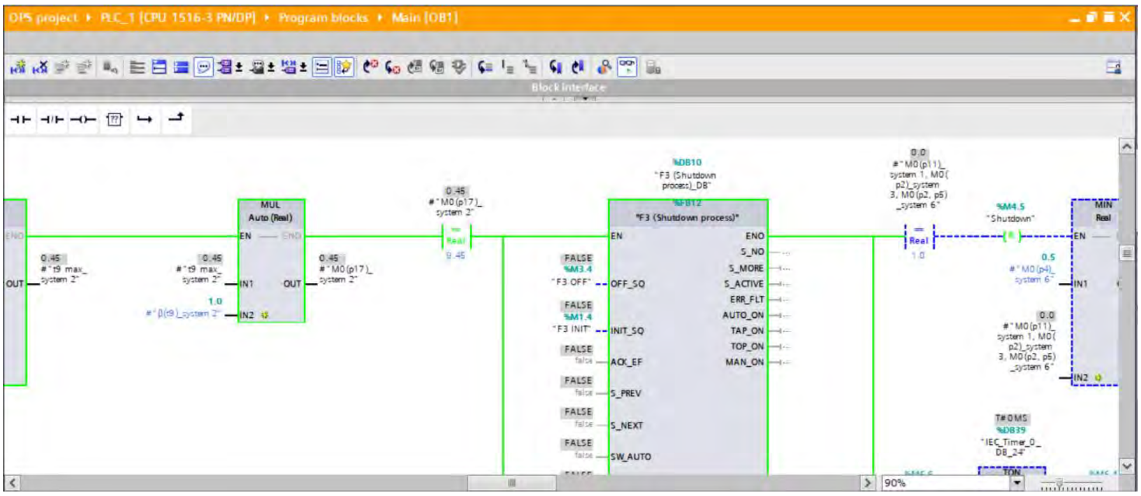
6.1.4.7. The Intelligent Algorithm for Scenario B

The intelligent algorithm for scenario B allows the operator to place the program at the running in verification mode disorderly (F4) at any point of the shutdown process. Similarly to the intelligent algorithm for scenario A, it allows the operator to do any action in the crane while the program is at the shutdown process. This algorithm is very important for the control system of a machine and helps to prevent failures that may occur during the shutdown process. This algorithm is explained deeply in the Section 5.3.

When the program is placed at the shutdown process mode (F3) and the operator desires to stop the process for some reason, he is able to do it by pressing the verification 1 button. At that moment, the algorithm will place the program at the normal production mode (F1) in order to arrive to the running in verification mode disorderly (F4) according to the GEMMA rules. The figure below presents the situation that the program is placed at the shutdown process mode (F3) while the arm is closing.



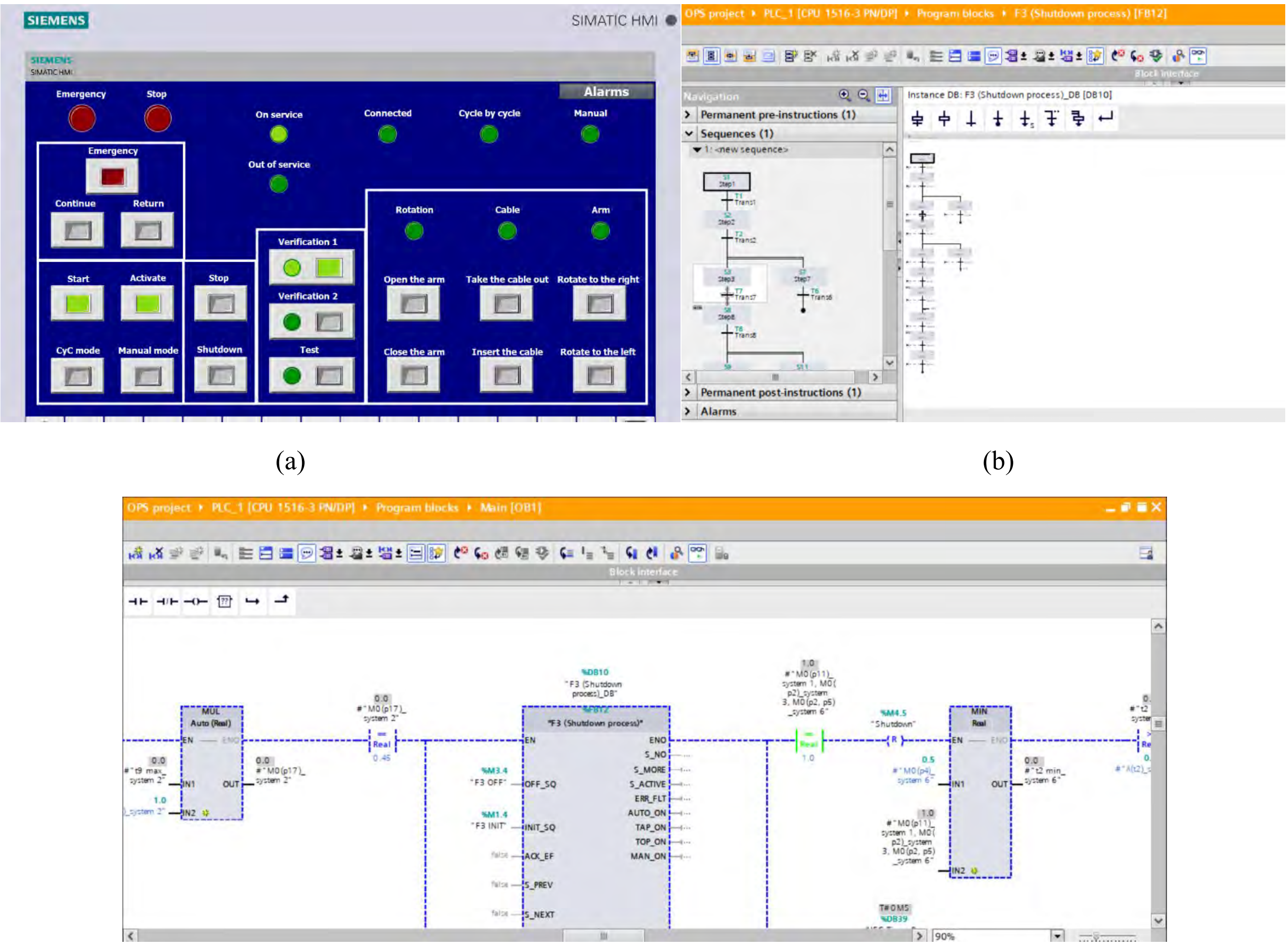
(a) (b)



(c)

Figure 6.131: The program is placed at the shutdown process mode (F3) of GEMMA, while the shutdown process is operated, arm is closing. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

At the moment that the operator desires to stop the shutdown process in order to do some action in the crane, he is able to do it by pressing the verification 1 button as it is explained before. As soon as the operator presses the button, the algorithm deactivates the motors that are working, and switches off the shutdown process mode (F3). It is possible to see this situation in the figure below when the button has been pressed, and the F3 mode is switched off.

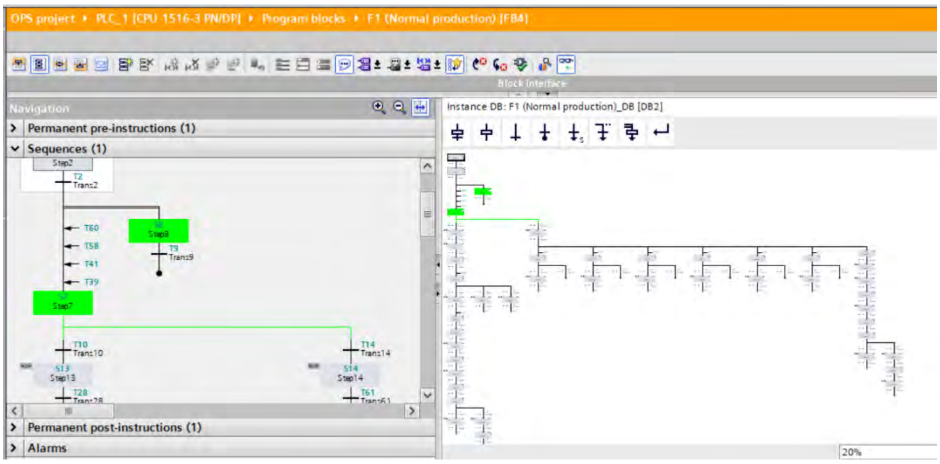


(a) (b)

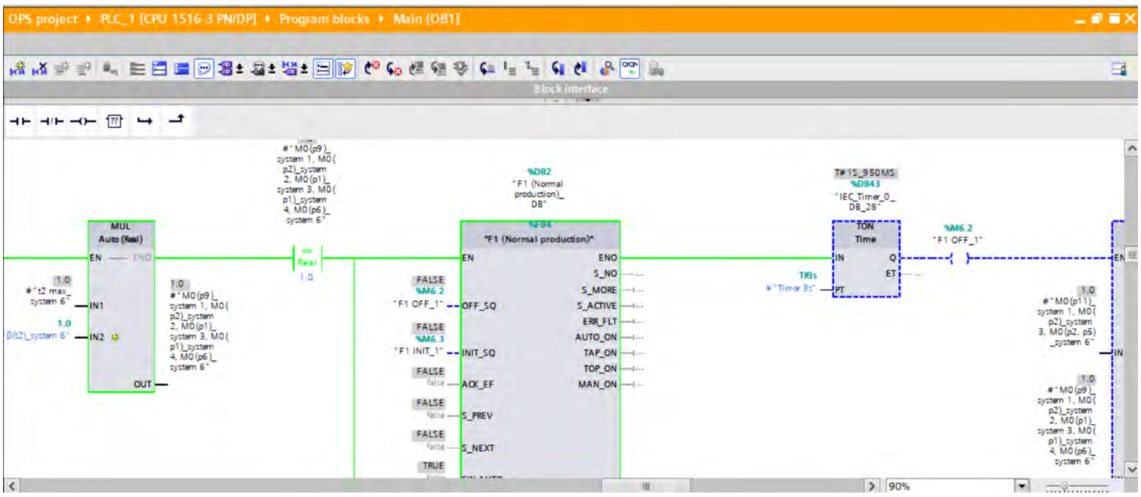
(c)

Figure 6.132: The shutdown process mode (F3) of GEMMA is off, while the verification button 1 is pressed. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

When the operator has pressed the verification 1 button, the algorithm placed the program at the normal production mode (F1) according to the GEMMA rules. At this stage, the operator is able either to operate the crane from this mode or to continue to the running in verification mode disorderly (F4). The figure below shows the program, and the Fuzzy Petri Net intelligent algorithm while the program is placed at the normal production mode (F1).



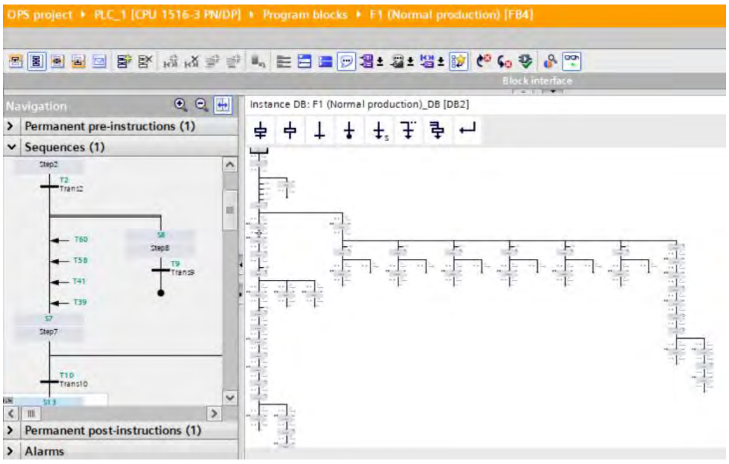
(a)



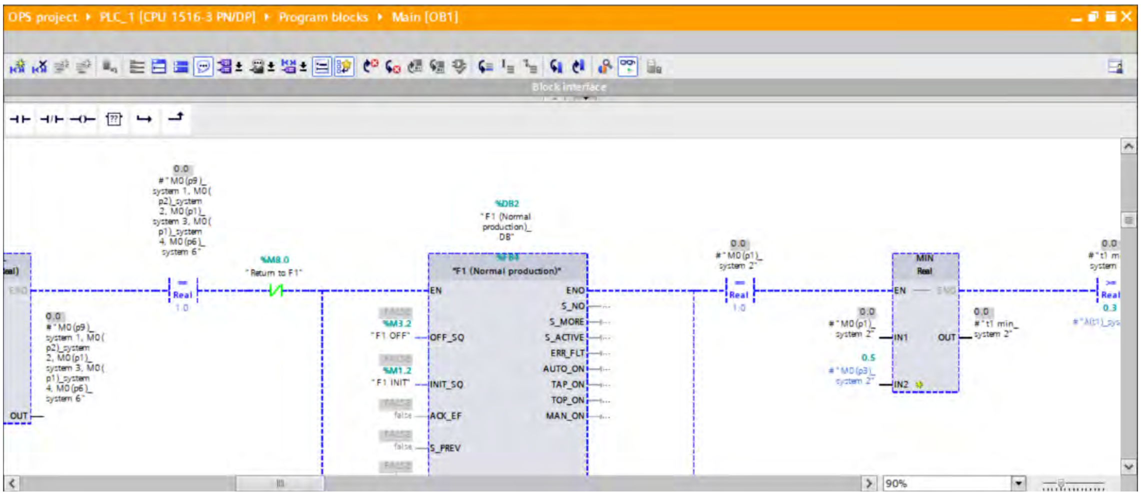
(b)

Figure 6.133: The program is placed at the normal production mode (F1) of GEMMA. (a) the program, (b) the Fuzzy Petri Nets intelligent algorithm

In the situation that the operator desires to operate the crane from the running in verification mode disorderly (F4), the algorithm will continue to the next stage and will place the program at the F4 mode. At that moment, the algorithm will switch off the normal production mode (F1) in order to place the program at the next stage. Figure 6.134 presents the next stage of the transition which the F1 mode is off. The figure shows the program, and the Fuzzy Petri Nets intelligent algorithm.



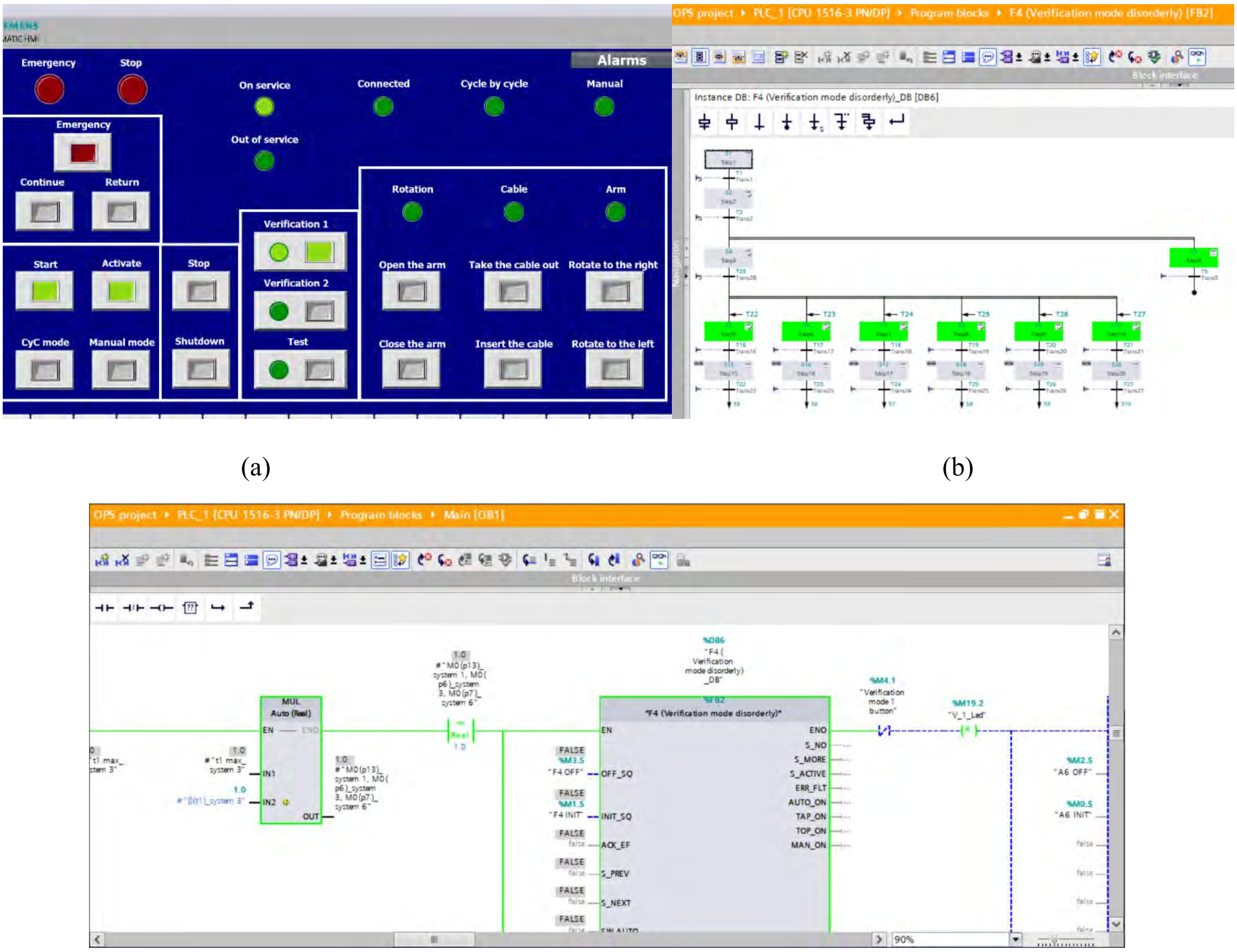
(a)



(b)

Figure 6.134: The normal production mode (F1) of GEMMA is off. (a) the program, (b) the Fuzzy Petri Nets intelligent transition

At the same moment, the algorithm places the program at the running in verification mode disorderly (F4). It allows the operator to activate each part of the crane that he desires without limitation as it is explained in the Subsection 3.3.1. The figure below presents the operation screen, the program, and the Fuzzy Petri Nets intelligent algorithm while the program is placed at this mode.



(a) (b)

(c)

Figure 6.135: The crane is placed at the running in verification mode disorderly (F4) of GEMMA, while it is ready for the different verification modes actions. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

6.1.5. Conclusion

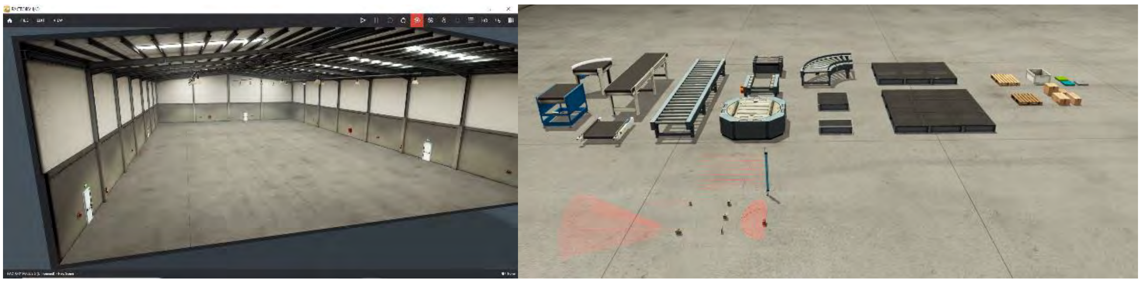
In the first part of this subchapter, the OPS (Onshore power supply) crane was presented, this crane supplies the electrical cable to the ship in order to connect it to the onshore power. By connecting the ship to the onshore power, the life quality is improving. That is to say, the onshore power supply reduces the emission from the ships and the noise. The design of this crane was described in this subchapter including the different components and its control. Moreover, the crane prototype was presented, it was shown the operation of the crane with examples of all the situations and cases including photos of the crane and control at each stage.

In the second part of this subchapter the intelligent algorithms were implemented on the OPS crane. The aim of the implementations was to test the intelligent algorithms on the crane and to validate their safety, control and decision making. All the algorithms were tested with the crane prototype in order to check the crane's operation with these algorithms and to test their appropriate control and decision making in the different situations and cases. It was seen that the operation of the crane is properly, and the algorithms provide a good control system to the crane. Additionally, the decision-making system was tested and proved that the algorithms work good and place the program at the appropriate mode according the situation. Also, in order to test the safety of the algorithms, different failures were made on purpose. The operation to failure procedure algorithm were proved a good emergency state and provides the best transitions for the different failure types. It means that the algorithm recognizes each failure's type and places the program at the appropriate mode in order to handle the failure in the best way. At last, the intelligent algorithms for scenarios A and B shown that the operator is able to stop properly the startup/shutdown process at any moment of the process when some action is needed and to place the program at either normal production mode (F1) or verification mode disorderly (F4). Also, it was proved that the operator is able to do the action that he needs in the crane without any problem and then either to shut down the crane or continue the normal operation.

6.2. Factory I/O

6.2.1. Introduction

Factory I/O is a simulation's software for control systems, it is a 3D software that provides to simulate automation technologies of a factory. Moreover, it allows to build a virtual factory by using industrial devices and simulate different industrial applications. In other words, this software is inspired of the real industrial factory and includes the common elements of a real factory including different type of sensors, conveyors, boxes and so on. These elements have digital and analog inputs and outputs that allow the connection to with the control system and emulate real situation. Additionally, this software has different type of stations like CNC, Elevator, Pick & Place device, Stacker crane etc. In figure 6.136 it is possible to see the interface of the software and examples of some elements, items and sensors. This software allows to train different type of controllers, such as SoftPC, TCP/IP etc. However, the most common controller that is used for this software for training and controlling is the PLC.



(a) (b)

Figure 6.136: Factory I/O. (a) the interface of the software, (b) examples of the different elements

This subchapter presents first the design of the project including the explanations of the factory that is designed and its components and machines. Then, the operation of the factory is explained including photos of the whole process. The main aim to design the virtual factory is to provide a complicated processe for testing the different intelligent algorithms. After the factory is explained and its processes are clear, the different intelligent algorithms are implemented and tested. The different intelligent algorithms allow to verify the following: the factory's production process, the proper work of the transitions between the GEMMA Guide Paradigm, the decision-making system of the algorithms and the safety of the control system. Moreover, the implementation of the intelligent algorithms on this factory aid to validate that the algorithms are working properly and can provide the best control and decision-making system for the different machines and processes.

6.2.2. Project Design

The project has been designed by the software Factory I/O. It is a production line that produce a plastic base and lid, assemblies them together to the desired product, packs and deliver it. Figure 6.137 shows the production line project in Factory I/O.

The product line consists of the following:

- Two CNC machines
- Two robots
- Conveyors
- Two positioner devices

- Two Pick & Place machines
- Three emitters
- Remover

In order to understand the product line operation, it is necessary to divided it into three parts of operations. The first part is the production stage, at the second part the product is assembling, and the at the last part the product is packed and delivered.

First, the emitters are providing the plastic material that has to be produced. When the plastic raw materials are emitted, the conveyors deliver them to the machine for the production. At that moment, the robots detect that the raw material has been arrived, they collect them and place them in the CNC machine in order to produce them. The CNC machines are programed differently in order to produce different items. One of them produces a plastic base and the other one a plastic lid. At the moment that the production has been finished, the robots take out the items from the CNC machines and place them on the conveyors for the next stage.

Second, the conveyors deliver both items to the assembly point. As soon as the base and lid arrive to the assembly point, the positioner devices are activated in order to place the items in the correct position for the assembling. At the next stage, the Pick & Place machine is operated and assemblies the item. In other words, it grabs the lid from the first conveyor and place it on the base that is located on the second conveyor.

At the last stage, the production and assembling of the product has been finished and it is ready for packing and delivering. While the assembly Pick & Place machine has been finished the assembling of the product, the packing conveyor is operated, and the positioner device is raised in order to allow the product to move to the next stage. Moreover, at that moment, the box emitter is activated and emits a box for the delivery of the product. Also, the roller conveyor is activated in order to place the box at the delivery stage. As soon as the product arrives to the delivery point, the delivery Pick & Place machine collects the item and places it in the delivery box. In the end, the roller delivery conveyor and the remover are activated, and the box moves on the delivery roller conveyor for the delivery.

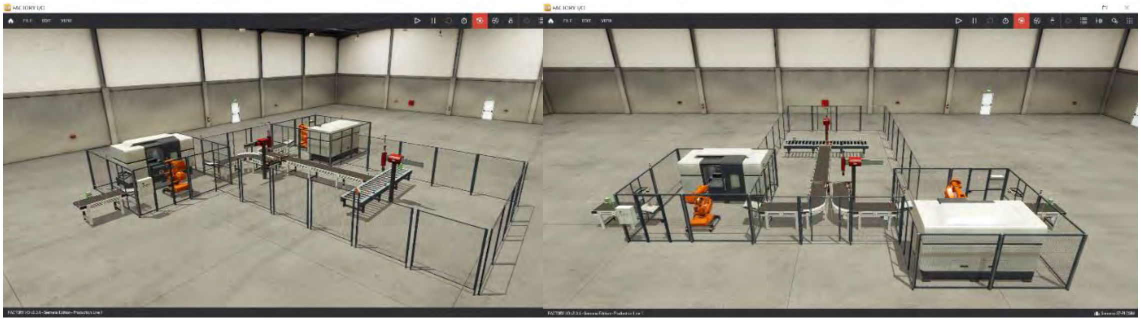
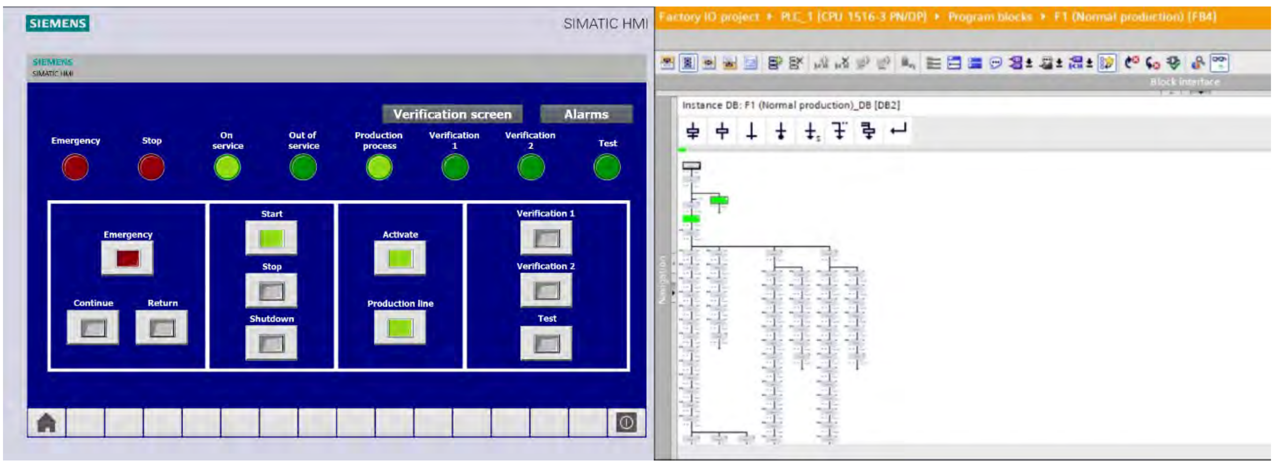


Figure 6.137: The Factory I/O production line

6.2.3. Project Operation

The control system of the production line is designed in a way that provides the operator a comfortable and easy interface. It designed by the graphical programing language Grafcet and it is based on the GEMMA Guide Paradigm. According to the GEMMA, the production of the machine is operated in the normal production mode (F1). This mode allows the operator the normal operation of the machine. In this project, the production line is designed to produce three items at one cycle. As it is explained in the Subsection 6.2.2, each item consists of a base and a lid. The product line produces each base and lid, assembling them for the required item, packing each item, and at last deliver the three items that have been produced.

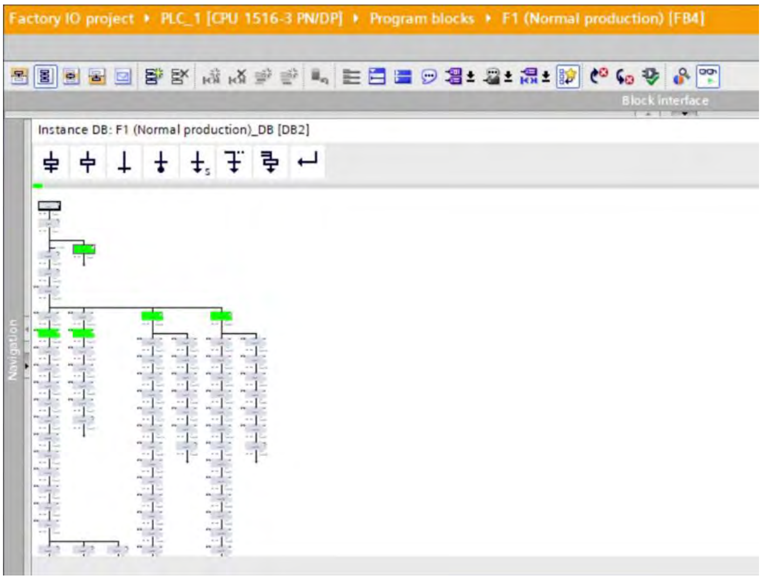
The figure below shows the operation screen, and the program at the first stage of the normal production mode (F1). It is possible to see that the program is on service, the activation and the production line buttons are pressed. Moreover, the production line led indicates that the production line cycle is on. At that moment, the operator has pressed the production line button and the production cycle is going to start. As it is possible to see, the program is at the first stage.



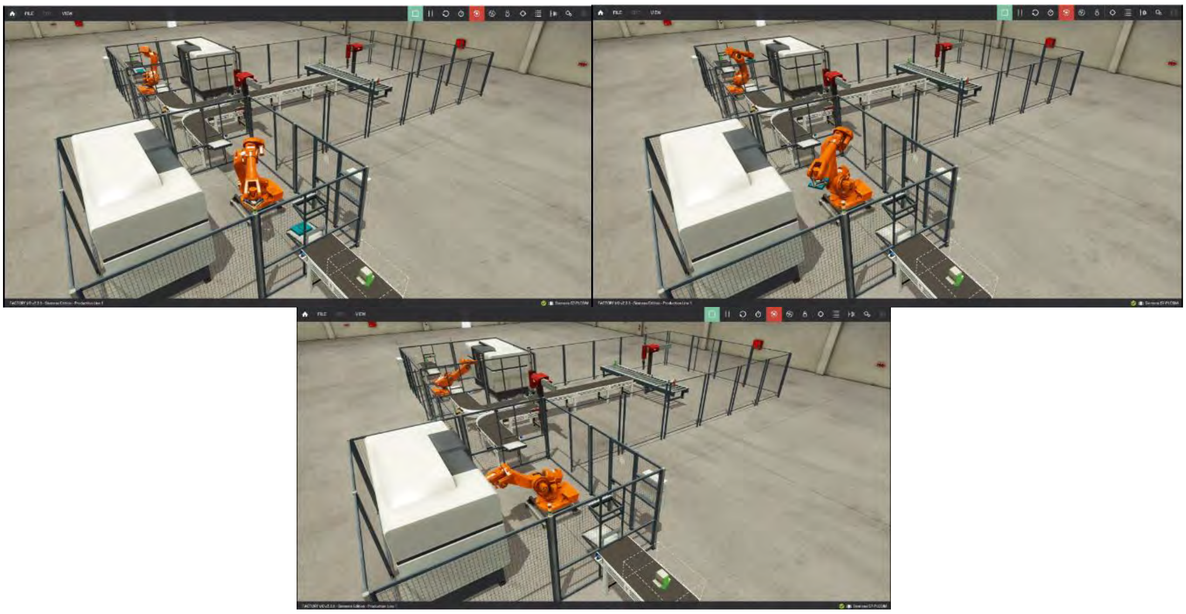
(a) (b)

Figure 6.138: The program is placed at the normal production mode (F1) of GEMMA, while the production line button is pressed. (a) the screen, (b) the program

After a delay of three minutes, the first stage of the product line is activated. At this stage, the emitters provide the first plastic raw material for both CNCs machines and the raw material conveyors are activated. When the raw materials arrive to the collecting point, the raw material conveyors are deactivated, and each robot collects and places the raw material in the CNC machine for the production. The figure below presents the program and the product line at this stage. It is possible to see in the figure the point that the raw materials have arrived to the collecting point, and the robots' activation for placing them in the CNC machine.



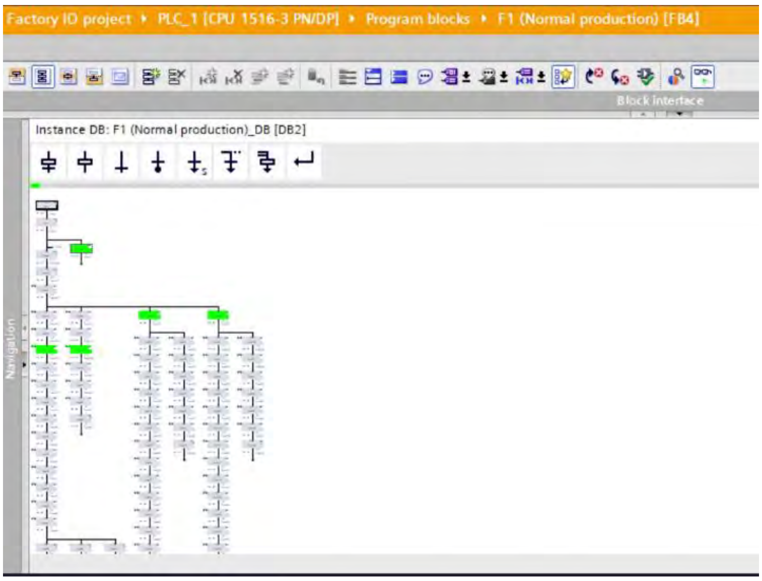
(a)



(b)

Figure 6.139: The program is placed at the normal production mode (F1) of GEMMA, while the first base and lid are emitted, and the robots collect and place them for the production. (a) the screen, (b) Factory I/O

The next stage of the production line is the production of the first base and lid. At this stage, the CNC machines are working according the requirements. One of them produces the base, and one the lid. Figure 6.140 shows the program, and the product line at that stage. It is possible to see that the robots are in their initial sate, and the doors of the CNC machines are closed while they operate.

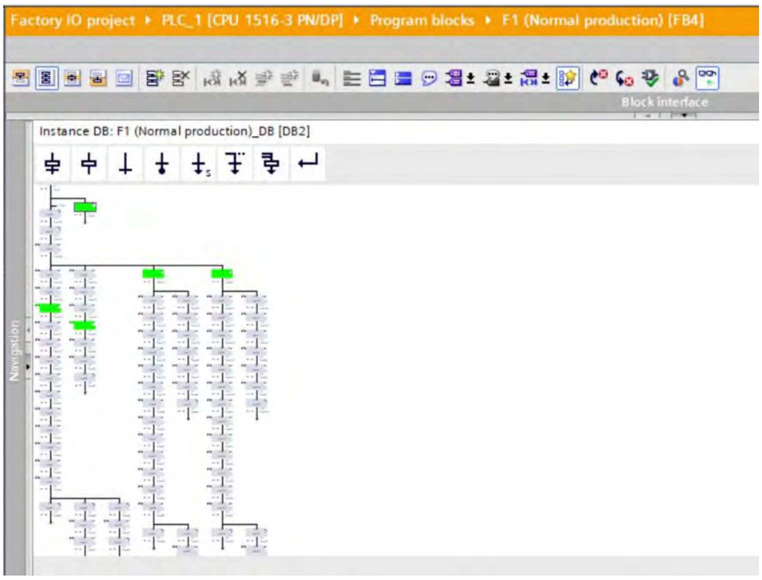


(a)

(b)

Figure 6.140: The program is placed at the normal production mode (F1) of GEMMA, while the first base and lid are produced. (a) the screen, (b) Factory I/O

First, the base is produced, due to its lower production time compared to the lid production time. As it is possible to see in the figure below, the production of the base has finished while the lid is still in production. At this stage, the robot detects that the base production has finished, and it collect the base. The figure presents the program at that stage.

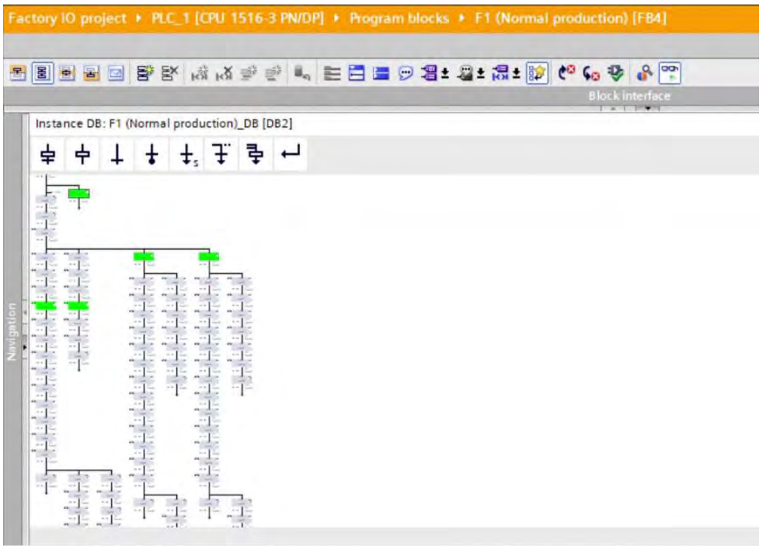


(a)

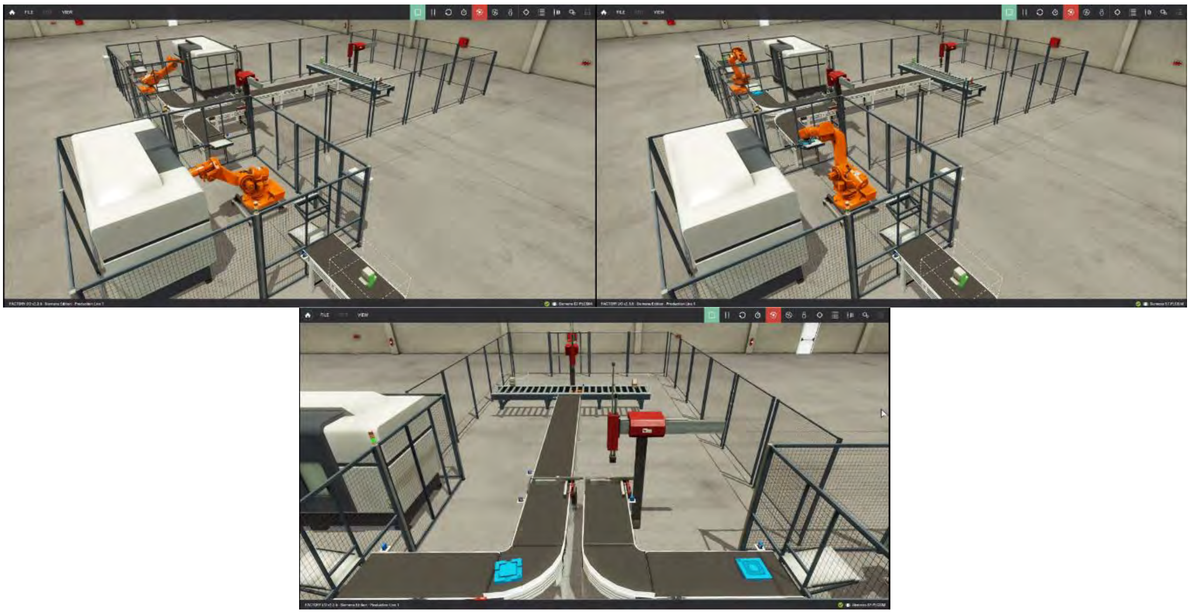
(b)

Figure 6.141: The program is placed at the normal production mode (F1) of GEMMA, while the first base production has been finished, and the lid is produced. (a) the screen, (b) Factory I/O

At the next stage, the lid's production has finished as well. At that moment, the robot detects that the lid production has finished, and collects it. At this stage, the robot of the base is still working also. That is to say, both of the robots are collecting the produced base and lid. Moreover, they place the base and lid on the conveyors for the next stage. The figure below presents the program and the production line at this stage. It is possible to see that the base and lid are placed on the conveyors and are moving for the next stage.



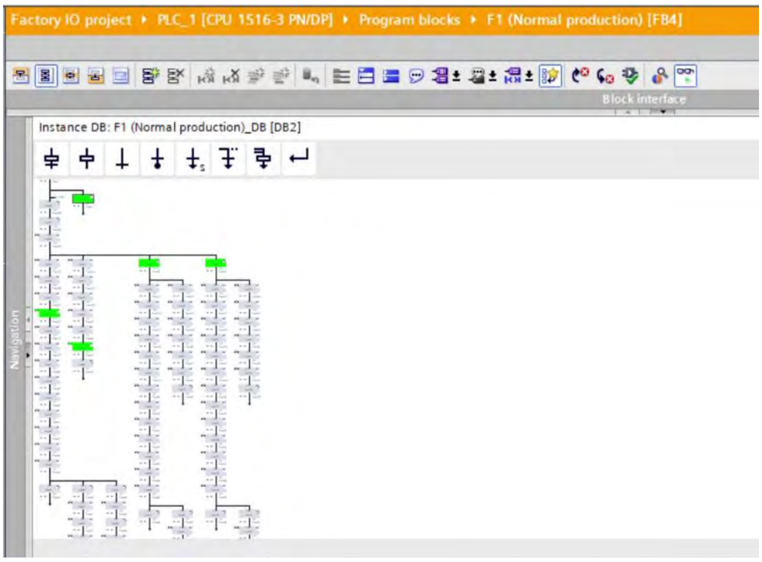
(a)



(b)

Figure 6.142: The program is placed at the normal production mode (F1) of GEMMA, while the first base and lid production have been finished, and the conveyors are activated. (a) the screen, (b) Factory I/O

The conveyors of the base and lid are activated until they arrive to the assembly point. First, the first base is arrived to the assembly point, and the base positioner is clamped in order to place it in the correct place for the assembling. The figure below presents this stage, it is possible to see that the base positioner places the base in the required place. Moreover, the figure shows the program at that stage.

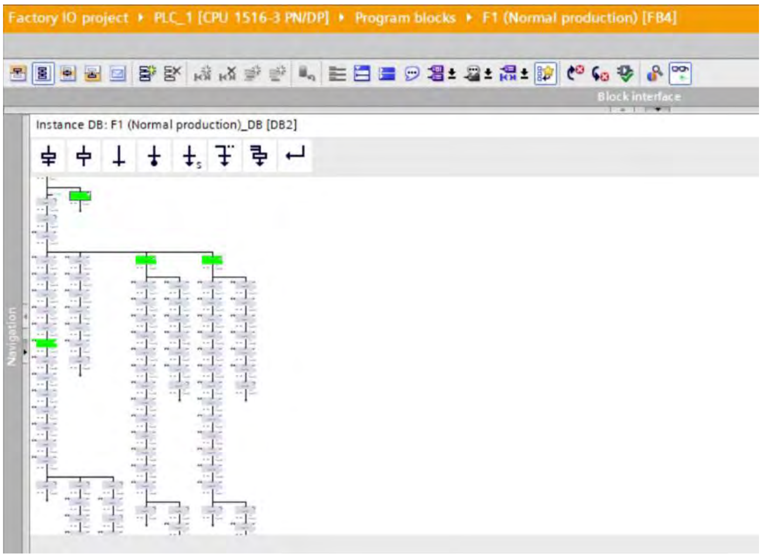


(a)

(b)

Figure 6.143: The program is placed at the normal production mode (F1) of GEMMA, while the base positioner is clamped. (a) the screen, (b) Factory I/O

When the first base is already placed at the assembly point, the first lid arrives as well. At the moment that the first lid arrives to the assembly point, the lid positioner is clamped in order to place it at the appropriate place for the assembling. In figure 6.144 it is possible to see the production line while the lid positioner is clamped. Also, the figure shows the program at this stage.



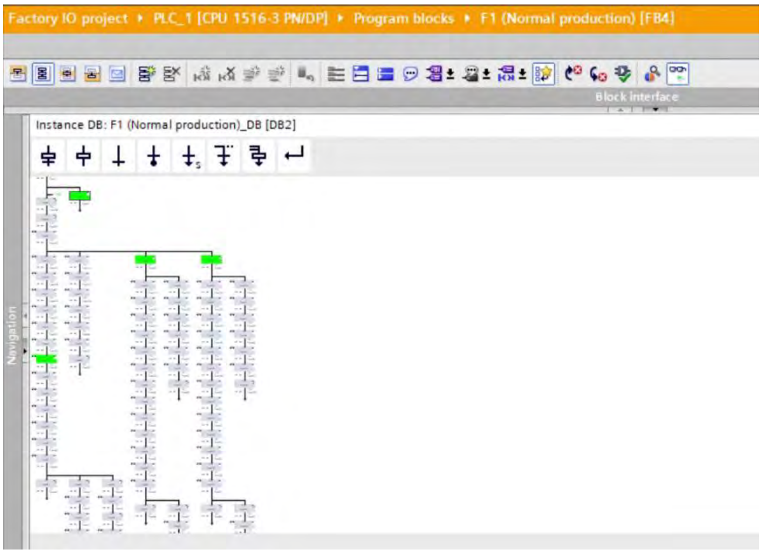
(a)

(b)

Figure 6.144: The program is placed at the normal production mode (F1) of GEMMA, while the lid positioner is clamped. (a) the screen, (b) Factory I/O

As soon as the first base and lid are placed at the appropriate assembly point, the program moves to the next stage. At that stage, the assembly Pick & Place machine is activated in order to assembly the first item. This stage is divided into five steps as the following:

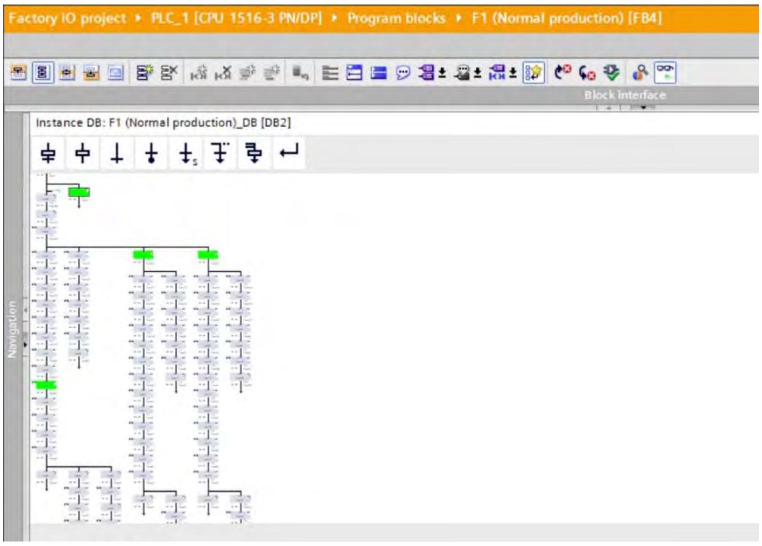
The z axis, and suction of the assembly Pick & Place machine is activated in order to reach the lid as it is shown in figure 6.145. Afterwards, the z axis of Pick & Place machine is deactivated, and the suction is still activated in order to elevate the lid as it is presented in figure 6.146. The next step is presented in figure 6.147, in this step, the x axis of the assembly Pick & Place machine is activated till the appropriate place according to the base location. Moreover, the suction is still activated as well. As soon as the lid arrives to the right location, the z axis of the assembly Pick & Place machine is activated in order to assembly the item as it is shown in figure 6.148. During this step, the assembly Pick & Place machine suction is activated continuously. In the last step, the item is assembled, and it is ready for the packing. At that step, the assembly Pick & Place machine is deactivated. In other words, the machine returns to its initial state, and it switches off. Figure 6.149 presents the last step of this stage including the program, and the production line.



(a)

(b)

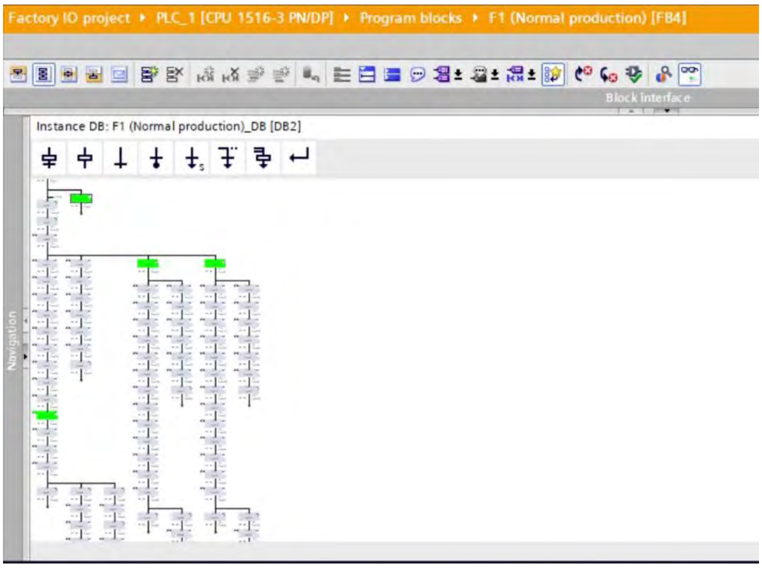
Figure 6.145: The program is placed at the normal production mode (F1) of GEMMA, while the Pick & Place z axis and suction are activated. (a) the screen, (b) Factory I/O



(a)

(b)

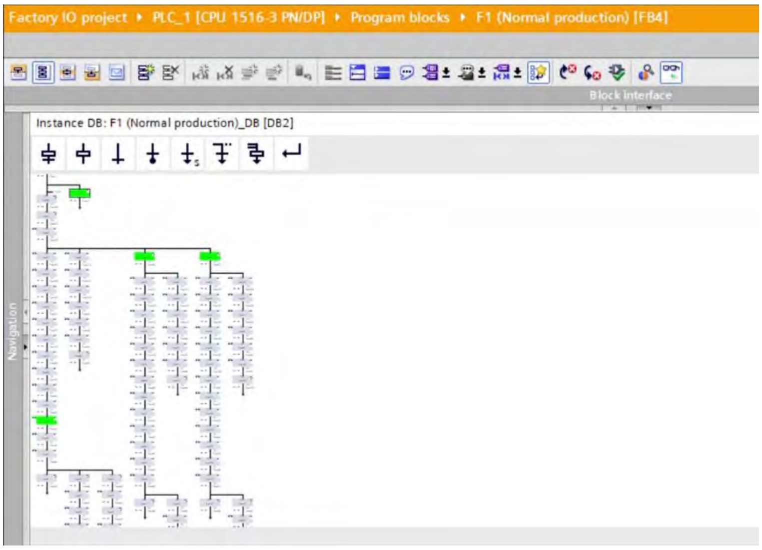
Figure 6.146: The program is placed at the normal production mode (F1) of GEMMA, while the Pick & Place z axis is deactivated, and suction is activated. (a) the screen, (b) Factory I/O



(a)

(b)

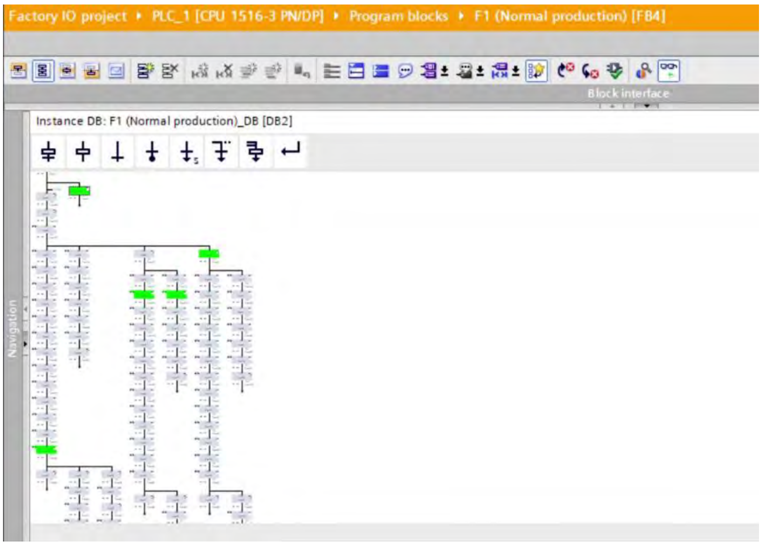
Figure 6.147: The program is placed at the normal production mode (F1) of GEMMA, while the Pick & Place x axis and suction are activated. (a) the screen, (b) Factory I/O



(a)

(b)

Figure 6.148: The program is placed at the normal production mode (F1) of GEMMA, while the Pick & Place x and z axes, and suction are activated. (a) the screen, (b) Factory I/O

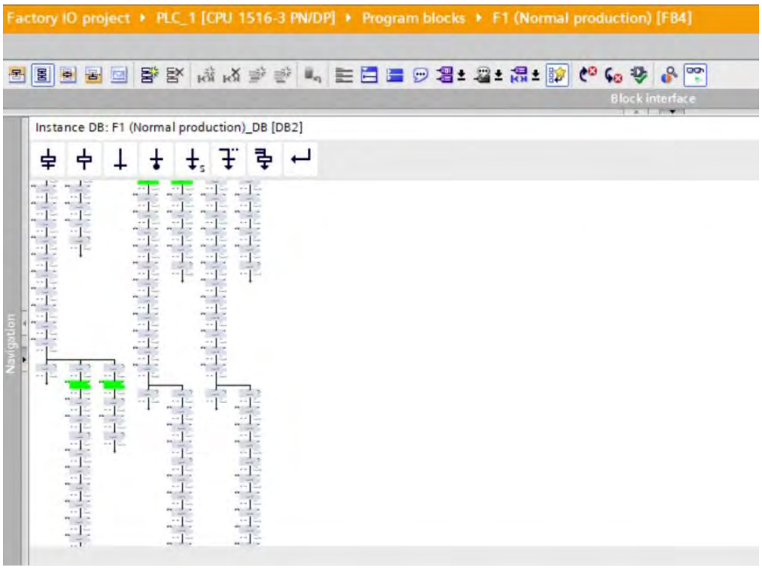


(a)

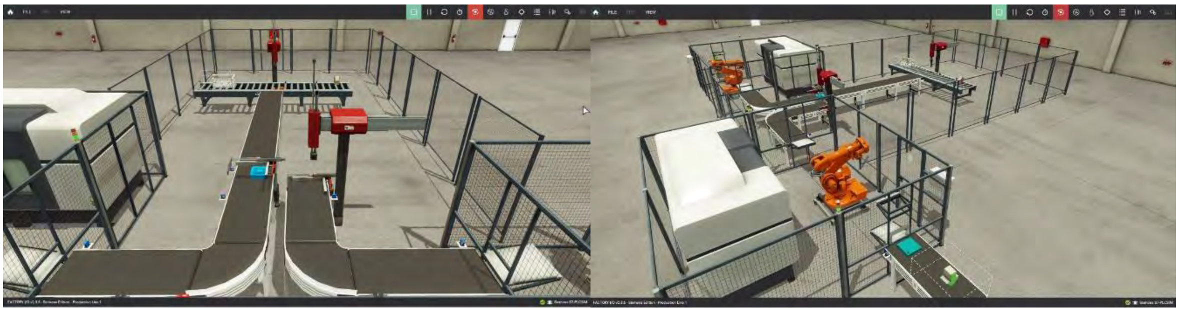
(b)

Figure 6.149: The program is placed at the normal production mode (F1) of GEMMA, while the Pick & Place z axis and suction are deactivated. (a) the screen, (b) Factory I/O

When the first item is assembled, it is ready for packing. In the next stage of the production process, the packing conveyor is activated in order to move the item to the packing point, and the positioner is raised to allow the movement of the item. Moreover, the delivery box, and the second raw materials are emitted at this stage. It is presented in the figure below including the program, and the production line. The figure shows the production line from two different angle which allows to see the production process situation.



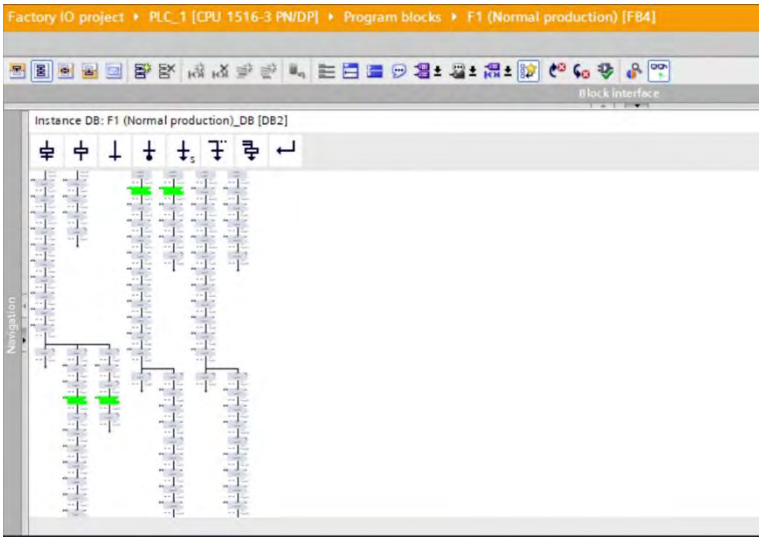
(a)



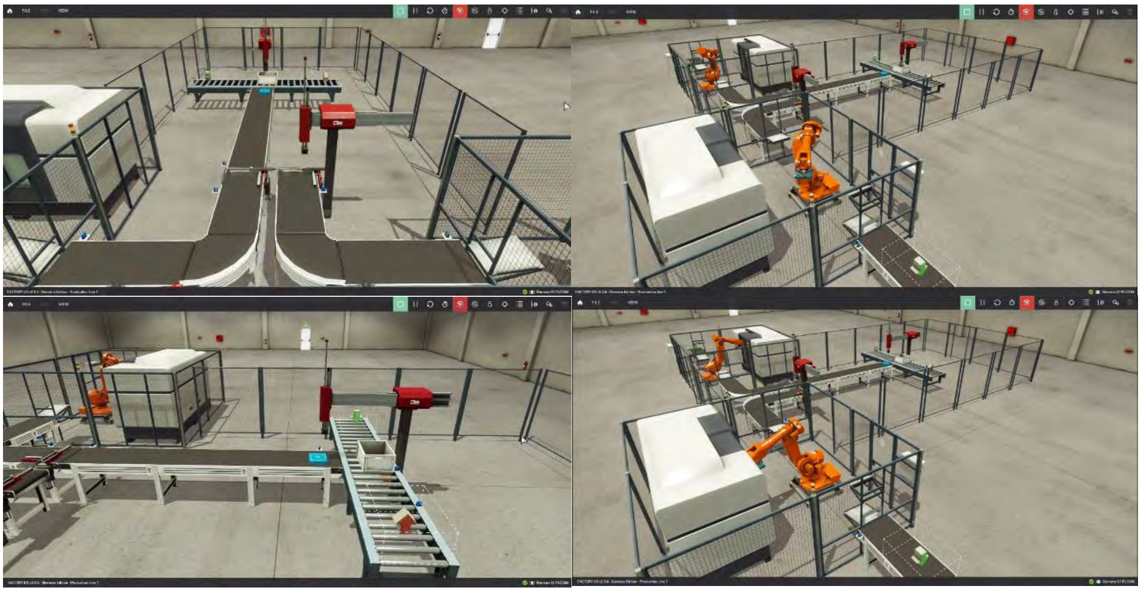
(b)

Figure 6.150: The program is placed at the normal production mode (F1) of GEMMA, while the Pick & Place machine is turned off, the positioner is raised, the conveyor is activated, the delivery box is emitted, and the second base and lid are emitted. (a) the screen, (b) Factory I/O

At the next stage, the first item and the delivery box have arrived to the packing point. Also, the robots collect the second raw materials and place them in the CNC machine for the production of the second base and lid. Additionally, the packing Pick & Place machine is activated. At that moment, the x axis of the packing Pick & Place is activated and arrived to the right location according to the item's place. Figure 6.151 presents this stage of the production process.



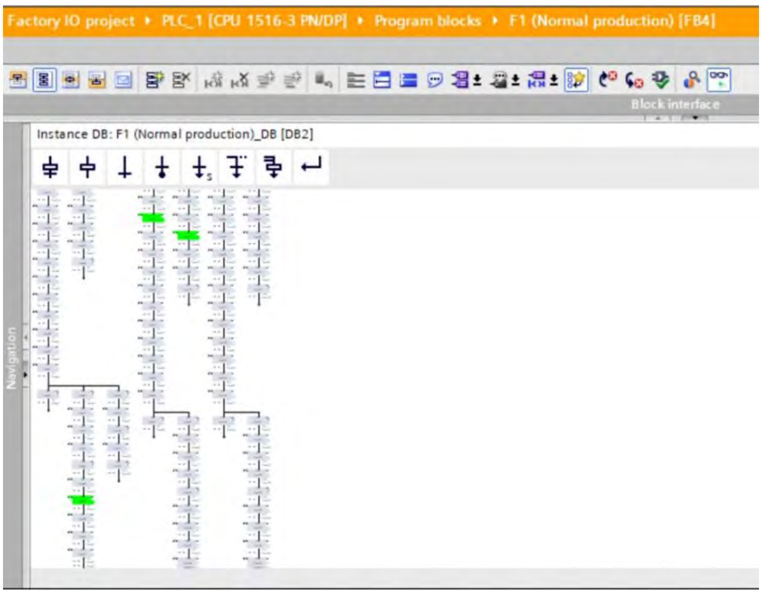
(a)



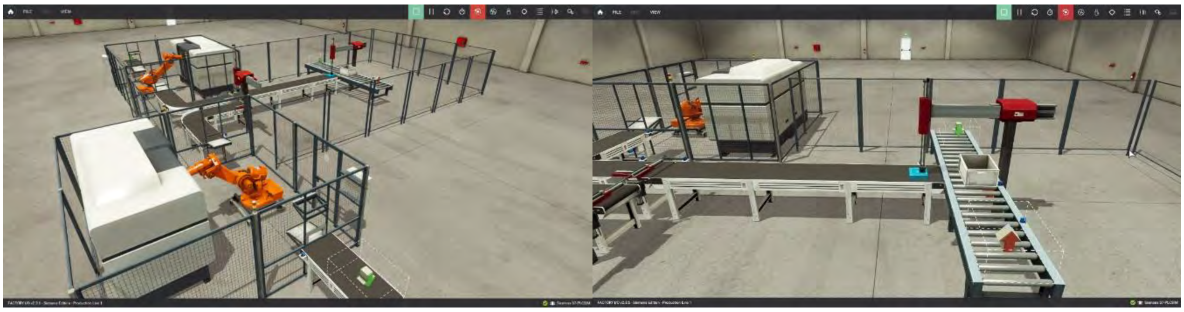
(b)

Figure 6.151: The program is placed at the normal production mode (F1) of GEMMA, while the Pick & Place x axis is activated, and the second base and lid are placed at the CNC machines for the production. (a) the screen, (b) Factory I/O

At the next stage, the packing Pick & Place machine is continued in order to collect the item, and places it in the delivery box. First, the x and z axes, and the suction are activated as it is shown in figure 6.152. Then, the z axis is deactivated, and the item is elevated as figure 6.153 presents. Afterwards, the x axis is deactivated in order to place the item in the right position according the place of the delivery box as it is presented in figure 6.154. At last, the z axis and the suction are deactivated. In the last step, the item is placed appropriately in the delivery box as figure 6.155 presents.

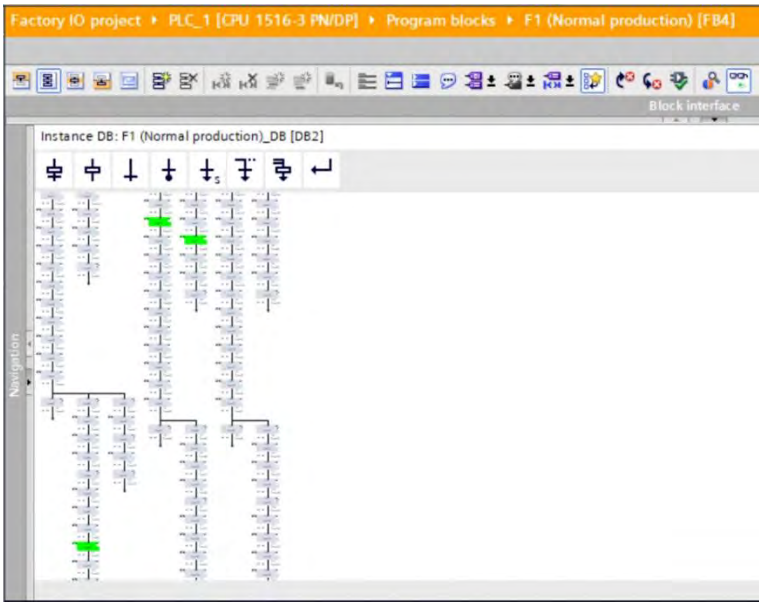


(a)

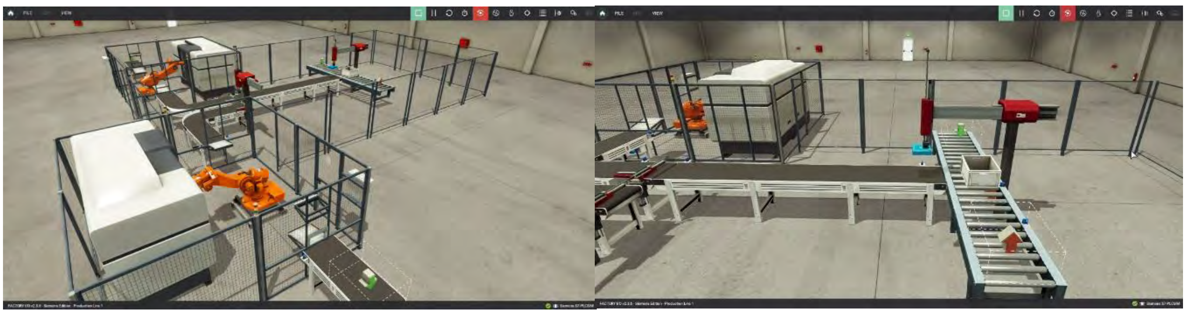


(b)

Figure 6.152: The program is placed at the normal production mode (F1) of GEMMA, while the Pick & Place x and z axes, and suction are activated, and the second base and lid are placed for the production. (a) the screen, (b) Factory I/O

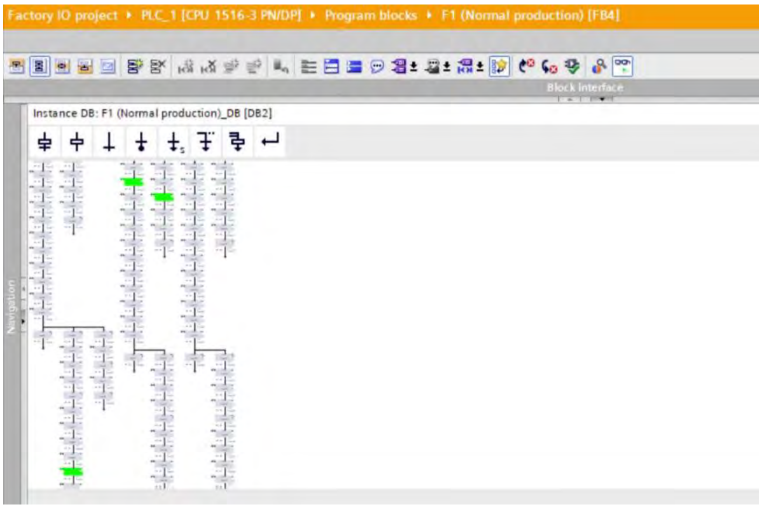


(a)

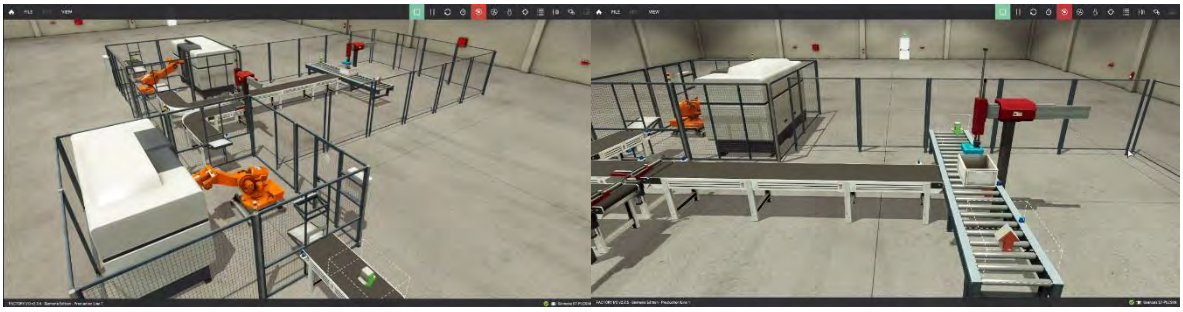


(b)

Figure 6.153: The program is placed at the normal production mode (F1) of GEMMA, while the Pick & Place x axis and suction are activated, and the second base and lid are placed for the production. (a) the screen, (b) Factory I/O

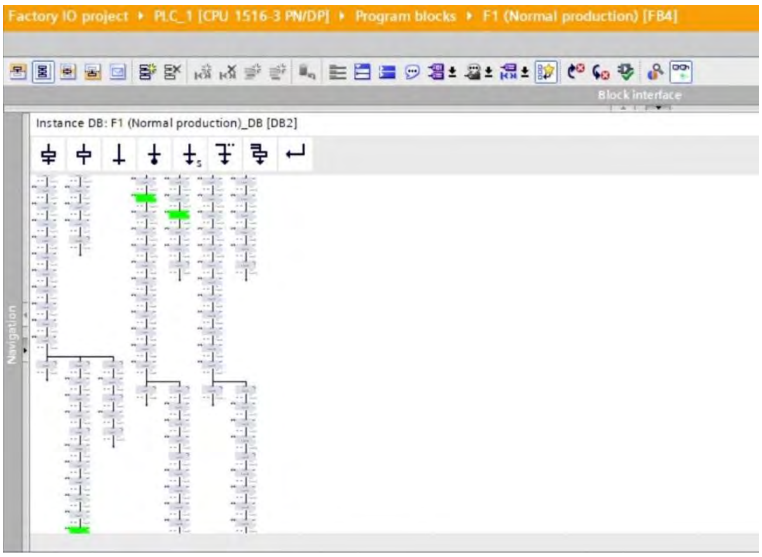


(a)

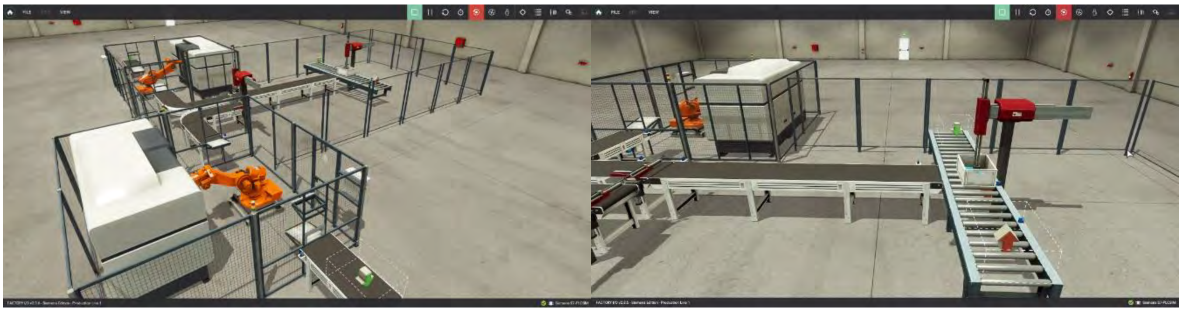


(b)

Figure 6.154: The program is placed at the normal production mode (F1) of GEMMA, while the Pick & Place suction is activated, and the second base and lid are located for the production. (a) the screen, (b) Factory I/O



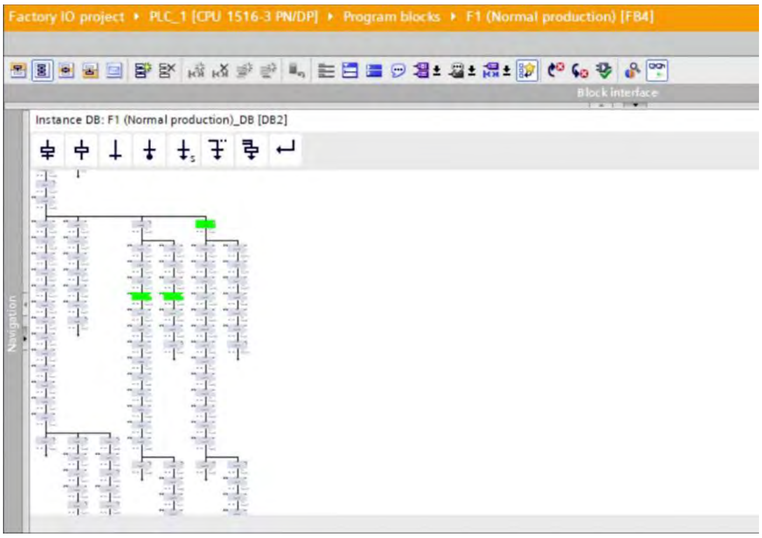
(a)



(b)

Figure 6.155: The program is placed at the normal production mode (F1) of GEMMA, while the Pick & Place z axis is activated, suction is deactivated, and the second base and lid are placed for the production. (a) the screen, (b) Factory I/O

At that moment, the first item is already placed at the delivery box, and the second base and lid are produced in the CNC machines. The figure below shows this stage of the production process including the program, and the production line.

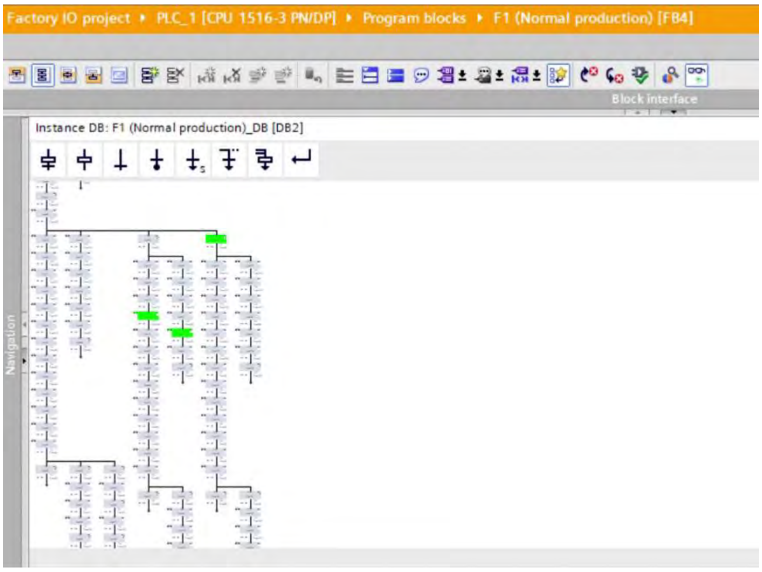


(a)

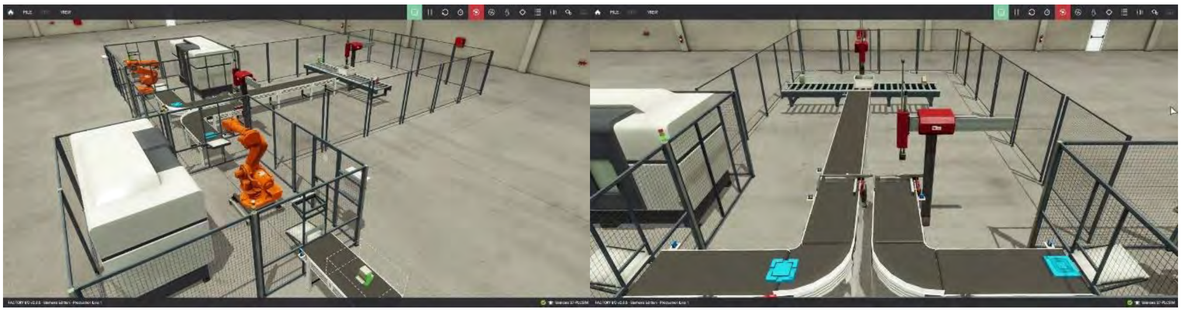
(b)

Figure 6.156: The program is placed at the normal production mode (F1) of GEMMA, while the second base and lid are produced. (a) the screen, (b) Factory I/O

As soon as the second base and lid production finishes, the robots place them on the conveyors for the next stage. Figure 6.157 shows that stage of the production. It is possible to notice that the second base and lid are on the conveyors and on the way to the assembly point. The figure presents the program, and the production line at this stage.



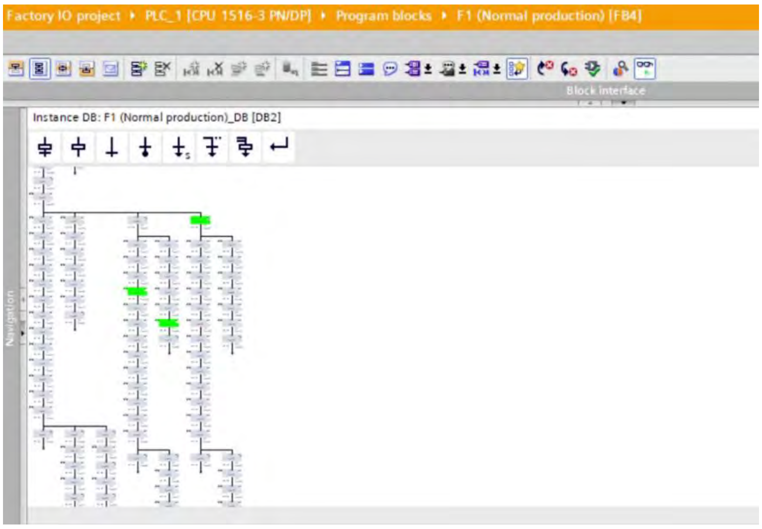
(a)



(b)

Figure 6.157: The program is placed at the normal production mode (F1) of GEMMA, while the base and lid conveyors are activated. (a) the screen, (b) Factory I/O

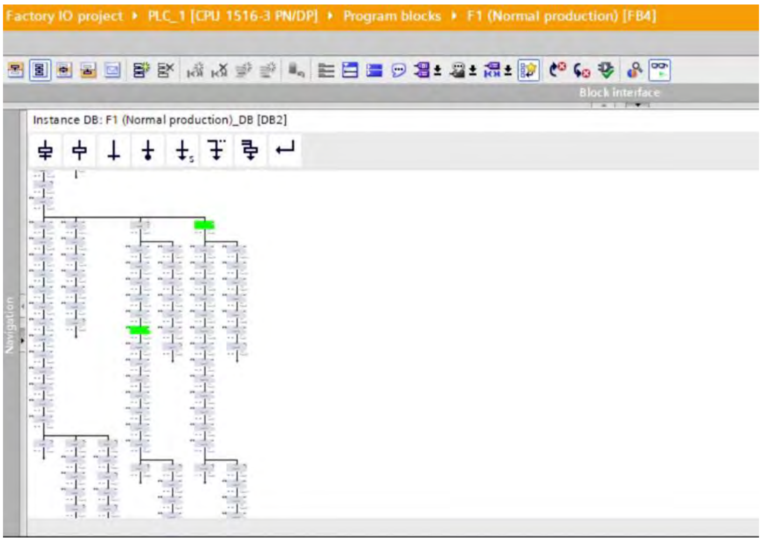
In the next stage of the production process, the second base is arriving to the assembly point while the second lid is still on the way. Moreover, the base positioner is clamped in order to place the second base at the right place for the assembly. Figure 6.158 presents this stage of the production process including the program, and the production line. Then, the second lid arrives to the assembly point, and the lid positioner is clamped as it is shown in figure 6.159.



(a)

(b)

Figure 6.158: The program is placed at the normal production mode (F1) of GEMMA, while the base positioner is clamped. (a) the screen, (b) Factory I/O

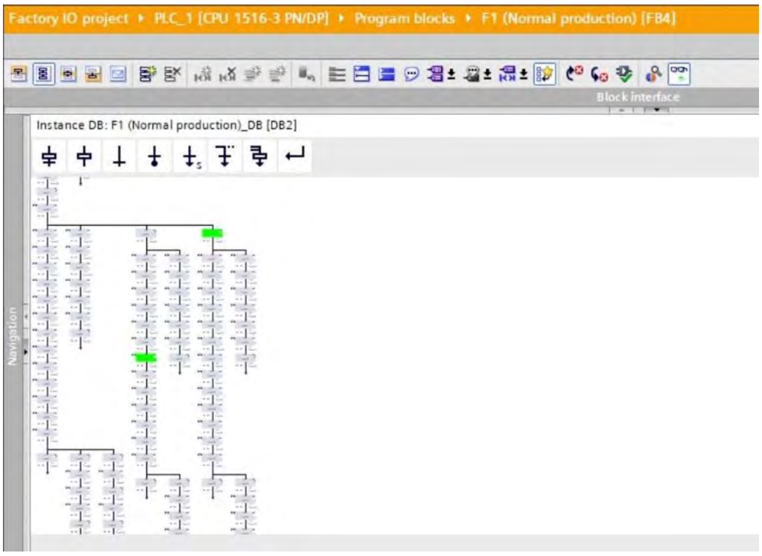


(a)

(b)

Figure 6.159: The program is placed at the normal production mode (F1) of GEMMA, while the lid positioner is clamped. (a) the screen, (b) Factory I/O

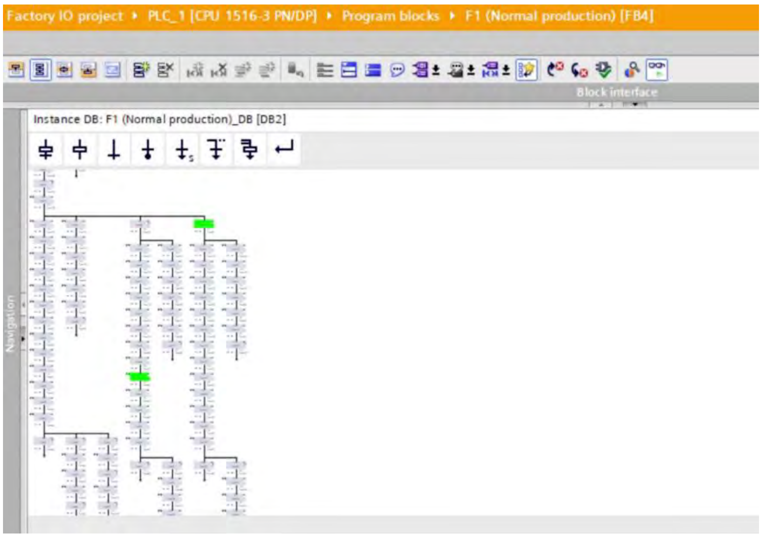
When the second base and lid are placed at their right place for the assembly, the assembly Pick & Place machine is activated in order to assembly the second item. First of all, the z axis and the suction are activated as it is shown in figure 6.160. In this step, the lid is collected for the assembly. Second, the z axis is deactivated while the suction is still activated. The assembly Pick & Place machine elevates the lid in this step as it is presented in figure 6.161. In the next step, the x axis is activated as well in order to reach the correct place of the lid with the base, figure 6.162 presents this step. At last, the z axis is activated, and the item is assembled. In this step, the suction is deactivated in order to release the lid in the right place. This step is shown in figure 6.163.



(a)

(b)

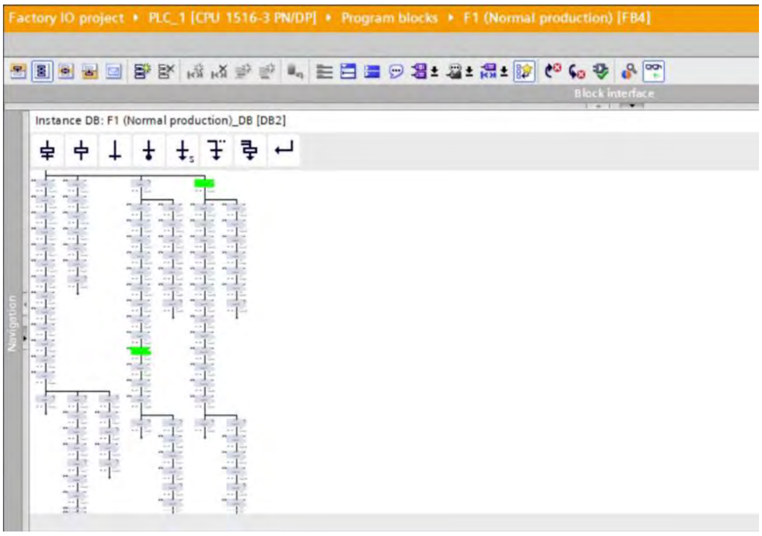
Figure 6.160: The program is placed at the normal production mode (F1) of GEMMA, while the Pick & Place z axis and suction are activated. (a) the screen, (b) Factory I/O



(a)

(b)

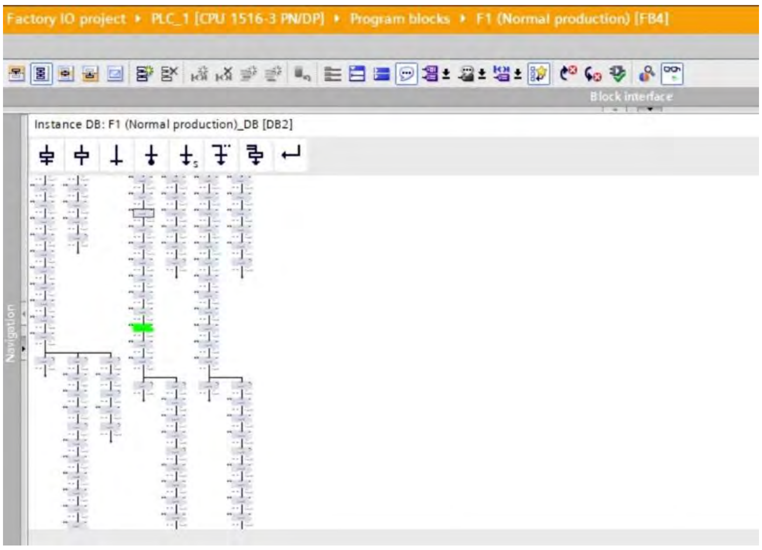
Figure 6.161: The program is placed at the normal production mode (F1) of GEMMA, while the Pick & Place z axis is disactivated and suction is activated. (a) the screen, (b) Factory I/O



(a)

(b)

Figure 6.162: The program is placed at the normal production mode (F1) of GEMMA, while the assembly pick & place x axis and suction are activated. (a) the screen, (b) Factory I/O

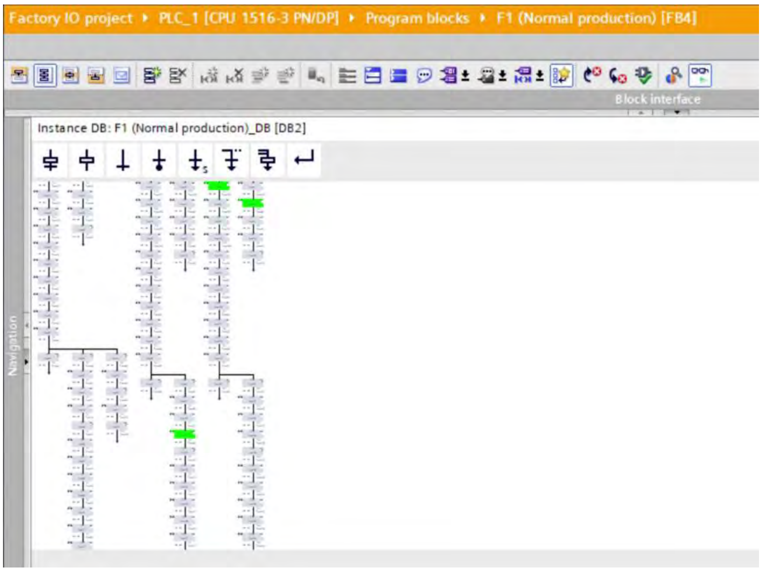


(a)

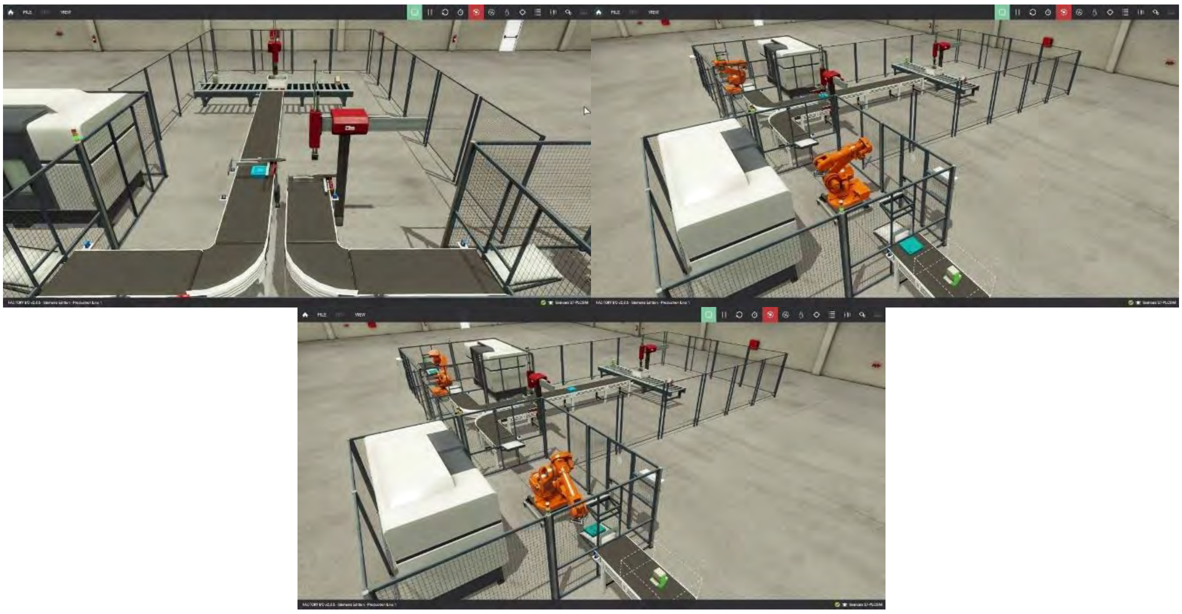
(b)

Figure 6.163: The program is placed at the normal production mode (F1) of GEMMA, while the Pick & Place x and z axes are activated, and suction is disactivated. (a) the screen, (b) Factory I/O

As soon as the second item has been assembled, the packing conveyer is activated, and positioner is raised in order to let the item to move to the packing point. Additionally, in this stage, the third raw materials are emitted, and the robots detect them. The figure below presents this stage of the production process including the program, and the production line.



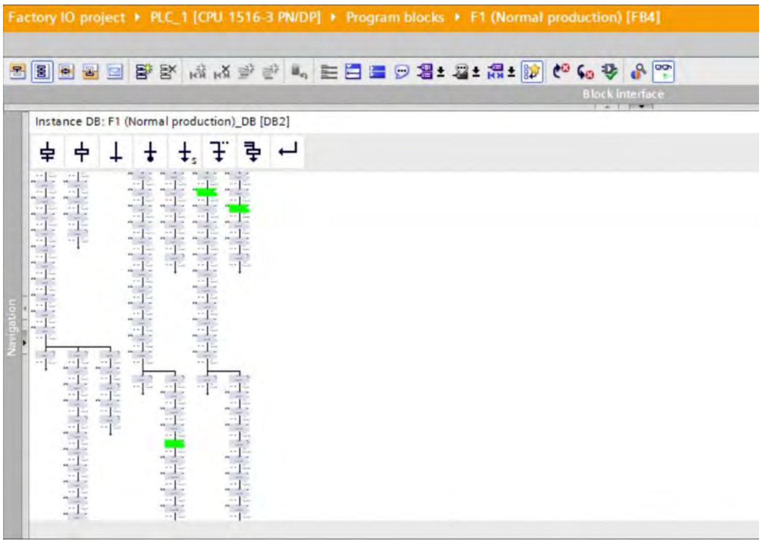
(a)



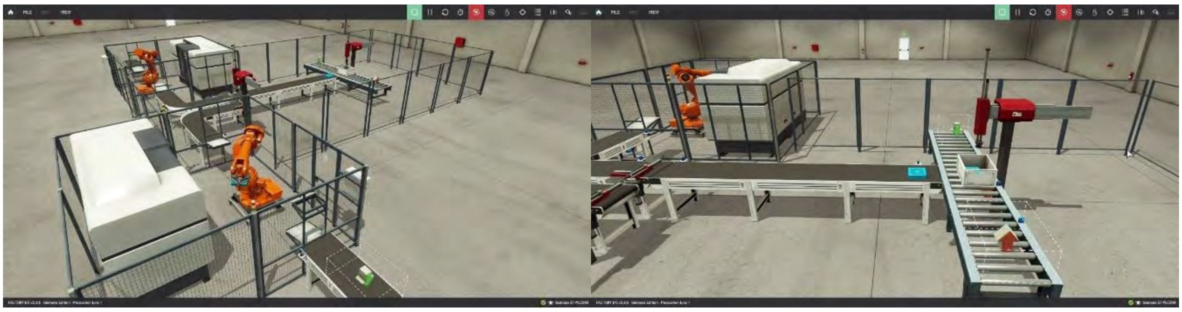
(b)

Figure 6.164: The program is placed at the normal production mode (F1) of GEMMA, while the assembly pick & place is disactivated, the positioner is raised, the conveyor is activated, and the third raw material are emitted. (a) the screen, (b) Factory I/O

In the next stage, the second item arrives to the packing point as it is shown in figure 6.165. Moreover, the robots have collected the third raw materials in order to place them in the CNC machines. The figure shows the program, and the production line from two angles which present the production process situation at this stage.



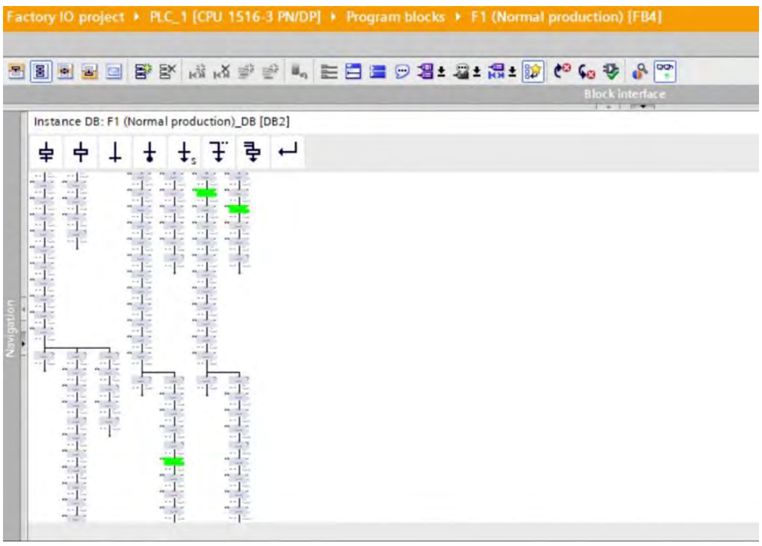
(a)



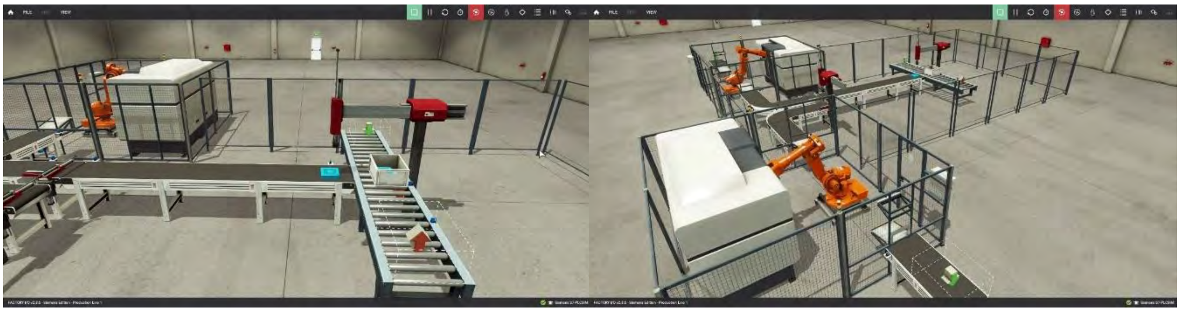
(b)

Figure 6.165: The program is placed at the normal production mode (F1) of GEMMA, while the second item has been arrived to the packing point, and the robots have collected the third raw materials. (a) the screen, (b) Factory I/O

When the packing Pick & Place machine detects that the second item has arrived to the packing point, it is activated in order to place it in the delivery box. This stage is divided into few steps in the same way of the first item packing. First of all, the x axis is activated in order to reach the exact location of the item as it is shown in figure 6.166. Then, the z axis and suction are activated as well for the collection of the item as it is presented in figure 6.167. In the next step, the z axis is deactivated, and the item is elevated, this step is shown in figure 6.168. Afterwards, the x axis is deactivated for reaching the delivery box place as it is presented in figure 6.169. At the end, the z axis is activated, and the suction is deactivated. In this step, the second item is placed appropriately in the delivery box. Figure 6.170 shows this packing step. During these packing steps, the robots place the third raw materials in the CNC machines for the production of the third base and lid. The figures show the program, and the production line from two angles which allows to notice the production situation in each step.

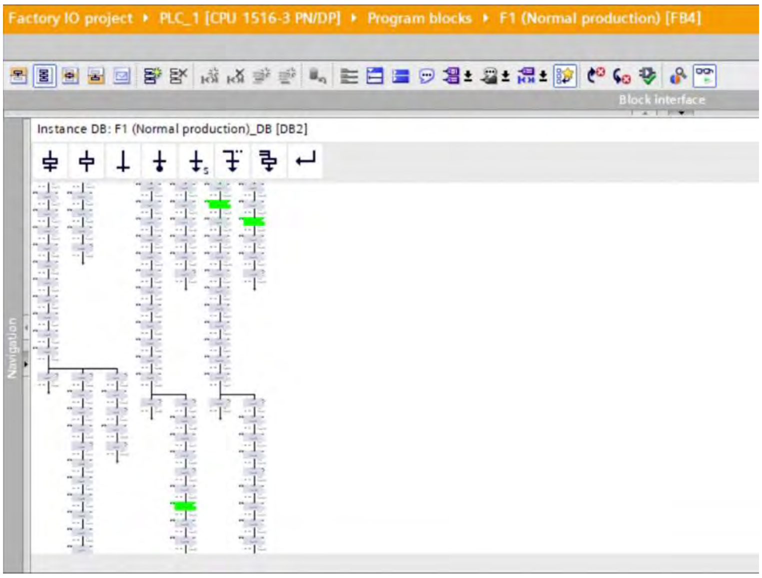


(a)

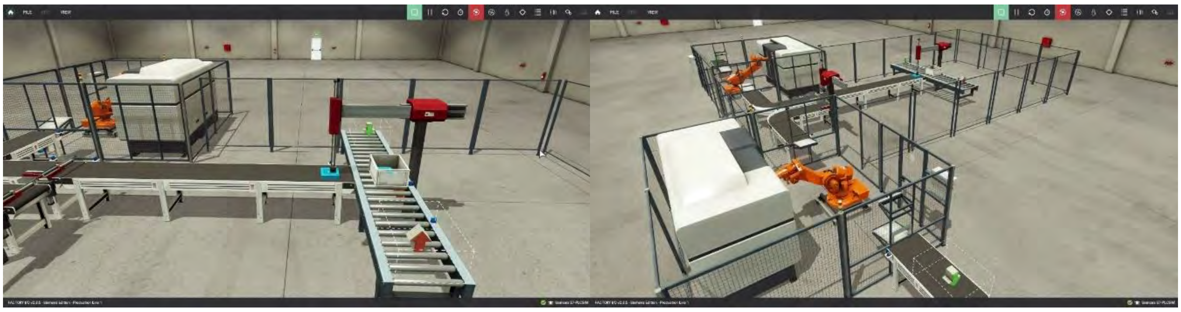


(b)

Figure 6.166: The program is placed at the normal production mode (F1) of GEMMA, while the Pick & Place x axis is activated, and the robots placed the third raw materials in the CNC machines. (a) the screen, (b) Factory I/O

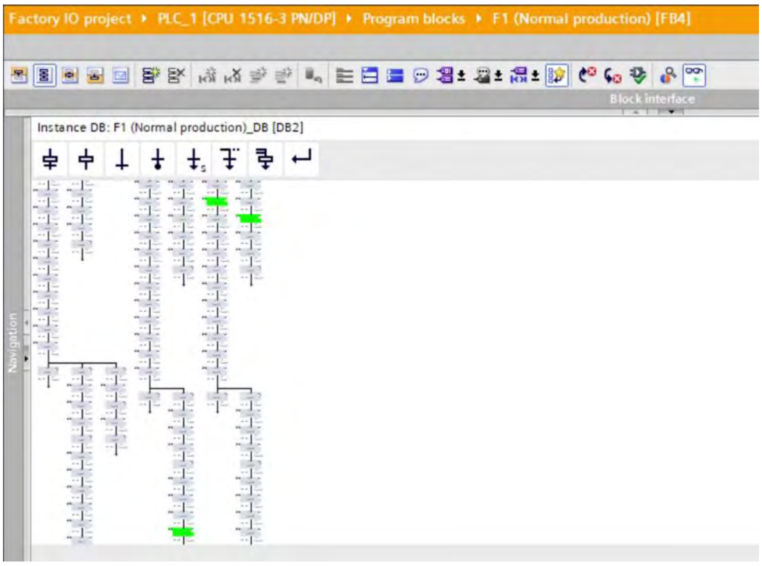


(a)



(b)

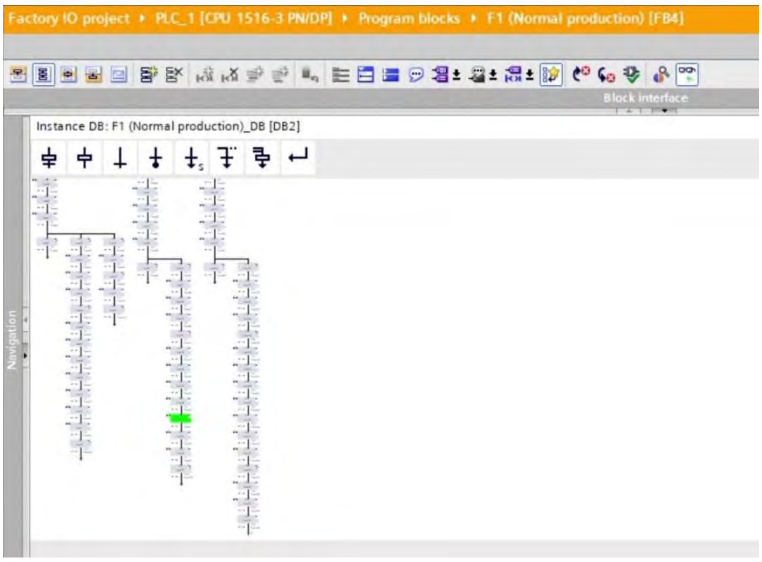
Figure 6.167: The program is placed at the normal production mode (F1) of GEMMA, while the Pick & Place x, z axes, and suction are activated, and the robots place the third raw materials in the CNC machines. (a) the screen, (b) Factory I/O



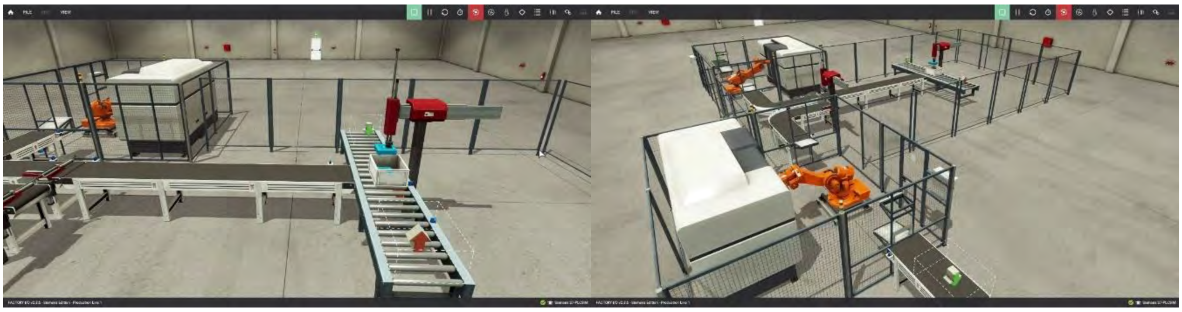
(a)

(b)

Figure 6.168: The program is placed at the normal production mode (F1) of GEMMA, while the Pick & Place x axis and suction are activated, and the robots place the third raw materials in the CNC machines. (a) the screen, (b) Factory I/O

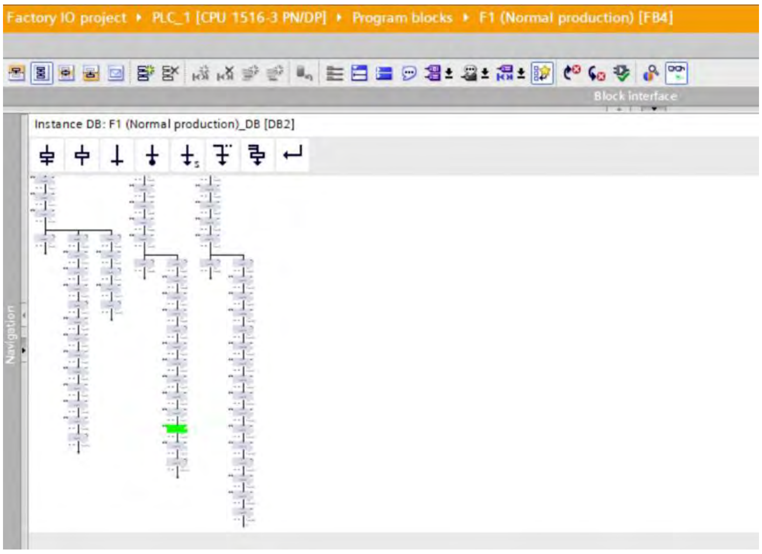


(a)



(b)

Figure 6.169: The program is placed at the normal production mode (F1) of GEMMA, while the Pick & Place suction is activated, and the robots place the third raw materials in the CNC machines. (a) the screen, (b) Factory I/O

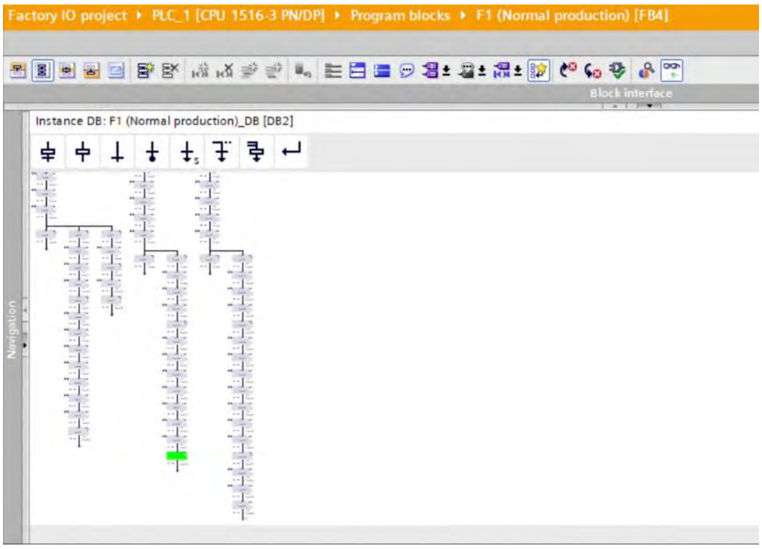


(a)

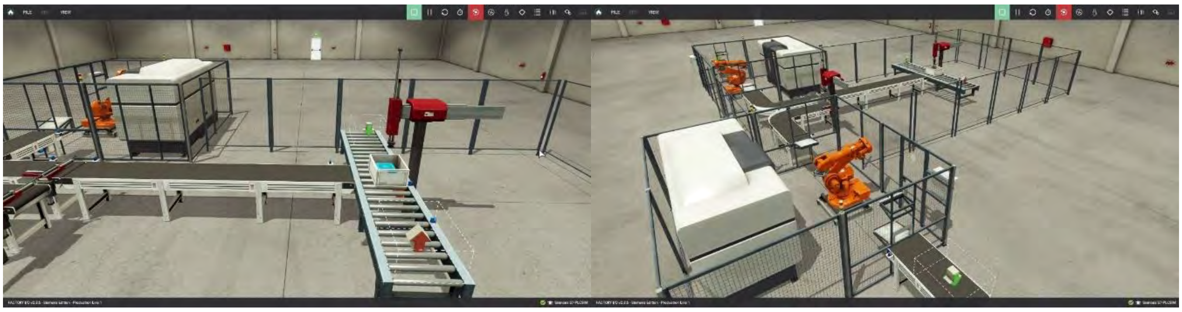
(b)

Figure 6.170: The program is placed at the normal production mode (F1) of GEMMA, while the Pick & Place z axis is activated, suction is deactivated, and the robots place the third raw materials in the CNC machines. (a) the screen, (b) Factory I/O

In the next stage, the second item is already placed at the delivery box, and the third base and lid are produced. In other words, the two items are placed at the delivery box, and the CNC machines are producing the third base and lid. The figure blow presents this stage of the production process including the program, and the production line.



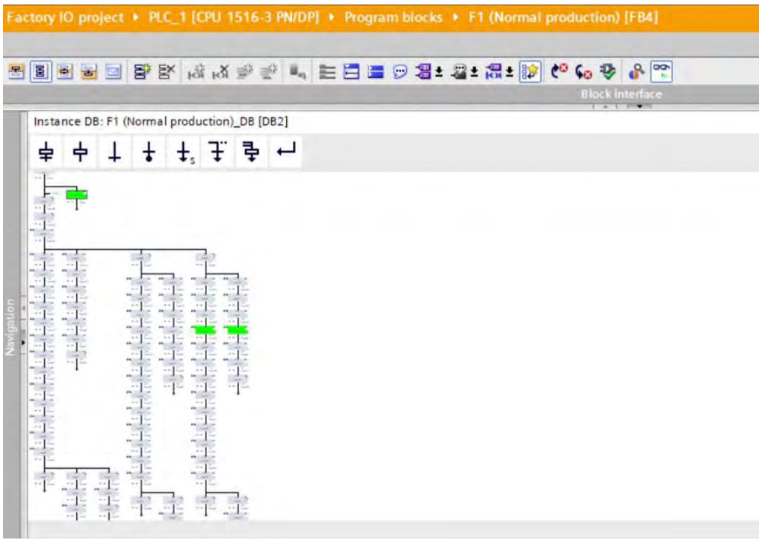
(a)



(b)

Figure 6.171: The program is placed at the normal production mode (F1) of GEMMA, while the Pick & Place is deactivated, and the third base and lid are produced. (a) the screen, (b) Factory I/O

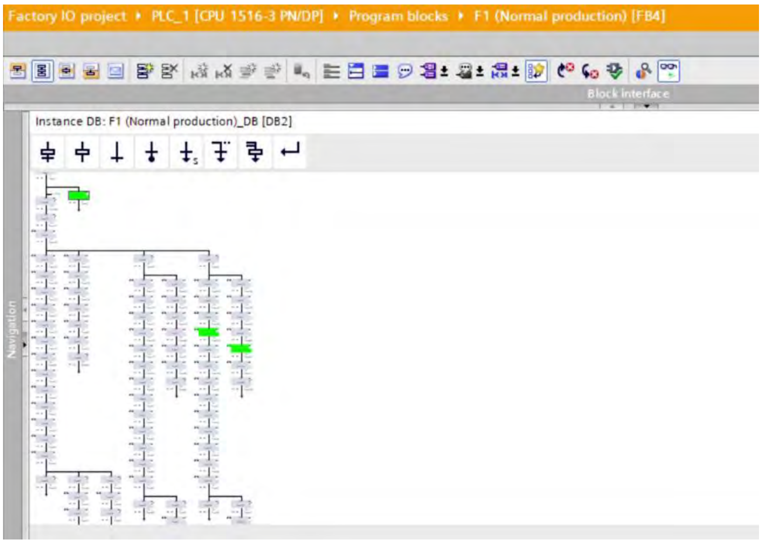
Similarly to the production process of the first and second item that is explained before, the base production is faster than the lid production, for this reason it finishes first. As it is possible to notice in figure 6.172, the robot collects the third base from the CNC machine while the third lid is still in production. In the next stage, the third lid's production has finished, and the robot collects it from the CNC machine as it is shown in figure 6.173. Moreover, it is possible to see that the robots place both the base and the lid on the conveyor for the next stage of the production.



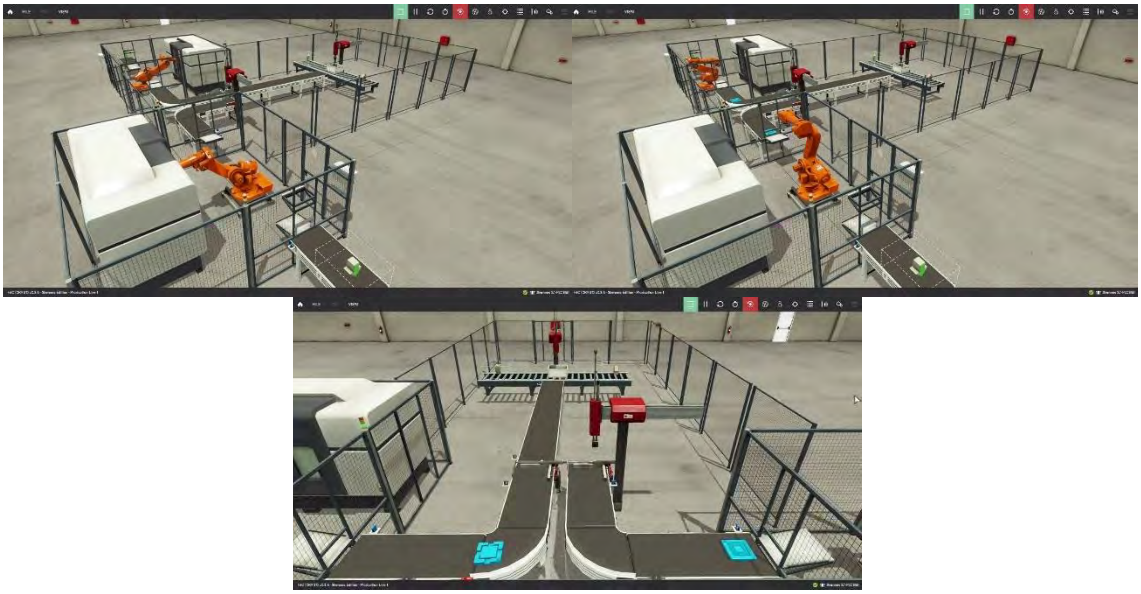
(a)

(b)

Figure 6.172: The program is placed at the normal production mode (F1) of GEMMA, while the third base production has been finished, and this lid is produced. (a) the screen, (b) Factory I/O



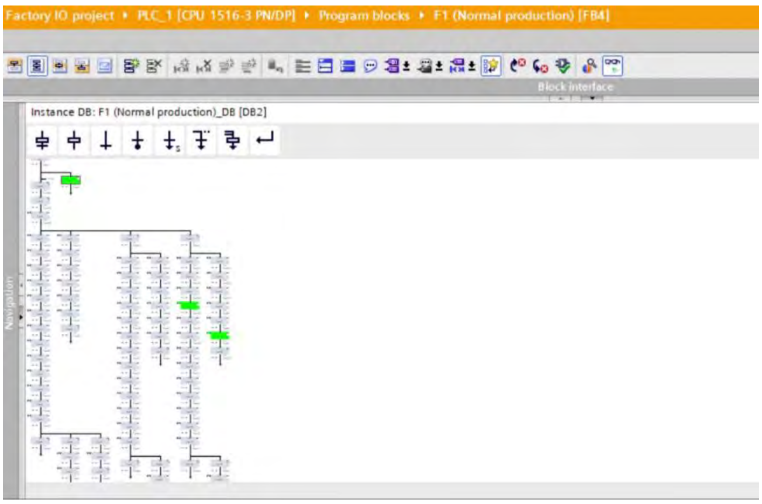
(a)



(b)

Figure 6.173: The program is placed at the normal production mode (F1) of GEMMA, while the third base and lid production have been finished, and the conveyor is activated. (a) the screen, (b) Factory I/O

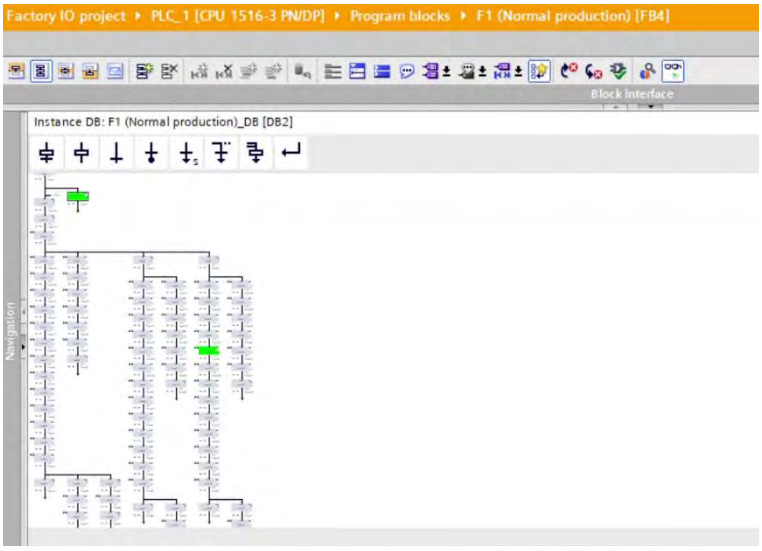
The first item that arrives to the assembly point is the base due to its faster production time. At that moment, the base positioner is clamped in order to place it in the right assembly's place. Figure 6.174 presents this stage of the production process. Afterwards, the third lid arrives as well to the assembly point, and the lid positioner is clamped as it is shown in figure 6.175. While both the base and lid are placed at the right assembly point, the production process is able to move to the next stage.



(a)

(b)

Figure 6.174: The program is placed at the normal production mode (F1) of GEMMA, while the base positioner is clamped. (a) the screen, (b) Factory I/O

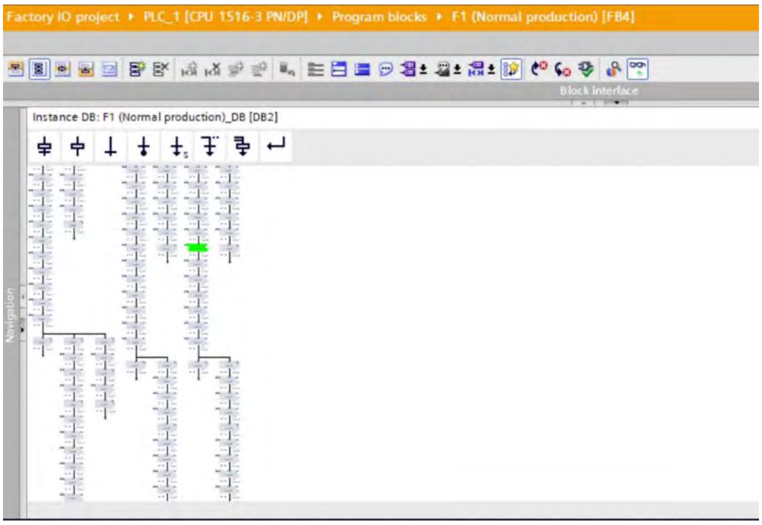


(a)

(b)

Figure 6.175: The program is placed at the normal production mode (F1) of GEMMA, while the lid positioner is clamped. (a) the screen, (b) Factory I/O

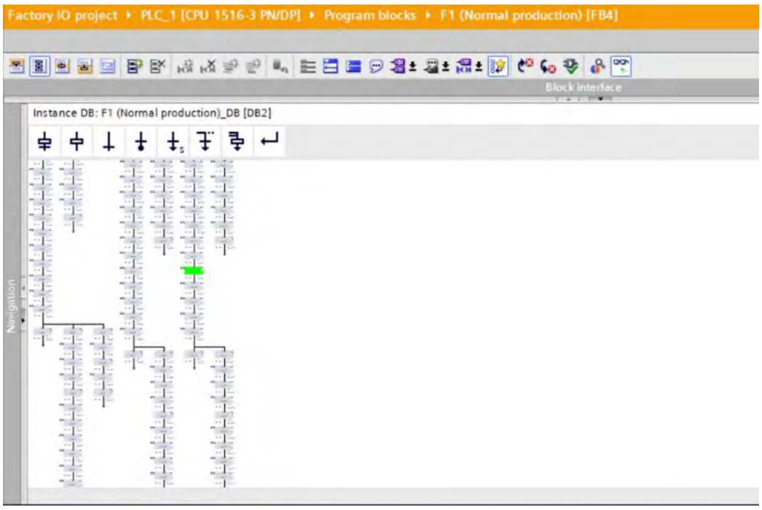
In the next stage, the assembly Pick & Place machine assemblies the third item in the same way as before. First the z axis and suction are activated, then the z axis is deactivated for elevating the lid. Thereafter, the x axis is activated for reaching the base's place. At the end, the z axis is activated, and the item is assembled. At that moment, the assembly process has finished, and item is ready for the next stage of the production. Figures 6.176 – 6.179 include show the assembly process of the third item.



(a)

(b)

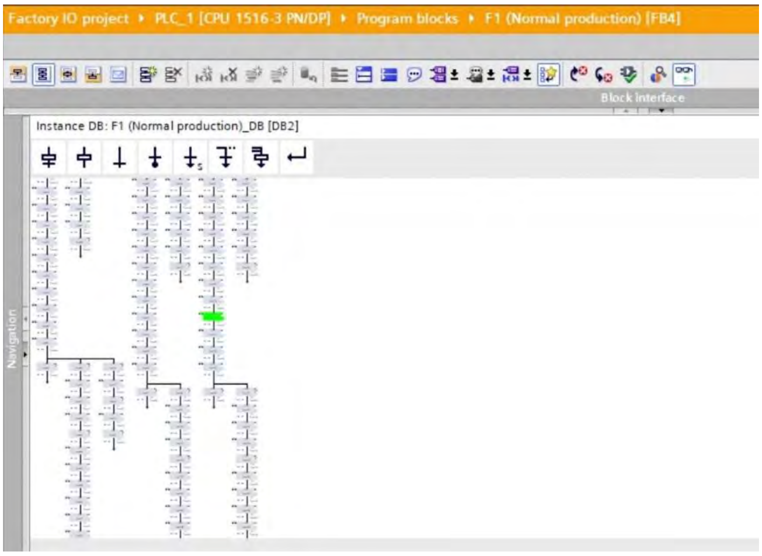
Figure 6.176: The program is placed at the normal production mode (F1) of GEMMA, while Pick & Place z axis and suction are activated. (a) the screen, (b) Factory I/O



(a)

(b)

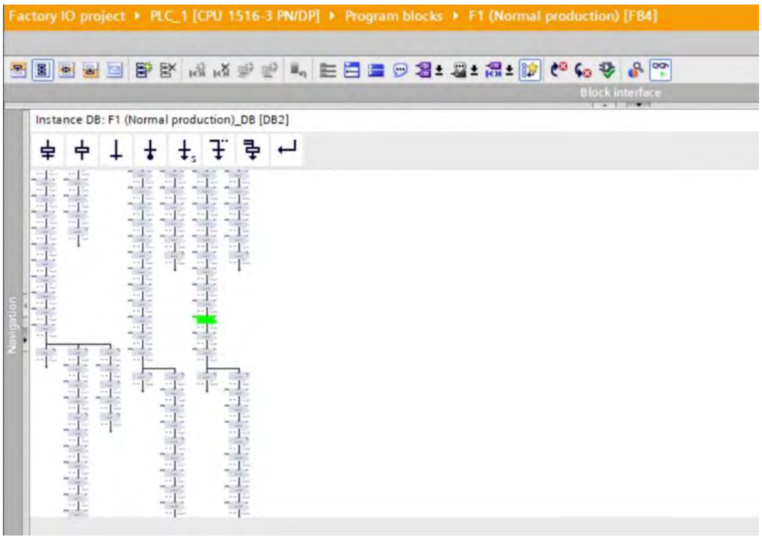
Figure 6.177: The program is placed at the normal production mode (F1) of GEMMA, while Pick & Place z axis is deactivated, and suction is activated. (a) the screen, (b) Factory I/O



(a)

(b)

Figure 6.178: The program is placed at the normal production mode (F1) of GEMMA, while Pick & Place x axis and suction are activated. (a) the screen, (b) Factory I/O

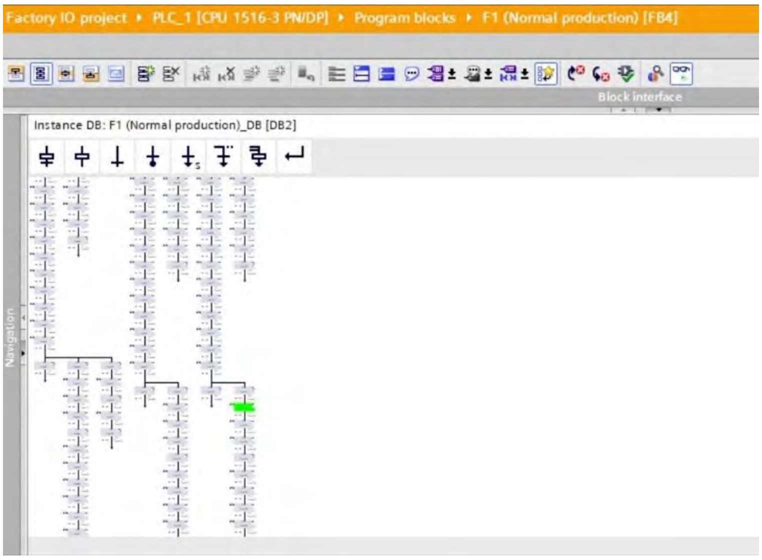


(a)

(b)

Figure 6.179: The program is placed at the normal production mode (F1) of GEMMA, while the Pick & Place x and z axes are activated, and section is deactivated. (a) the screen, (b) Factory I/O

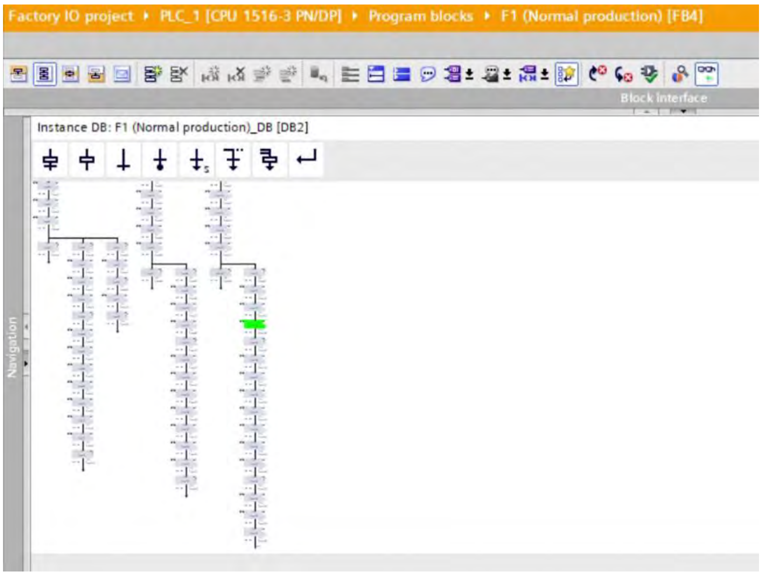
When the assembly process has finished, the item is ready for packing. In the next stage, the positioner is raised, and the conveyor is activated. In this stage, the third item is transferred to the packing point. It is possible to see this stage of the production process in figure 6.180. In the next stage the item arrives to the packing point as it is sown in figure 6.181. The figures present the program, and the production line.



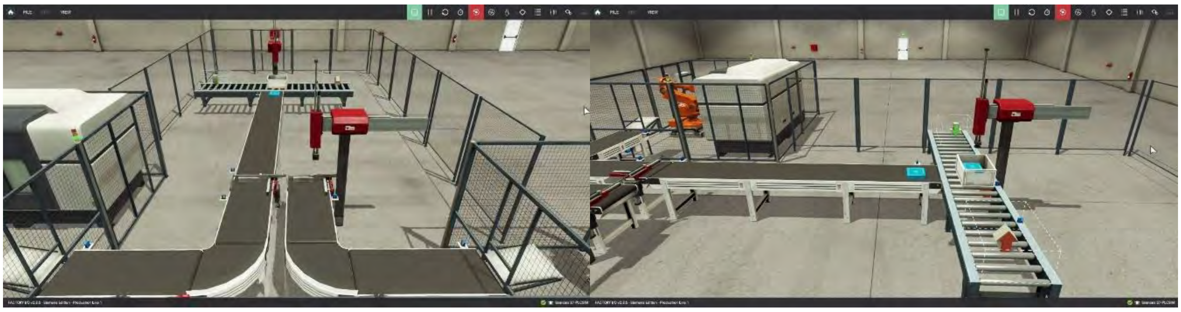
(a)

(b)

Figure 6.180: The program is placed at the normal production mode (F1) of GEMMA, while the Pick & Place is deactivated, the positioner is raised, and the conveyor is activated. (a) the screen, (b) Factory I/O



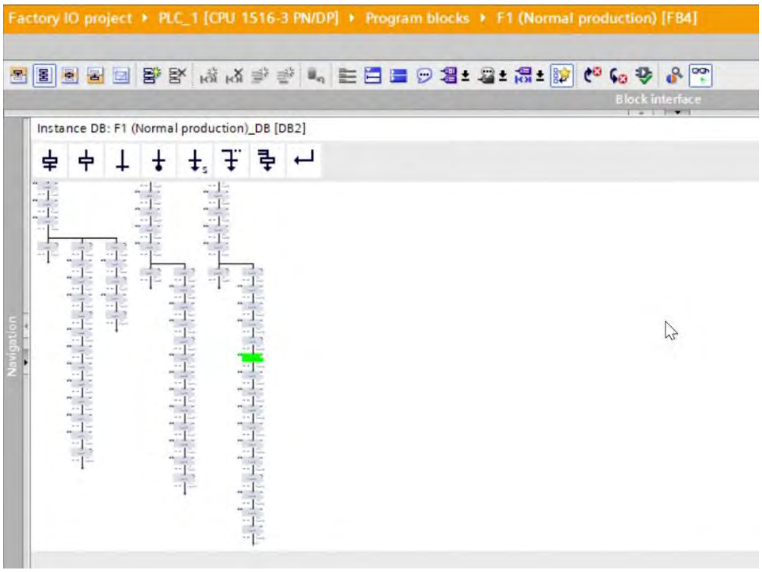
(a)



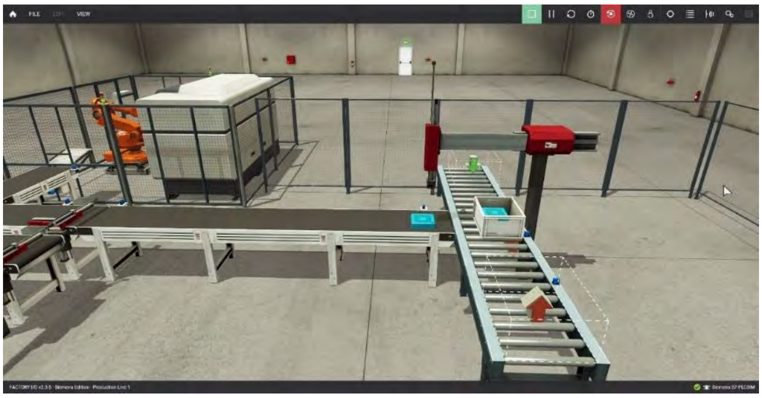
(b)

Figure 6.181: The program is placed at the normal production mode (F1) of GEMMA, while the third item has arrived to the packing point, and conveyor is deactivated. (a) the screen, (b) Factory I/O

In the moment that the third item arrives to the packing point, the packing process of the third item starts. That is to say, the packing Pick & Place machine is activated in order to collect the item and place it in the delivery box. In this production line, as it is explained in before, one cycle of the production produces three items. For this reason, it is the last item of this production line cycle. The packing process of the third item is operated in the same way as the previous packing processes which it is explained for the second item. Figures 6.182 – 6.187 present the packing process of the third item including the program, and the product line in each stage of the process.

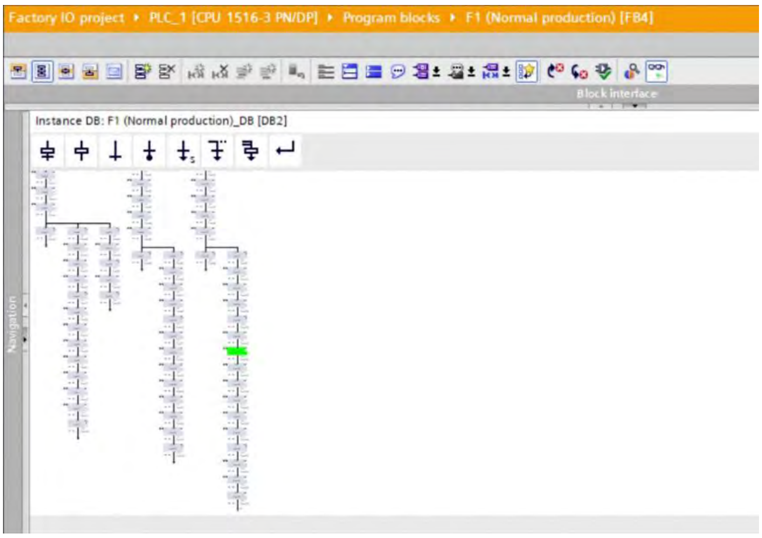


(a)

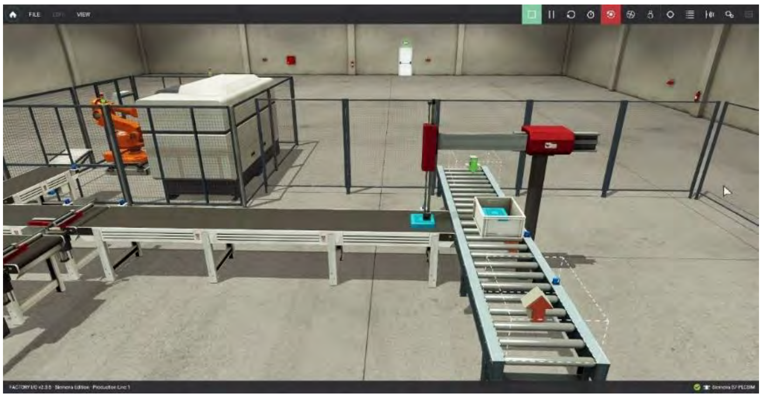


(b)

Figure 6.182: The program is placed at the normal production mode (F1) of GEMMA, while Pick & Place x axis is activated. (a) the screen, (b) Factory I/O

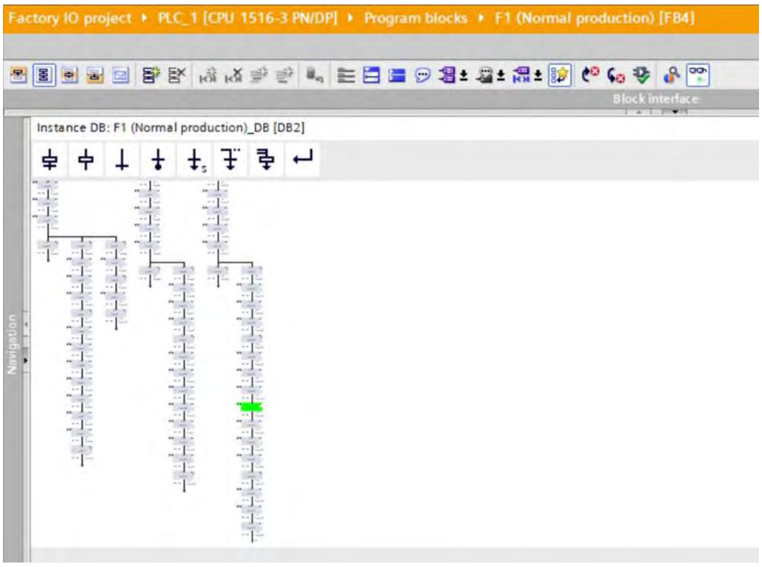


(a)

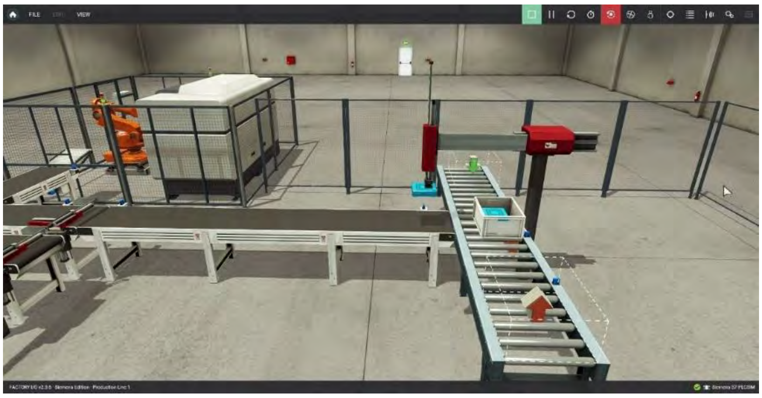


(b)

Figure 6.183: The program is placed at the normal production mode (F1) of GEMMA, while Pick & Place x and z axes, and suction are activated. (a) the screen, (b) Factory I/O

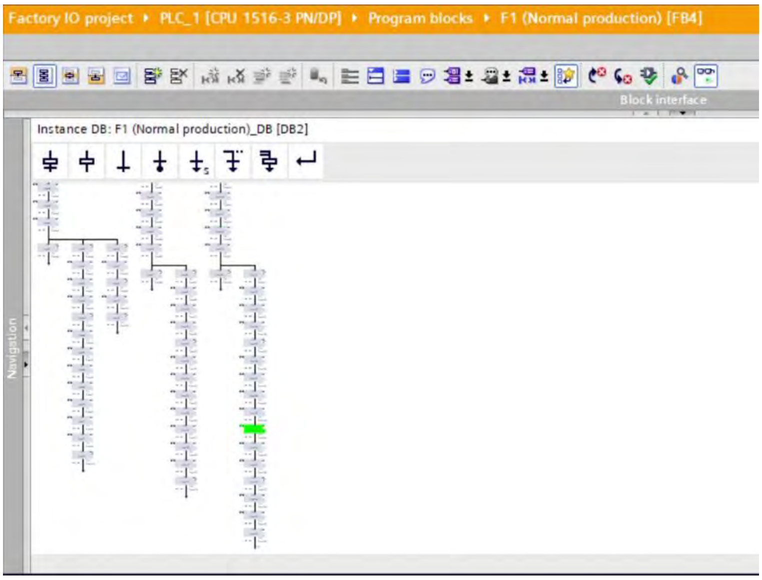


(a)

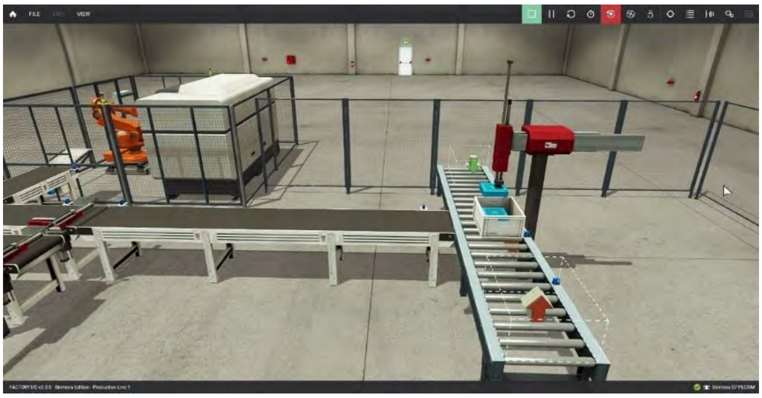


(b)

Figure 6.184: The program is placed at the normal production mode (F1) of GEMMA, while Pick & Place x axis and suction are activated. (a) the screen, (b) Factory I/O

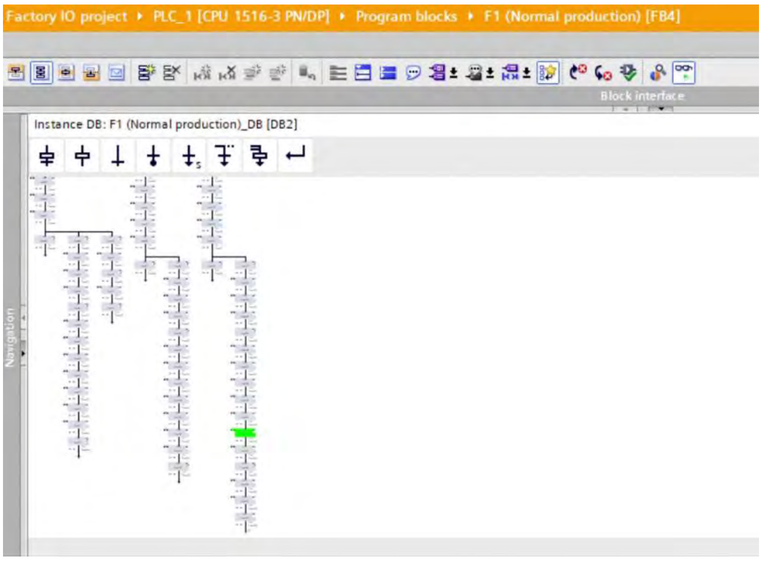


(a)

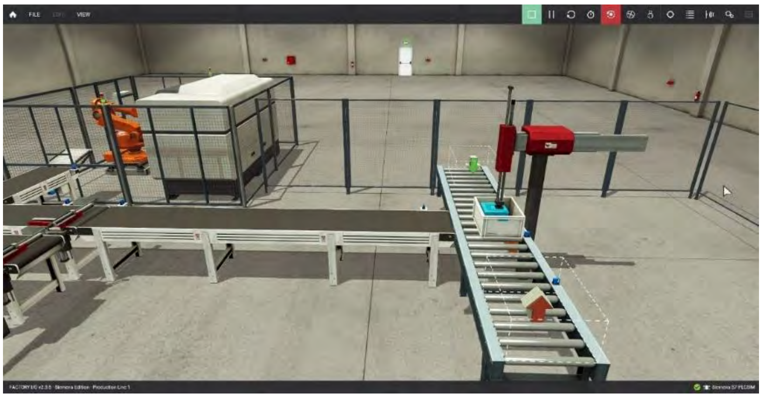


(b)

Figure 6.185: The program is placed at the normal production mode (F1) of GEMMA, while Pick & Place section is activated. (a) the screen, (b) Factory I/O

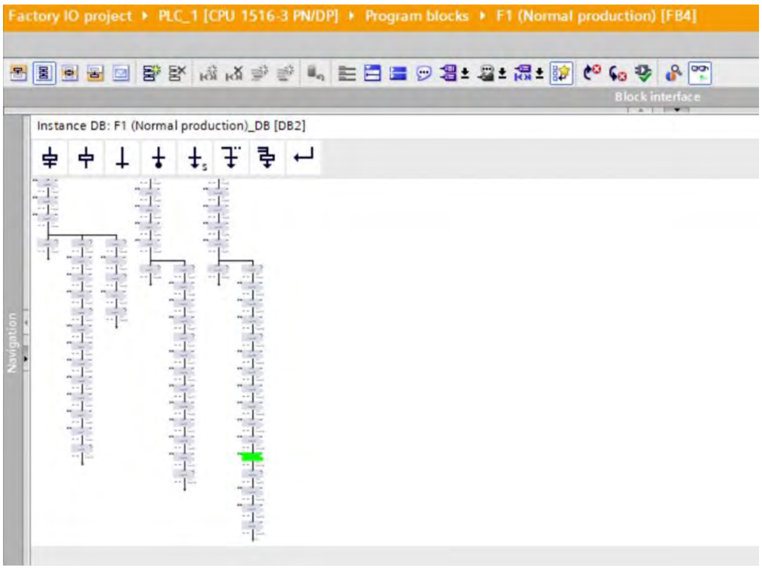


(a)

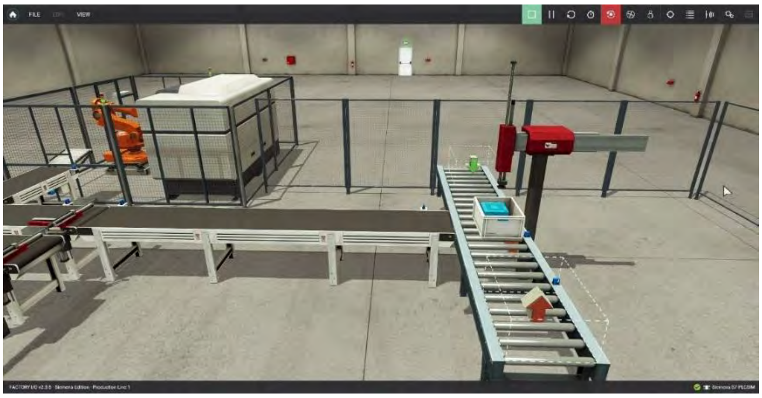


(b)

Figure 6.186: The program is placed at the normal production mode (F1) of GEMMA, while Pick & Place z axis is activated. (a) the screen, (b) Factory I/O



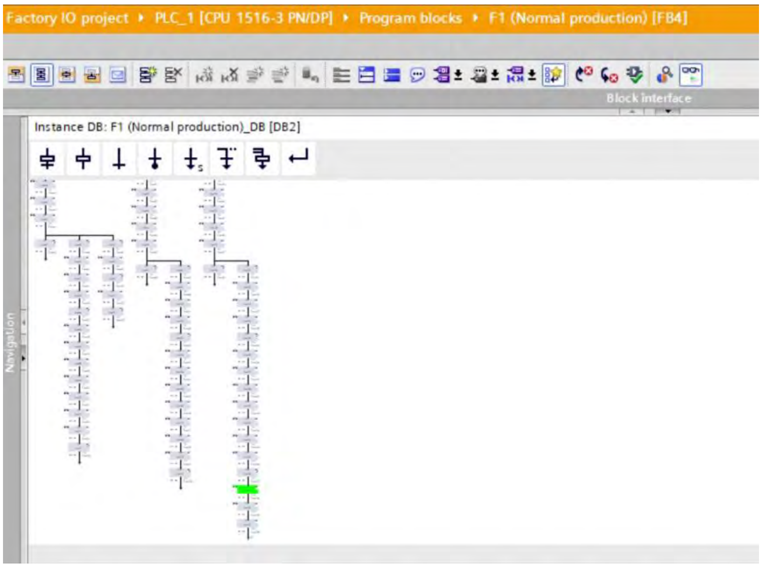
(a)



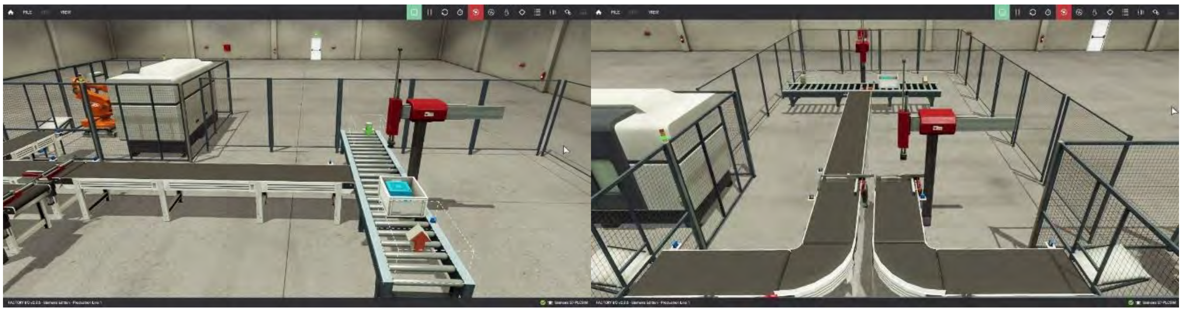
(b)

Figure 6.187: The program is placed at the normal production mode (F1) of GEMMA, while Pick & Place is deactivated, and the three items are placed at the delivery box. (a) the screen, (b) Factory I/O

At the moment that the packing process of the third item has finished, the delivery box contains the three items, and it is ready for the delivery. The next stage of the production process is the last stage of the production cycle. At this stage, the roller conveyor is activated in order to transfer the box to the delivery. Then, the delivery box arrives to the delivery point, and the remover is activated. Figures 6.188 – 6.190 present the delivery process. It is possible to see first how the box is transferred, then that it removes while it arrives to the remover. The last figure shows the next moment while it has removed and the program of the production cycle has finished.

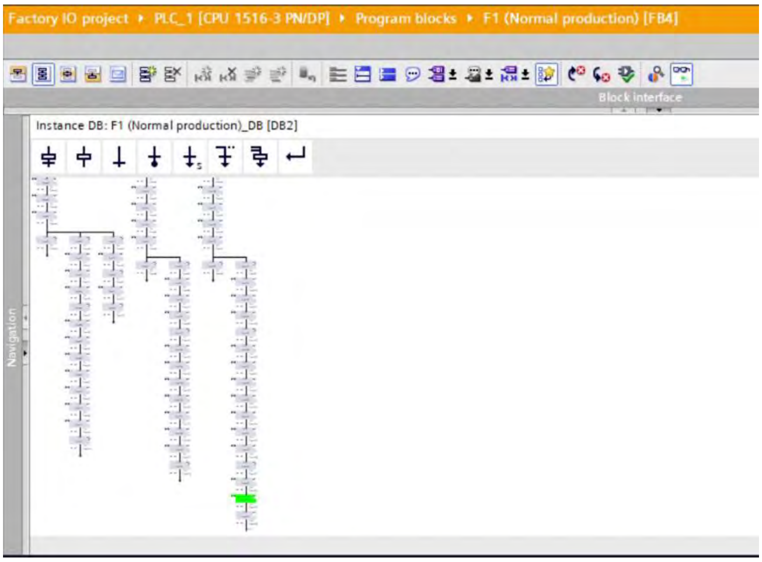


(a)

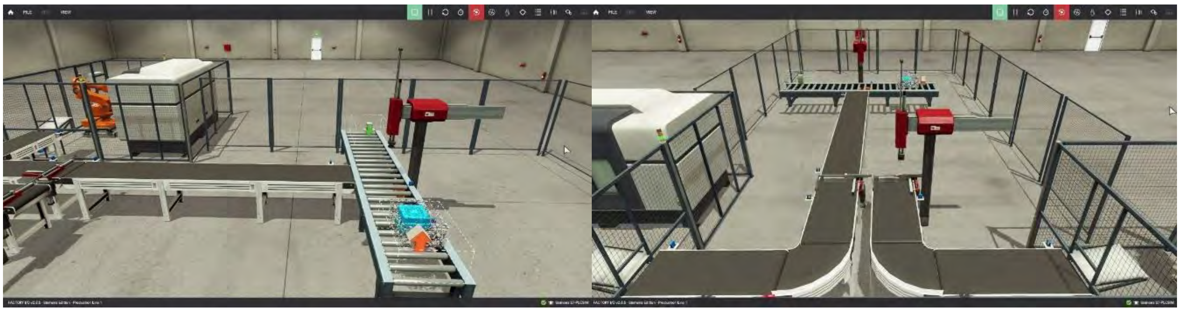


(b)

Figure 6.188: The program is placed at the normal production mode (F1) of GEMMA, while the roller delivery box is activated. (a) the screen, (b) Factory I/O

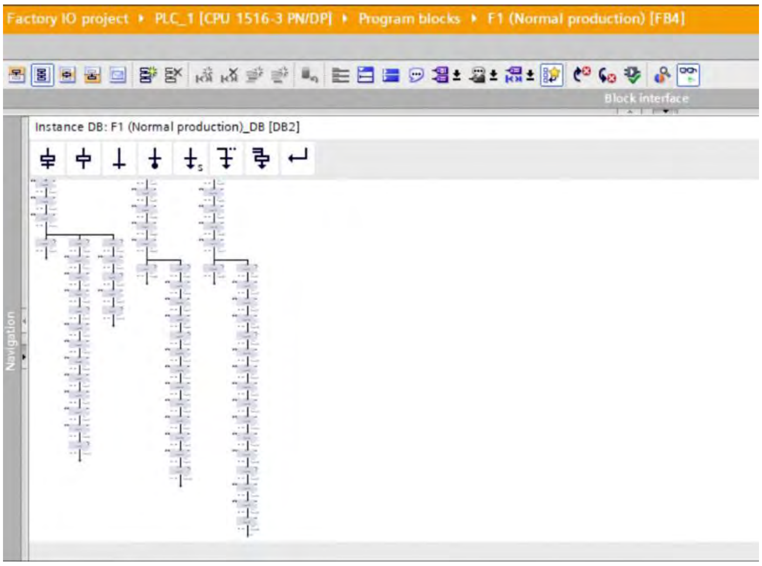


(a)

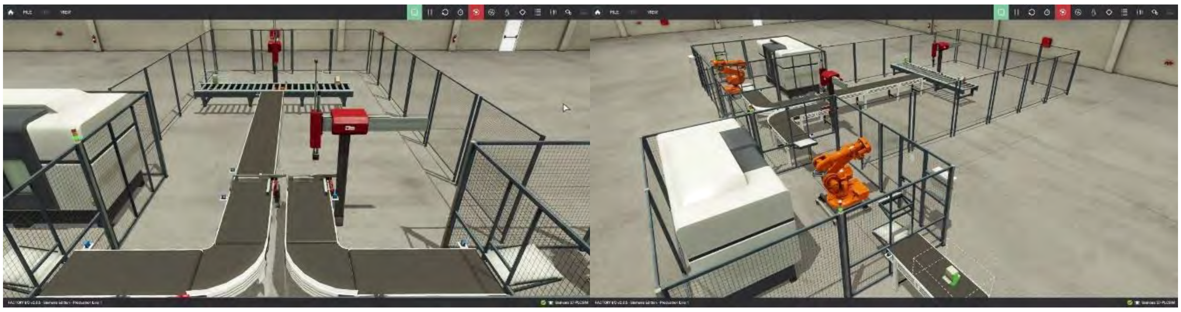


(b)

Figure 6.189: The program is placed at the normal production mode (F1) of GEMMA, while the delivery box is removed. (a) the screen, (b) Factory I/O



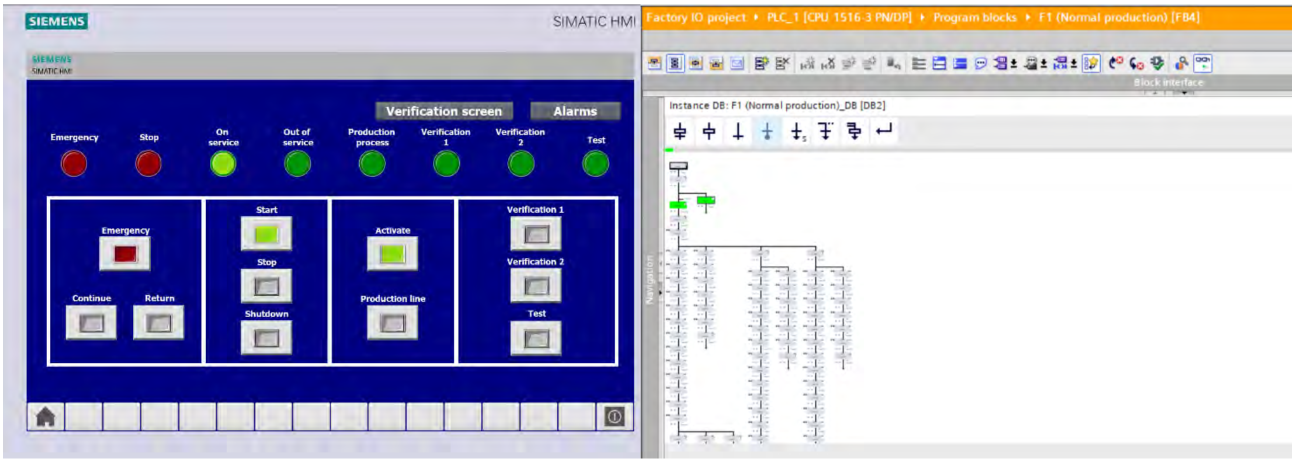
(a)



(b)

Figure 6.190: The program is placed at the normal production mode (F1) of GEMMA, while the production cycle has been finished. (a) the screen, (b) Factory I/O

At the same moment, the program is placed at the initial state of the normal production mode (F1). That is to say, both the program and production line are ready for the next production cycle. The figure below shows the operation screen, and the program at that moment. It is possible to notice that the program in on service, and it waits for the next operation cycle.

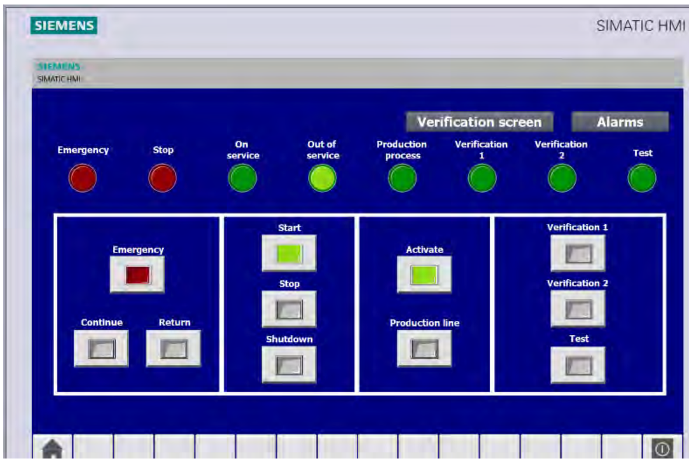


(a) (b)

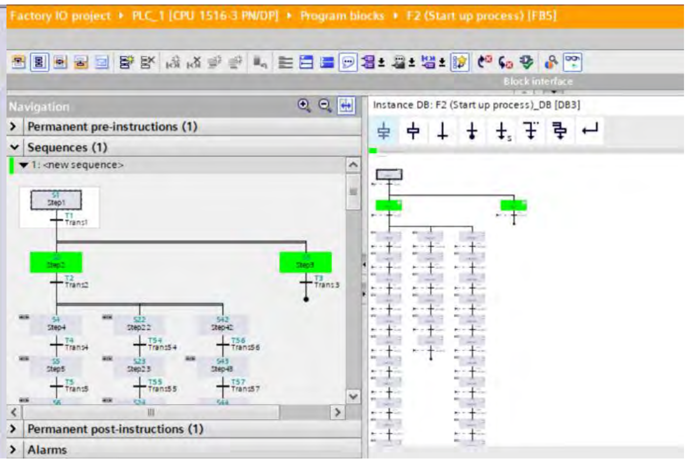
Figure 6.191: The program is placed at the normal production mode (F1) of GEMMA, and it is ready for the production cycle. (a) the screen, (b) Factory I/O

The startup process of the production line is activated while the production line is not prepared for the operation, and the program is placed at the initial stop state. The production line may be in this situation if at any reason the production process did not finish correctly, and for this reason, the production cannot start properly. For example, there are raw materials in the CNC machines at some point of the production, there are items at some place of the production line that did not finished the assembly or the delivery, etc. When the operator presses the activation button in this situation, the program will detect that the production line needs the startup process for starting the production. At this moment, the algorithm will place the program automatically at the startup process mode (F2) in order to prepare the production line for the next operation. In this way, the operator is able to activate the program for the operation even in a situation that the production line is not prepared. It provides safe and comfortable operation and allows the operator to start the production at any situation without being worried for the production line situation at a certain moment.

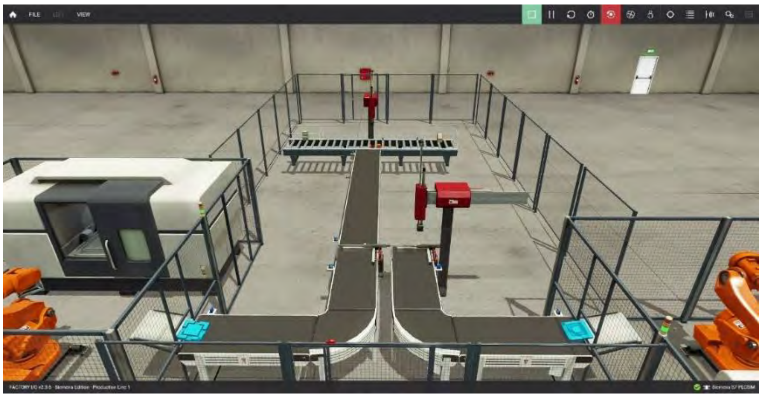
During the startup process, the program is out of service as it is possible to notice in figure 6.192. Moreover, the program is placed at the initial state of the startup process mode (F2). At this state, the program detects the situation of the production line in order to start the appropriate startup process. The situation of the production line of this example is presented in the figure below. It is possible to notice that the production process stopped improperly while the first base and lid production finished, and they are placed on the conveyors on the way to the assembly point.



(a)



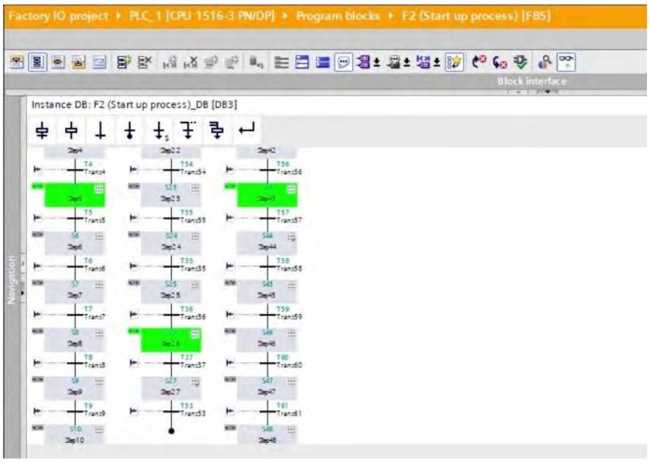
(b)



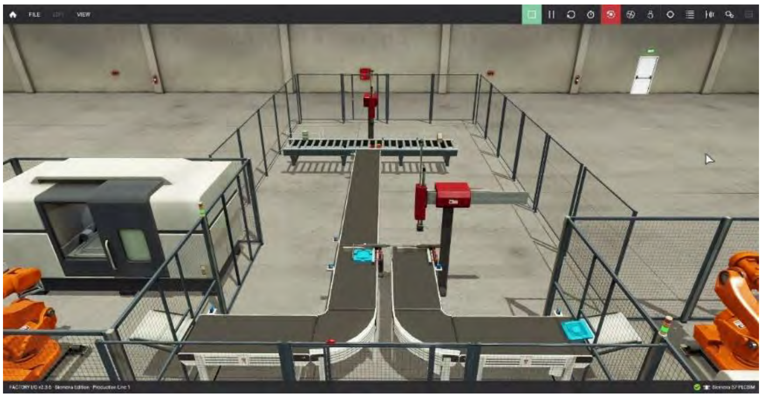
(c)

Figure 6.192: The program is placed at the startup process mode (F2) of GEMMA, while the activation button is pressed. (a) the screen, (b) the program, (c) Factory I/O

The program detects the situation of the production line and operates the startup process for this particular situation as it is explained before. In this situation, the program jumps to the second stage in order to transfer the base and lid to the assembly point as it is shown in the figure below. It is possible to notice that first the program transfers the base to the assembly point, and then the base positioner is clamped. The figure presents the program, and the product line at this stage of the startup process.



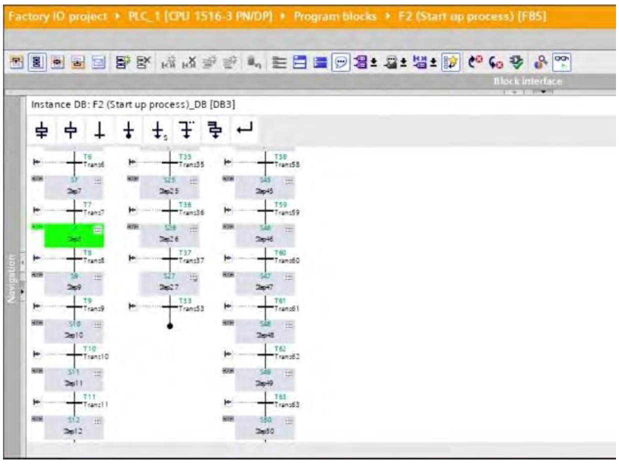
(a)



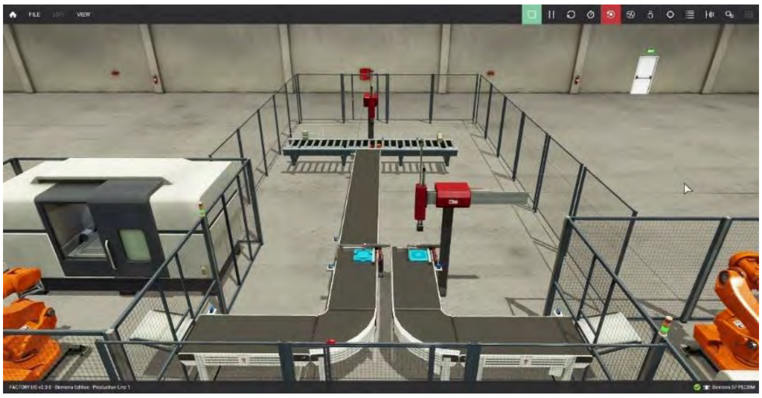
(b)

Figure 6.193: The program is placed at the startup process mode (F2) of GEMMA, while the base positioner is clamped. (a) the program, (b) Factory I/O

In the next stage, the program transfers the lid to the assembly point as it is shown in figure 6.194. As soon as the lid arrives to the assembly point, the lid positioner is clamped for placing it in the appropriate place for the assembly. The figure shows the program, and the product line at this stage.



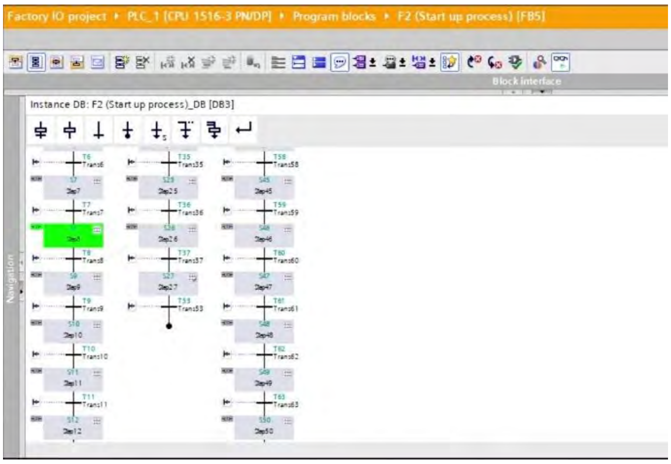
(a)



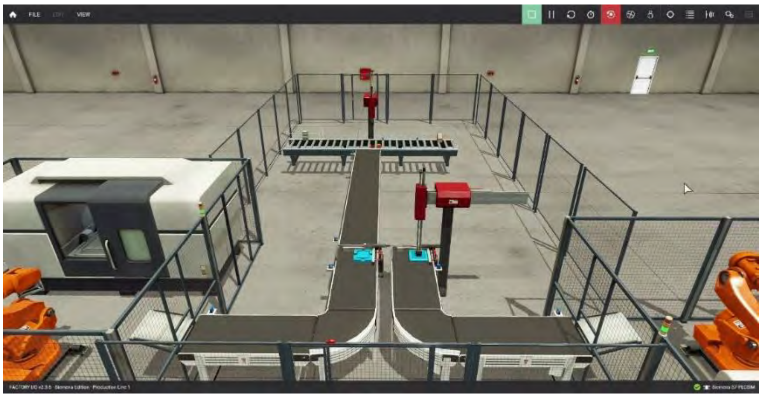
(b)

Figure 6.194: The program is placed at the startup process mode (F2) of GEMMA, while the lid positioner is clamped. (a) the program, (b) Factory I/O

When both the base and lid are placed at the correct location for the assembly, the program moves to the assembly stage, and activates the assembly Pick & Place machine. First the z axis and suction are activated as it is shown in figure 6.195, then the z axis is deactivated for elevating the lid as it is presented in figure 6.196. Afterwards, the x axis is activated in order to reach the exact place of the base while the suction is activated continuously. Figure 6.197 shows this assembly step. At the end, the z axis is activated for assembling the item as it is illustrated in figure 6.198.

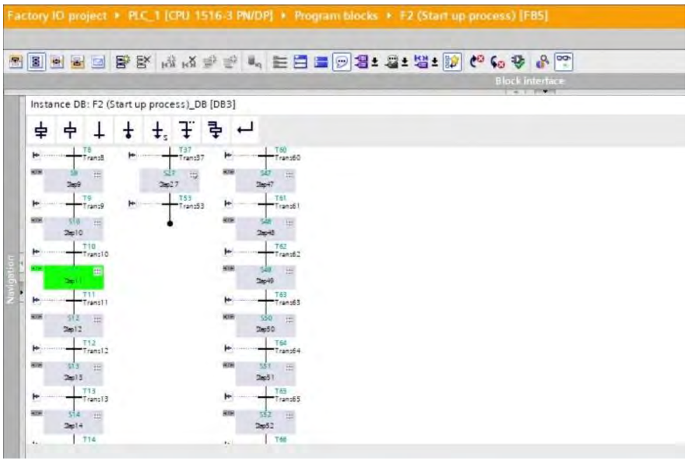


(a)

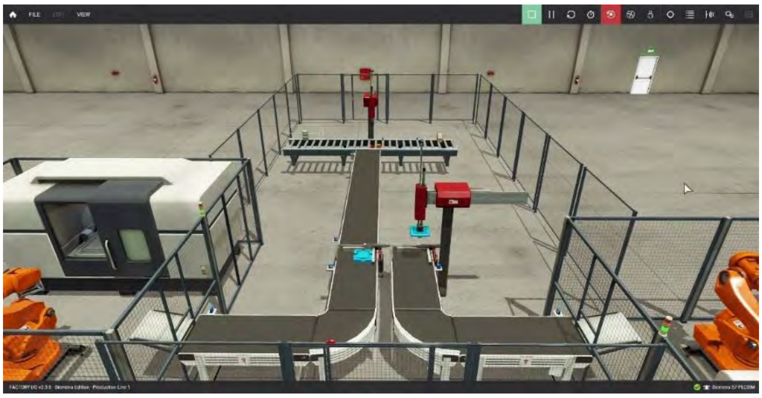


(b)

Figure 6.195: The program is placed at the startup process mode (F2) of GEMMA, while the Pick & Place z axis and suction are activated. (a) the program, (b) Factory I/O

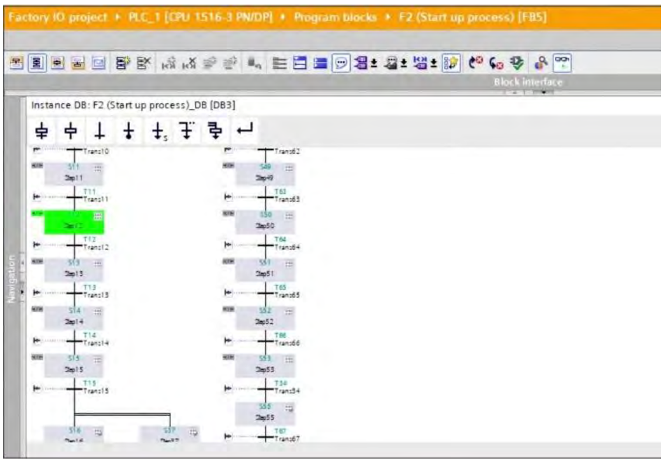


(a)

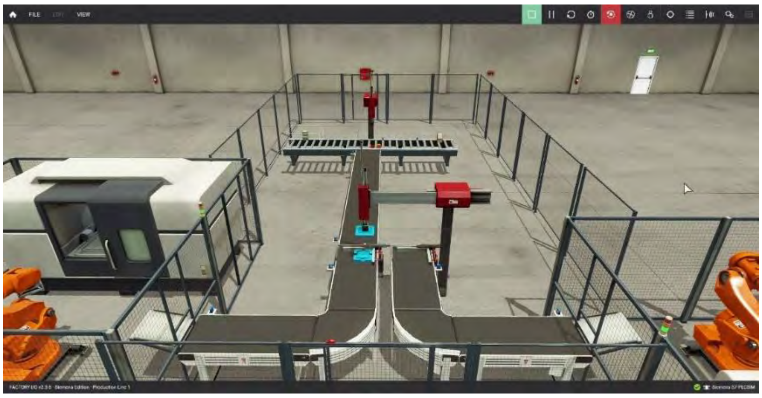


(b)

Figure 6. 196: The program is placed at the startup process mode (F2) of GEMMA, while the Pick & Place z axis is deactivated, and suction is activated. (a) the program, (b) Factory I/O

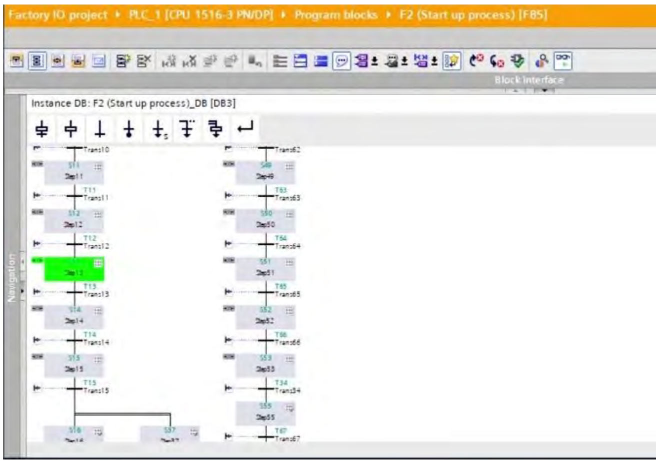


(a)

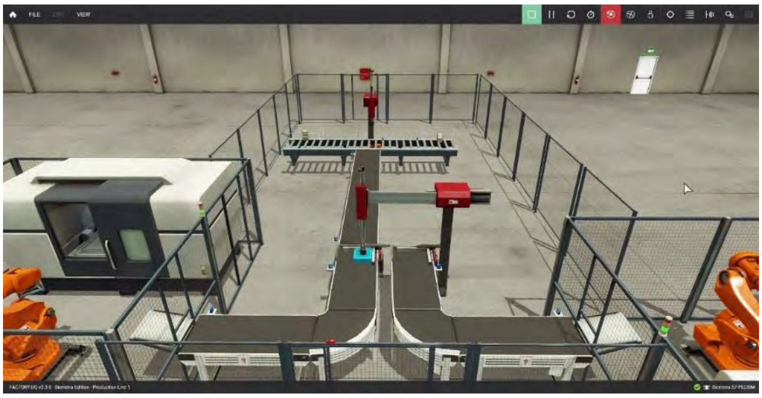


(b)

Figure 6.197: The program is placed at the startup process mode (F2) of GEMMA, while the Pick & Place x axis and suction are activated. (a) the program, (b) Factory I/O



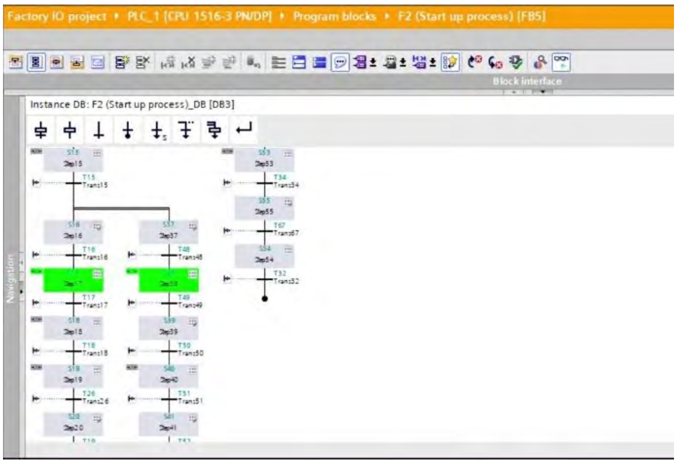
(a)



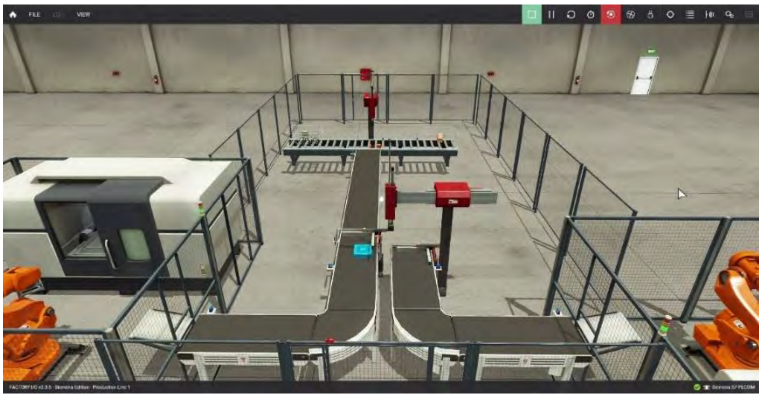
(b)

Figure 6.198: The program is placed at the startup process mode (F2) of GEMMA, while the Pick & Place x and z axes are activated, and suction is deactivated. (a) the program, (b) Factory I/O

At the moment that the assembly process finishes, the program moves to the next stage. At that stage, the item is ready for packing, the positioner is raised for allowing the transition, and the conveyor is activated in order to transfer the item to the packing point. Figure 6.199 below presents the program and production line at this stage of the startup process. Moreover, it is possible to see in figure 6.200 at the same stage that the delivery box has emitted and is transferred to the delivery point. Also, at the same moment, the item is transferred to the packing point.

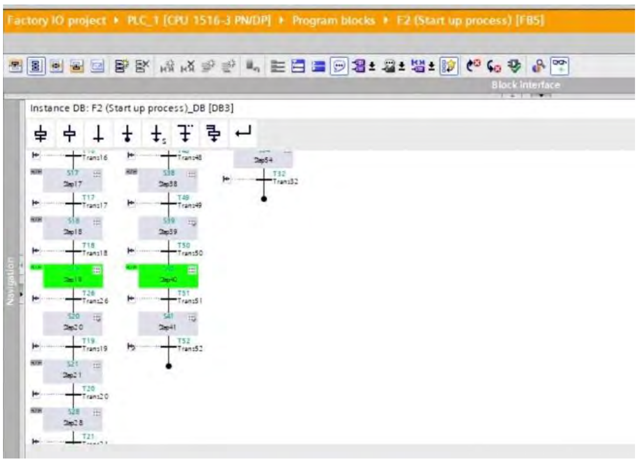


(a)



(b)

Figure 6.199: The program is placed at the startup process mode (F2) of GEMMA, while the Pick & Place is deactivated, the positioner is raised, and the conveyor is activated. (a) the program, (b) Factory I/O

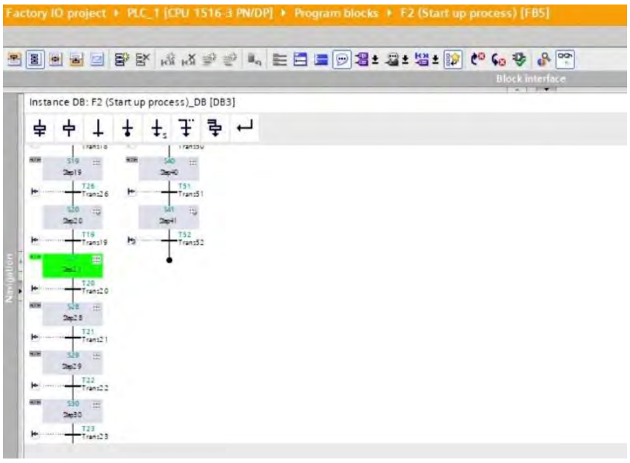


(a)

(b)

Figure 6.200: The program is placed at the startup process mode (F2) of GEMMA, while the conveyor transfers the item, and roller conveyor transfers the delivery box. (a) the program, (b) Factory I/O

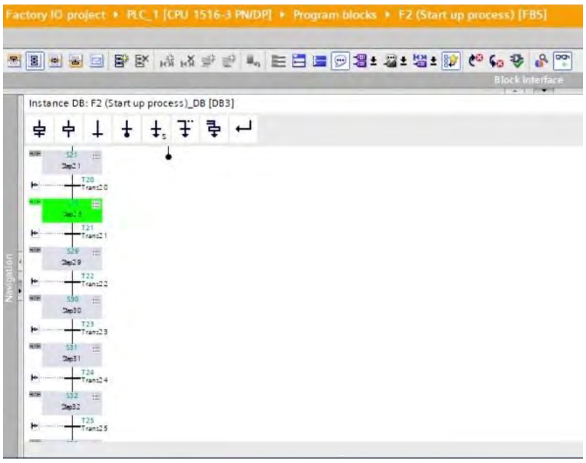
As soon as both the item and box arrive to the packing point, the program moves to the next stage, and the packing Pick & Place machine is activated for packing the item. The packing process is divided into few steps. First, the x axis is activated in order to reach the item location as it is shown in figure 6.201. Second, the z axis and suction are activated for grabbing the item, figure 6.202 presents this step. Then, the z axis is deactivated, and the item is elevated as it is possible to see in figure 6.203. In the next step, the x axis is deactivated for reaching the delivery place of the box, figure 6.204 shows this step. At the end, the z axis and suction are deactivated. In this step the packing Pick & Place machine places the item in the deliver box as it is presented in figure 6.205.



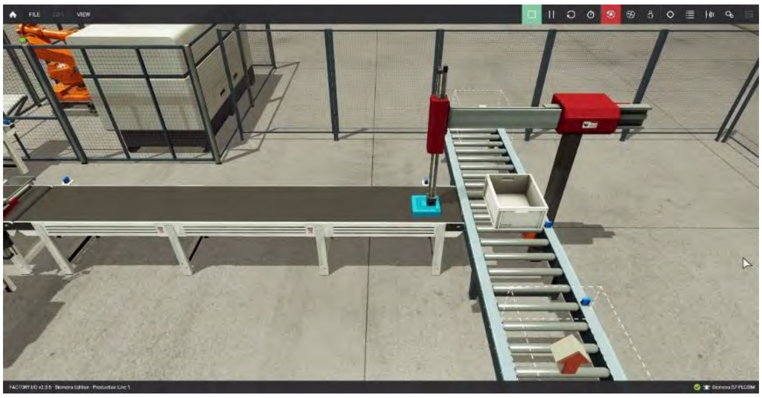
(a)

(b)

Figure 6.201: The program is placed at the startup process mode (F2) of GEMMA, while the Pick & Place x axis is activated. (a) the program, (b) Factory I/O

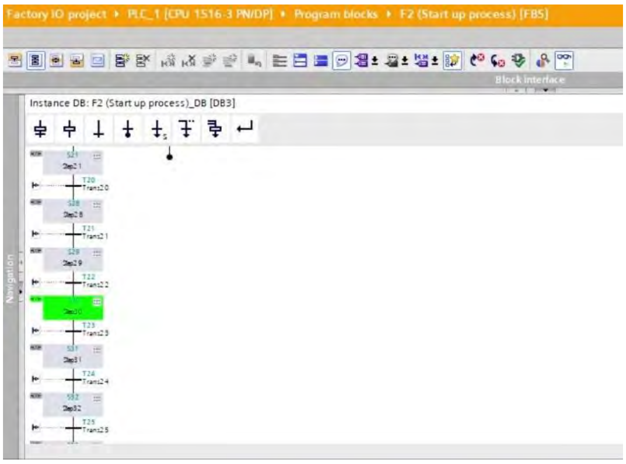


(a)



(b)

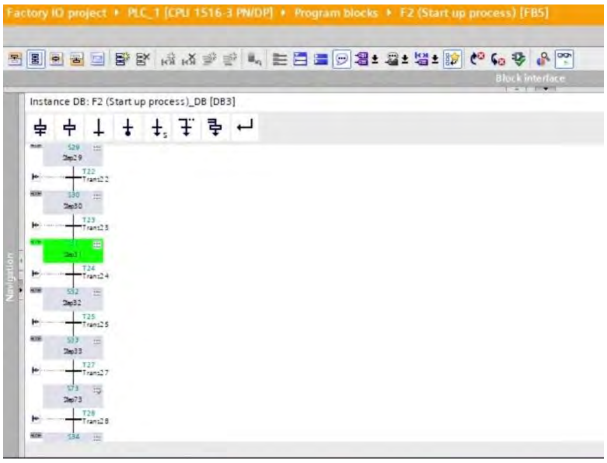
Figure 6.202: The program is placed at the startup process mode (F2) of GEMMA, while the Pick & Place x, z axes and suction are activated. (a) the program, (b) Factory I/O



(a)

(b)

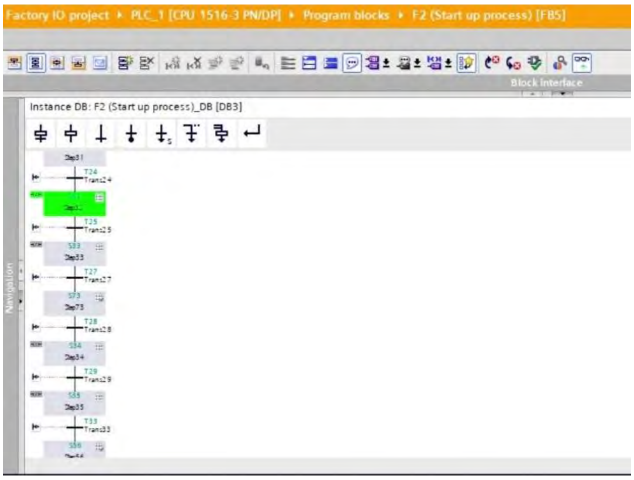
Figure 6.203: The program is placed at the startup process mode (F2) of GEMMA, while the Pick & Place x axis and suction are activated. (a) the program, (b) Factory I/O



(a)

(b)

Figure 6.204: The program is placed at the startup process mode (F2) of GEMMA, while the suction is activated. (a) the program, (b) Factory I/O

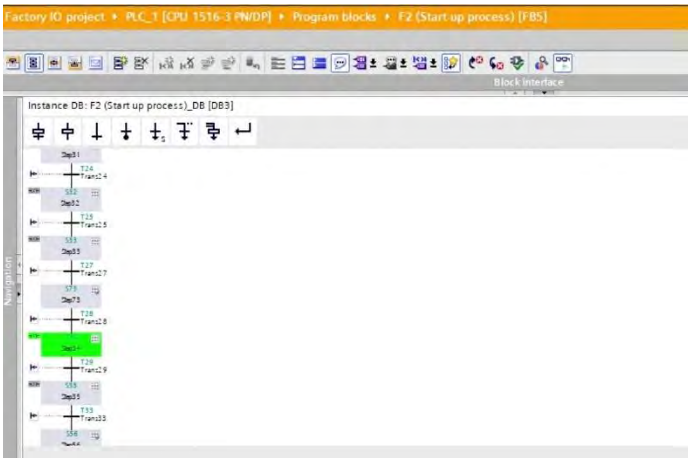


(a)

(b)

Figure 6.205: The program is placed at the startup process mode (F2) of GEMMA, while the Pick & Place z axis is activated, and suction is deactivated. (a) the program, (b) Factory I/O

At the moment that the packing process finishes, the program moves to the next stage as it is shown in the figure below. At this stage, roller conveyor is activated, and the delivery box is transferred for the delivery. The figure presents the program, and the production line at this stage of the startup process.

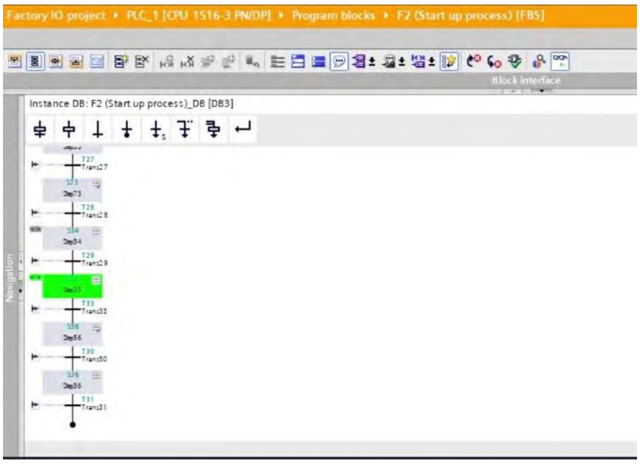


(a)

(b)

Figure 6.206: The program is placed at the startup process mode (F2) of GEMMA, while the roller conveyor is activated. (a) the program, (b) Factory I/O

When the delivery box arrives to the delivery point, the remover is activated in order to remove to delivery box. This stage of the startup process is shown in figure 6.207, it is possible to see the program, and the production line at this stage. This is the last stage of the startup process. At the moment that the delivery box is removed, the algorithm switches off the startup process mode (F2) as it is possible to see in figure 6.208. At that moment, the algorithm places the program at the normal production mode for the normal operation. Figure 6.209 presents the operation screen, and the program while the startup process has finished, and the program is placed at the normal production mode (F1).



(a)

(b)

Figure 6.207: The program is placed at the startup process mode (F2) of GEMMA, while the remover is activated, and the delivery box is removed. (a) the program, (b) Factory I/O

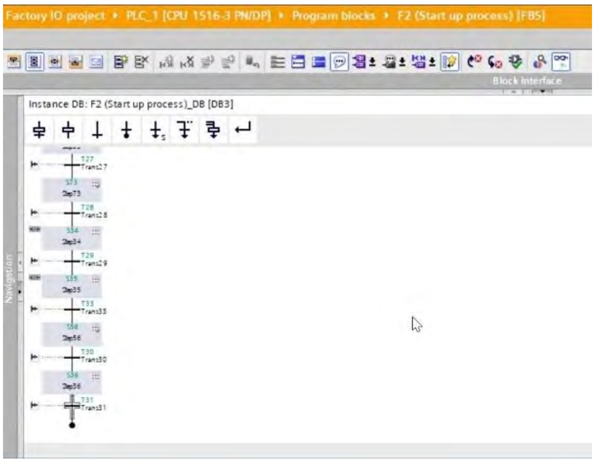
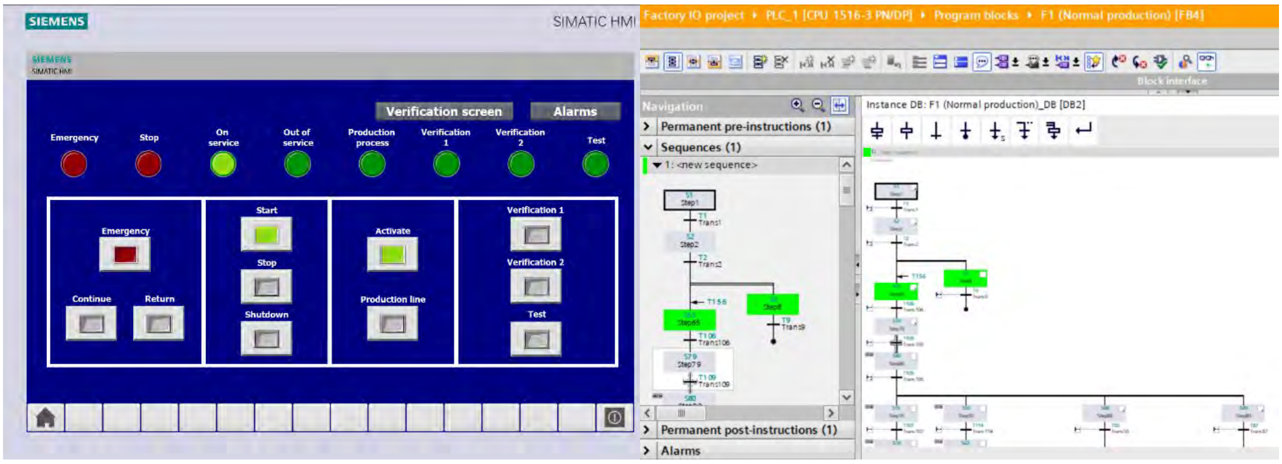


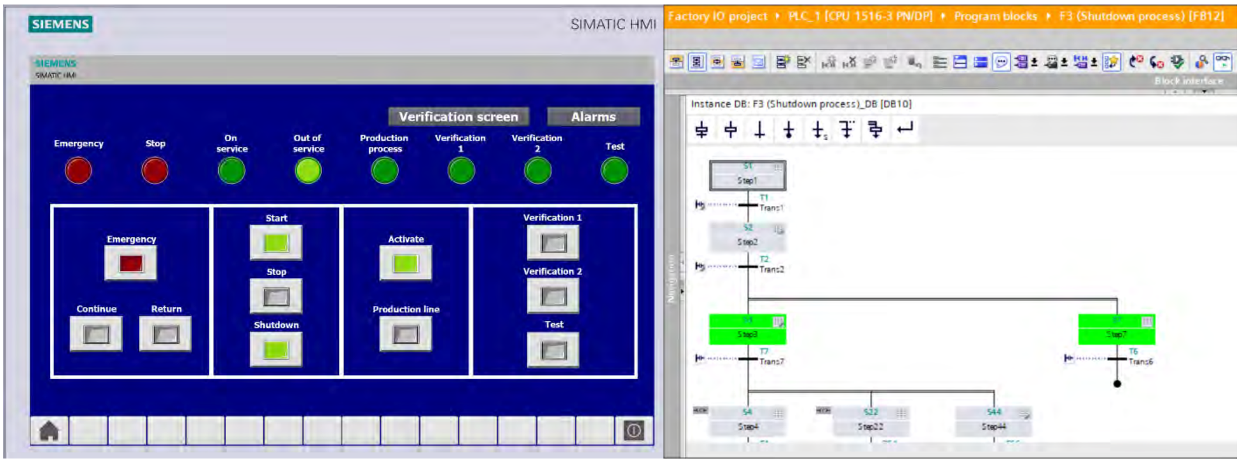
Figure 6.208: The startup process mode (F2) of GEMMA is off



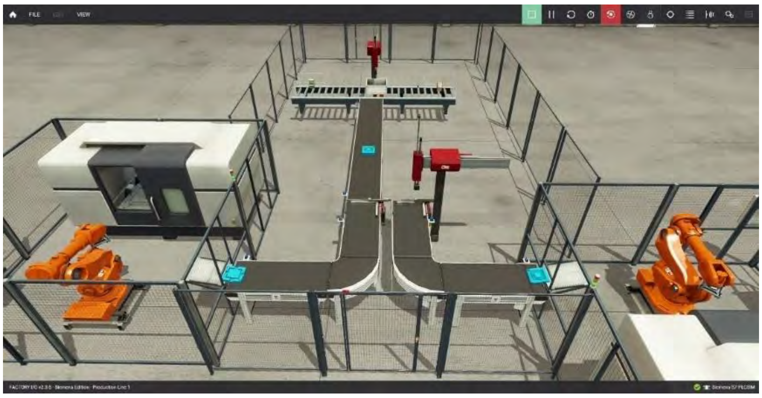
(a) (b)

Figure 6.209: The program is placed at the normal production mode (F1) of GEMMA, while the startup process has been finished. (a) the screen, (b) the program

In a similar way, the shutdown process of the production line is working. This process is activated in a situation that at any reason the production line did not finish properly the operation, and the operator desires to shut the program down. When the operator presses the shutdown button, the program detects that the shutdown process is necessary, and the algorithm places the program in the shutdown process mode (F3) as it is presented in the figure below. It is possible to notice that in this moment the program is in out of service, it is placed at the initial state of the F3 mode and it is ready for the shutdown process. Moreover, it is possible to see the situation of the production line at that moment which the first item is assembled and is on the way for the packing point, and the second base and lid are already produced.



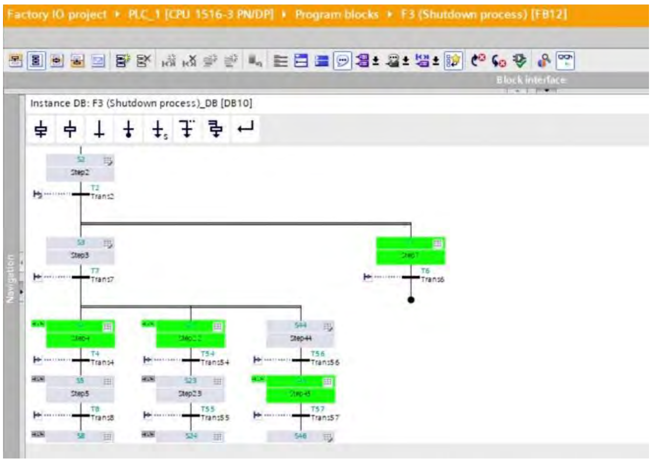
(a) (b)



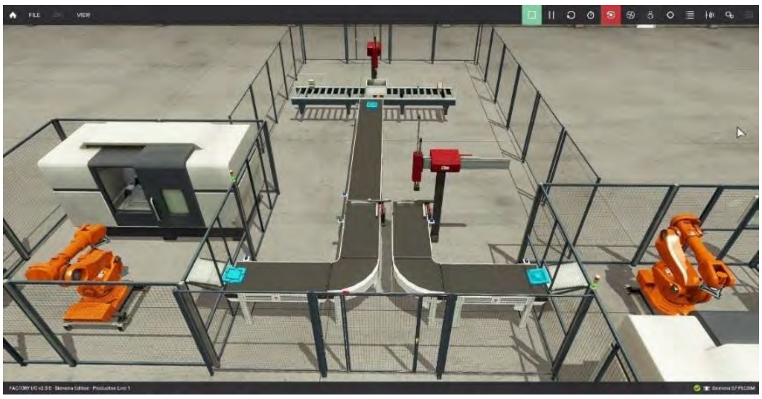
(c)

Figure 6.210: The program is placed at the shutdown process mode (F3) of GEMMA. (a) the screen, (b) the program, (c) Factory I/O

The program detects the situation of the production line in order to start the appropriate shutdown process. In this example, first the assembled item is transferred to the packing point as it is presented in figure 6.211.



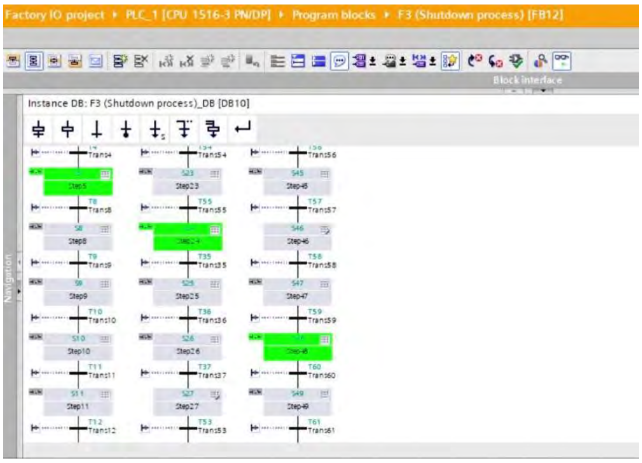
(a)



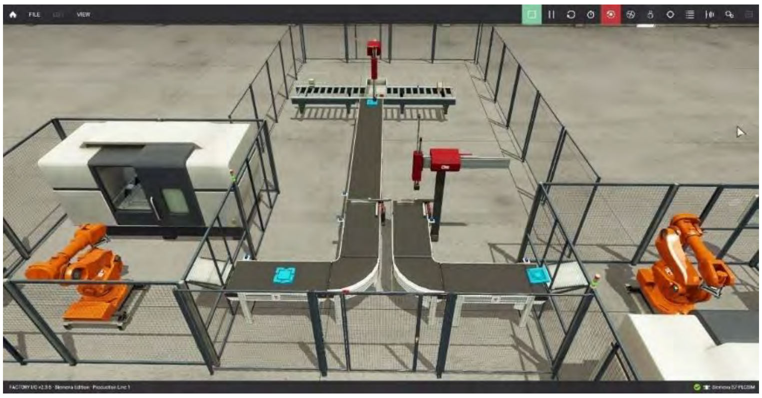
(b)

Figure 6.211: The program is placed at the shutdown process mode (F3) of GEMMA, while the delivery conveyor is activated until the product arrives to the packing point. (a) the program, (b) Factory I/O

As soon as the item arrives to the packing point, the packing Pick & Place machine is activated in order to pack the item into the delivery box. At the first step, the x axis is activated. Then the z axis and the suction as well as it is shown in the figure below. Moreover, at this moment, the base conveyor is activated for transferring the second base to the assembly point. The figure presents the program, and the product line at this stage of the shutdown process.



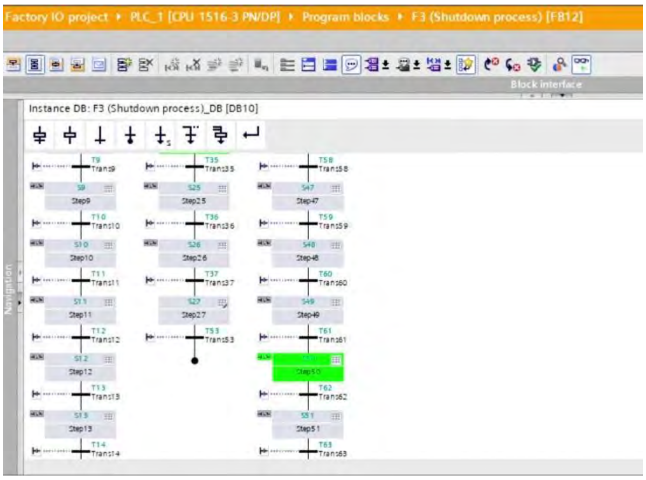
(a)



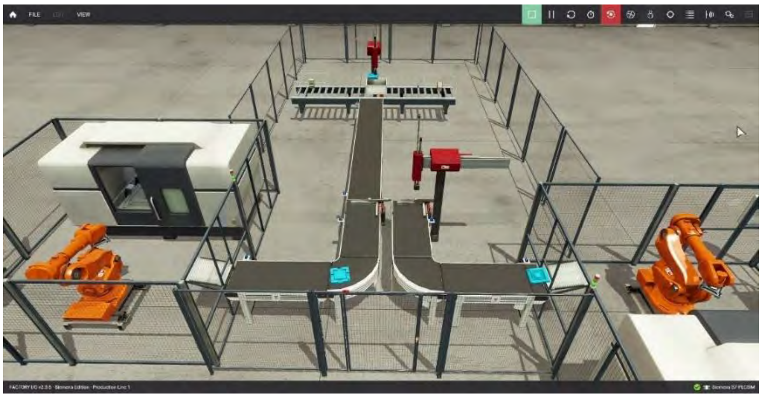
(b)

Figure 6.212: The program is placed at the shutdown process mode (F3) of GEMMA, while the base conveyor is activated, the Pick & Place x, z axes and suction are activated. (a) the program, (b) Factory I/O

At the next stage, the z and x axes of the packing Pick & Place machine are deactivated in order to reach the place of the delivery box. Moreover, the base conveyor is still activated, and the second base is transferred to the assembly point. Figure 6.213 presents this stage of the shutdown process including the program, and the production line.



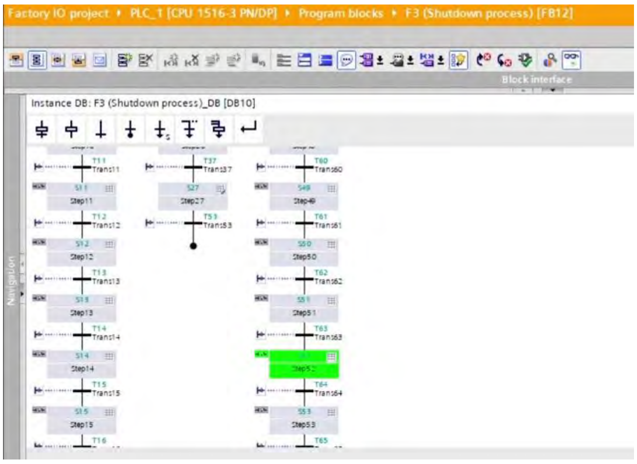
(a)



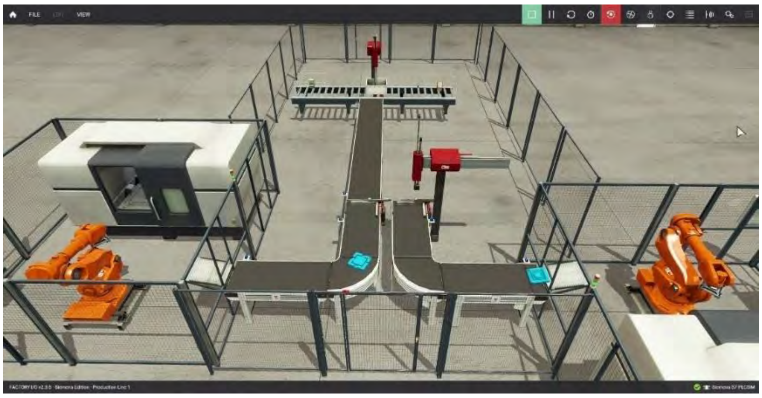
(b)

Figure 6.213: The program is placed at the shutdown process mode (F3) of GEMMA, while the base conveyor is activated, and the Pick & Place suction is activated. (a) the program, (b) Factory I/O

As soon as the packing Pick & place machine has reached the place of the delivery box, the z axis and suction are deactivated for placing the item in the delivery box. At that moment, the base conveyor is still activated for transferring the second base to the assembly point. The figure below shows this stage of the shutdown process.



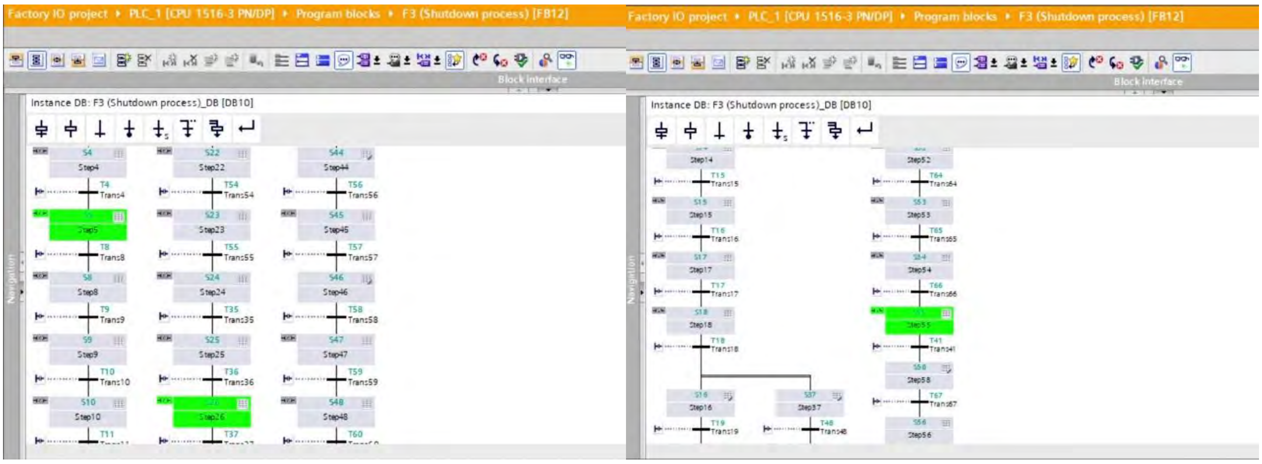
(a)



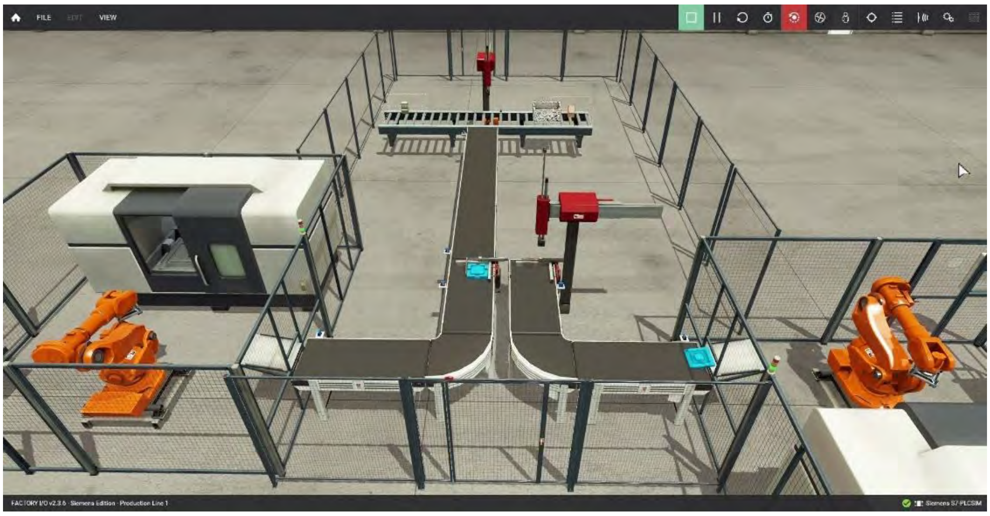
(b)

Figure 6.214: The program is placed at the shutdown process mode (F3) of GEMMA, while the base conveyor is activated, Pick & Place z axis is activated, and the suction is deactivated. (a) the program, (b) Factory I/O

At the moment that the item has placed at the delivery box, the packing Pick & Place machine switches off and returns to its initial state. Moreover, the roller conveyor and remover are activated for the box delivery as it is presented in figure 6.215. Also, at this stage, the second base has arrived to the assembly point, and the base positioner is clamped. The figure shows the program, and the production line at this stage.



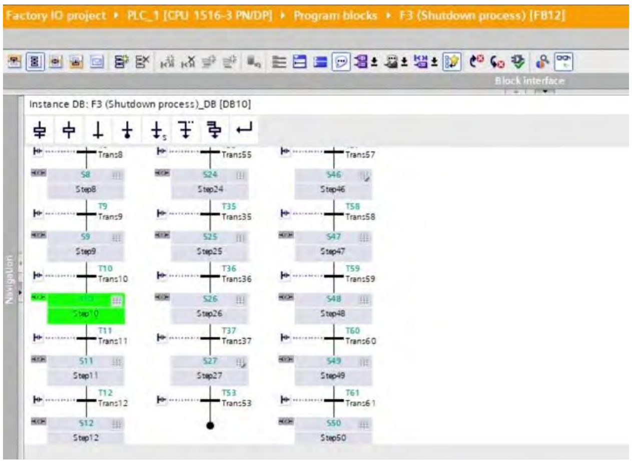
(a)



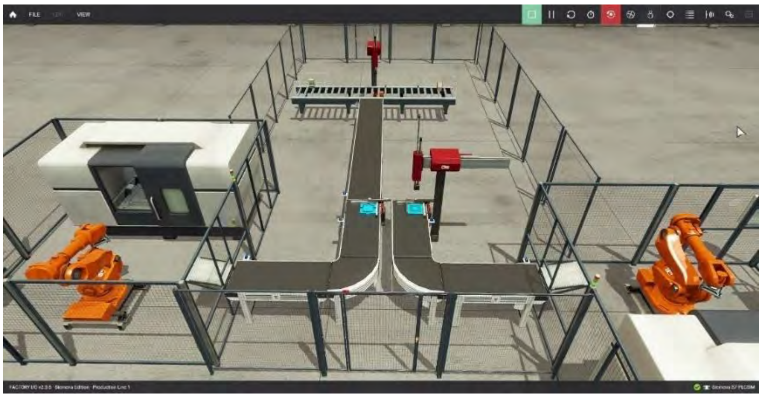
(b)

Figure 6.215: The program is placed at the shutdown process mode (F3) of GEMMA, while the base positioner is clamped, and the first packing box is removed. (a) the program, (b) Factory I/O

When the second base is placed at the appropriate place for the assembly, the lid conveyor is activated for transferring the second lid to the assembly point. At the moment that the second lid arrives, the lid positioner is clamped and places it in the appropriate assembly location. The figure below shows the program, and the product line at this stage. It is possible to notice that the second lid has arrived to the assembly point, and the lid positioner is clamped.



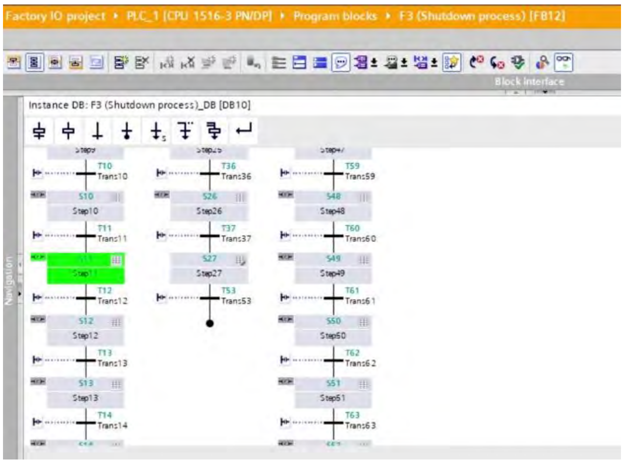
(a)



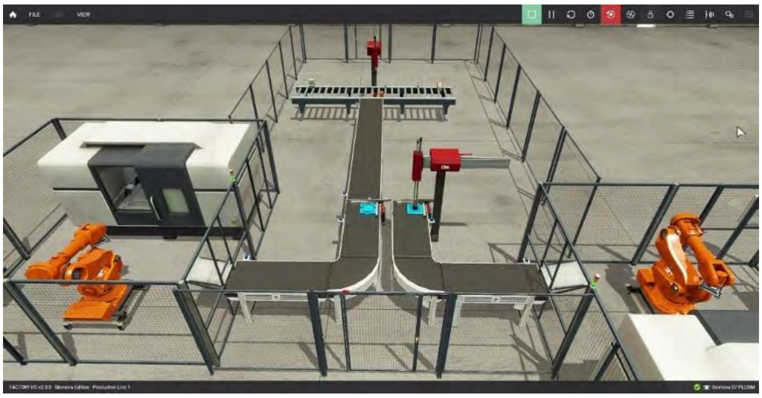
(b)

Figure 6.216: The program is placed at the shutdown process mode (F3) of GEMMA, while the lid positioner is clamped. (a) the program, (b) Factory I/O

In the next stage, the assembly Pick & Place machine is activated in order to assembly the item. The assembly process is as the following. First, the z axis and suction are activated (Figure 6.217). Second, the z axis is deactivated, and the lid is elevated (Figure 6.218). Then, the x axis is activated in order to reach the place of the base for the assembly (Figure 6.219). At the end, the z axis is activated, the item is assembled, and the suction is deactivated (Figure 6.220). The figures present the assembly process as it is explained.

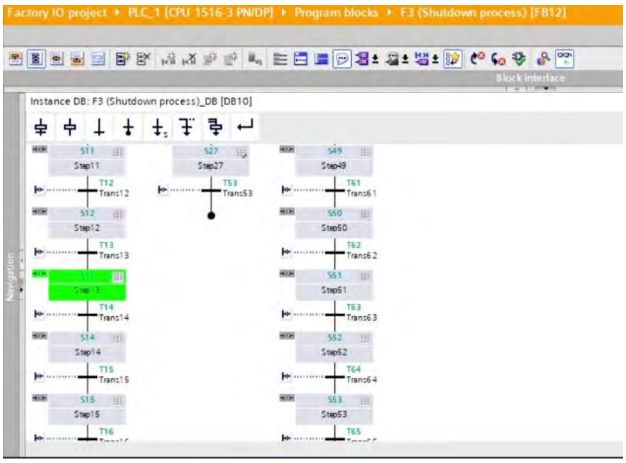


(a)

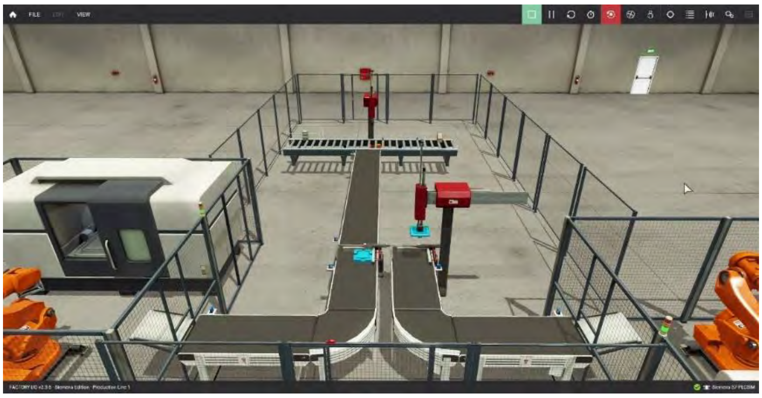


(b)

Figure 6.217: The program is placed at the shutdown process mode (F3) of GEMMA, while Pick & Place z axis and suction are activated. (a) the program, (b) Factory I/O

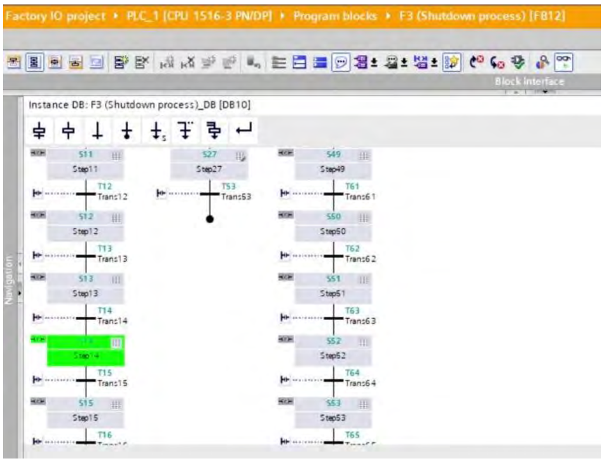


(a)

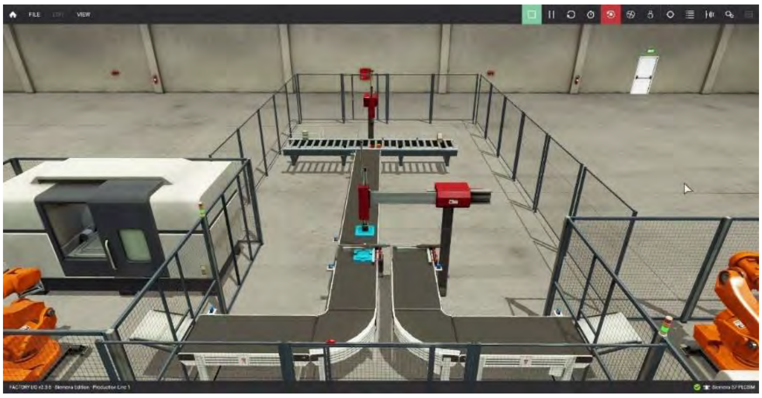


(b)

Figure 6.218: The program is placed at the shutdown process mode (F3) of GEMMA, while Pick & Place z axis is deactivated, and suction is activated. (a) the program, (b) Factory I/O

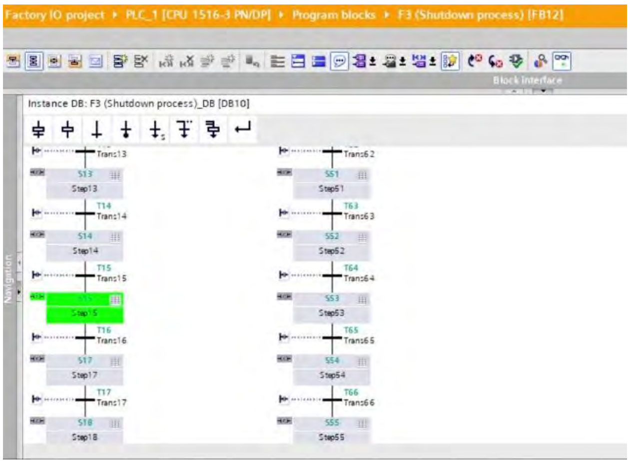


(a)

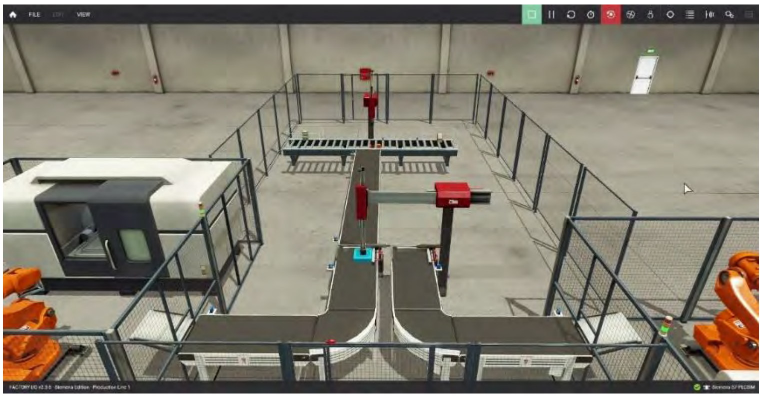


(b)

Figure 6.219: The program is placed at the shutdown process mode (F3) of GEMMA, while Pick & Place x axis and suction are activated. (a) the program, (b) Factory I/O



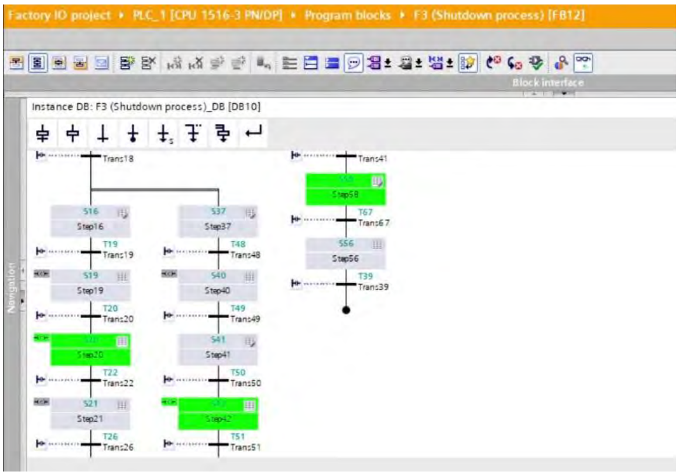
(a)



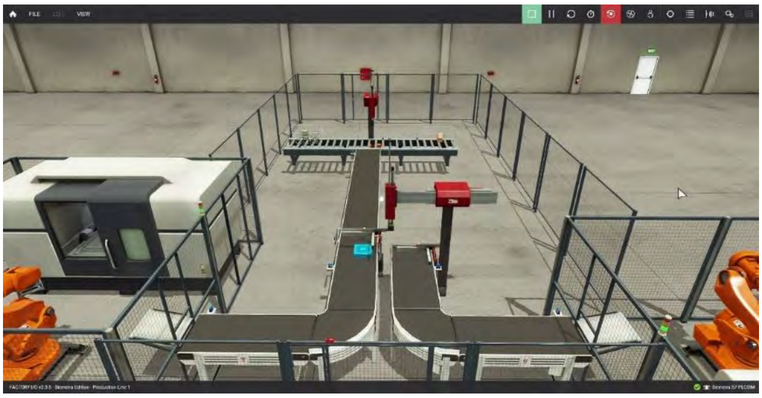
(b)

Figure 6.220: The program is placed at the shutdown process mode (F3) of GEMMA, while the Pick & Place x and z axes are activated, and suction is deactivated. (a) the program, (b) Factory I/O

At the moment that the item is assembled, the assembly Pick & Place machine is turned off, the positioner is raised for allowing the item transition, and the conveyor is activated. At this stage, the item is transferred to the packing stage. Figure 6.221 presents this stage of the shutdown process. At the moment that the item is on the way to the packing point, the delivery box is emitted, and the roller conveyor is activated in order to transfer the delivery box to the packing point as it is presented in figure 6.222.

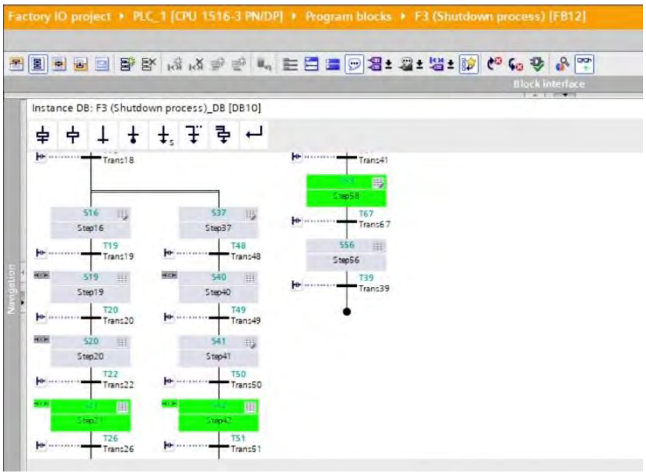


(a)



(b)

Figure 6.221: The program is placed at the shutdown process mode (F3) of GEMMA, while the Pick & Place is deactivated, the positioner is raised, and the conveyor is activated. (a) the program, (b) Factory I/O

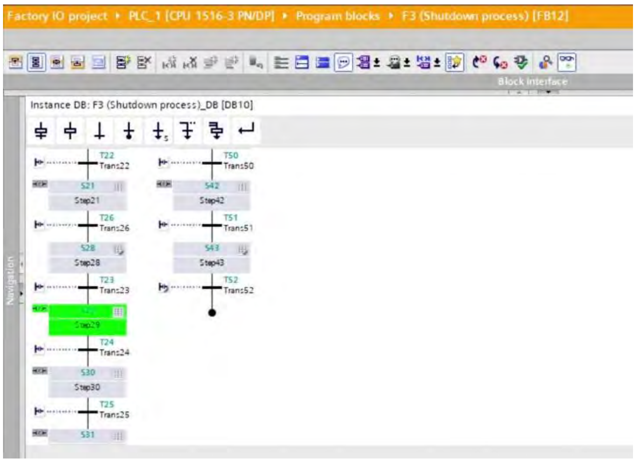


(a)

(b)

Figure 6.222: The program is placed at the shutdown process mode (F3) of GEMMA, while the item and delivery box conveyors are activated. (a) the program, (b) Factory I/O

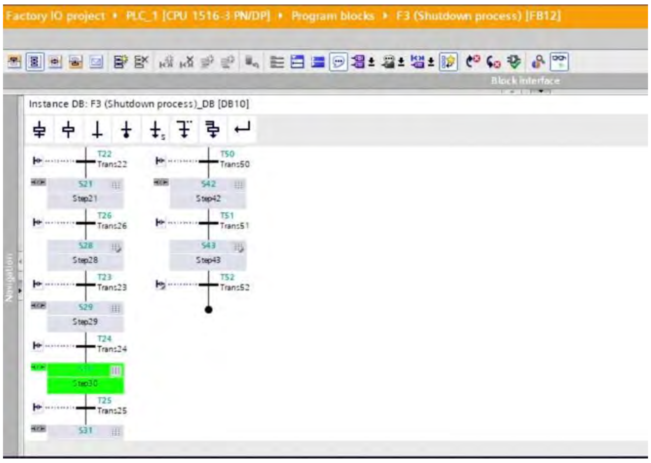
As soon as both item and delivery box arrive to the packing point, the packing Pick & Place machine is operated in order to pack the item into the delivery box. The packing process of the item is operated in the same way as it is explained before. First, the x axis is activated (Figure 6.223). Second, the z axis and suction are activated (Figure 6.224). Then, the z axis is deactivated for the item's elevation (Figure 6.225). Afterwards, the x axis is deactivated for reaching the place of the delivery box (Figure 6.226). At the end, the z axis is activated, and suction is deactivated for placing the item into the delivery box (Figure 6.227). The figures present the explained packing process including the program, and the production line in each step.



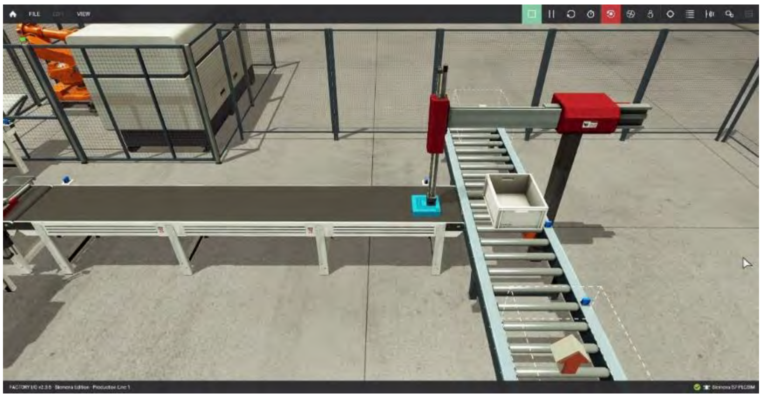
(a)

(b)

Figure 6.223: The program is placed at the shutdown process mode (F3) of GEMMA, while Pick & Place x axis is activated. (a) the program, (b) Factory I/O

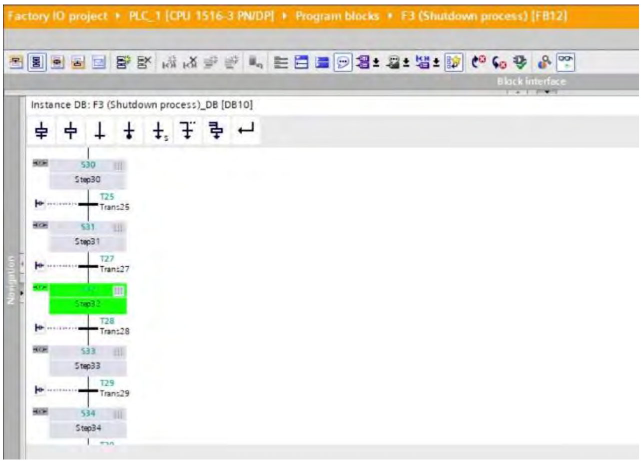


(a)



(b)

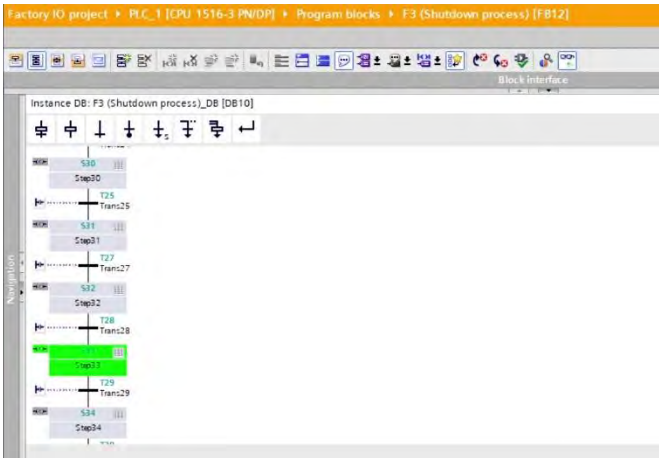
Figure 6.224: The program is placed at shutdown process mode (F3) of GEMMA, while Pick & Place x, z axes and suction are activated. (a) the program, (b) Factory I/O



(a)

(b)

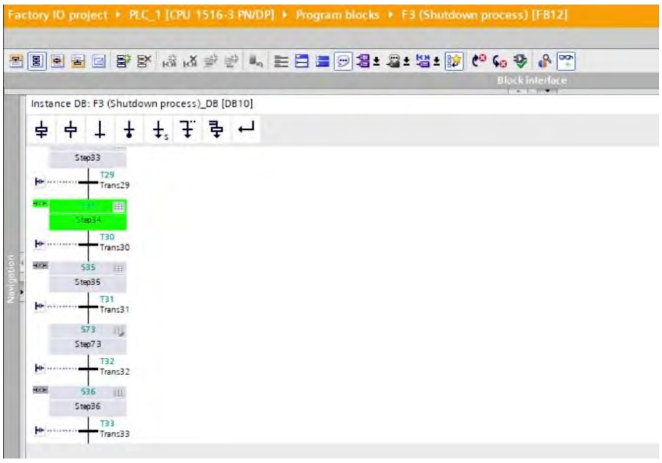
Figure 6.225: The program is placed at the shutdown process mode (F3) of GEMMA, while Pick & Place x axis and suction are activated. (a) the program, (b) Factory I/O



(a)

(b)

Figure 6.226: The program is placed at the shutdown process mode (F3) of GEMMA, while Pick & Place suction is activated. (a) the program, (b) Factory I/O

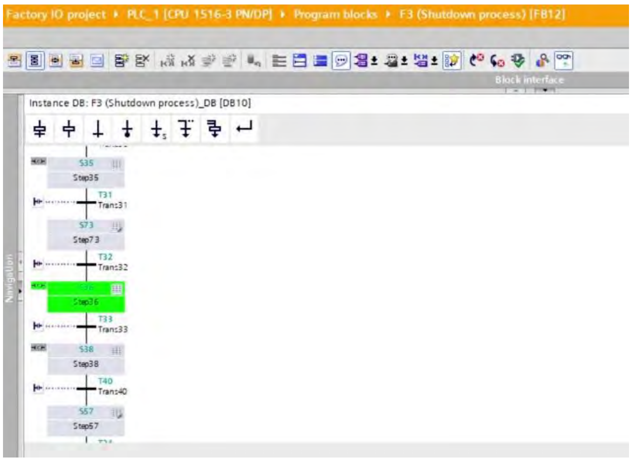


(a)

(b)

Figure 6.227: The program is placed at the shutdown process mode (F3) of GEMMA, while Pick & Place z axis is activated, and suction is deactivated. (a) the program, (b) Factory I/O

At the moment that the packing process finishes, the packing Pick & place machine turns off, and the box is ready for the delivery. The program moves to the next stage of the shutdown process and the roller conveyors is activated in order to transfer the box for the delivery. In the figure below it is possible to see the program, and the production line at this stage.

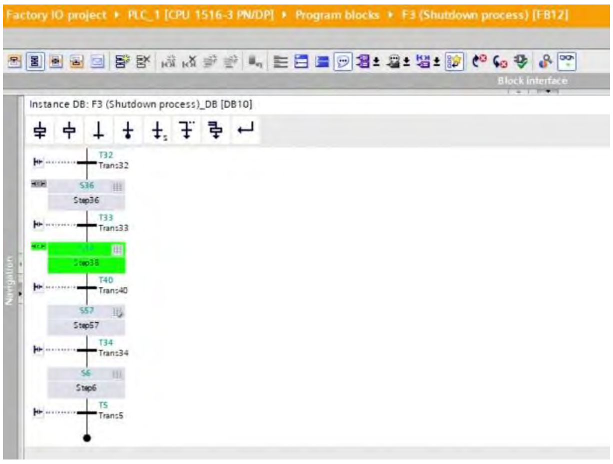


(a)

(b)

Figure 6.228: The program is placed at the shutdown process mode (F3) of GEMMA, while the roller conveyor is activated. (a) the program, (b) Factory I/O

At the last stage of the shutdown process, the remover is activated for the delivery of the box as it is shown in figure 6.229. When the box has removed, both the roller conveyor and remover are deactivated. Additionally, at this moment, the shutdown process mode (F3) switches off (Figure 6.230) and the algorithm places the program at the initial stop state (A1) (Figure 6.231). As it is possible to notice, the program is on service, and it is ready for the next production.



(a)

(b)

Figure 6.229: The program is placed at the shutdown process mode (F3) of GEMMA, while the delivery box is removed. (a) the program, (b) Factory I/O

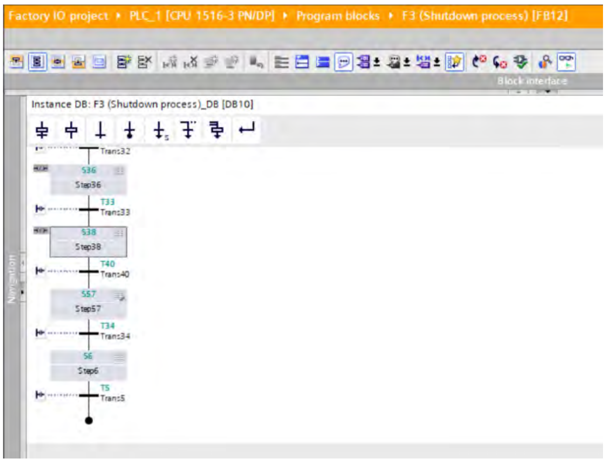
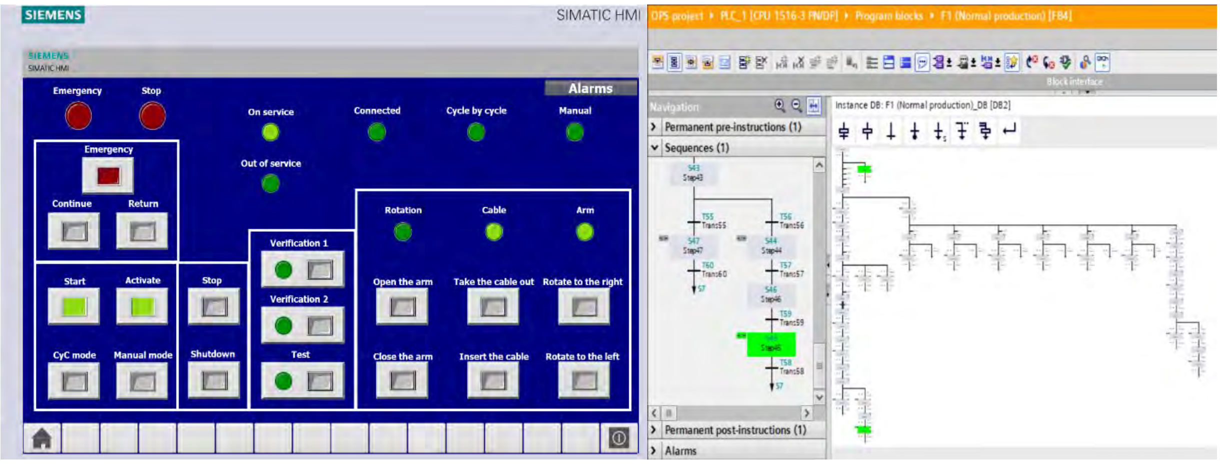


Figure 6.230: The shutdown process mode (F3) of GEMMA is off

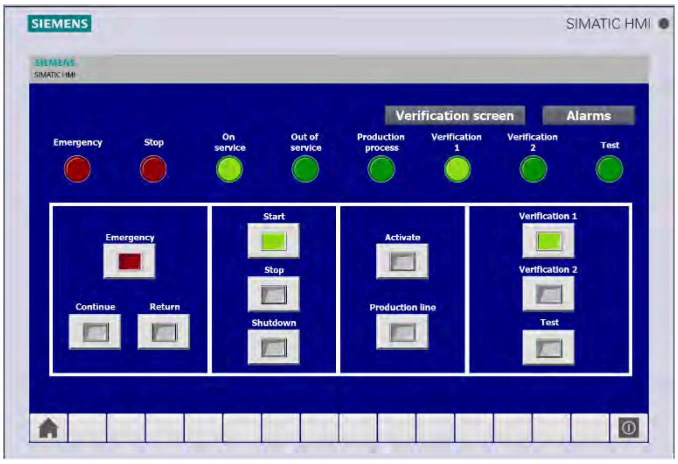


(a) (b)

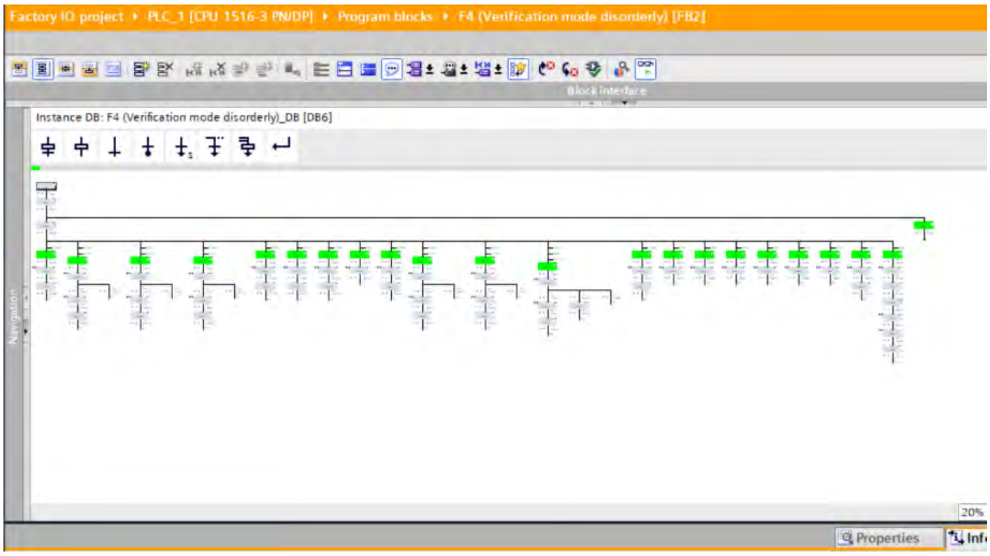
Figure 6.231: The program is placed at the initial stop state (A1) of GEMMA. (a) the screen, (b) the program

As it is explained in the Subsection 3.3.1, the GEMMA Guide paradigm has two verification modes, and a test mode. Each mode is designed according the requirements of the machine and the operator needs. The difference between verification mode 1 and verification mode 2 is the verification process of the machine. Verification mode 1 is running in verification mode disorderly (F4) which allows the operator to activate each part of the machine without any limitation. Verification mode 2 is running in verification mode orderly (F5) which operates one cycle of the machine automatically. The test mode (F6) is similar to the F4 mode, the difference is the transitions to this mode, and from this mode after the it finishes. That is to say, the GEMMA Guide Paradigm allows the operator to place the machine in the F4 mode from the initial stop state (A1), and from the normal production mode (F1). When the verification of the machine has finished, the machine resets to the initial state, and the program will be placed at the A1 mode. However, the transition for the F6 mode is only from F1 mode, and when the verification of the machine finishes, the operator is able to return only to the F1 mode.

The program of the production line contains the different verification and test modes. Verification mode 1 (F4) allows the operator the activation of each part that he desires without any limitation in order to verify the desired part of the production line, figure 6.232 presents the operation screen, and the program when the operator has pressed the verification 1 button. It is possible to see that the program is placed at the running in verification mode disorderly (F4) and it is ready for the different verification actions.



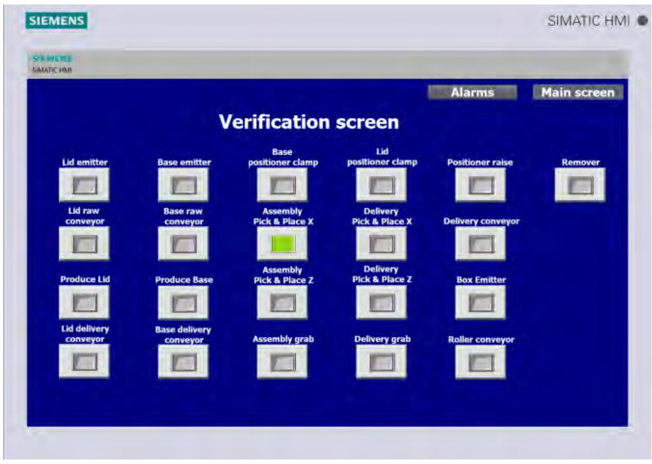
(a)



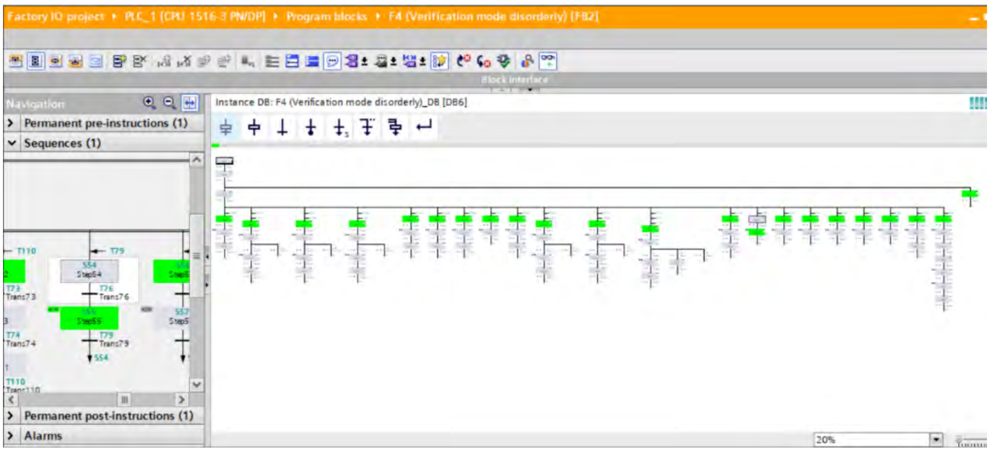
(b)

Figure 6.232: The program is placed at the running in verification mode disorderly (F4) of GEMMA, and it is ready for the different verification actions. (a) the screen, (b) the program

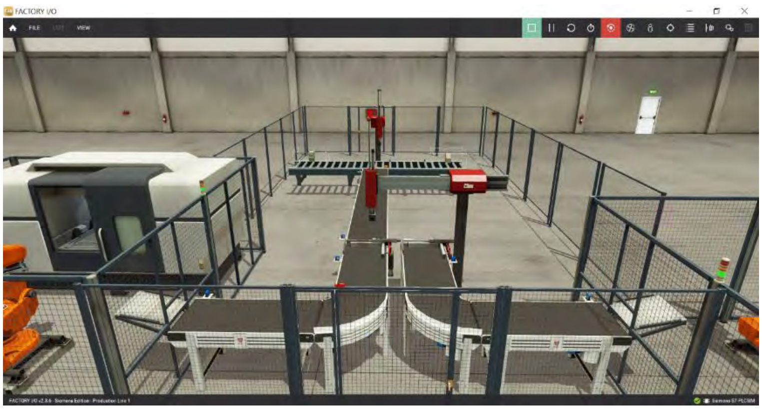
At this moment, the operator is able to activate the desired part of the production line without any limitation in order to verify the desired parts. The operation screen contains a verification screen including the necessary buttons of each part as it is shown in the figure below. In this example, the operator has chosen to activate the x axis of the assembly Pick & Place machine. It is possible to see in the figure that the appropriate button is pressed, and the x axis of the assembly Pick & Place machine is activated. The figure presents the verification screen, the program, and the production line at this verification action.



(a)



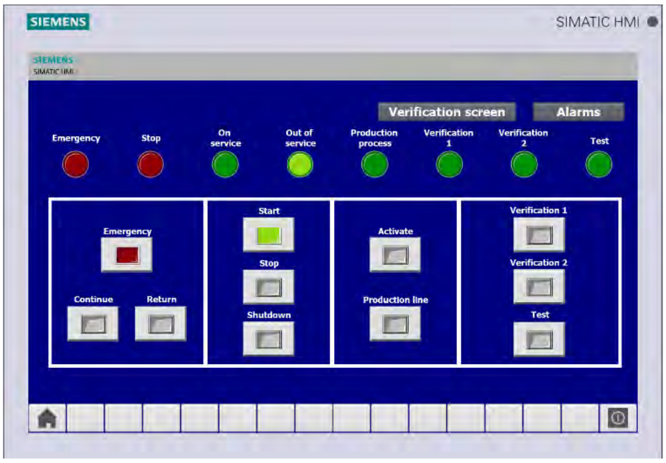
(b)



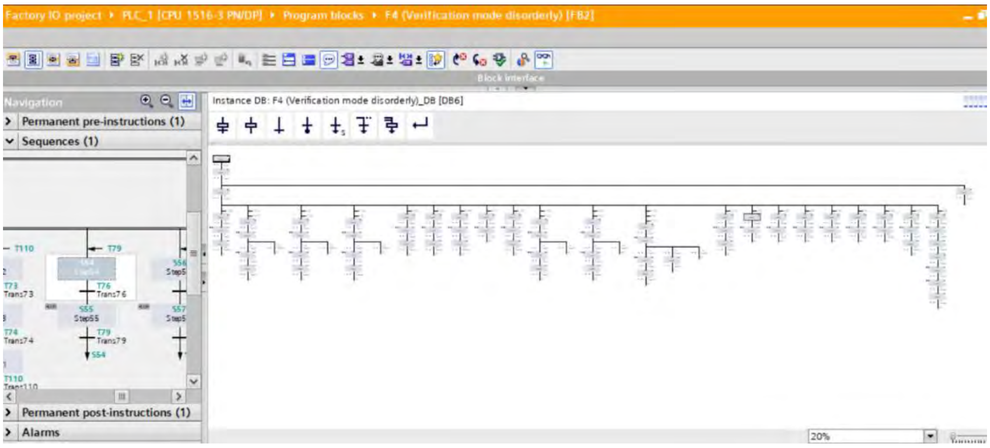
(c)

Figure 6.233: The program is placed at the running in verification mode disorderly (F4) of GEMMA while the assembly Pick & Place x axis is activated. (a) the screen, (b) the program, (c) Factory I/O

When the operator has finished to verify the production line, he deactivated the verification 1 button. At this moment, the algorithm switches off the running in verification mode disorderly (F4) as it is shown in the figure below. It is possible to see that the program is still out of service.



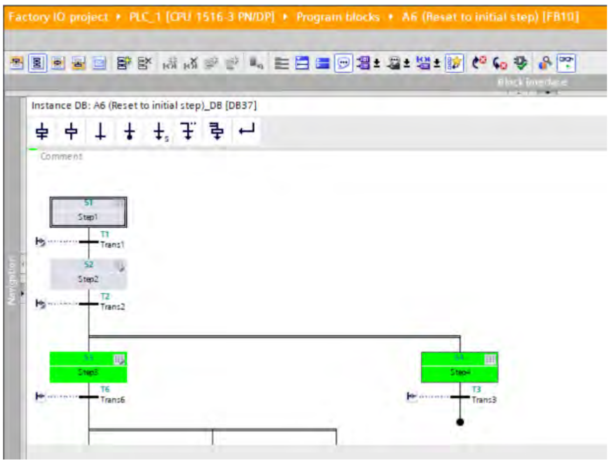
(a)



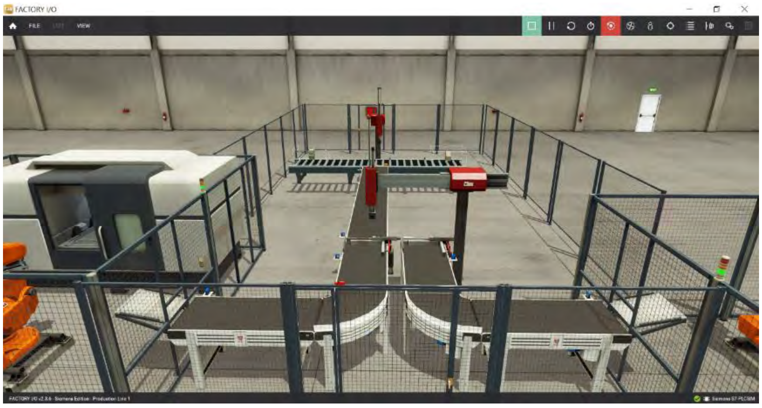
(b)

Figure 6.234: The running in verification mode disorderly (F4) is off while the verification button 1 is deactivated. (a) the screen, (b) the program (F4)

At the same moment that the operator has deactivated the verification 1 button, the algorithm places the program at the reset to initial step (A6). In this mode, the program resets the production line to its initial state in order to prepare it for the next operation. In this example, only the assembly Pick & place x axis was activated, the program detects it, and jumps to the appropriate stage. In figure 6.235 the program is placed at the initial state of the A6 mode ant it is ready for the reset process. It is possible to notice that the x axis of the assembly Pick & Place is still out.



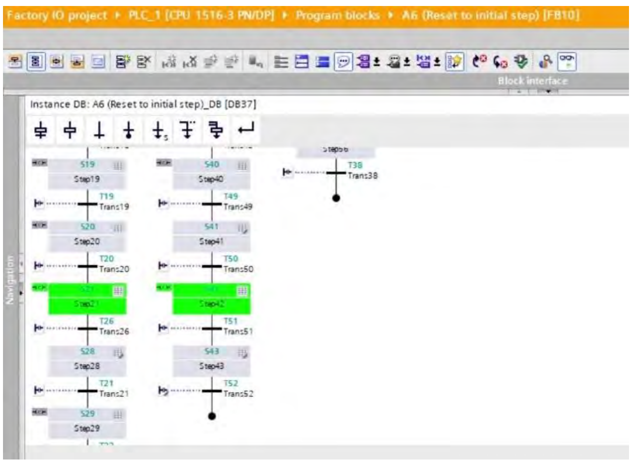
(a)



(b)

Figure 6.235: The program is placed at the reset to initial state (A6) of GEMMA. (a) the screen, (b) Factory I/O

When the program detects the production line situation, it jumps to the necessary stage as it is shown in the figure below. In this case, the reset process has to close the x axis of the assembly Pick & Place machine. It is possible to see in the figure the program, ant the production line at this stage.

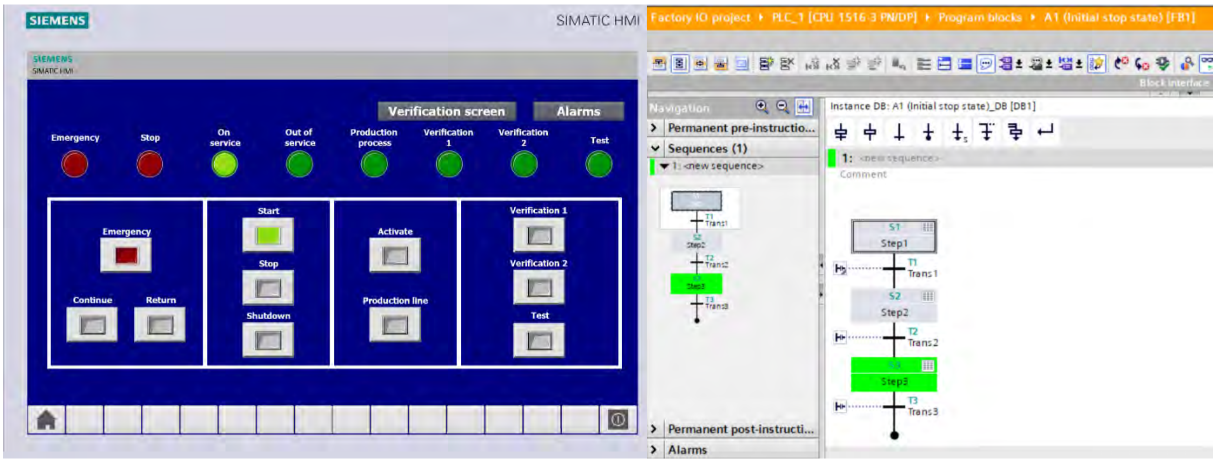


(a)

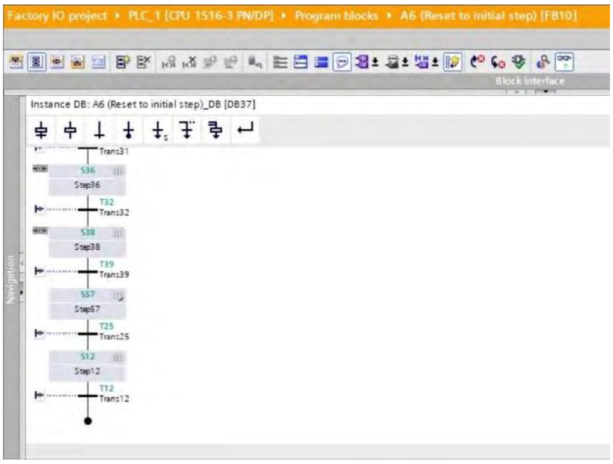
(b)

Figure 6.236: The production line is placed at the reset to initial state (A6) of GEMMA, while the assembly Pick & Place x axis is deactivated. (a) the program, (b) Factory I/O

As soon as the reset process has finished, the algorithm switches off the reset to initial state (A1) and places the program at the initial stop state (A1) for the next operation. Figure 6.237 presents the operation screen, and the program. It is possible to notice that the A6 mode is off the A1 mode is on. At this moment, both the program and production line are ready for the next operation.



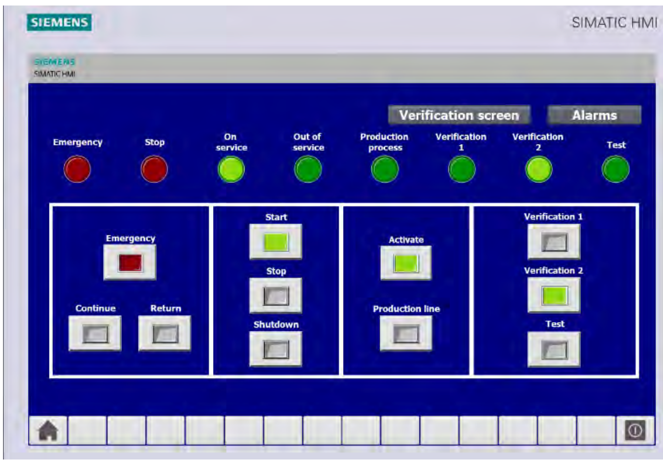
(a) (b)

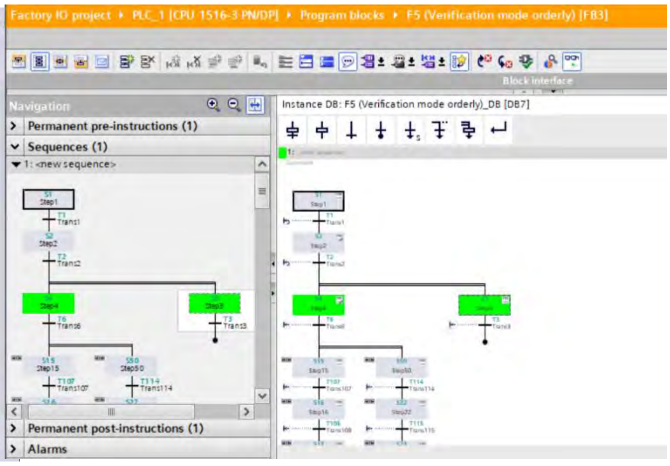


(c)

Figure 6.237: The program is placed at the initial stop state (A1) of GEMMA, the reset to initial state (A6) is off. (a) the screen, (b) the program (A1), (c) the program (A6)

Verification 2 is the activation of running in verification mode orderly (F5). This verification mode allows the operator to verify on cycle of the production line. In other words, the production line produces one base and lid, assemblies the item, packs it, and at the end delivers it. In the moment that the operator desires to verify the production line by the F5 mode, he presses the verification 2 button. The algorithm places the program at the F5 mode as it is shown in figure 6.238. It is possible to see the operation screen and program.

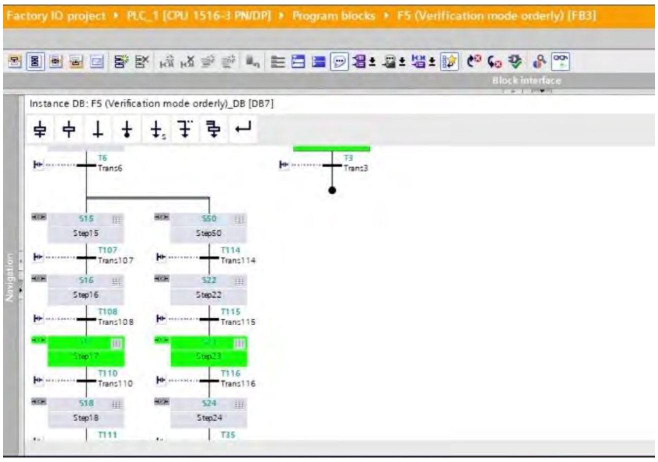




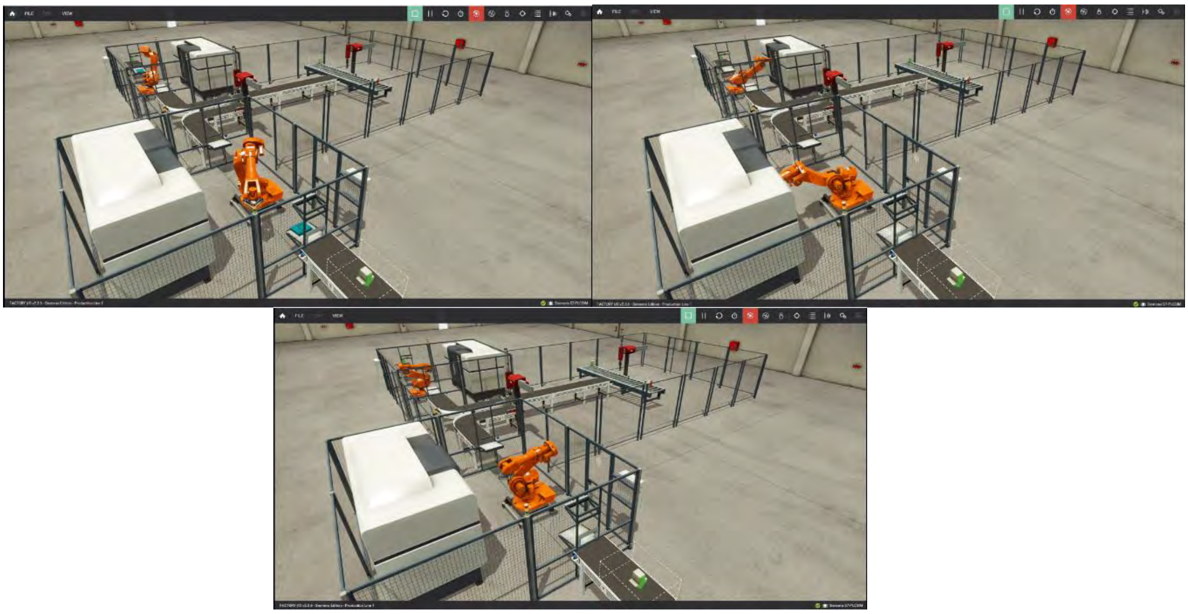
(a) (b)

Figure 6.238: The program is placed at the running in verification mode orderly (F5) of GEMMA, while the verification button 2 is pressed and it is ready to the verification process. (a) the screen, (b) the program

In the first stage of the verification 2 mode, the raw materials are emitted. Afterwards, the robots collect them and place them in the CNC machine for the base and lid production. Moreover, at this stage the CNC machines produce both the lid and base. The figure below presents this stage, it is possible to see the program and production line steps of this stage.



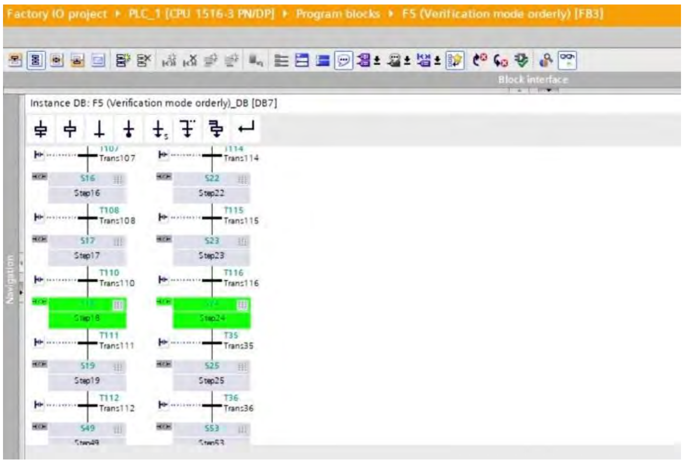
(a)



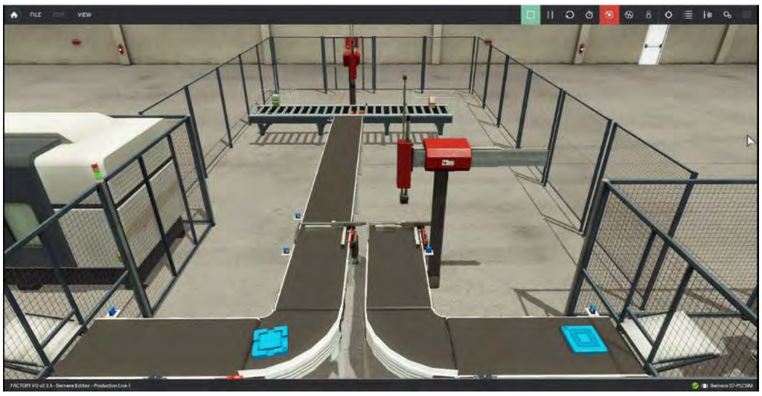
(b)

Figure 6.239: The program is placed at the running in verification mode orderly (F5) of GEMMA, while the base and lid are emitted, the robots collect the raw materials, place them in the CNC machines and they are produced. (a) the program, (b) Factory I/O

As soon as the production finishes, the program moves to the next stage. At this stage, the base and lid conveyors are activated in order to transfer both the base and lid to the assembly point as it is shown in the figure below.



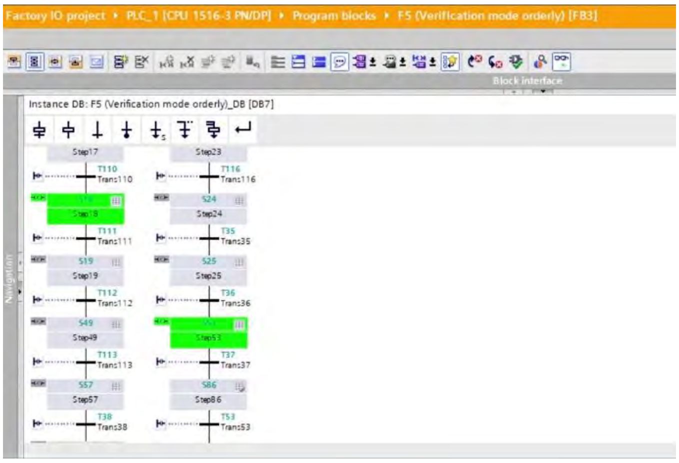
(a)



(b)

Figure 6.240: The program is placed at the running in verification mode orderly (F5) of GEMMA, while the base and lid conveyors are activated. (a) the program, (b) Factory I/O

The base is the first one that arrives to the assembly point due to its lower production time. When it arrives, the base's positioner is clamped in order to place it in the appropriate place for the assembly. Figure 6.241 presents this stage including the program and production line.

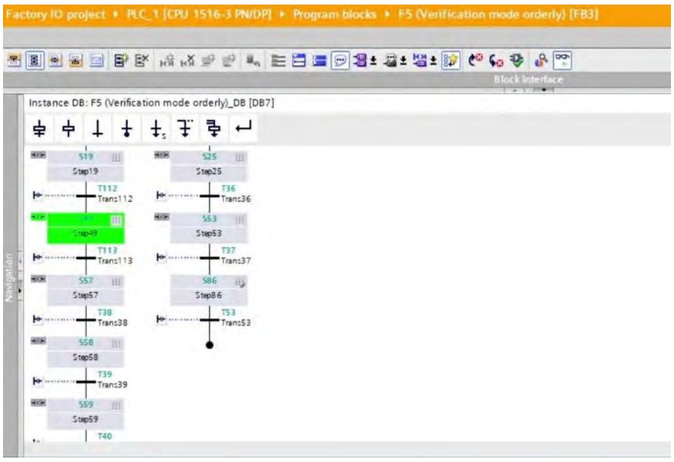


(a)

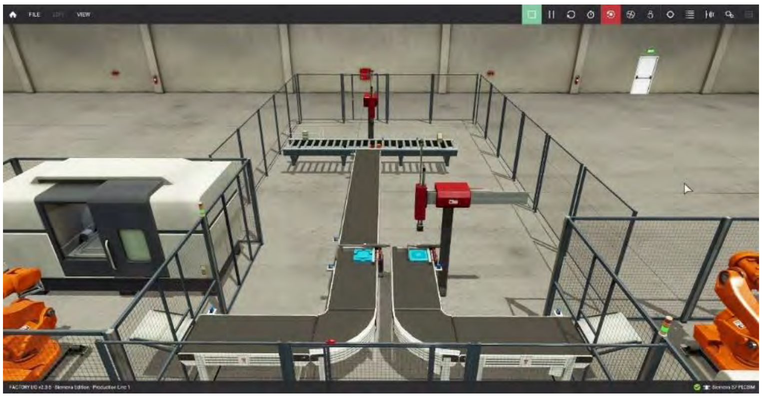
(b)

Figure 6.241: The program is placed at the running in verification mode orderly (F5) of GEMMA, while the base positioner is clamped. (a) the program, (b) Factory I/O

At the next stage, the lid arrives to the assembly point. At that moment, the lid's positioner is clamped for placing it at the assembly's place as it is shown in the figure below. The figure presents the program and production line at this stage.



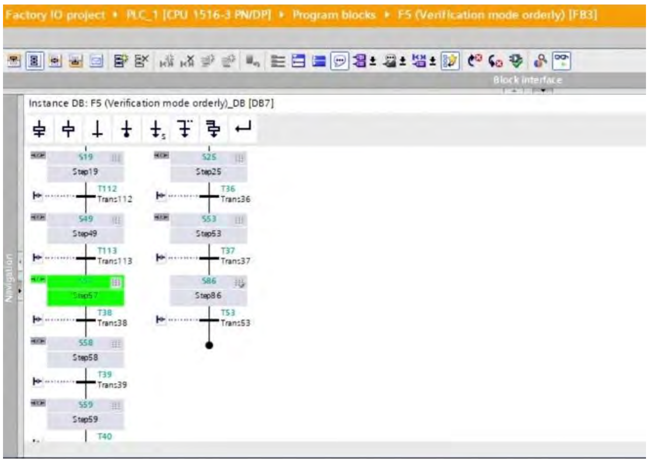
(a)



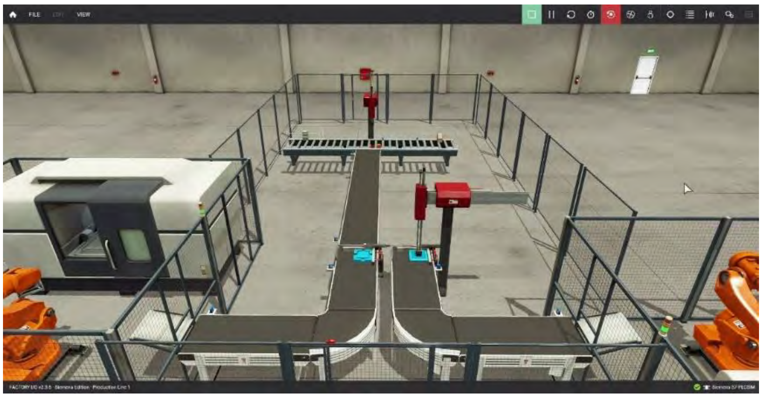
(b)

Figure 6.242: The program is placed at the running in verification mode orderly (F5) of GEMMA, while the lid positioner is clamped. (a) the program, (b) Factory I/O

At the moment that both the base and lid are placed at the appropriate assembly location, the assembly Pick & Place is operated in order to assembly the item. This stage is divided into few steps as following. First, the z axis and suction are activated (Figure 6.243). Afterwards, the z axis is deactivated for elevating the lid (Figure 6.244). Then, the x axis is activated for reaching the place of the base (Figure 6.245). At last, the z axis is activated, and suction is deactivated for assembly the item (Figure 6.246). The figures present the program and production line for each step of the assembly process.

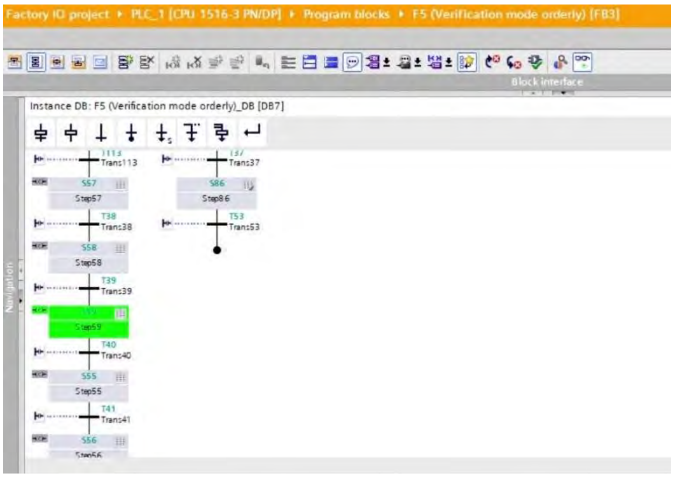


(a)

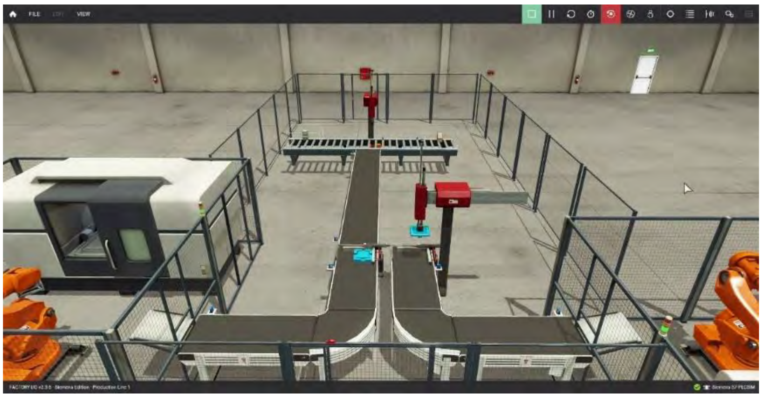


(b)

Figure 6.243: The program is placed at the running in verification mode orderly (F5) of GEMMA, while the assembly Pick & Place z axis and suction are activated. (a) the program, (b) Factory I/O

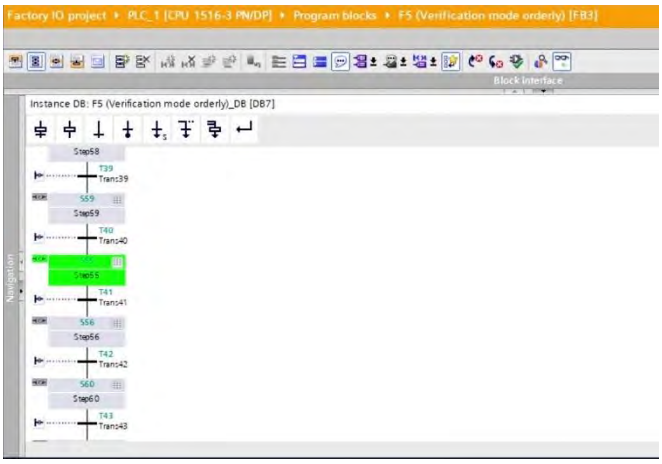


(a)

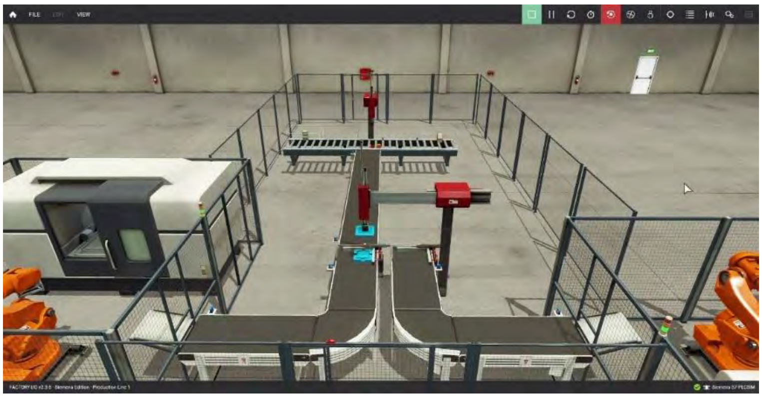


(b)

Figure 6.244: The program is placed at the running in verification mode orderly (F5) of GEMMA, while the assembly Pick & Place z axis is deactivated, and suction is activated. (a) the program, (b) Factory I/O

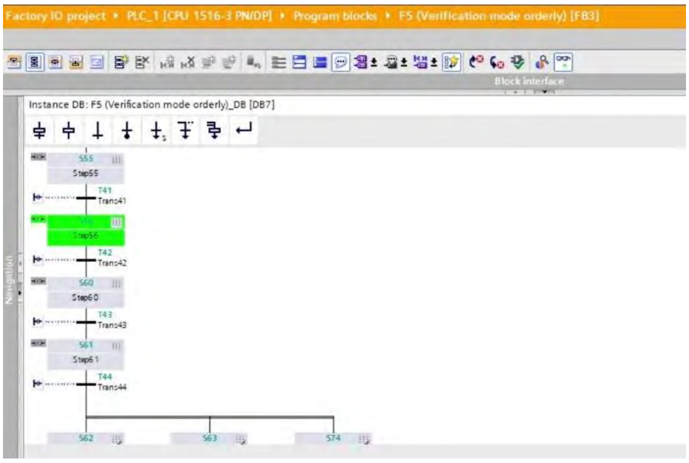


(a)

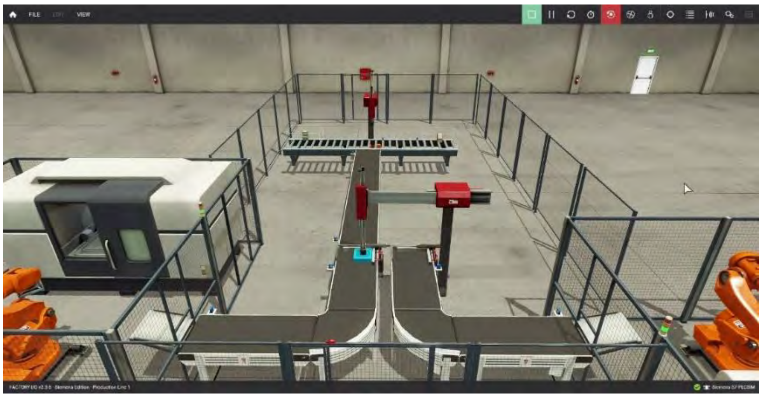


(b)

Figure 6.245: The program is placed at the running in verification mode orderly (F5) of GEMMA, while the assembly Pick & Place x axis and suction are activated. (a) the program, (b) Factory I/O



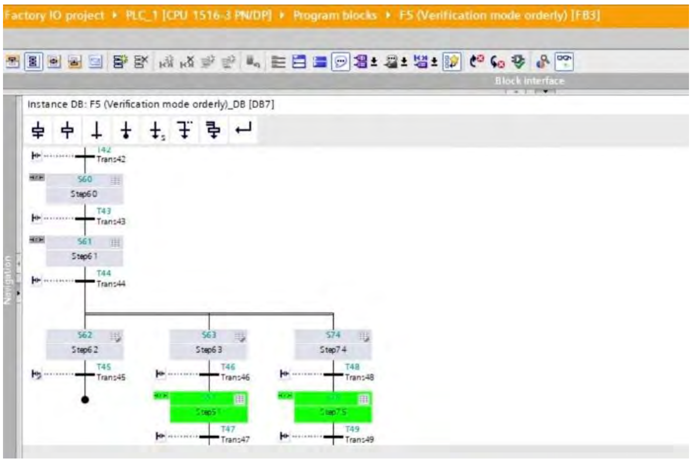
(a)



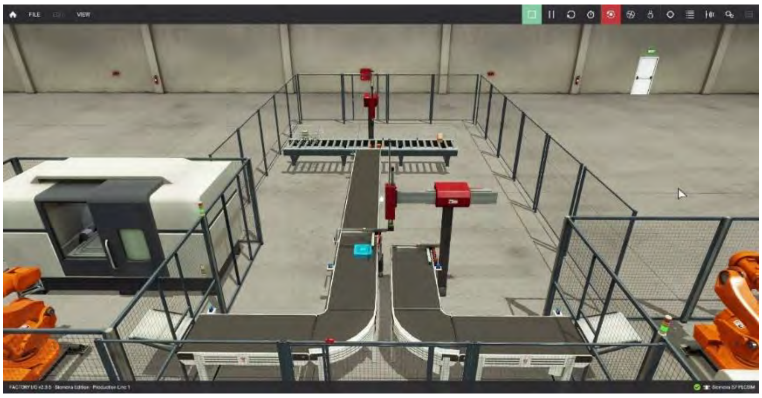
(b)

Figure 6.246: The program is placed at the running in verification mode orderly (F5) of GEMMA, while the assembly Pick & Place x and z axes are activated, and suction is deactivated. (a) the program, (b) Factory I/O

At the moment that the assembly process finishes, the assembly Pick & Place machine is turned off. Moreover, the positioner is raised for allowing the item's transition, and the packing conveyor is activated. In this stage, the item is transferred to the packing point. The figure below shows the program and production line at this stage.



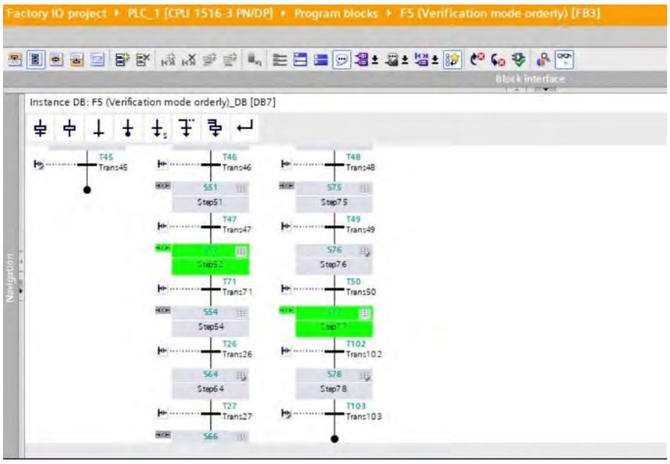
(a)



(b)

Figure 6.247: The program is placed at the running in verification mode orderly (F5) of GEMMA, while the assembly Pick & Place is deactivated, the positioner is raised, and the packing conveyor is activated. (a) the program, (b) Factory I/O

At the same time, the delivery box is emitted, and the roller conveyer is activated in order to transfer the delivery box to the packing point. As it is possible to see in the figure below, both item and delivery box are transferring to the packing point.

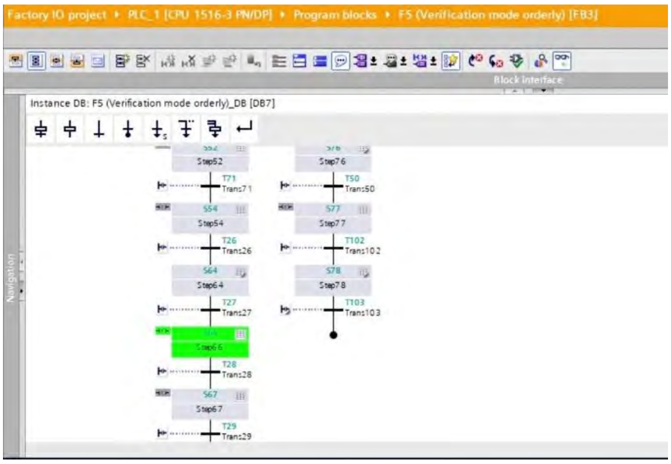


(a)

(b)

Figure 6.248: The program is placed at the running in verification mode orderly (F5) of GEMMA, while the conveyors of the product and delivery box are activated. (a) the program, (b) Factory I/O

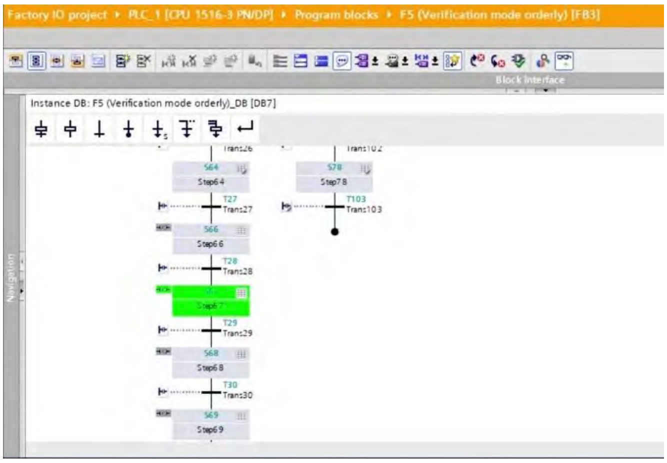
At the next stage both the item and delivery box are placed at the packing point. At this moment, the packing Pick & Place machine is operated in order to pack the item in the delivery box. This process is operated similarly to the assembly process and it involves several steps. First, the x axis is activated for reaching the place of the base base (Figure 6.249). Second, the z axis and suction are activated in order to collect the item (Figure 6.250). Then the z axis is deactivated, and the item is elevated (Figure 6.251). Afterwards, the x axis is deactivated for reaching the place of the delivery box (Figure 6.252). At last, the z axis is activated, and suction is deactivated in order to place the item in the delivery box (Figure 6.253). The figures present the program and production line for each step of the packing process.



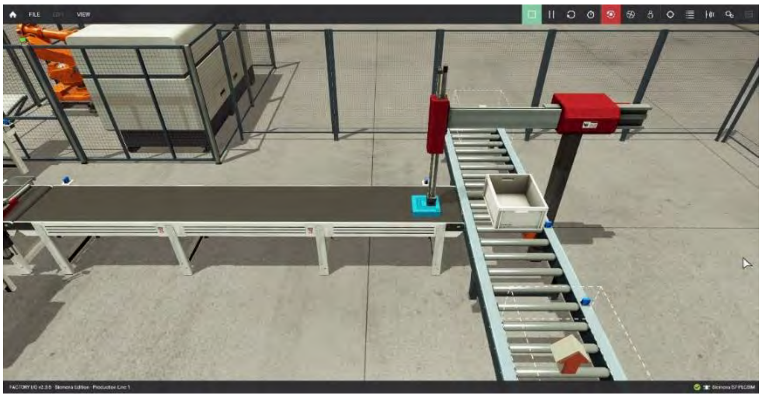
(a)

(b)

Figure 6.249: The program is placed at the running in verification mode orderly (F5) of GEMMA, while the packing Pick & Place x axis is activated. (a) the program, (b) Factory I/O

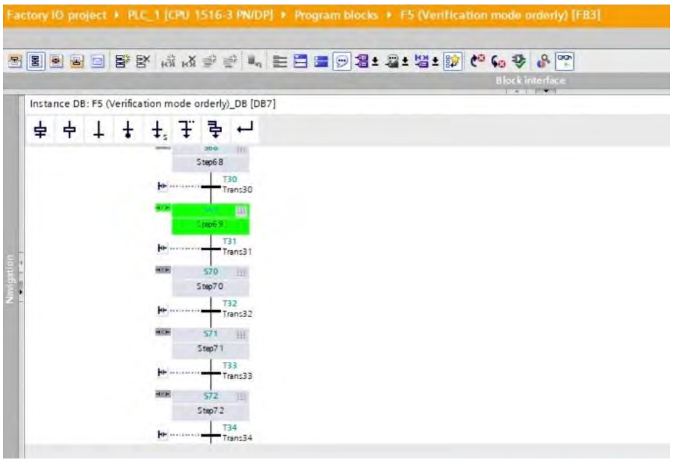


(a)



(b)

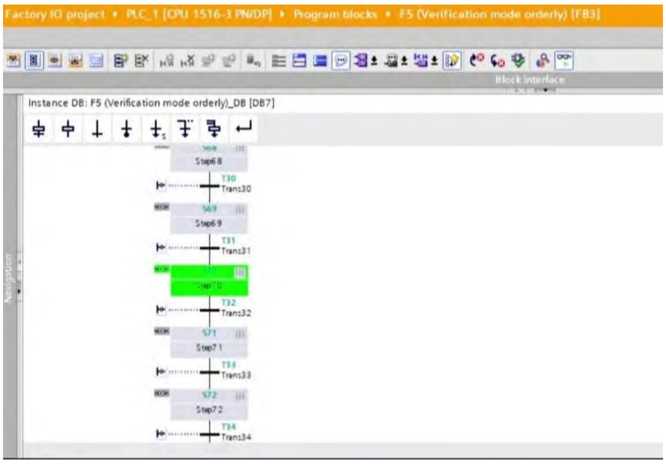
Figure 6.250: The program is placed at the running in verification mode orderly (F5) of GEMMA, while the packing Pick & Place x, z axes and suction are activated. (a) the program, (b) Factory I/O



(a)

(b)

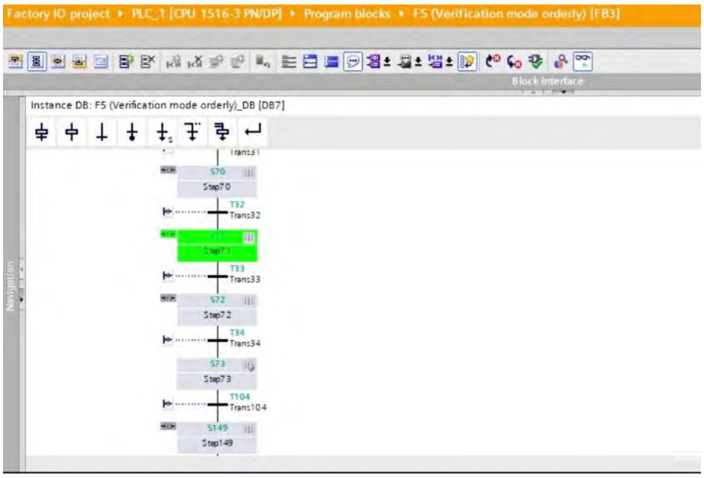
Figure 6.251: The program is placed at the running in verification mode orderly (F5) of GEMMA, while the packing Pick & Place x axis and suction are activated. (a) the program, (b) Factory I/O



(a)

(b)

Figure 6.252: The program is placed at the running in verification mode orderly (F5) of GEMMA, while the suction is activated. (a) the program, (b) Factory I/O

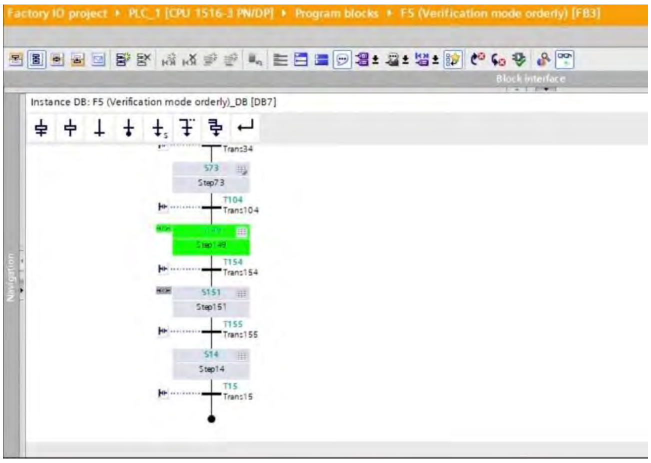


(a)

(b)

Figure 6.253: The program is placed at the running in verification mode orderly (F5) of GEMMA, while the packing Pick & Place z axis is activated, and suction is deactivated. (a) the program, (b) Factory I/O

At the moment that the packing process finishes, the packing Pick & Place machine is turned off. Additionally, the roller conveyor is activated in order to transfer the box to the delivery point. The figure below shows the program and production line at this stage.

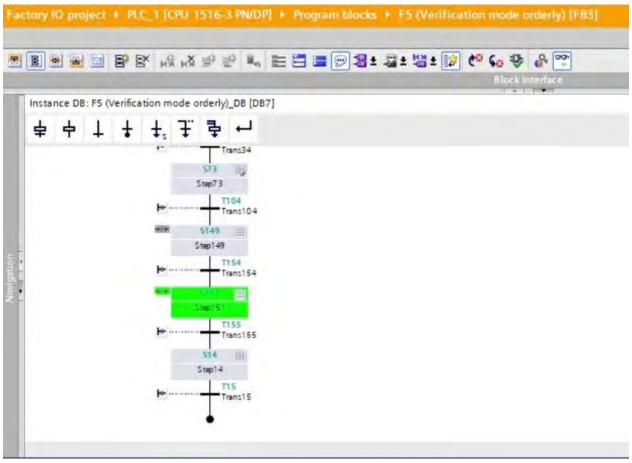


(a)

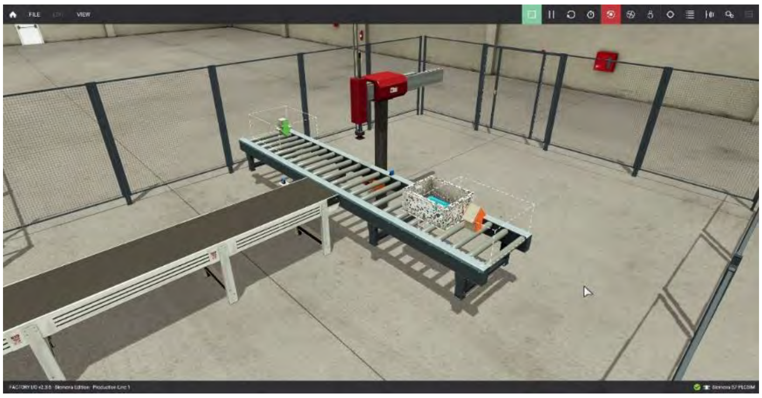
(b)

Figure 6.254: The program is placed at the running in verification mode orderly (F5) of GEMMA, while the roller conveyor is activated. (a) the program, (b) Factory I/O

The roller conveyor is activated till the box arrives to the delivery point. At this moment, the roller conveyor is deactivated, and the remover is activated. Figure 6.255 presents the program and production line at this stage. It is possible to notice that the box is removed at this stage. It means that the verification mode has finished to verify the process and the product line is ready for the next operation. When the operator deactivates the verification 2 button, the algorithm places the program at the normal production mode (F1) as it is presented in figure 6.256. It is possible to see that the program is placed at the initial state of the F1 mode and it is ready for the next operation.

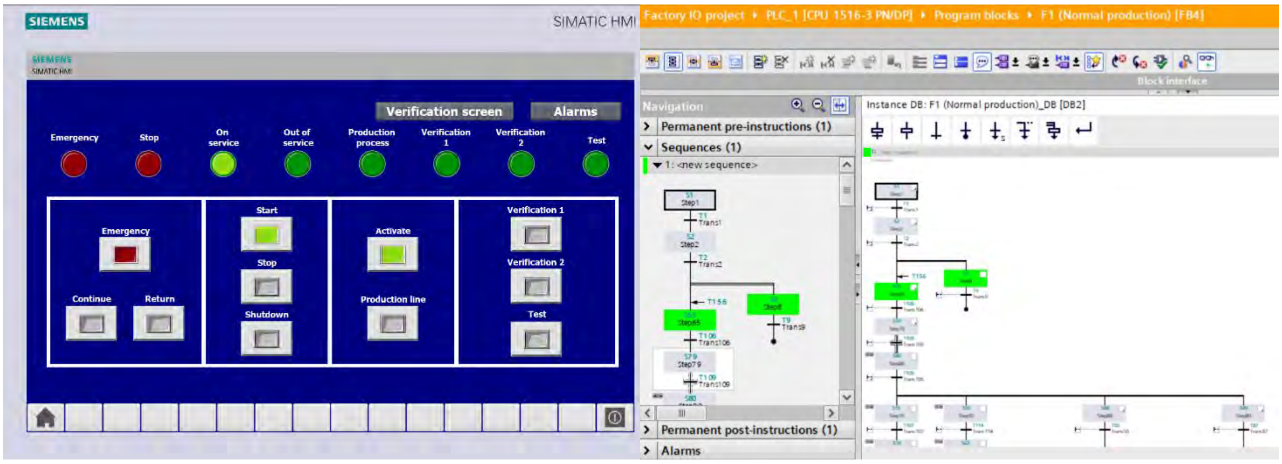


(a)



(b)

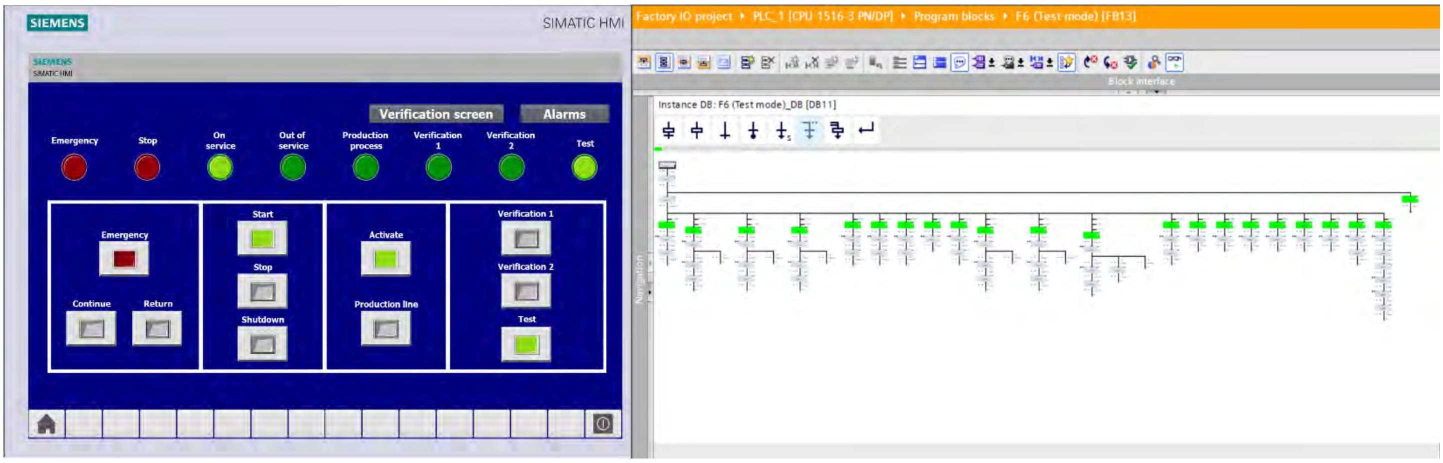
Figure 6.255: The program is placed at the running in verification mode orderly (F5) of GEMMA, while the delivery box is removed. (a) the program, (b) Factory I/O



(a) (b)

Figure 6.256: The program is placed at the normal production mode (F1) of GEMMA, while the verification button 2 is deactivated. (a) the screen, (b) the program

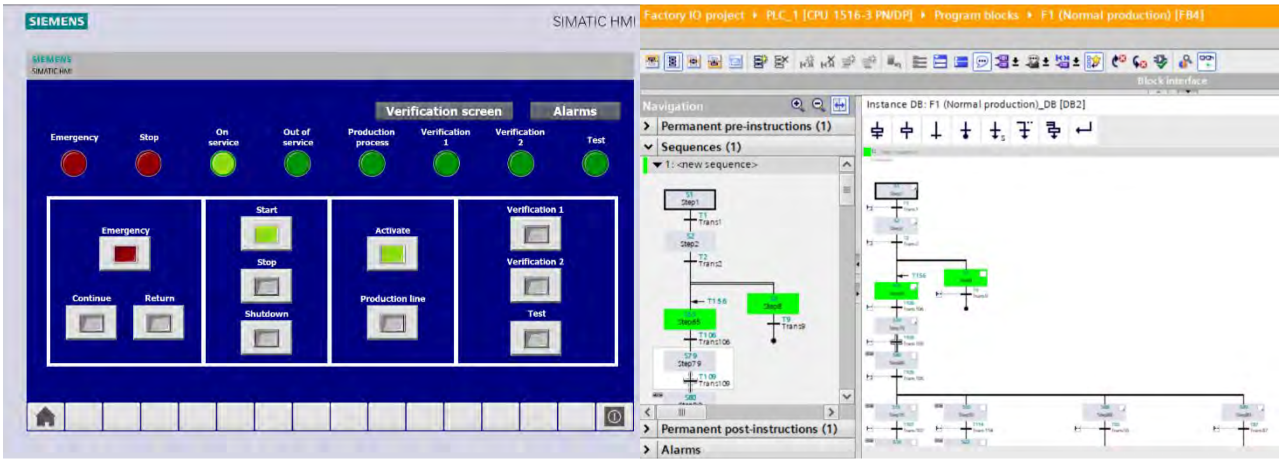
The test mode (F6) allows the operator to activate each part of the production line that he desires without any limitation similarly to the running in verification mode disorderly (F4). This mode provides to verify the desired part while the operator has this need. As it is explained before, the difference between F4 and F6 are the transitions between the modes. That is to say, the operator is able to place the program from the normal production mode (F1) mode to either F4 or F6. However, in the moment that he finishes the verification he can return to F1 mode only from the F6 mode, and from F4 mode he can only start over the program. It allows the operator to choose the best verification mode according to his needs. Figure 6.257 presents the situation that the operator has pressed the test button. In this situation, the program is placed at the F6 mode.



(a) (b)

Figure 6.256: The program is placed at the test mode (F6) of GEMMA, while the test button is pressed, and it is ready to the different test actions. (a) the screen, (b) the program

When the operator has finished to verify the desired parts of the production line, he is able to place the program back at the normal production mode (F1) by deactivating the test button. The figure below shows the operation screen and program at the moment that the operator has deactivated the test button. It is possible to notice that the program is placed at the initial state of the F1 mode and it is ready for the next production.



(a) (b)

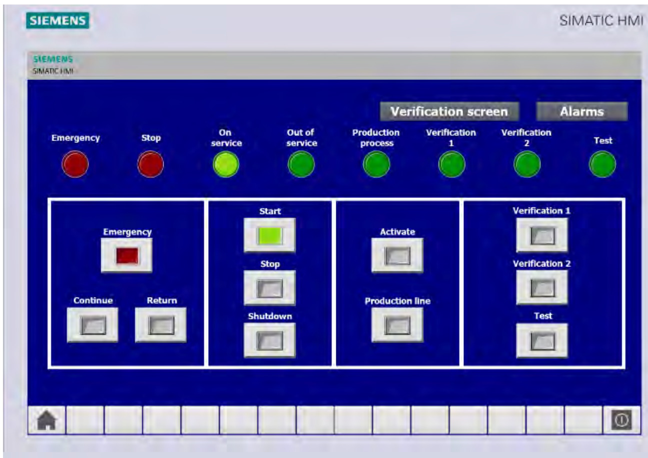
Figure 6.257: The program is placed at the normal production mode (F1) of GEMMA, while the test button is deactivated. (a) the screen, (b) the program

6.2.4. Implementation of the Algorithms

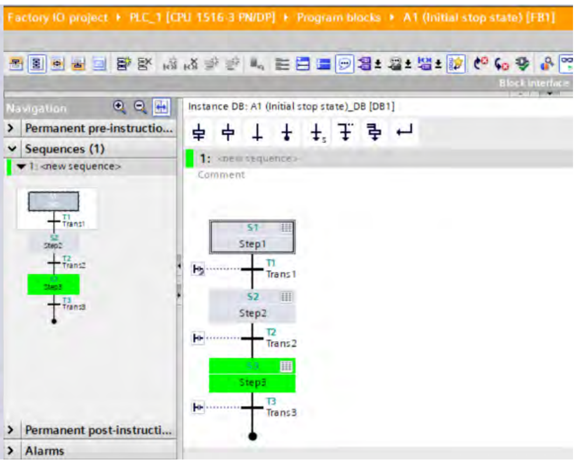
The algorithms of each transition for the GEMMA Guide Paradigm are explained and mathematically proof in Chapter 4. In this subsection the experiments of each transition on the Factory I/O production line are presented. The main goal of this subsection is to validate the algorithms for the product line project. Moreover, it shows the experiments of each algorithm and the results.

6.2.4.1. Stop Procedure to Operation Procedure

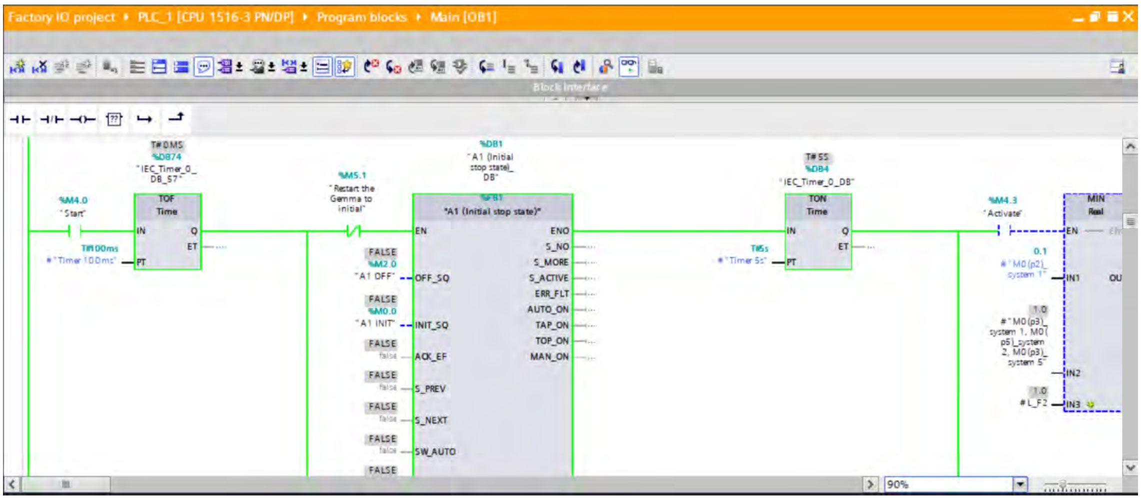
The stop procedure to operation procedure algorithm is very important for the proper operation of the production line. It allows to place the program in the appropriate mode according the production line situation and operator requirements as it is explained in the subchapter 4.2. The figure below presents the operation mode and program while it is placed at the initial stop state (A1) and it is ready for the operation.



(a)



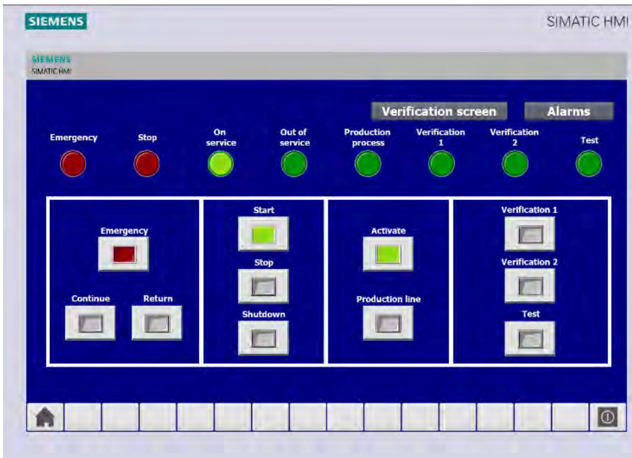
(b)



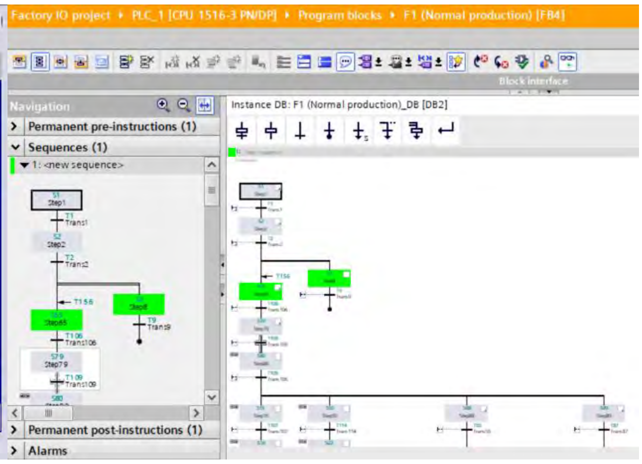
(c)

Figure 6.258: The program is placed at the initial stop state (A1) of GEMMA. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

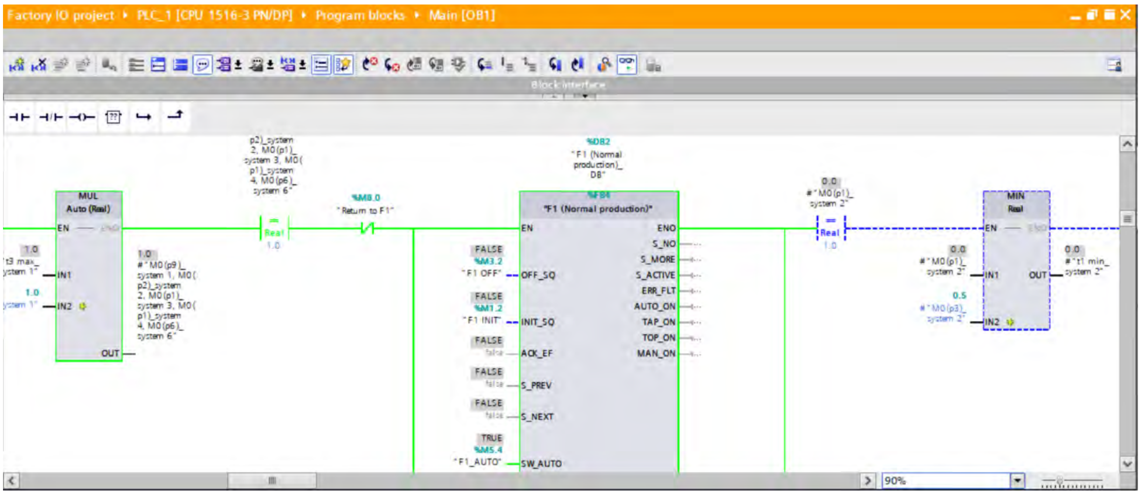
At the moment that the operator desires to start the operation, he is able to do it by pressing the activation button as it is shown in the figure below. The algorithm detects that the production line is in its initial state and places the program in the normal production mode (F1). The figure presents the operation screen, program and Fuzzy Petri Nets intelligent algorithm at this moment.



(a)



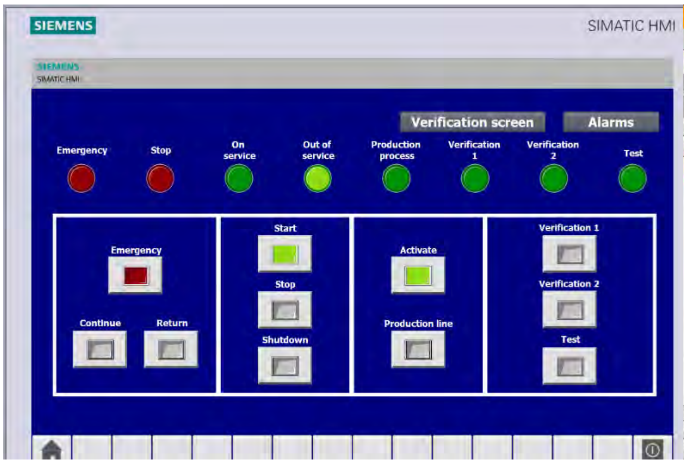
(b)



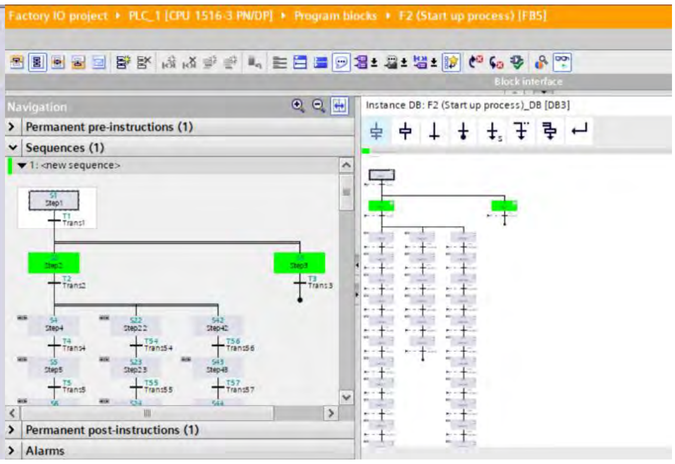
(c)

Figure 6.259: The program is placed at the normal production mode (F1) of GEMMA, while the activation button is pressed. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

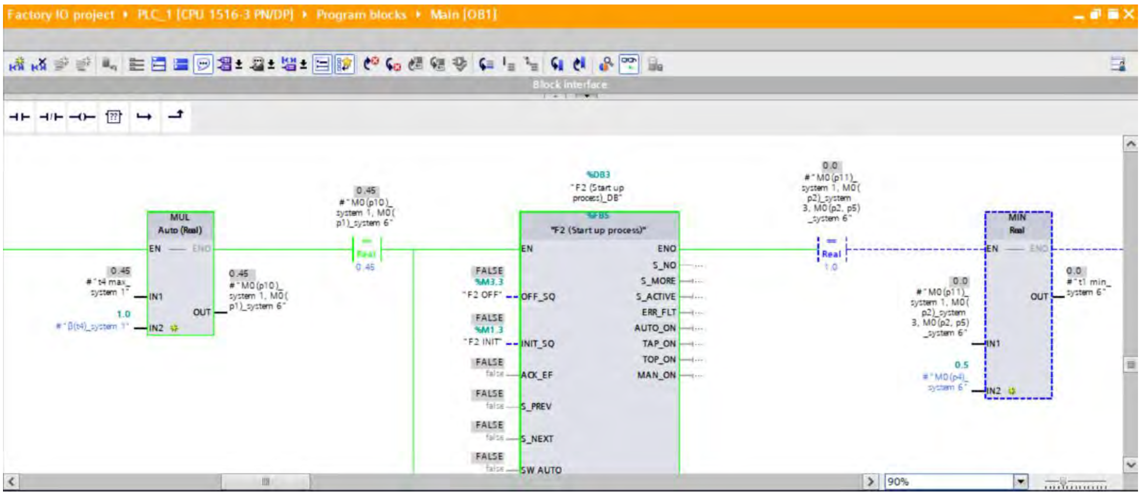
In a situation that the operator desires to start the operation and the production line is not in its initial state. For example, the production line has stopped from any reason at some point of the production. The algorithm will detect the production line situation by the different sensors of the production line. Moreover, the last position of the production line is memorized. At this situation, the algorithm will place the program at the startup process mode (F2) in order to prepare the production line for the next operation. Figure 6.260 presents the operation screen, program, and Fuzzy Petri Nets intelligent algorithm.



(a)



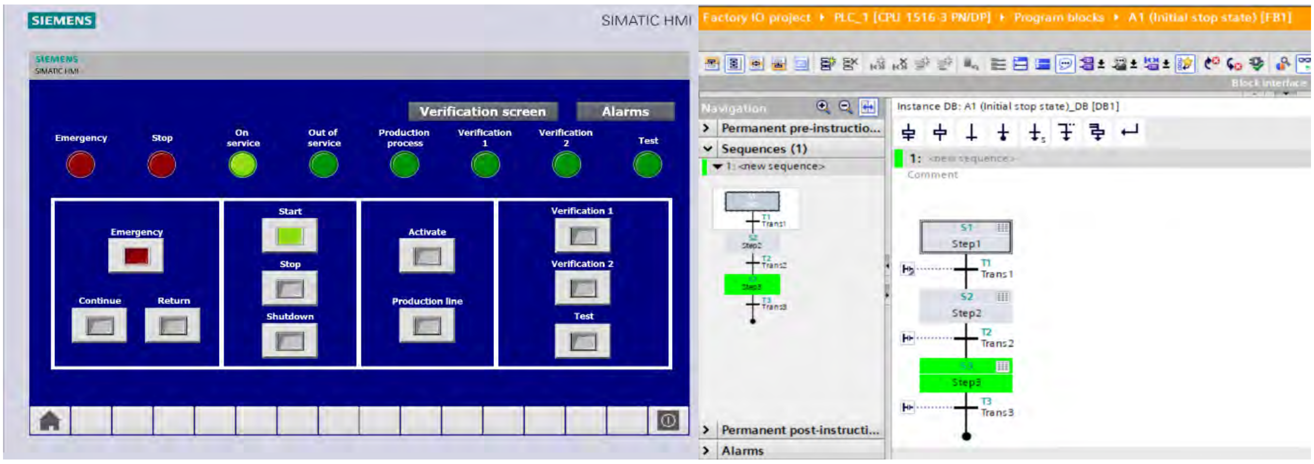
(b)



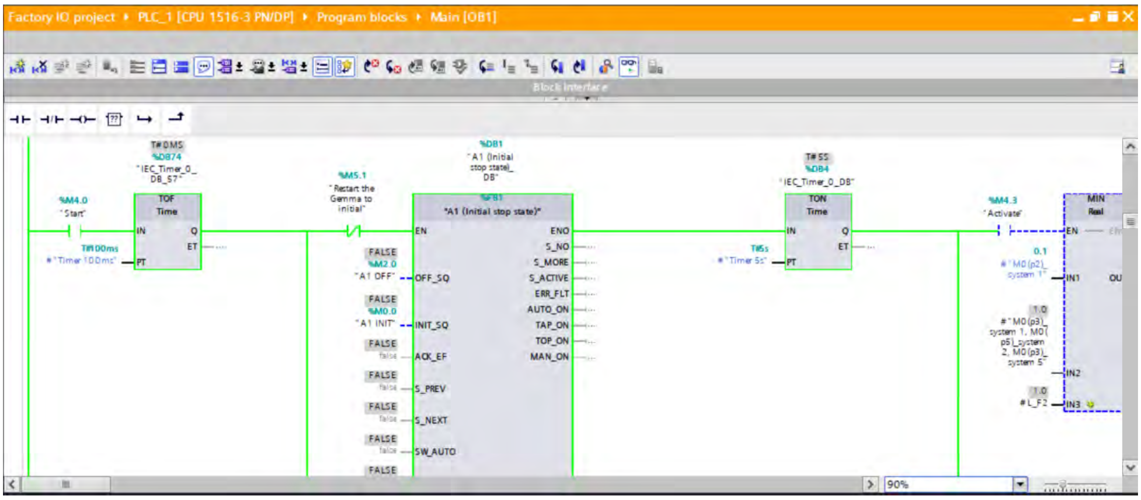
(c)

Figure 6.260: The program is placed at the startup process mode (F2) of GEMMA, while the activation button is pressed. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent transitions

The second transition of this algorithm is the transition between the initial stop state (A1) and running in verification mode disorderly (F4). This transition allows the operator to place the program in the F4 mode in order to verify the desired part of the production line at any moment from the A1 mode. In the figure below, it is possible to see the operation screen, program and Fuzzy Petri Nets intelligent algorithm while the program is placed at the A1 mode.



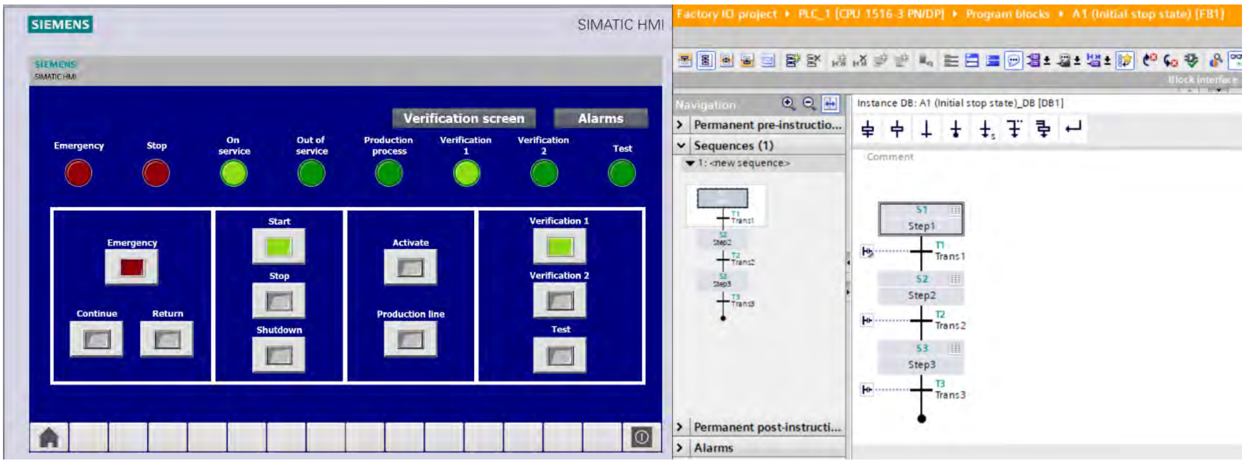
(a) (b)



(c)

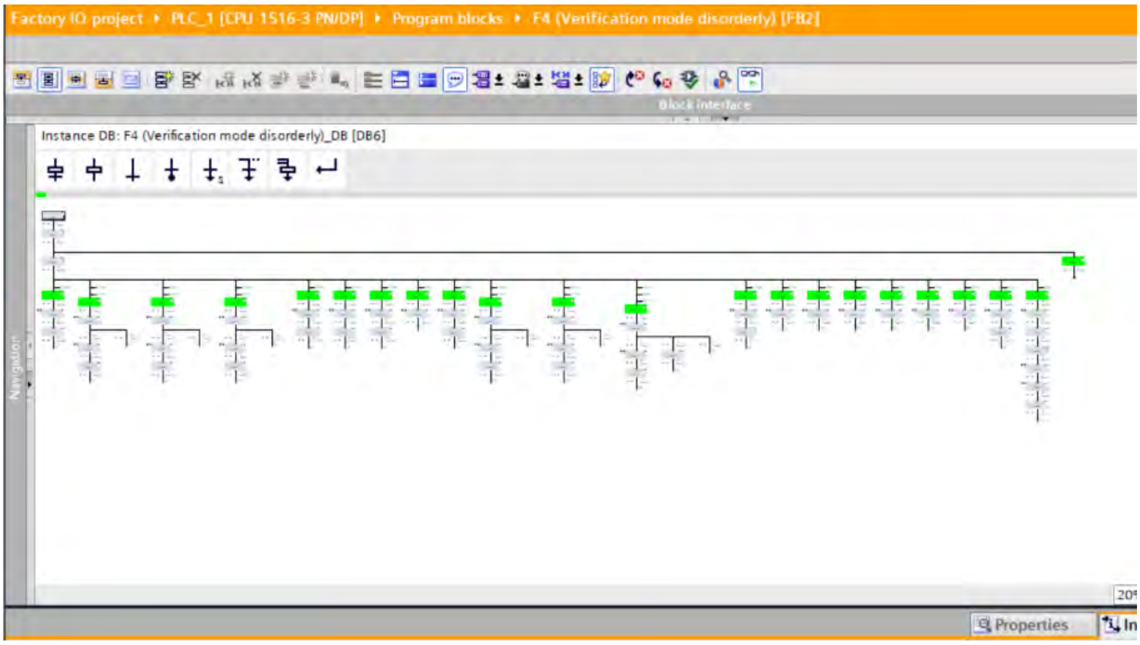
Figure 6.261: The program is placed at the initial stop state (A1) of GEMMA. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

At the moment that the operator presses the verification 1 button, the algorithm switches off the initial stop state (A1) as it is shown in figure 6.262. The figure presents the operation screen and program. At the same time, the algorithm places the program at the running in verification mode disorderly (F4) as it is presented in figure 6.263 and the program is ready for the different desired verification actions.

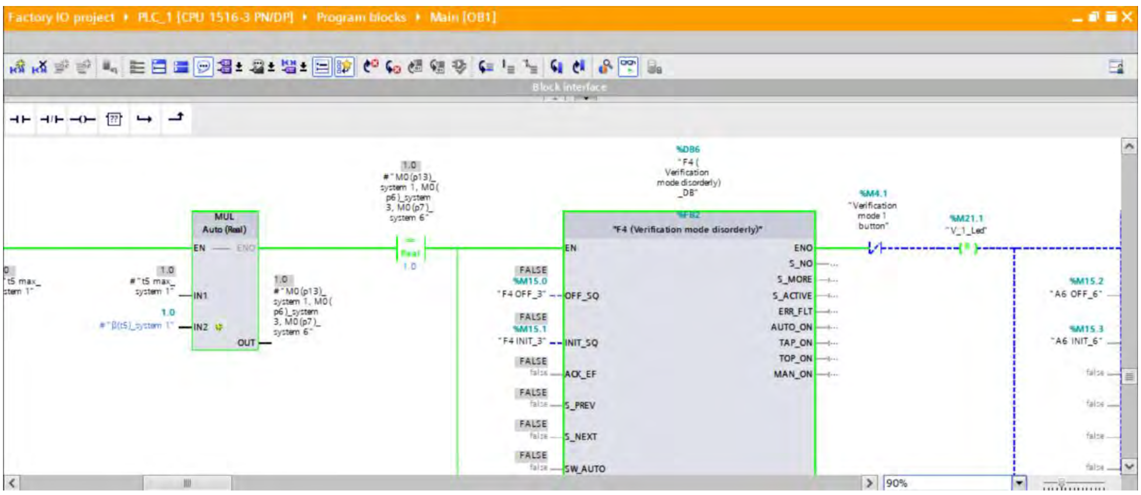


(a) (b)

Figure 6.262: The initial stop state (A1) is off while the verification button 1 is pressed. (a) the screen, (b) the program



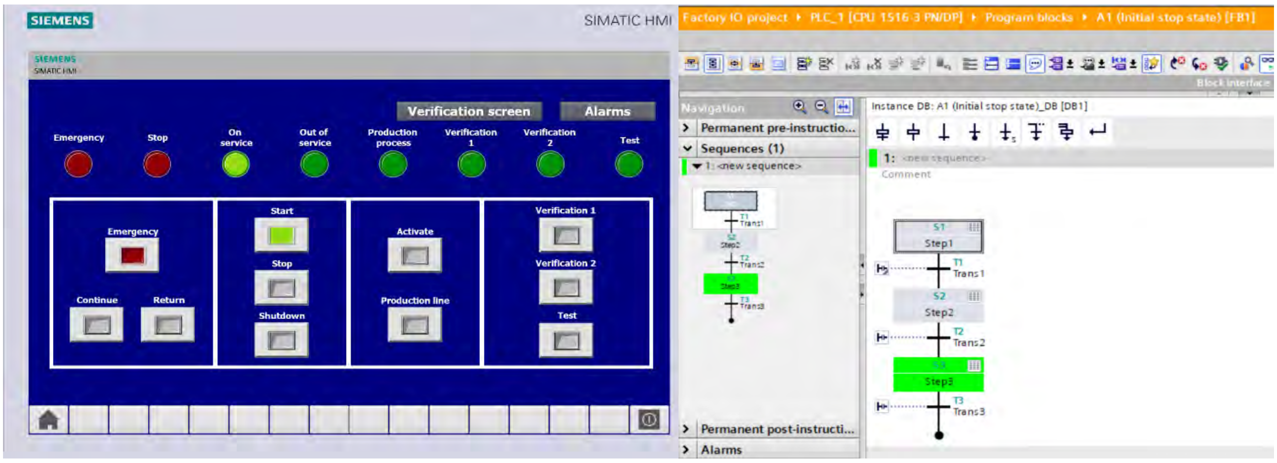
(a)



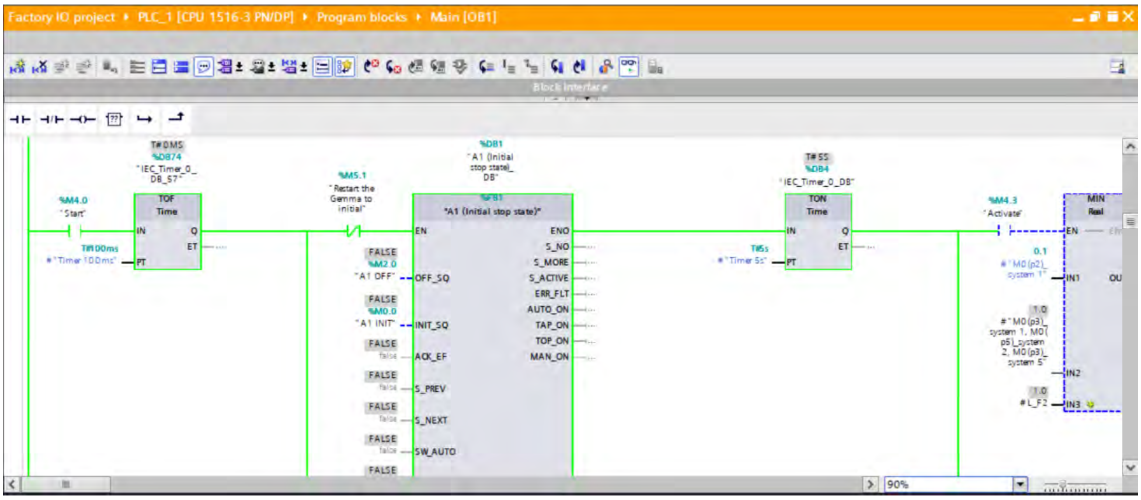
(b)

Figure 6.263: The program is placed at the running in verification mode disorderly (F4) of GEMMA, and it is ready for the different verification actions. (a) the program, (b) the Fuzzy Petri Nets intelligent algorithm

The last transition of this algorithm is the transition between the initial stop state (A1) and running in verification mode orderly (F5). This transition allows the operator to verify all the parts of the production line. That is to say, this verification mode operates one cycle of the production line as it is explained in the Subsection 6.1.3. The figure below presents the operation screen, program and Fuzzy Petri Net intelligent algorithm while the program is placed at the initial stop state (A1).



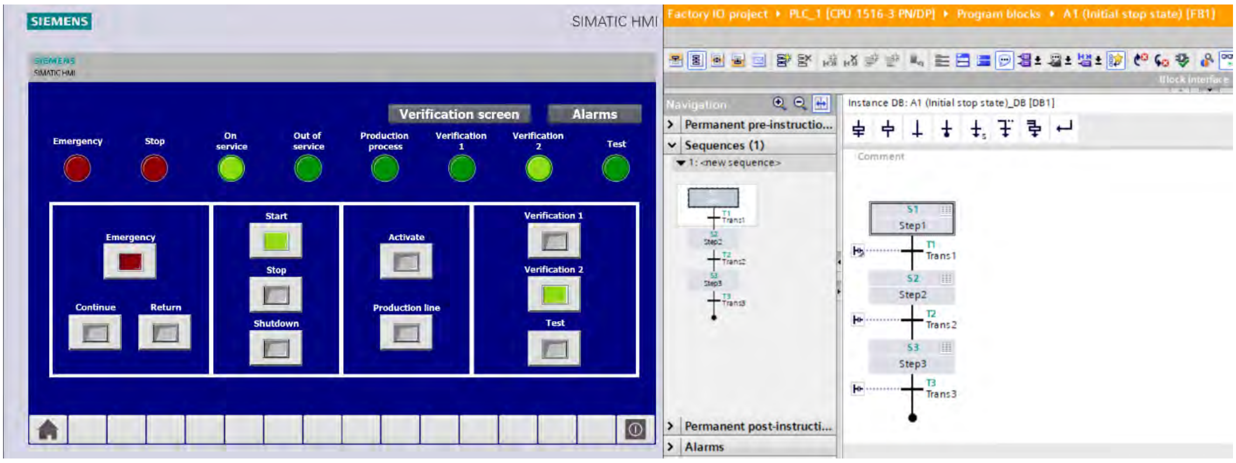
(a) (b)



(c)

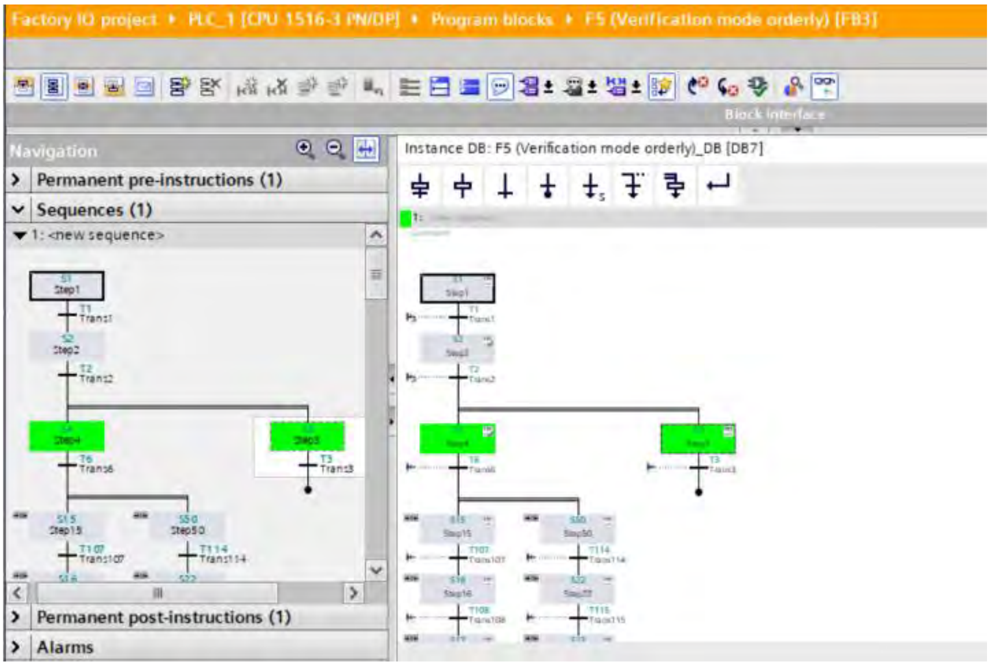
Figure 6.264: The program is placed at the initial stop state (A1) of GEMMA. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

When the operator desires to verify the production line by the running in verification mode orderly (F5), he is able to do it by pressing the verification 2 button. In this moment, the algorithm switches off the initial stop state (A1) as it is shown in figure 6.265 and places the program at the running in verification mode orderly (F5). Figure 6.266 presents the program while it is placed at the initial state of the F5 mode and it is ready for the verification process. Moreover, the figure shows the Fuzzy Petri Nets intelligent algorithm as this moment.

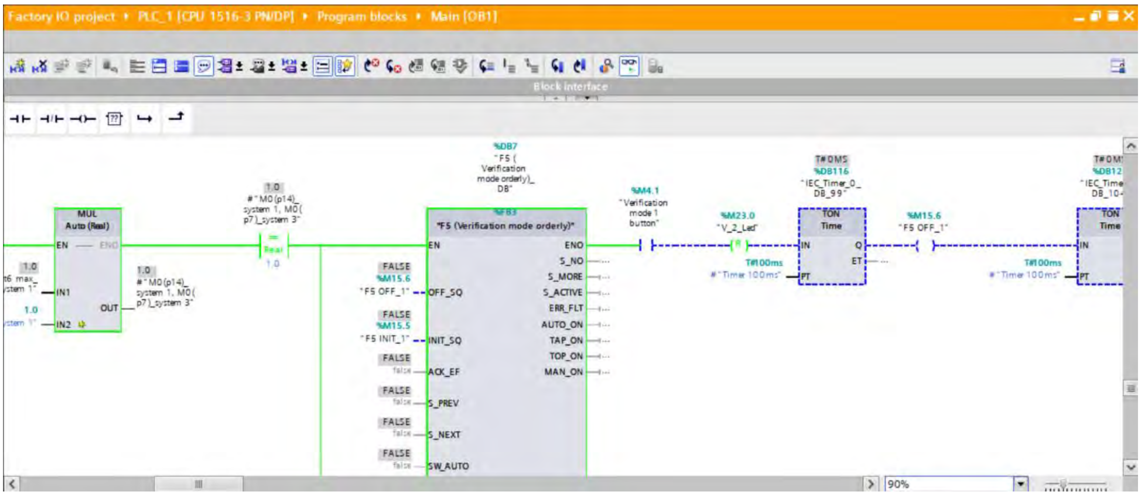


(a) (b)

Figure 6.265: The initial stop state (A1) is of while the verification button 2 is pressed. (a) the screen, (b) the program



(a)



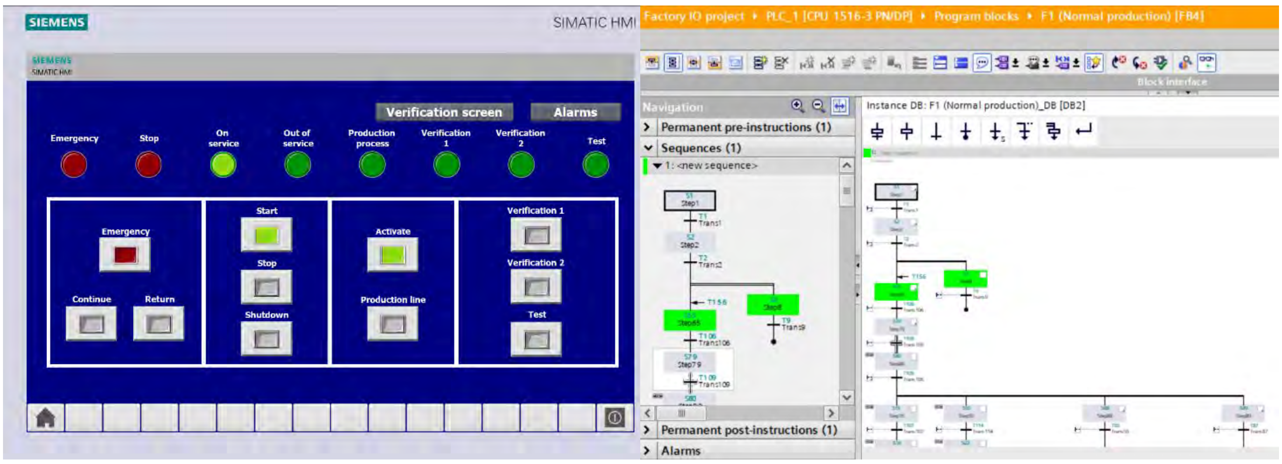
(b)

Figure 6.266: The program is placed at the running in verification mode orderly (F5) of GEMMA, and it is ready for the verification process. (a) the program, (b) the Fuzzy Petri Nets intelligent algorithm

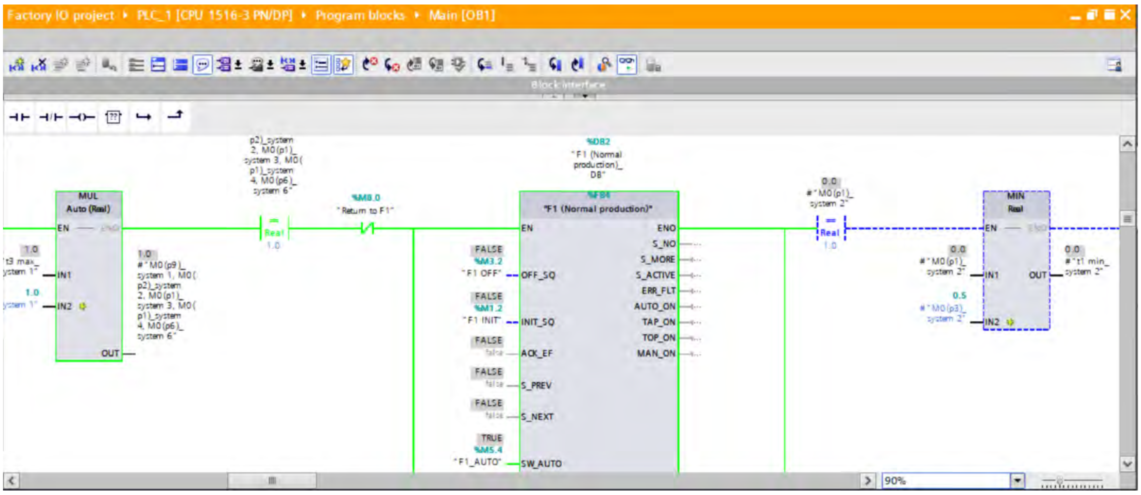
6.2.4.2. Operation Procedure

The operation procedures allow the operator to control the production line and make his decision to verify the production line while the program is placed at the normal production mode (F1) at any moment of the production. That is to say, by this transition, the operator is able to place the program in the desired verification mode according to his needs. This algorithm is explained deeply in the Section 4.3.

The figure below presents the operation screen, program, and Fuzzy Petri Nets intelligent algorithm while it is placed at the normal production mode (F1). In this example, the program is placed at the initial state of the F1 mode and it is ready for the production.



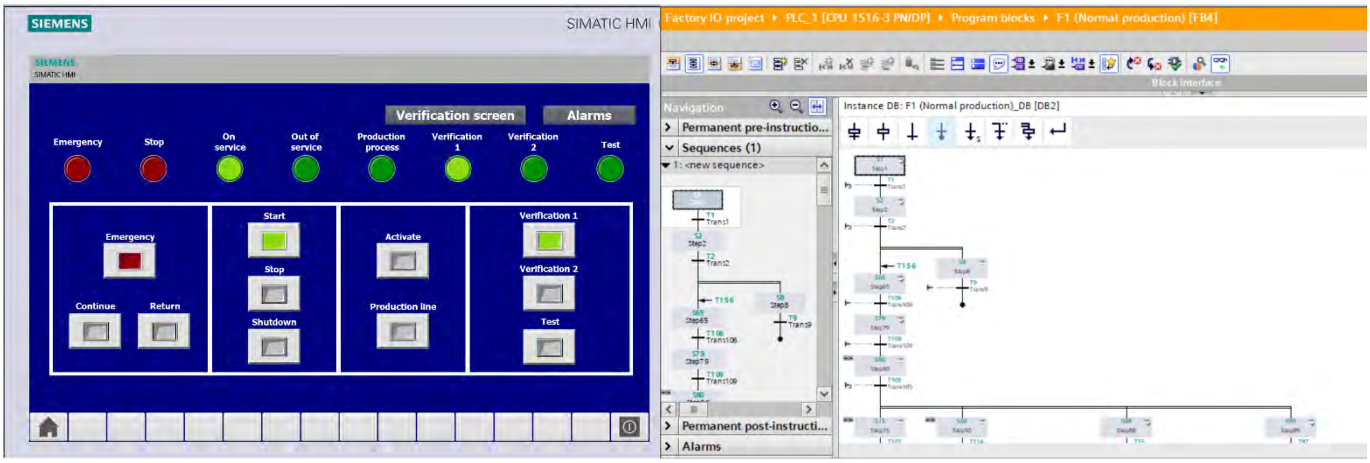
(a) (b)



(c)

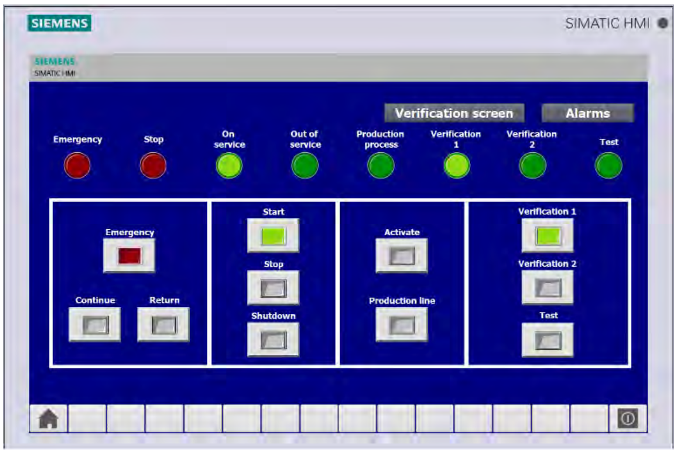
Figure 6.267: The program is placed at the normal production mode (F1) of GEMMA, while the activation button is pressed. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

At the moment that the operator desires to place the program in the running in verification mode disorderly (F4), he is able to do it by pressing the verification 1 button. When the operator presses the button, the algorithm switches off the normal production mode (F1) as it is shown in figure 6.268 and places the program in the F4 mode as it is presented in figure 6.269. At this situation, the program and production line are ready for the different verification actions, and the operator is able to verify the required part of the production line.

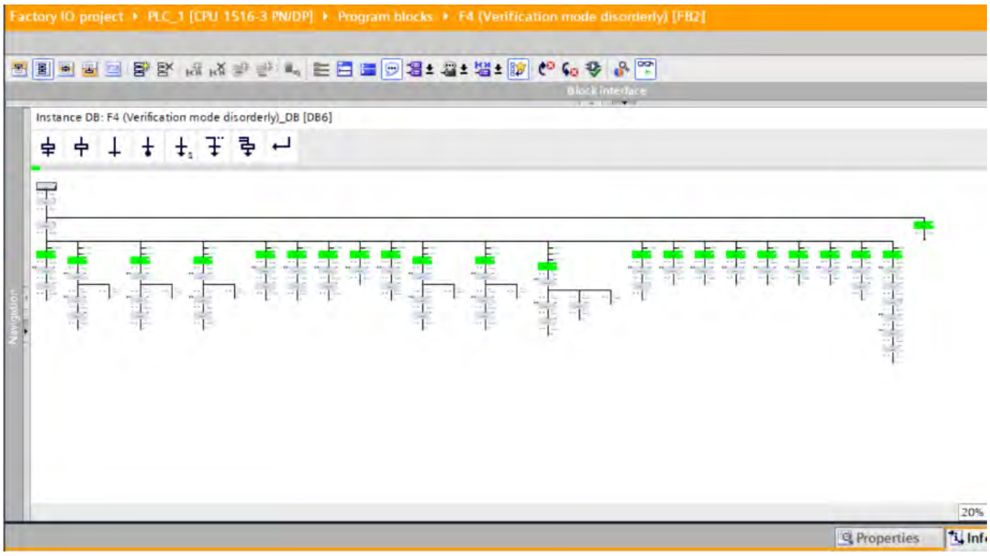


(a) (b)

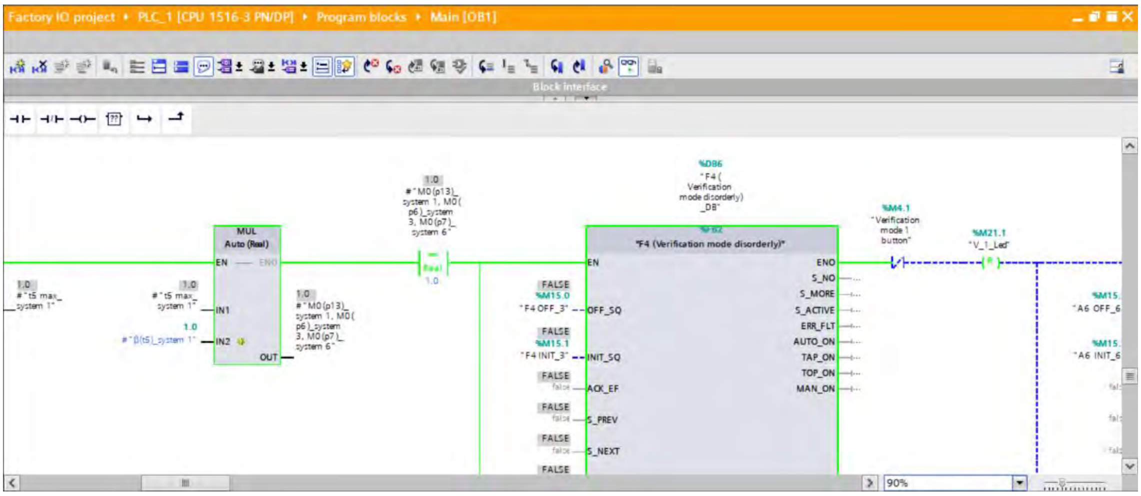
Figure 6.268: The normal production mode (F1) is off while the verification button 1 is pressed. (a) the screen, (b) the program


SIEMENS
SIMATIC HMI
Verification screen
Alarms
Emergency
Stop
On service
Out of service
Production process
Verification 1
Verification 2
Test
Emergency
Continue
Return
Start
Stop
Shutdown
Activate
Production line
Verification 1
Verification 2
Test

(a)


Factory IO project ▸ PLC_1 [CPU 1516-3 PN/DP] ▸ Program blocks ▸ F4 (Verification mode disorderly) [FB2]
Instance DB: F4 (Verification mode disorderly)_DB [DB6]
20%
Properties

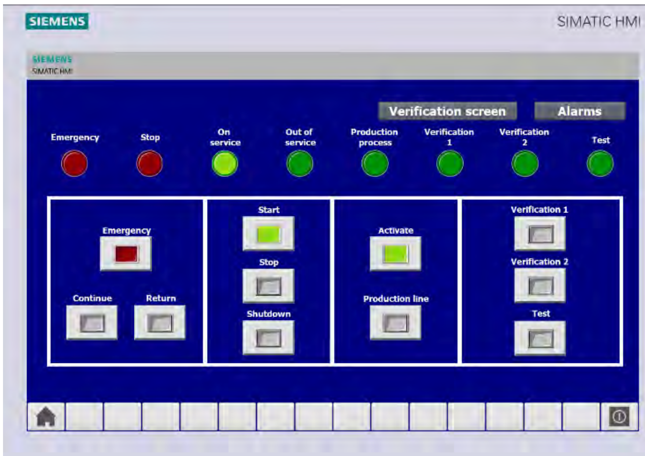
(b)


Factory IO project ▸ PLC_1 [CPU 1516-3 PN/DP] ▸ Program blocks ▸ Main [OB1]
MUL
Auto (Real)
EN
ENO
IN1
IN2
OUT
"F4 (Verification mode disorderly)"
OFF_SQ
INIT_SQ
ACK_EF
S_PREV
S_NEXT
S_NO
S_MORE
S_ACTIVE
ERR_FLT
AUTO_ON
TAP_ON
TOP_ON
MAN_ON
90%

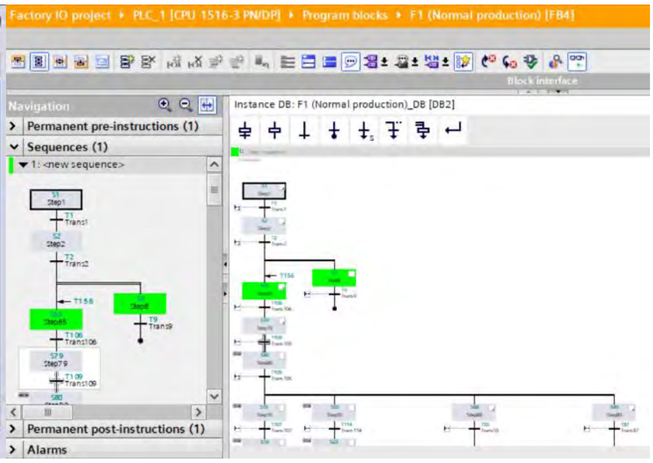
(c)

Figure 6.269: The program is placed at the running in verification mode disorderly (F4) of GEMMA, and it is ready for the different verification actions. (a) the screen, (b) the program, (c) Fuzzy Petri Nets intelligent algorithm

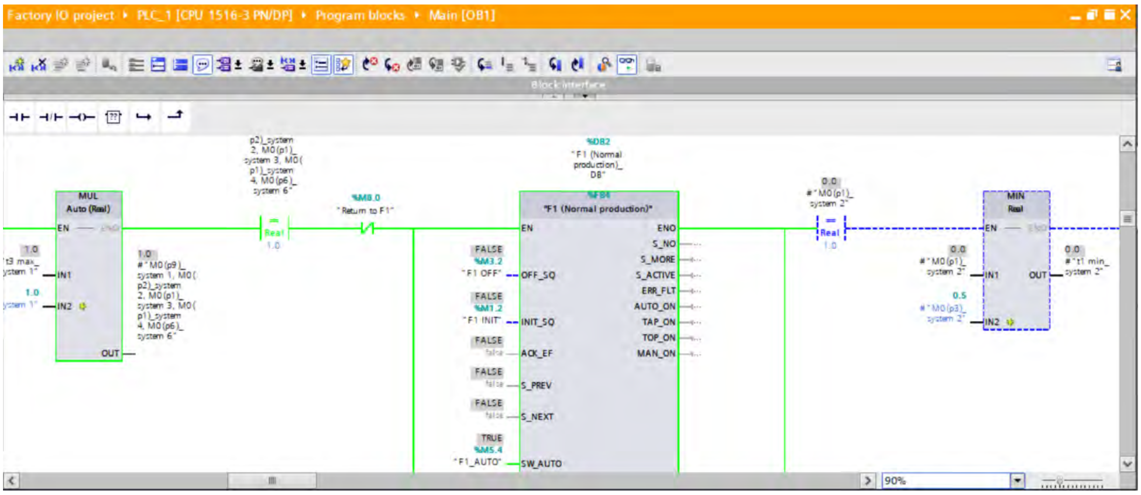
In a similar way, while the program is placed at the normal production mode (F1) and the operator desires to verify the production line by the running in verification mode orderly (F5) for any reason, he is able to do it by pressing the verification 2 button. Figure 6.270 presents the operation screen, program and Fuzzy Petri Nets intelligent algorithm while the program is placed at the initial state of the F1 mode.



(a)



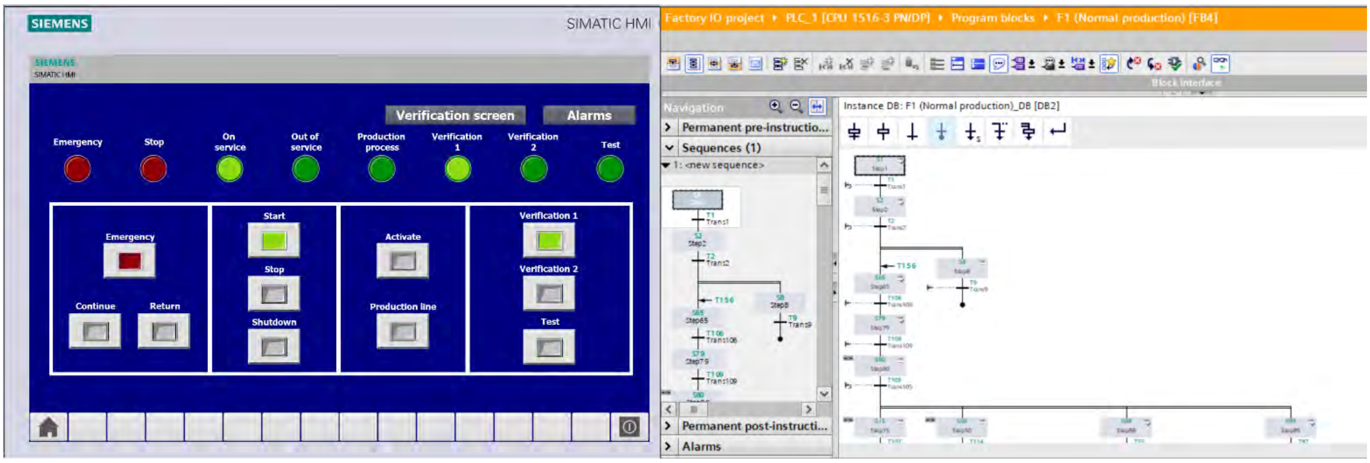
(b)



(c)

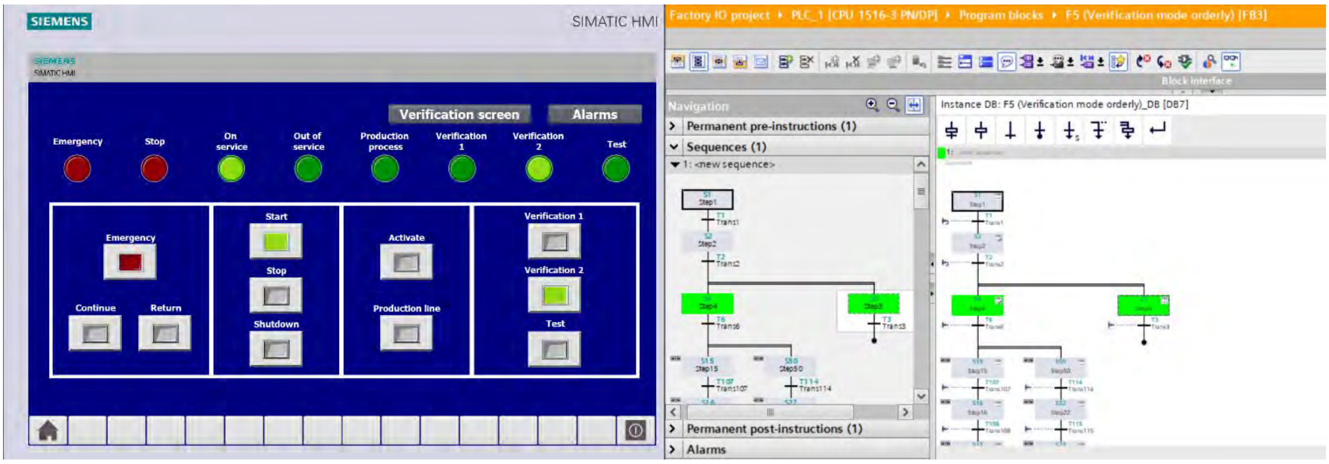
Figure 6.270: The program is placed at the normal production mode (F1) of GEMMA, while the activation button is pressed. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

As soon as the operator presses the verification 2 button, the algorithm switches off the normal production mode (F1) as it is shown in figure 6.271 and places the program at the running in verification mode orderly (F5) as it is presented in figure 6.272. At this moment, the program is placed at the initial state of the F5 mode and it is ready to start the verification cycle of the production line as it is explained in the Subsection 6.2.3.

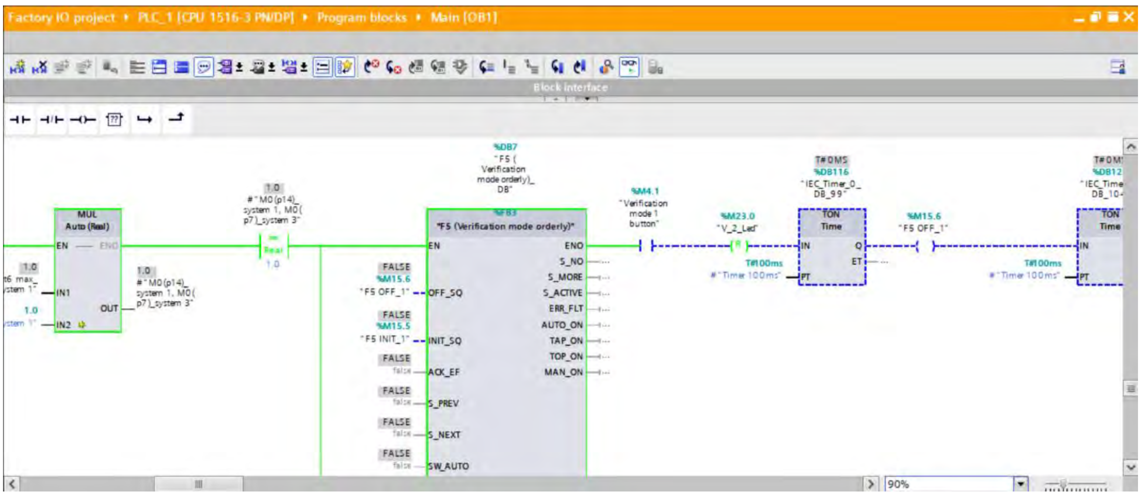


(a) (b)

Figure 6.271: The normal production mode (F1) is off while the verification button 1 is pressed. (a) the screen, (b) the program



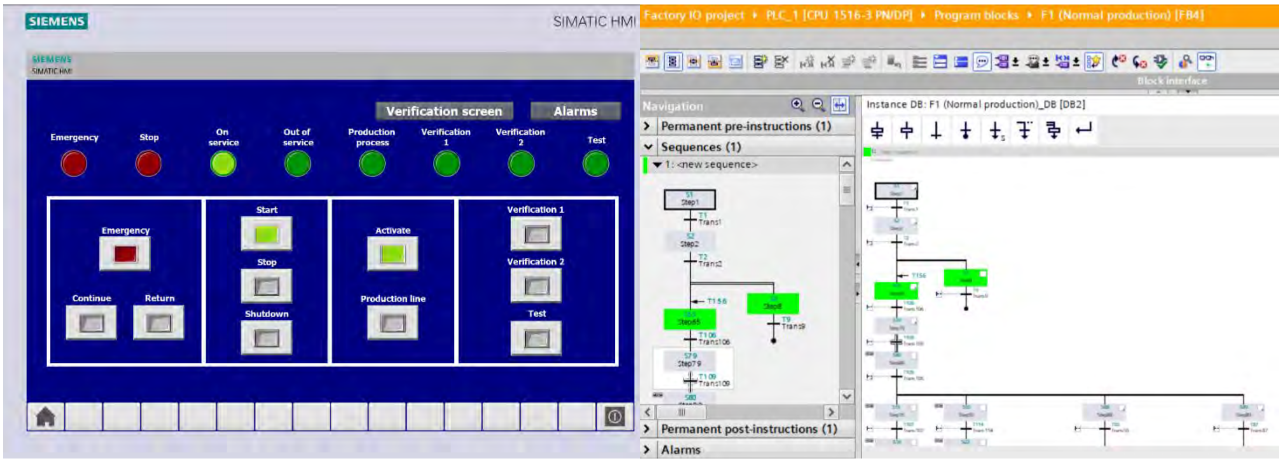
(a) (b)



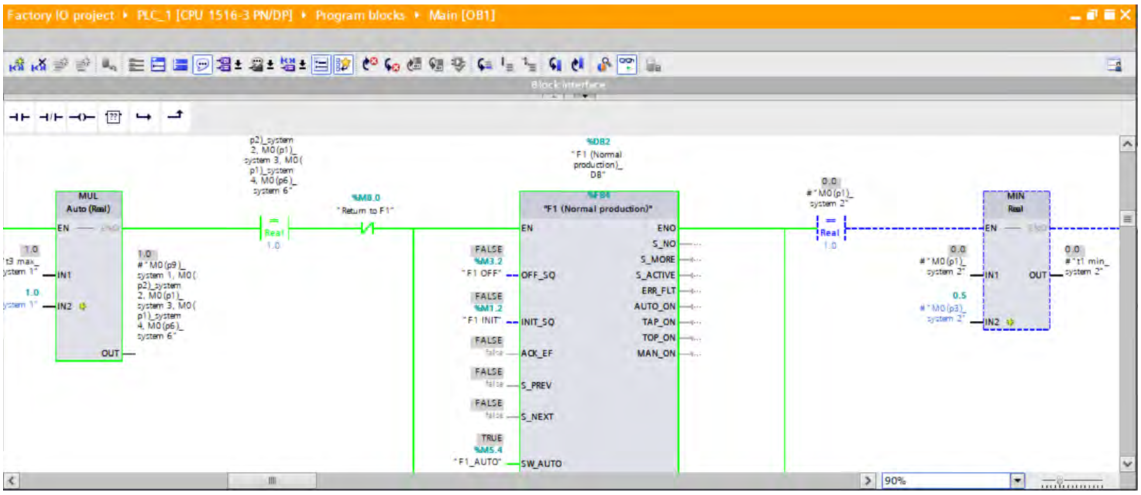
(c)

Figure 6.272: The program is placed at the running in verification mode orderly (F5) of GEMMA, while the verification button 2 is pressed and it is ready to the verification process. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

The last transition of this algorithm is the transition between the normal production mode (F1) and test mode (F6). At any moment of the production, the operator is able to place the program at the F6 mode in order to verify some part of the production line. Differently from running in verification mode disorderly (F4), this mode allows the operator returning to the normal production after the verification as it is explained in the Subsection 6.2.3. Figure 6.273 presents the operation screen, program and Fuzzy Petri Nets intelligent algorithm while the program is placed at the initial state of the F1 mode.



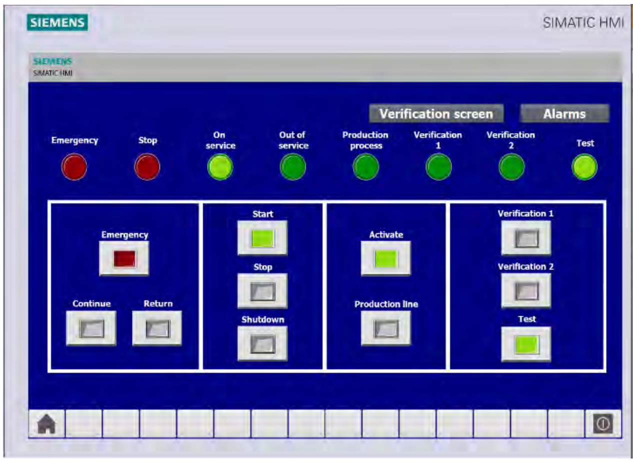
(a) (b)

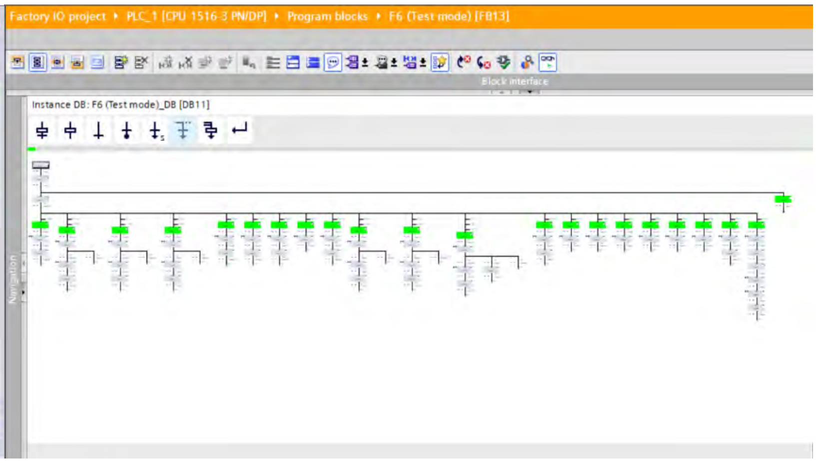


(c)

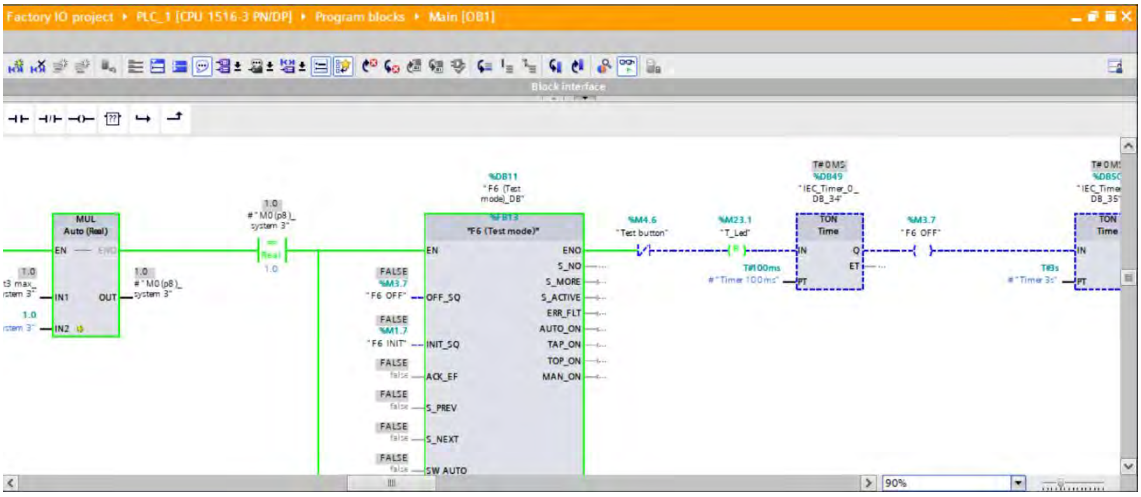
Figure 6.273: The program is placed at the normal production mode (F1) of GEMMA, while the activation button is pressed. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

As soon as the operator desires to place the program at the test mode (F6) in order to verify some part of the production line, he is able to do it by pressing the test button. Whren the button has pressed, the algorithm will switch off the normal production mode (F1) and will place the program at the test mode for starting the desired verification. The figure below shows the operation screen at this moment. It is possible to see that the test button is activated, and the program is placed at the test mode. Moreover, the figure presents the program and Fuzzy Petri Nets intelligent algorithm. As it is shown, the program is ready for the different test actions.





(a) (b)



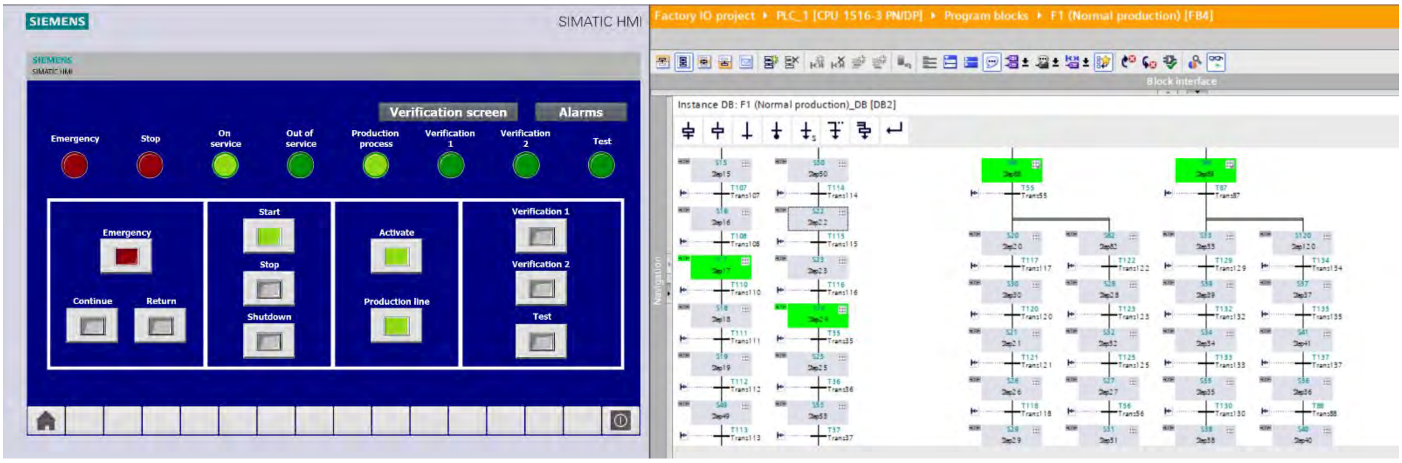
(c)

Figure 6.274: The program is placed at the test mode (F6) of GEMMA, while the test button is pressed, and it is ready to the different test actions. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

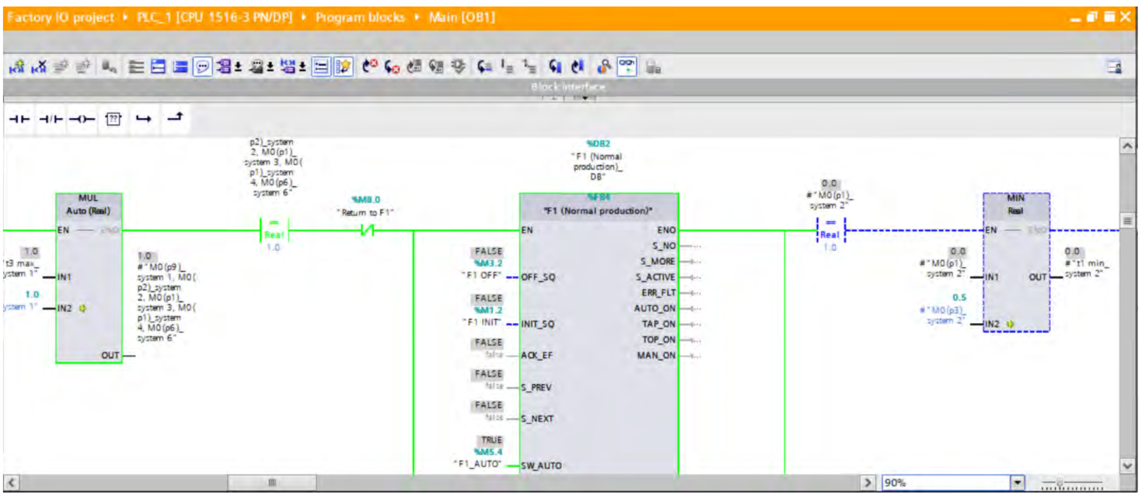
6.2.4.3. Operation Procedure to Stop Procedure

The operation procedure to stop procedure is explained in the Section 4.4. This procedure is very important for the safety and proper operation of the production line. That is to say, as soon as the operator has the need to stop production for any reason, the algorithm makes the best decision according to the production line situation in order to place the program in the appropriate mode. Additionally, this algorithm is responsible for the transitions between the operation modes and the shutdown modes of the program, and place the program in the appropriate mode in order to shut the production line down when the operator has this need.

The first transition that are descried is related to the stop processes of the production line. In the figure below the operation screen and program are presented. It is possible to see that the production line is in process, and the first base and lid are in production.



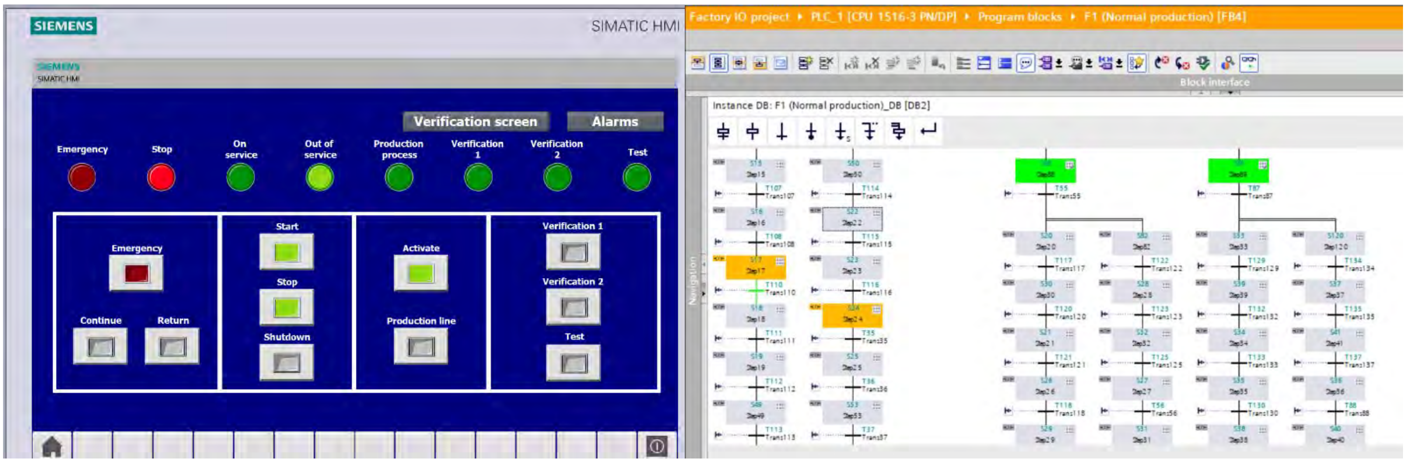
(a) (b)



(c)

Figure 6.275: The program is placed at the normal production mode (F1) of GEMMA, while the activation and the production line button are pressed. The product line produces the first base and lid. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

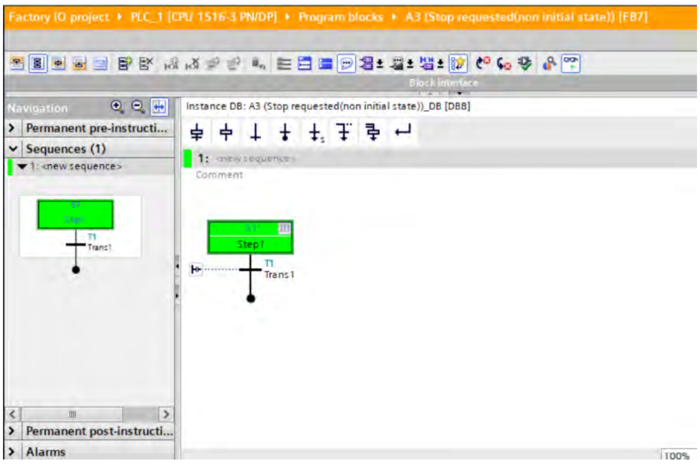
During the production, the operator is able to stop the production mode at any stage. When the operator has this need, he is able to stop the production mode by pressing the stop button. At this moment, the algorithm will stop all the activated parts and will freeze the normal production mode (F1). In the figure below it is possible to see the operation screen while the stop button has pressed, and the frozen steps (their color has changed to orange) of these parts of production line.



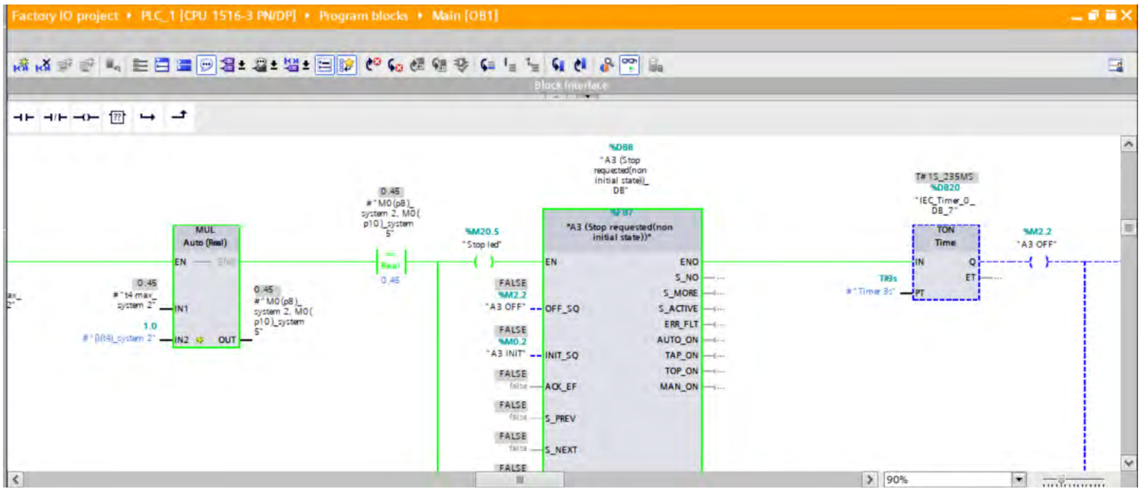
(a) (b)

Figure 6.276: The normal production mode (F1) of GEMMA is frozen, while the stop button has pressed. (a) the screen, (b) the program

As soon as the operator presses the stop button, the algorithm places the program at the requested stop (non-initial state) (A3). This is an intermediate mode, which allows to memorize the production stage. Figure 6.277 presents the program and Fuzzy Petri Nets intelligent algorithm while the program is placed at the A3 mode. Afterwards, the algorithm places the program at the stop mode (non-initial state) (A4). This mode is similar to the initial stop state (A1), the program will be placed at this mode till the moment that the operator will desire to continue the production. In other words, the program will be placed at the normal production mode (F1) at the moment that the operator will deactivate the stop button. Figure 6.278 shows the program and Fuzzy Petri Nets intelligent algorithm while the program is placed at the A4 mode.

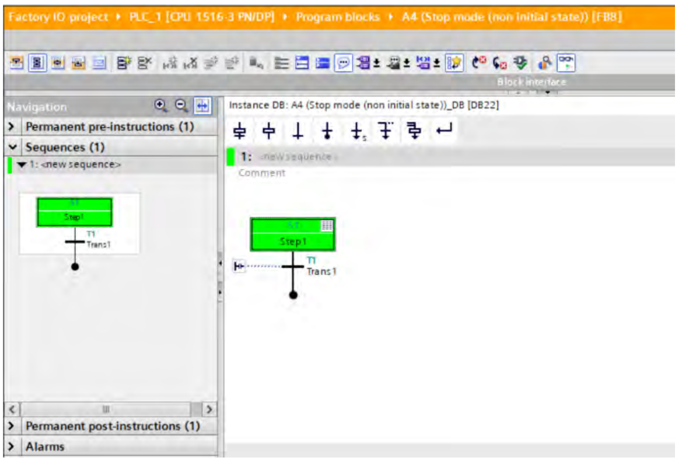


(a)

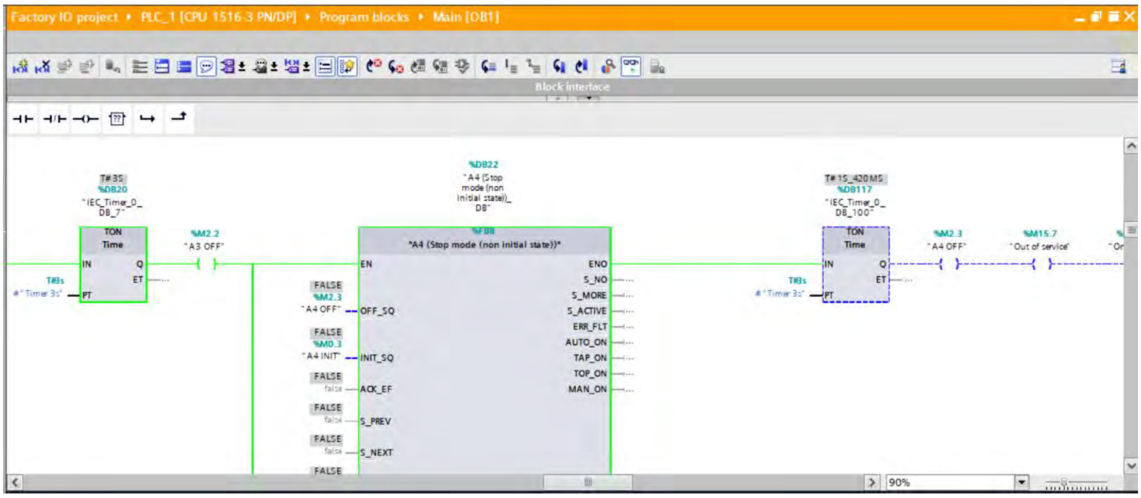


(b)

Figure 6.277: The program is placed at requested stop (non-initial state) (A3) of GEMMA. (a) the program, (b) the Fuzzy Petri Nets intelligent algorithm



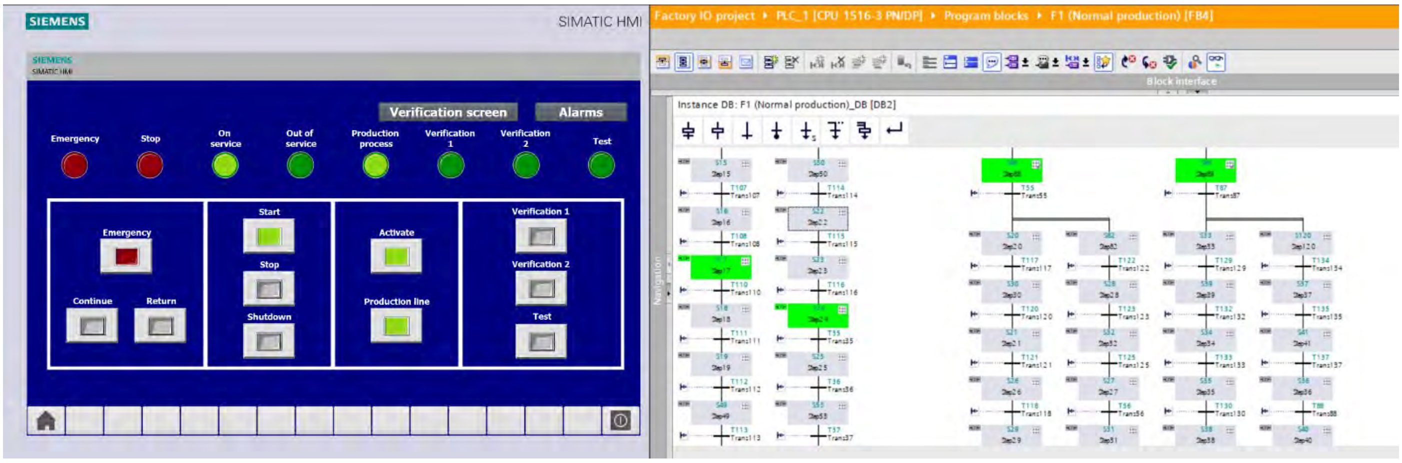
(a)



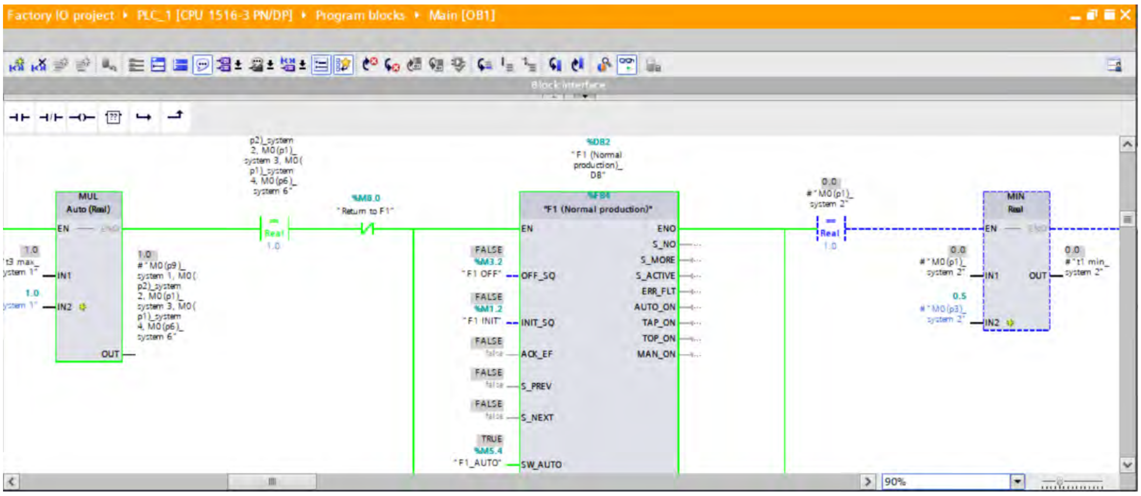
(b)

Figure 6.278: The program is placed at stop mode (non-initial state) (A4) of GEMMA. (a) the program, (b) the Fuzzy Petri Nets intelligent algorithm

The program will be placed at the stop mode (non-initial state) (A4) up to the moment that the operator wants to continue the production as it is explained before. At the moment that the operator will deactivate the stop button, the algorithm will place the program at the normal production mode (F1) at the exact point of the production that it was before the stop button was pressed. Figure 6.279 presents the operation screen, program and Fuzzy Petri Nets intelligent algorithm at this situation.



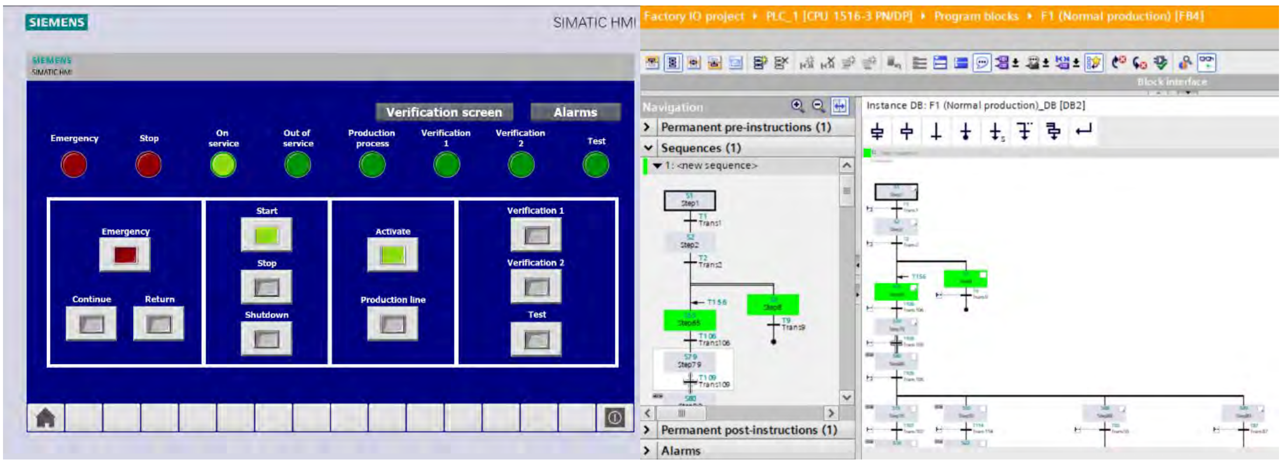
(a) (b)



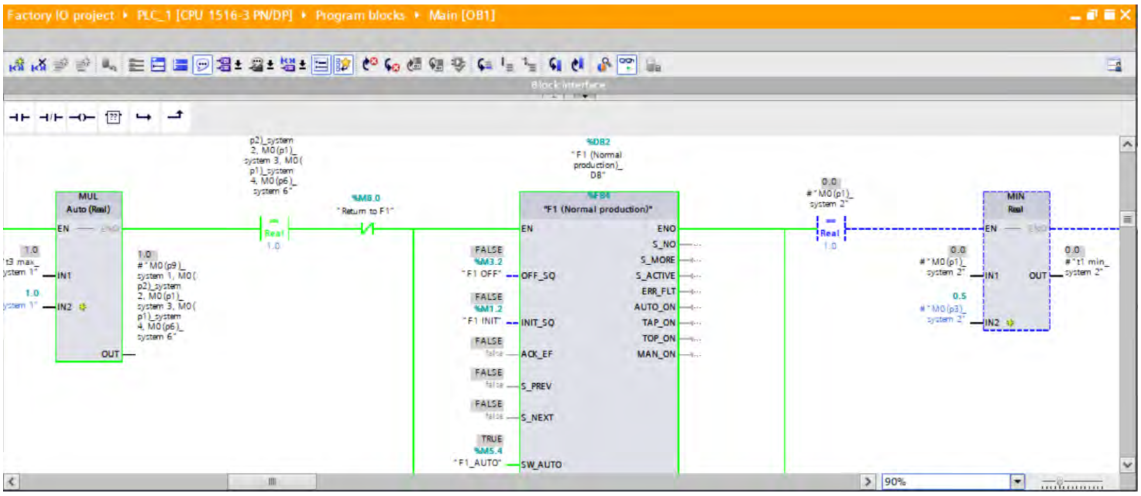
(c)

Figure 6.279: The program is placed at the normal production mode (F1) of GEMMA, while the stop button has deactivated. The product line produces the first base and lid. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

The second transition of this algorithm is responsible for the stop process of the program while the production line is in its initial state. That is to say, the operator presses the stop button while the program and production line are in their initial state. At this situation, the algorithm detects the production line situation and places the program at the appropriate mode. The figure below presents the operation screen, program and Fuzzy Petri Nets intelligent algorithm while the program is placed at the initial state of the normal production mode (F1).



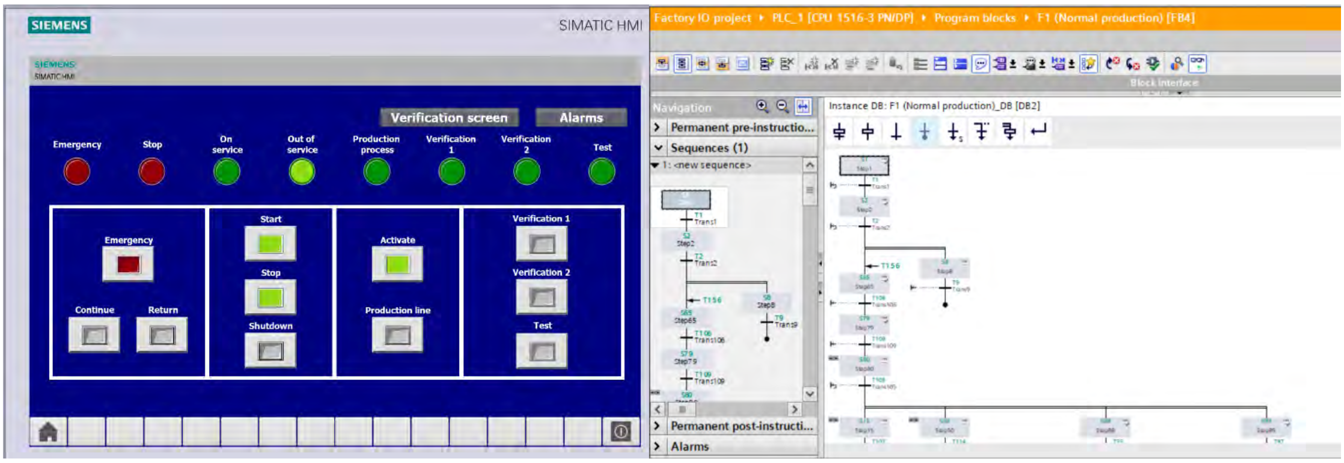
(a) (b)



(c)

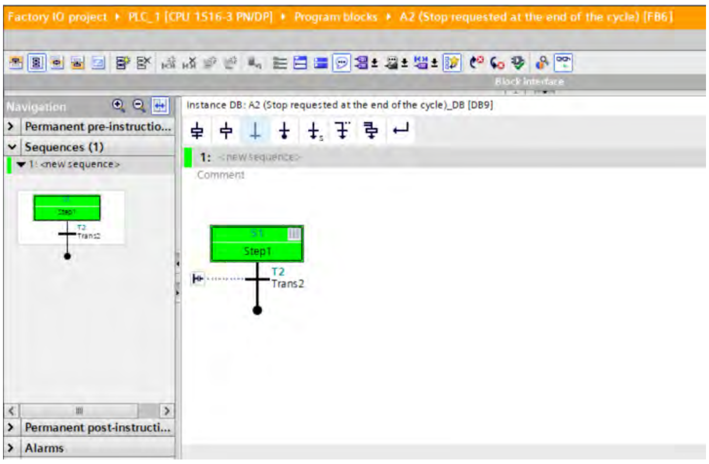
Figure 6.280: The program is placed at the initial state of the normal production mode (F1) of GEMMA. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent transitions

At the moment that the operator presses the stop button while the program and production line are placed at their initial state, the algorithm switches off the normal production mode (F1), this stage is presented in figure 6.281. Moreover, the algorithm will place the program in the temporal mode requested stop at the end of the cycle (A2) for preparing the program to the initial stop state (A1) as it is show in figure 6.282.

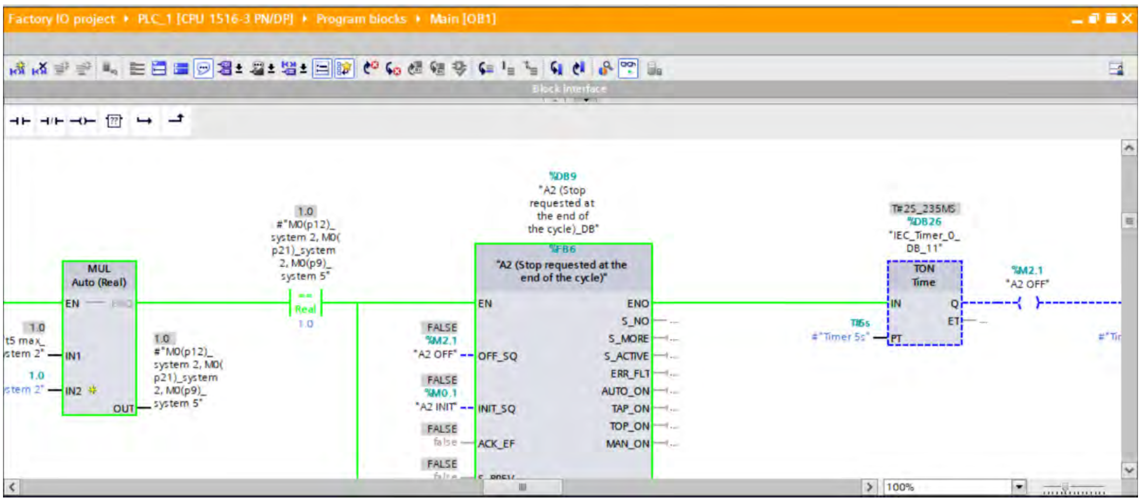


(a) (b)

Figure 6.281: The normal production mode (F1) of GEMMA is off, while the stop button is pressed. (a) the screen, (b) the program



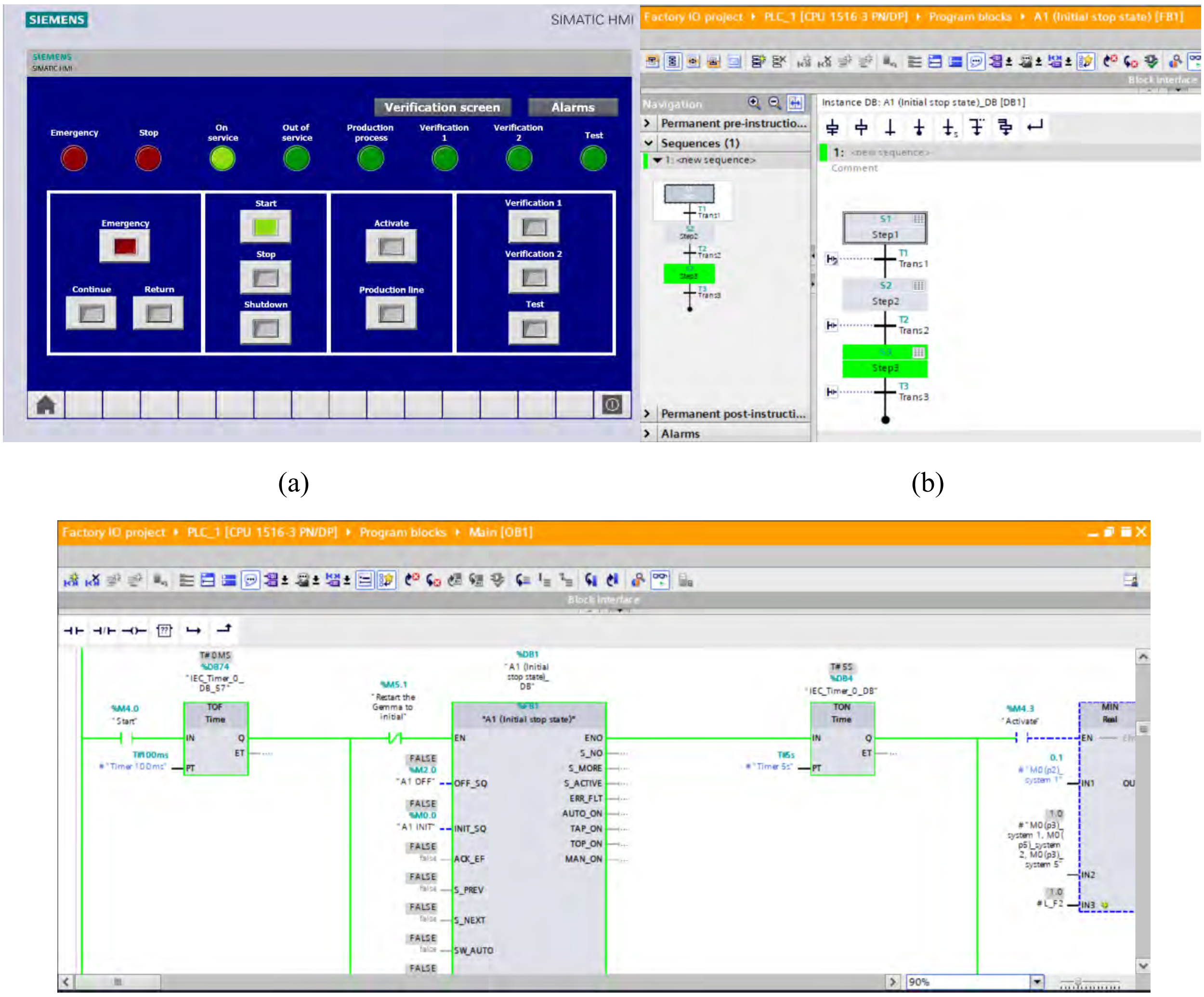
(a)



(b)

Figure 6.282: The program is placed at the requested stop at the end of the cycle (A2) of GEMMA. (a) the program, (b) the Fuzzy Petri Nets intelligent algorithm

The program will be placed at the requested stop at the end of the cycle (A2) until the moment that it will be prepared for the initial stop state (A1) as it is explained before. When the program is ready, the algorithm will place it at the A1 mode, and it will be ready for the next desired action. The figure below presented the operation screen, program and Fuzzy Petri Nets intelligent algorithm while the program is placed at the A1 mode.

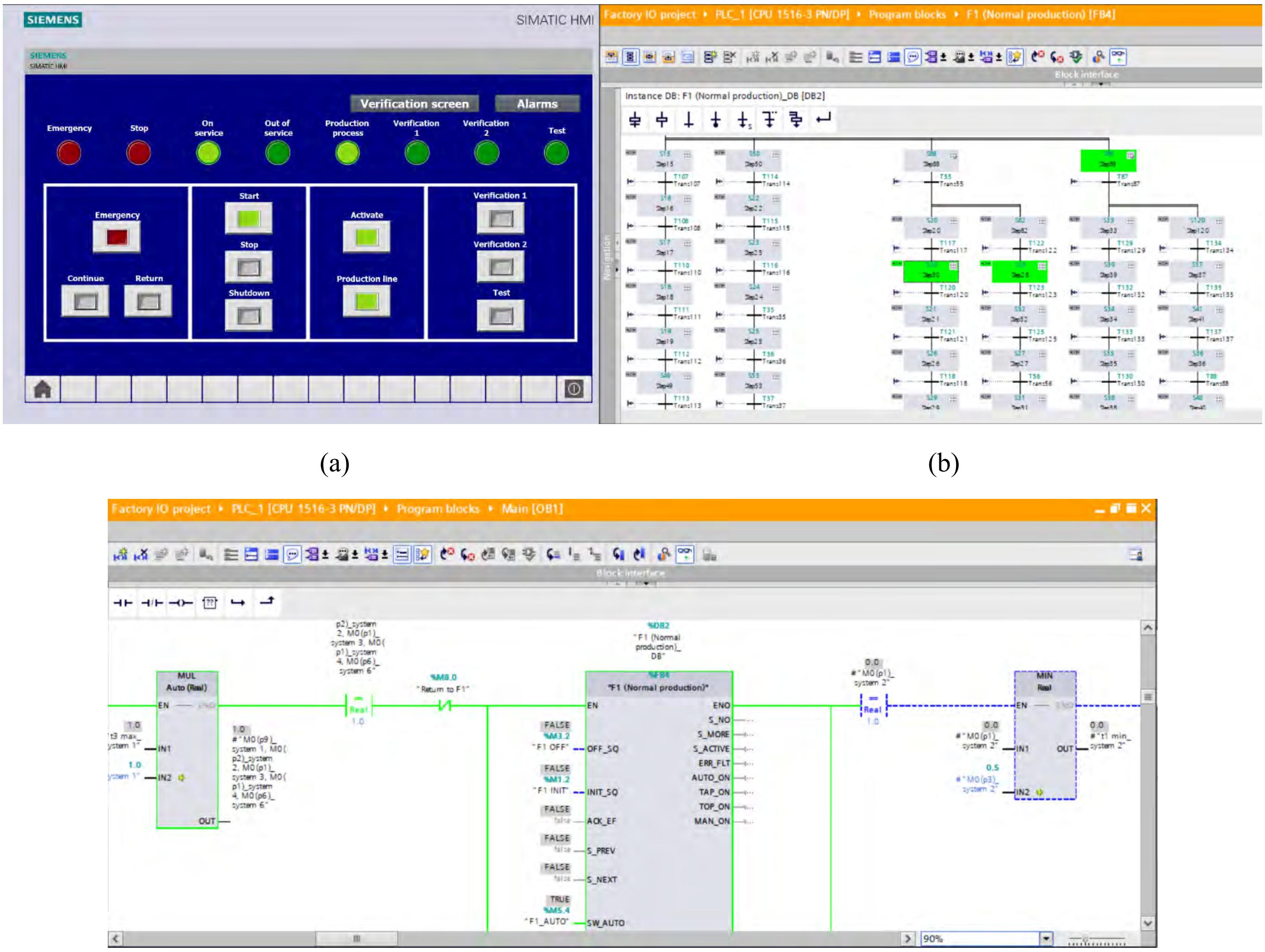


(a) (b)

(c)

Figure 6.283: The program is placed at the initial stop state (A1) of GEMMA. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

The transitions of the production line for shutdown are also operated by this algorithm. They are divided into two transitions, the first one is operated at some point of the production, and the second while the production line is in its initial state as it is explained in the Subsection 6.1.4.3. The figure below presents the operation screen, program and Fuzzy petri Nets intelligent algorithm while the first base and lid are in the packing process, and the second are in production.

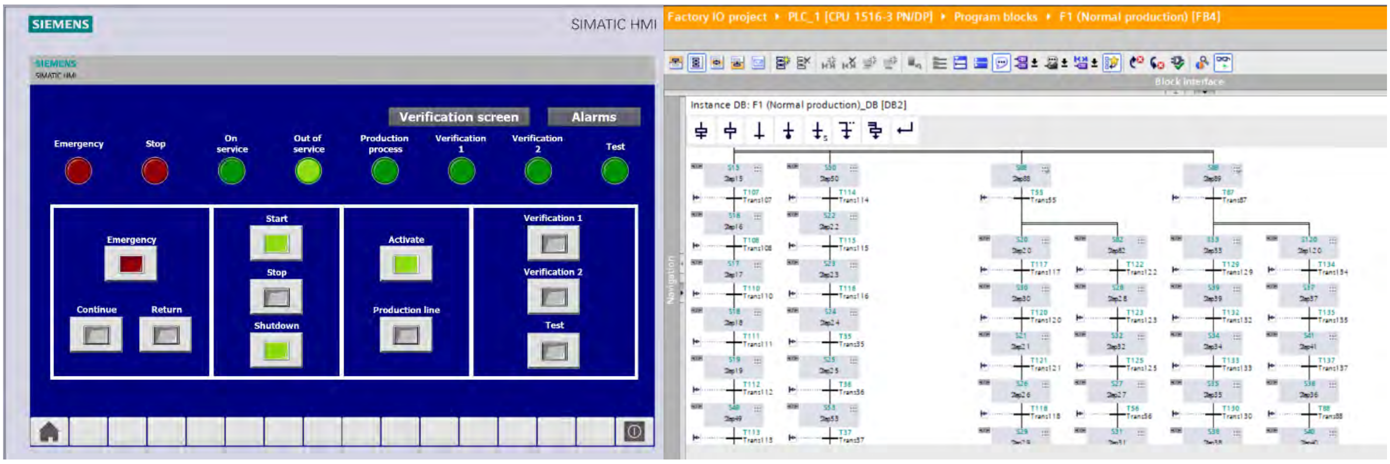


(a) (b)

(c)

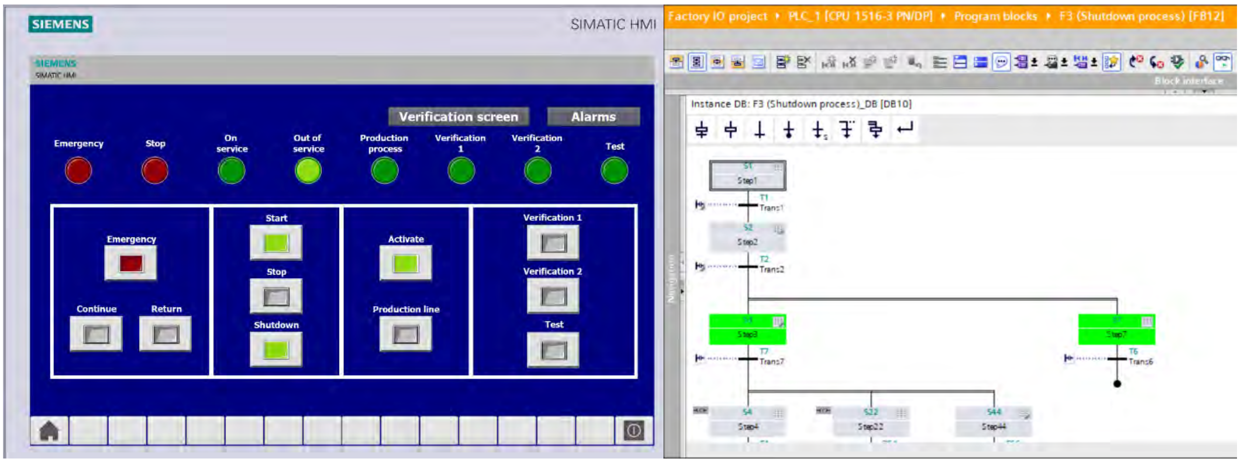
Figure 6.284: The program is placed at the normal production mode (F1) of GEMMA, while the first base and lid are in packing, and the second are in production. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

When the production line is at this situation, and the operator has the need to shut the production line down, he is able to do it by pressing the shutdown button. At this moment, the algorithm switches off the normal production mode as it is shown in figure 6.285. Additionally, the program is placed at the shutdown process mode (F3) to reset the production line and prepar it for the initial stop state (A1) as it is presented in figure 6.286. The figures show the operation screen, program and Fuzzy Petri Nets intelligent algorithm at each stage as it is explained.

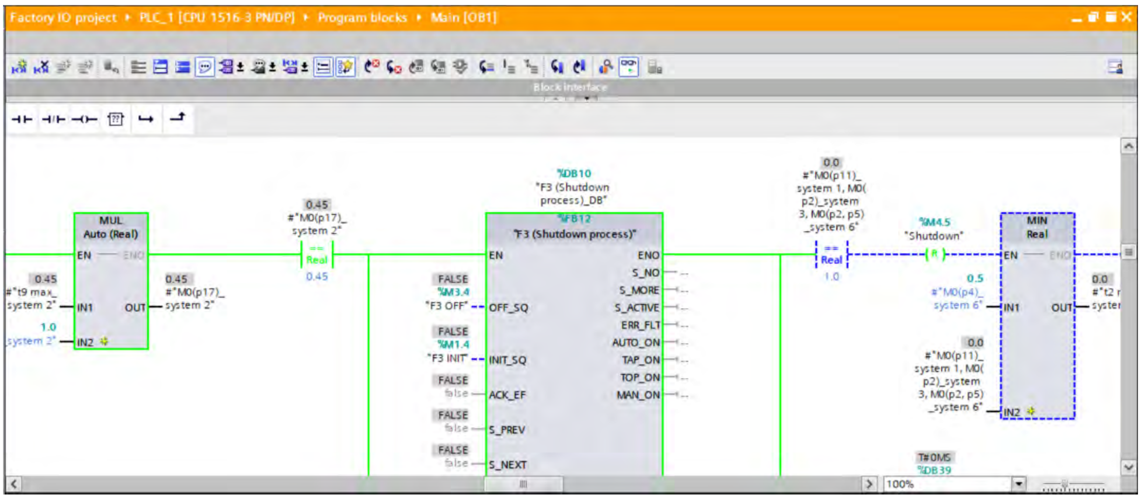


(a) (b)

Figure 6.285: The normal production mode (F1) of GEMMA is off, while the shutdown button is pressed. (a) the screen, (b) the program



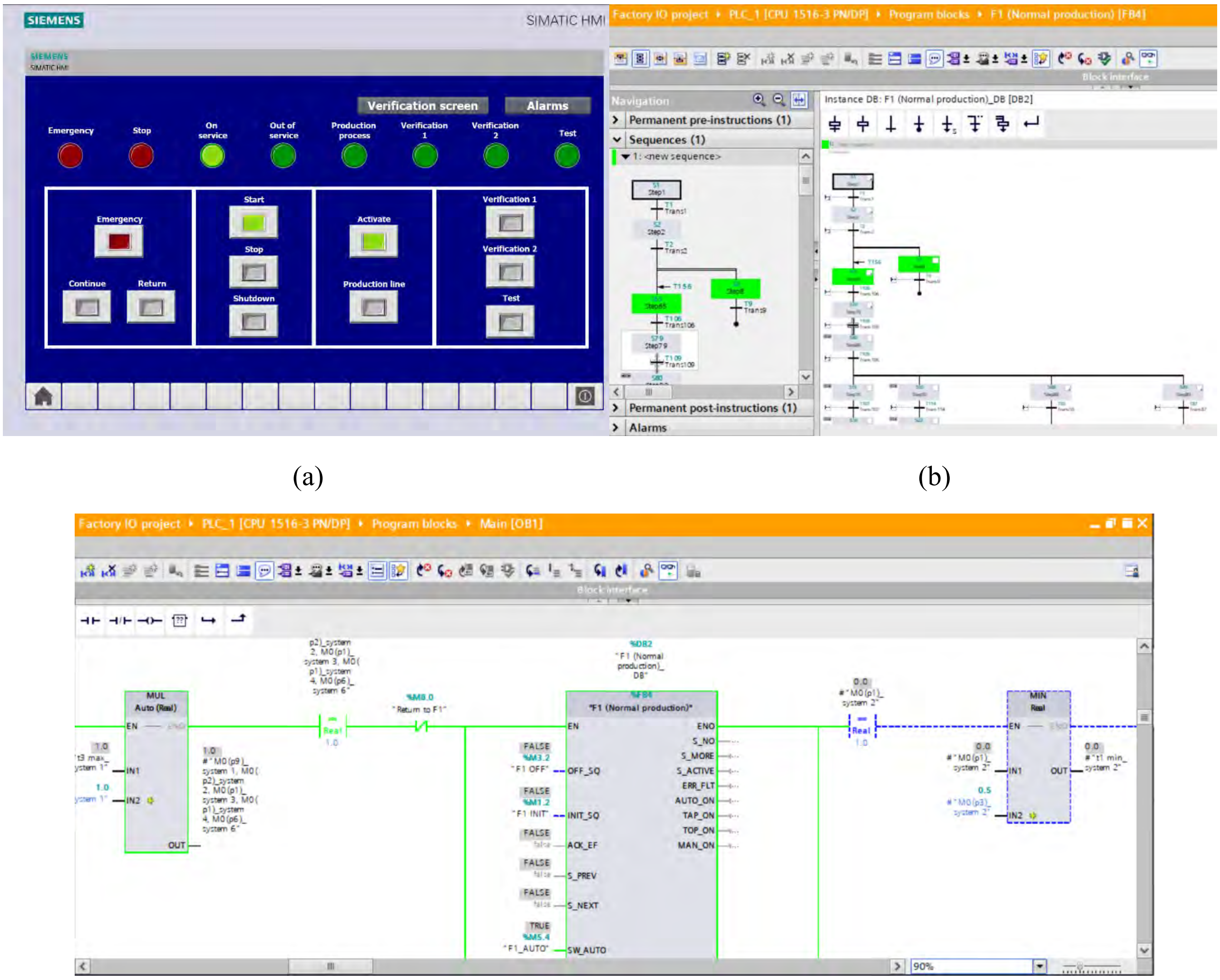
(a) (b)



(c)

Figure 6.286: The program is placed at the shutdown process mode (F3) of GEMMA. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

The second procedure of the shutdown transitions is occurred while the program is placed at the initial state of the normal production mode (F1) as it is shown in figure 6.287. When the program is in this situation and the operator desires to shut it down, the intelligent algorithm will recognize the program’s situation in order to place it in the appropriate mode.

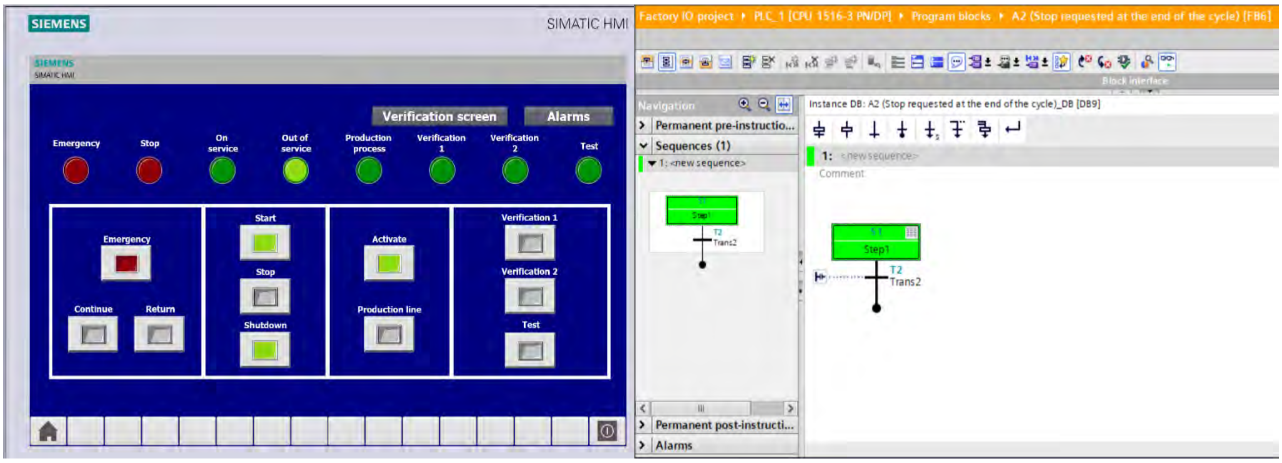


(a) (b)

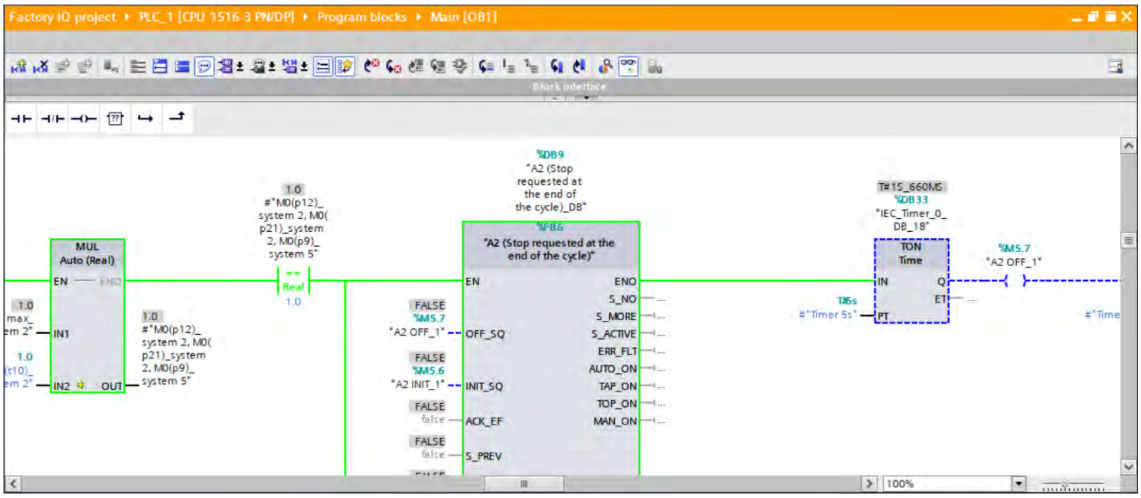
(c)

Figure 6.287: The program is placed at the normal production mode (F1) of GEMMA. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

At the moment that the operator presses the shutdown button, the intelligent algorithm will place the program at the requested stop at the end of the cycle (A2). Moreover, at the same moment, it switches off the normal production mode (F1). The A2 mode is a temporary mode which prepares the program to the initial stop state (A1) as it is explained in the Subsection 3.3.1. Figure 6.288 presents the operation screen, program and Fuzzy Petri Nets intelligent algorithm at this situation. As soon as the program is ready, the intelligent algorithm will place the program at the initial stop state (A1) as it is shown in figure 6.289

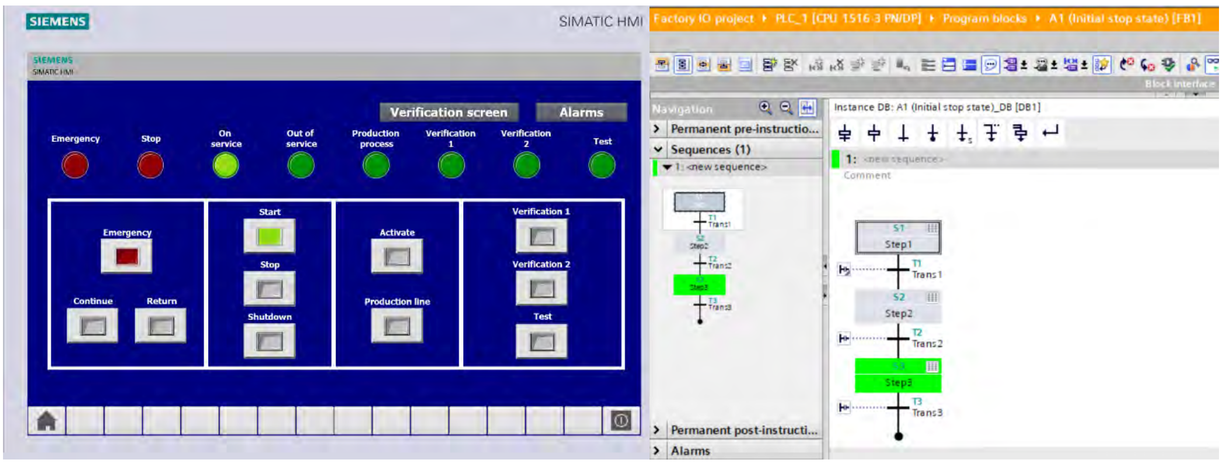


(a) (b)

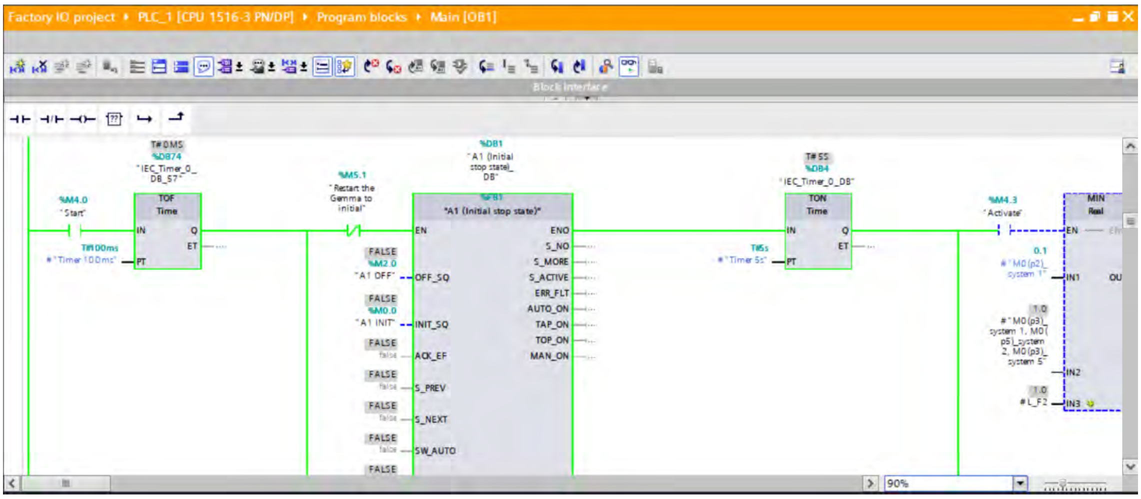


(c)

Figure 6.288: The program is placed at the requested stop at the end of the cycle (A2) of GEMMA, while the shutdown button is pressed. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm



(a) (b)



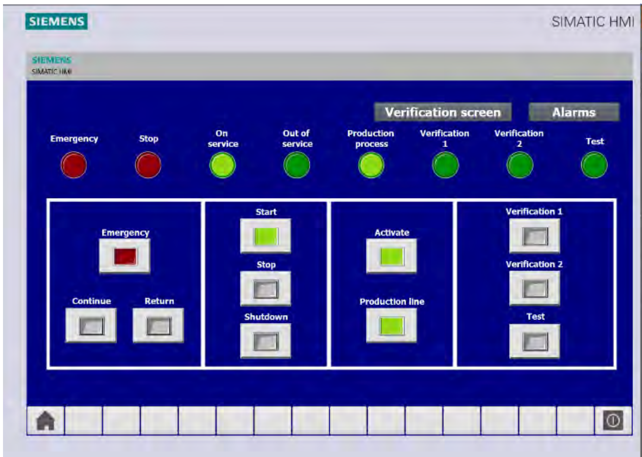
(c)

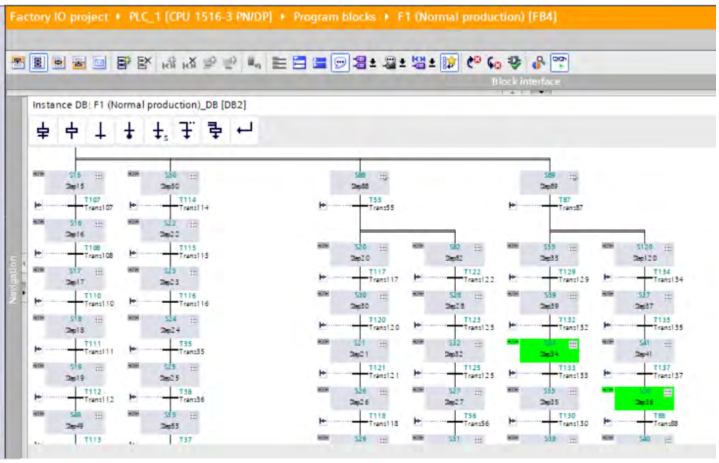
Figure 6.289: The program is placed at the initial stop state (A1) of GEMMA. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

6.2.4.4. Operation Procedure to Failure Procedure

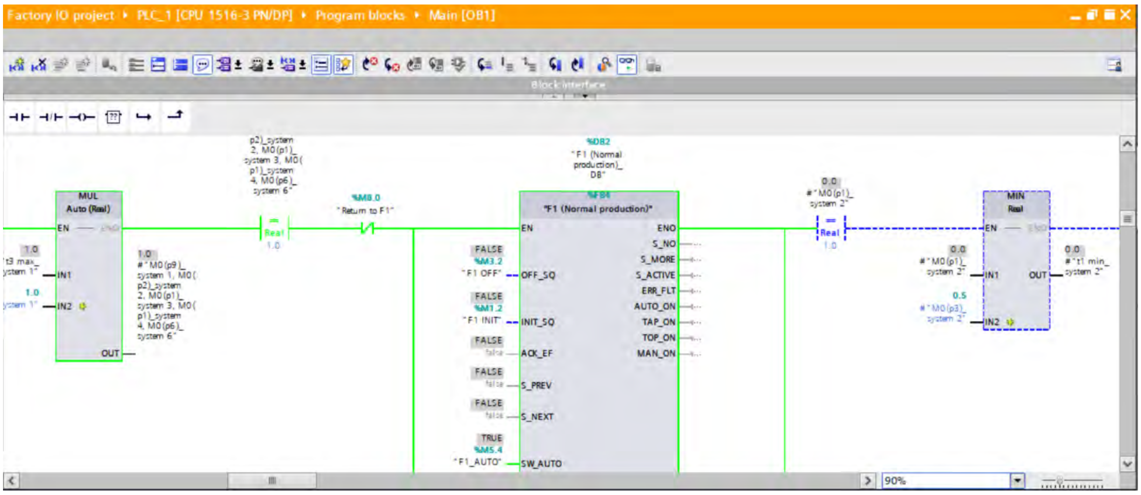
The operation procedure to failure procedure transitions are the most important for the safety of the human life, and prevention the machine’s damage. These transitions are divided into two different situations; emergency stop by button, and emergency stop automatically while the failure occur. The second situation contains three levels of failures, and the intelligent algorithm will make the best decision according to the failure’s level for choosing the appropriate mode.

The emergency stop by button is first transition that is shown. In this situation, the operator notices that either there is some failure in the production line or some failure is going to appear. In order to prevent danger to the human life or damage to the machine, the operator is able to stop the production line immediately by pressing the emergency button. Figure 6.290 presents the operation screen, program and Fuzzy Petri Nets intelligent algorithm while the program is placed at the normal production mode (F1) in the production of the third base and lid. At this moment, there is no failure, and everything works properly. It is possible to notice in figure 6.291 that the alarms screen.





(a) (b)

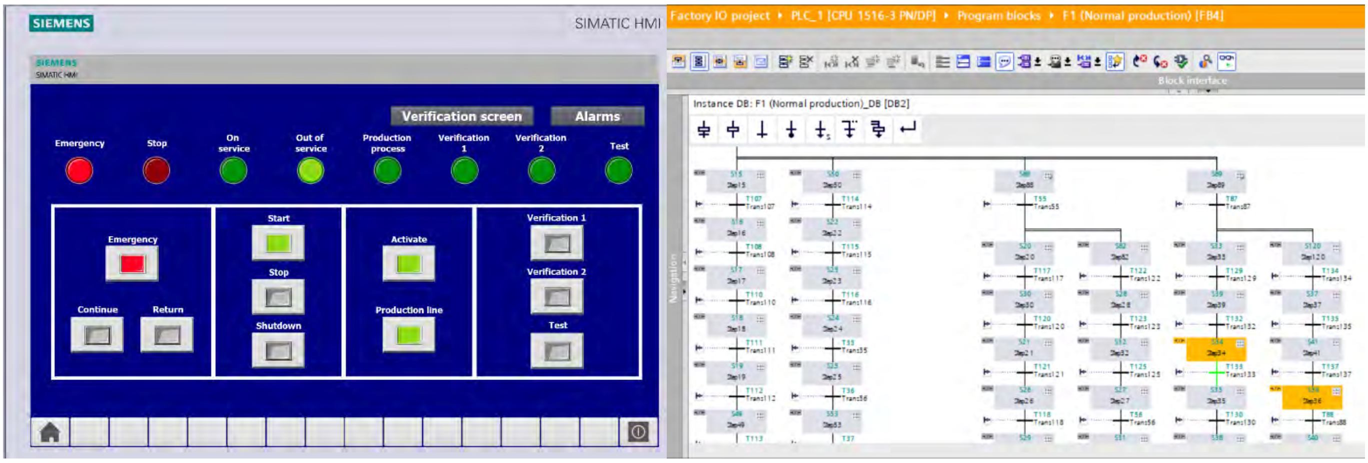


(c)

Figure 6.290: The program is placed at the normal production mode (F1) of GEMMA, while the third base and lid are produced. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

Figure 6.291: The alarm screen while there is no failure

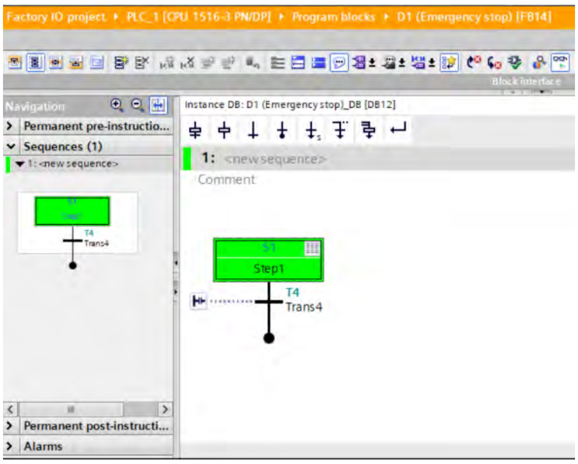
At the moment that the operator notices some problem which may lead to either danger or damage to the production line, he is able to press the emergency button in order to stop immediately the production. The figure below shows the operation screen and program while the emergency button has been pressed. It is possible to notice that the color of the activated steps has changed from green to orange which means that the steps are frozen, and everything has stopped.



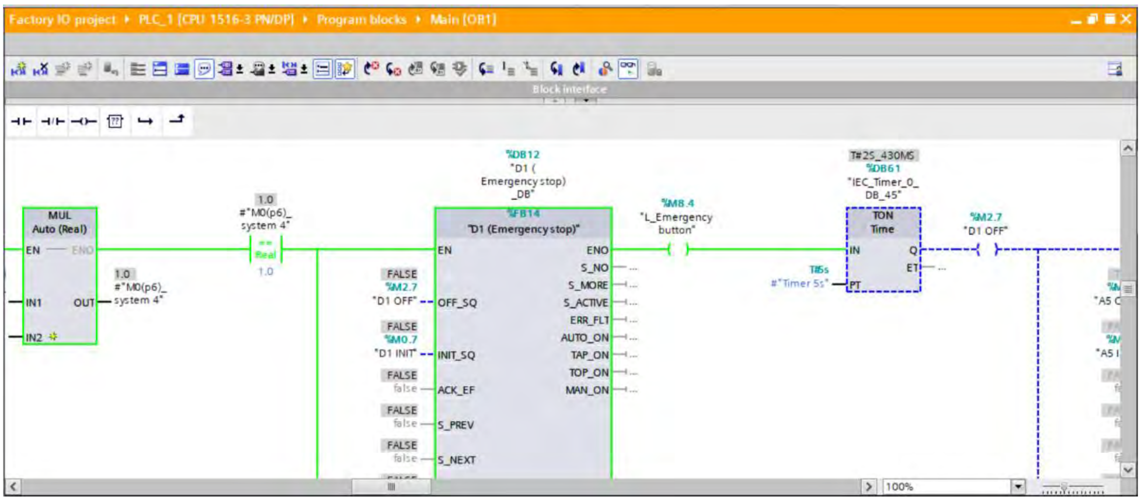
(a) (b)

Figure 6.292: The normal production mode (F1) of GEMMA is frozen, while the emergency button is pressed. (a) the screen, (b) the program

At this moment, the intelligent algorithm places the program at the emergency stop mode (D1) as it is shown in figure 6.293. This temporary mode put the production line in a safe mode and memorizes the state of the previous mode as it is explained in the Subsection 3.3.1. Next, the intelligent algorithm will place the program at the preparation for startup after a failure (A5) in order to detect the failure and presents it on the alarms screen. The alarms screen shows the failure including its details, at this situation ”The emergency button is on”. Figure 6.294 describes the alarms screen at this moment, program and Fuzzy Petri Nets intelligent algorithm.

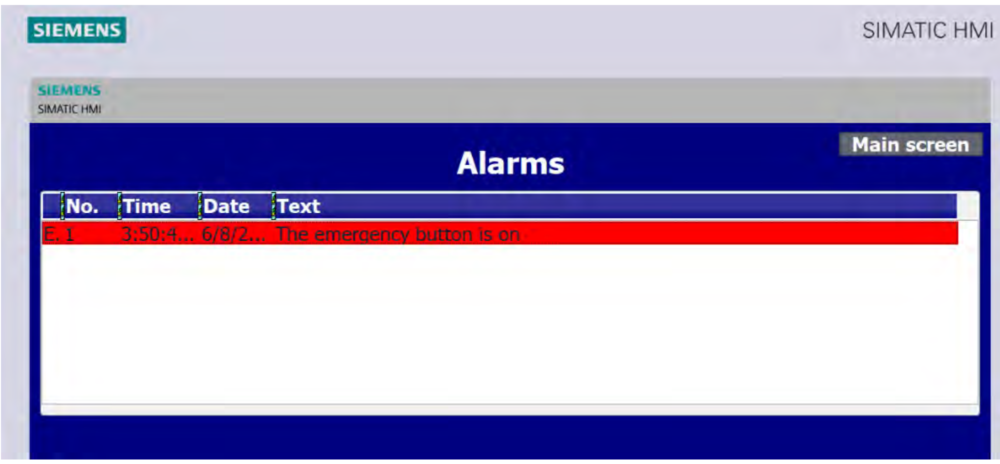


(a)

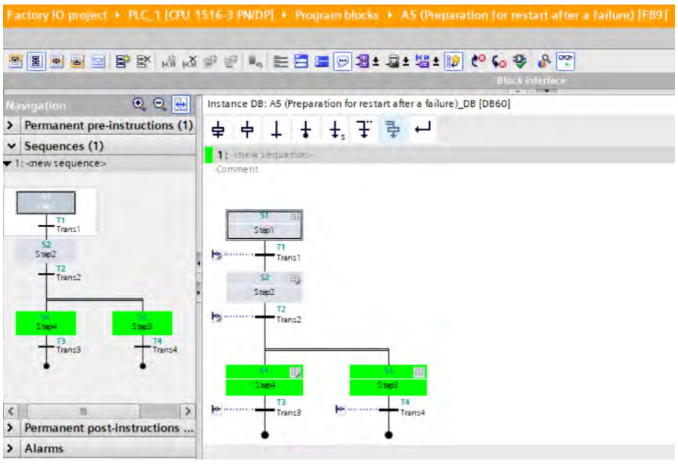


(b)

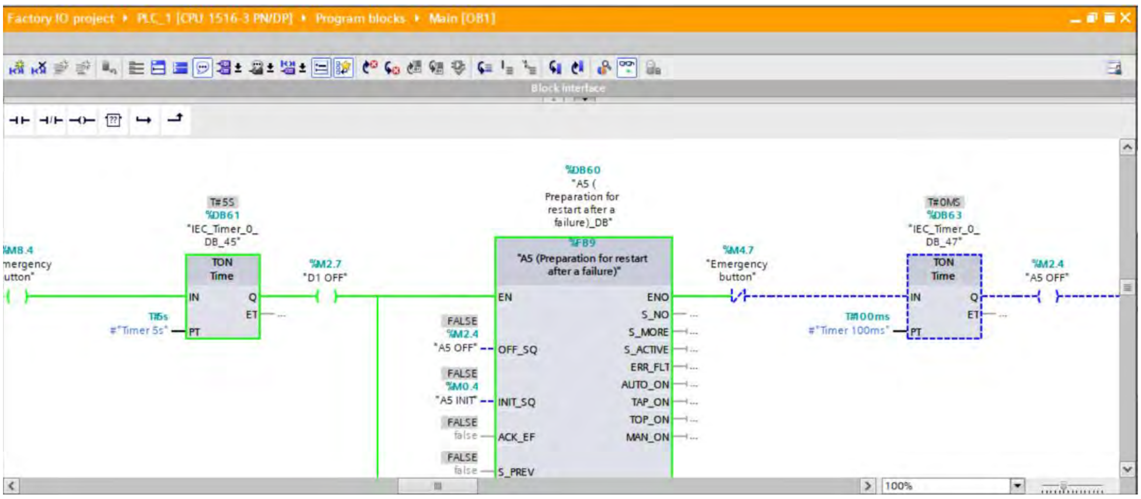
Figure 6.293: The program is placed at the emergency stop mode (D1) of GEMMA. (a) the screen, (b) the Fuzzy Petri Nets intelligent algorithm



(a)



(b)

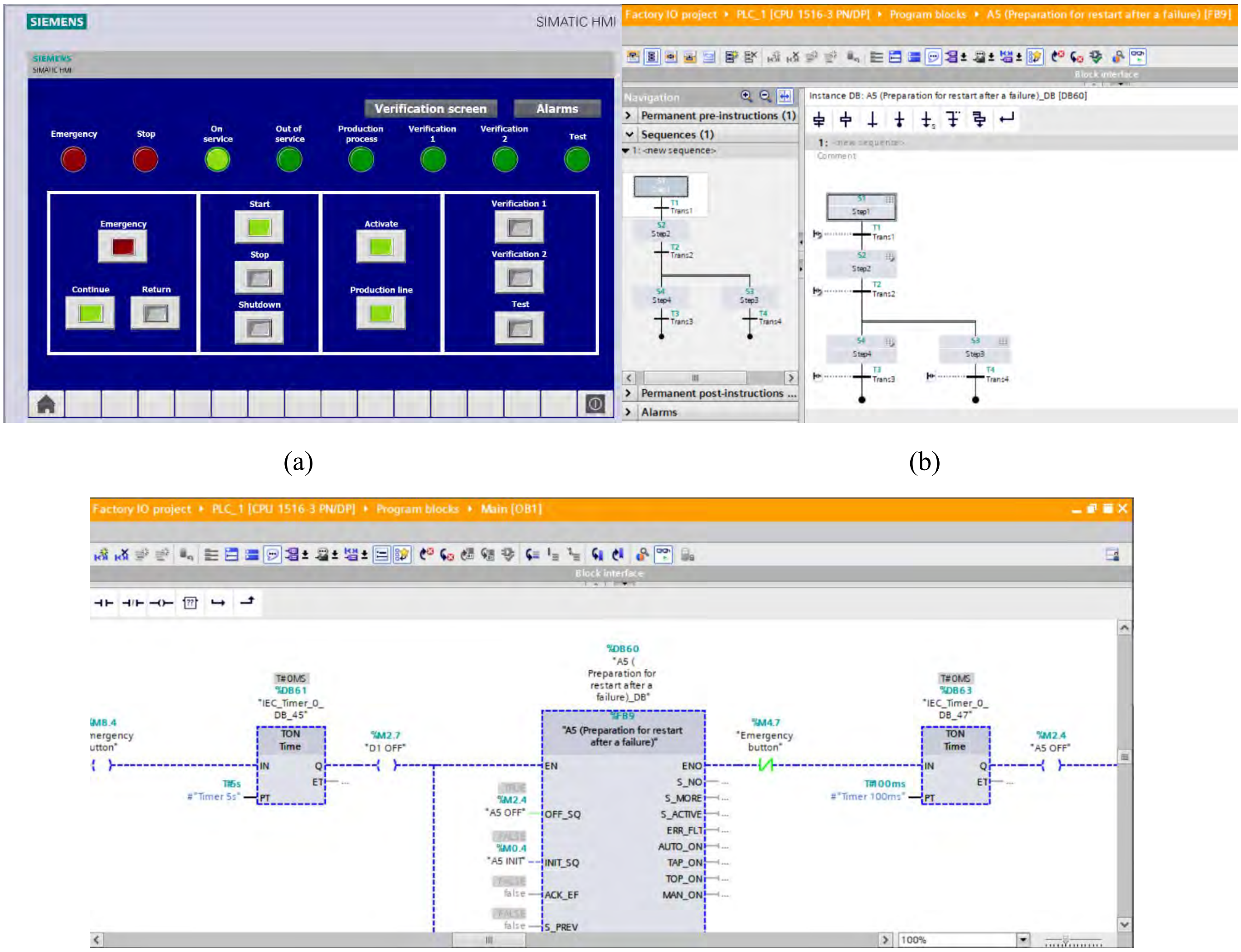


(c)

Figure 6.294: The program is placed at preparation for startup after a failure mode (A5) of GEMMA. (a) alarm screen including the failure presentation, (b) program, (c) the Fuzzy Petri Nets intelligent algorithm

As soon as the failure has fixed, the operator is able to choose whether to continue the production in the same moment that it was stopped or to restart the production line and the program to the initial stop state (A1). The first option that is presented is the choice of continuing the production.

In this case, the operator desires to continue the production at the same point that it was stopped when the failure occurred. The operator is able to do that by pressing the continue button. At the moment that the button has pressed, the intelligent algorithm switches off the preparation for startup after a failure (A5) as it is presented in the figure below. The figure presents the operation screen, program and Fuzzy Petri Nets intelligent algorithm at this moment.

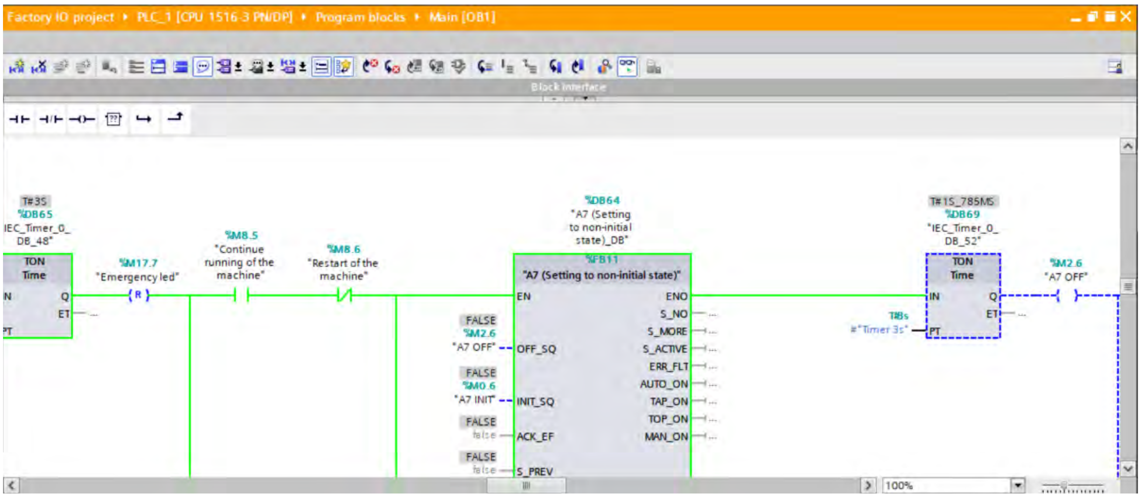


(a) (b)

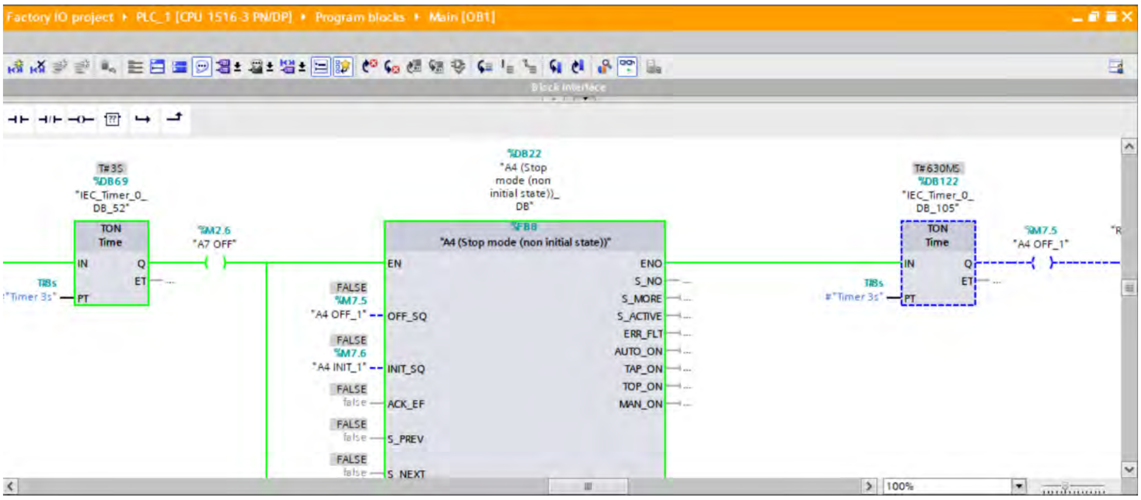
(c)

Figure 6.295: The preparation for startup after a failure mode (A5) of GEMMA is off, while the continue button has pressed. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

At this moment, the intelligent algorithm places the program at the setting to non-initial state (A7) in order to prepare the program for the exact point of the production. As soon as the program is ready, the intelligent algorithm places the program at the stop mode (non-initial state) (A4) in order to be ready to continue the production. Figure 6.296 shows the Fuzzy Petri Nets intelligent algorithm while the program is placed at A7 and A4.



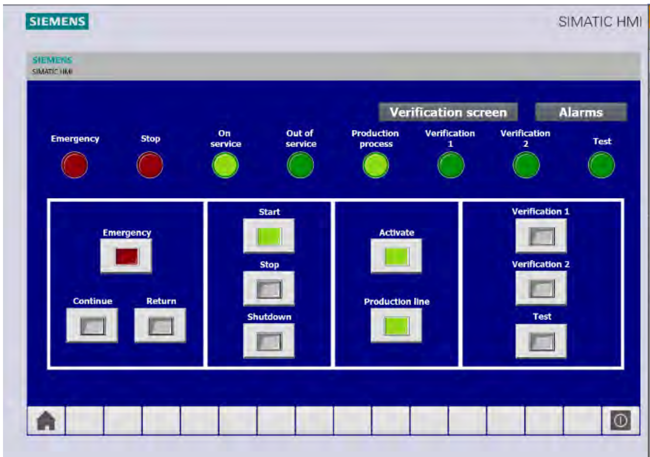
(a)



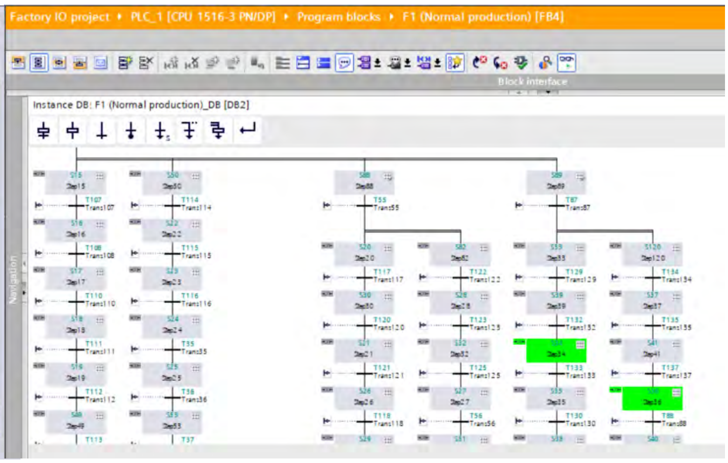
(b)

Figure 6.296: The preparation for startup after a failure mode, the Fuzzy Petri Nets intelligent algorithm. (a) setting to noninitial state (A7), (b) stop mode (non-initial state) (A4)

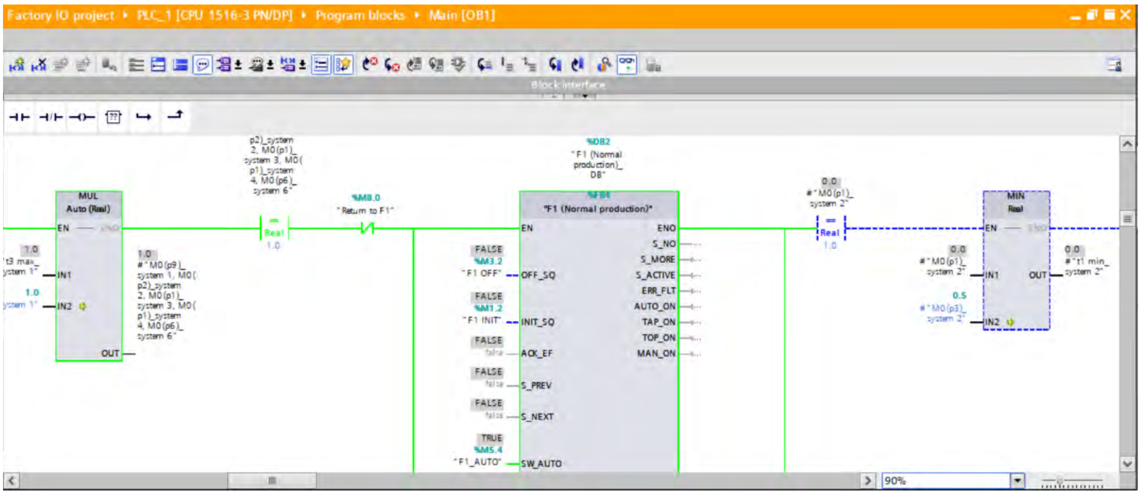
Afterwards, the intelligent algorithm places the machine at the normal production mode (F1) at the exact point of the production that it was when the failure occurred. In the figure below, it is possible to see that the program continues at the same point of the production that it was when it was stopped, and the production line continues to produce the third base and lid.



(a)



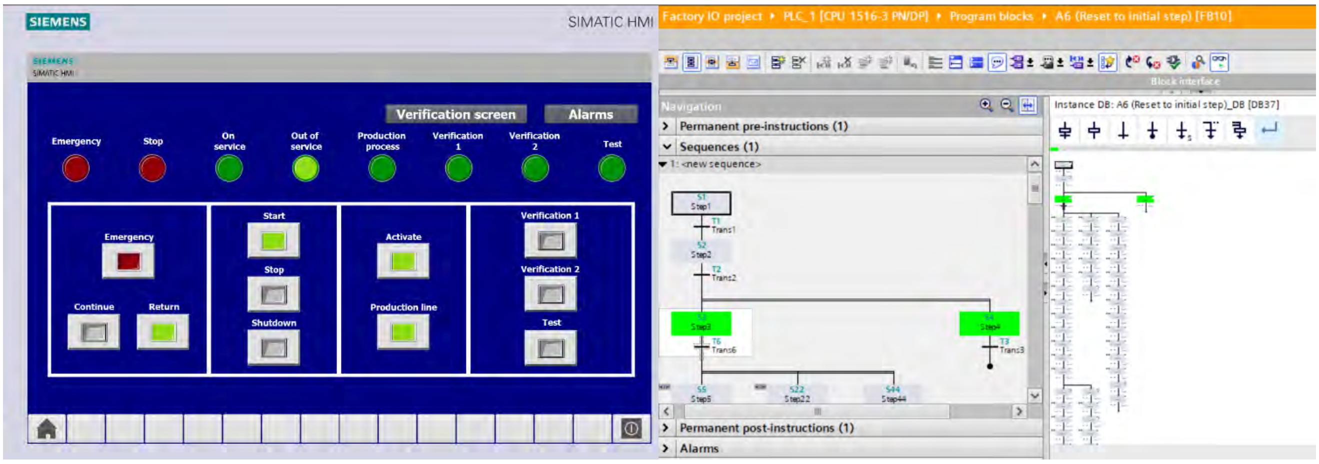
(b)



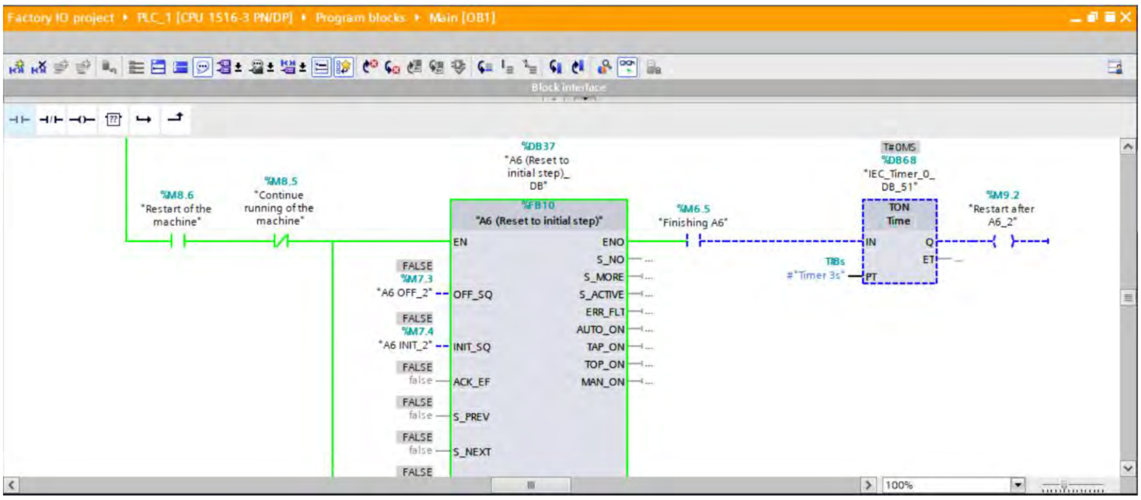
(c)

Figure 6.297: The production line is placed at the normal production mode (F1) of GEMMA, while the third base and lid are produced. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

The second option allows the operator to restart the production line and start over the machine. The operator is able to do it by pressing the return button. At that moment, the intelligent algorithm switches off the preparation for startup after a failure (A5) and places the program at the reset to initial state (A6). At this mode, the program detects the production line situation and reset it for the next production. Figure 6.298 shows the operation screen, program and Fuzzy Petri Nets in the moment that the return button has pressed.



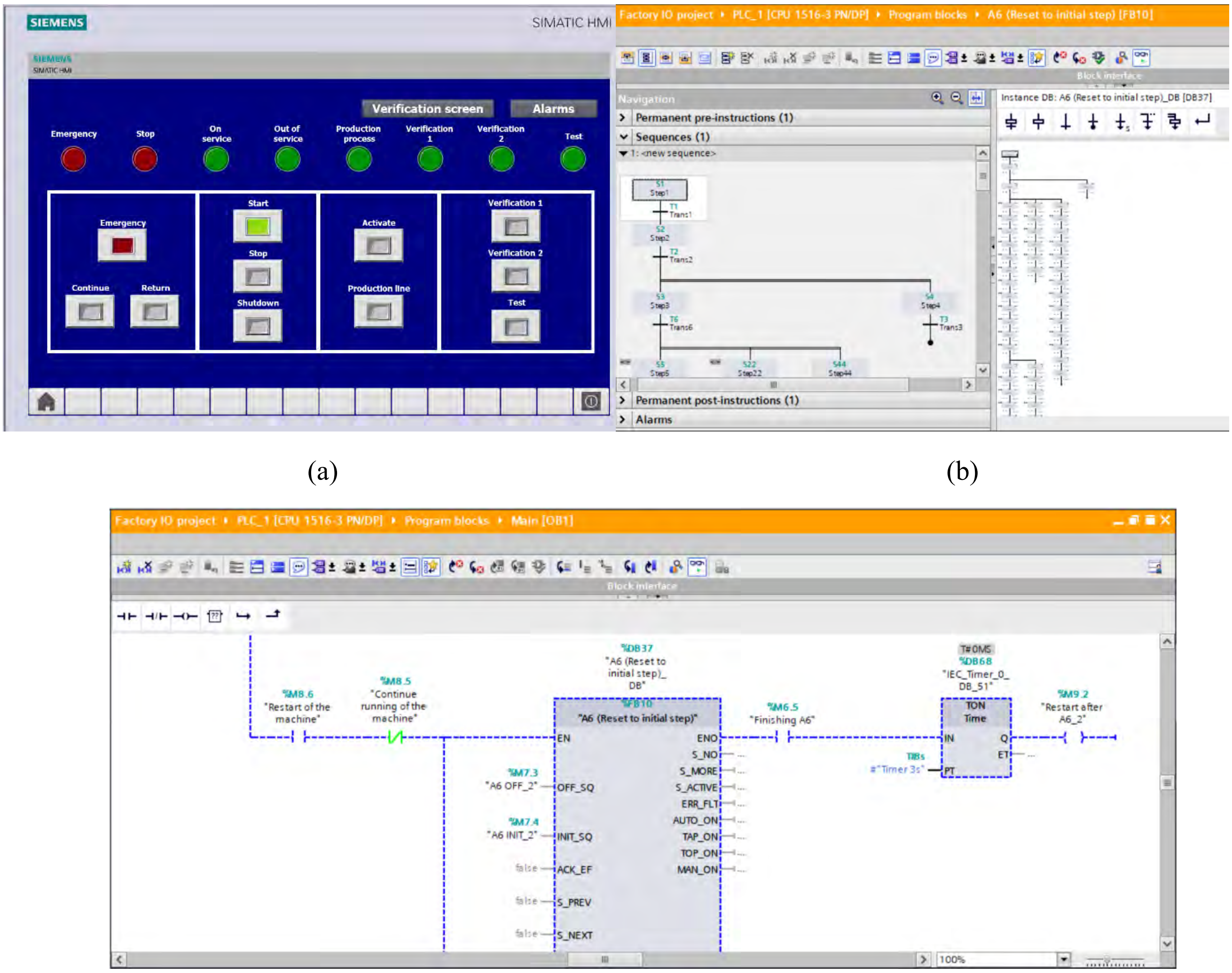
(a) (b)



(c)

Figure 6.298: The program is placed at reset to initial state mode (A6) of GEMMA, while the return button is pressed. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

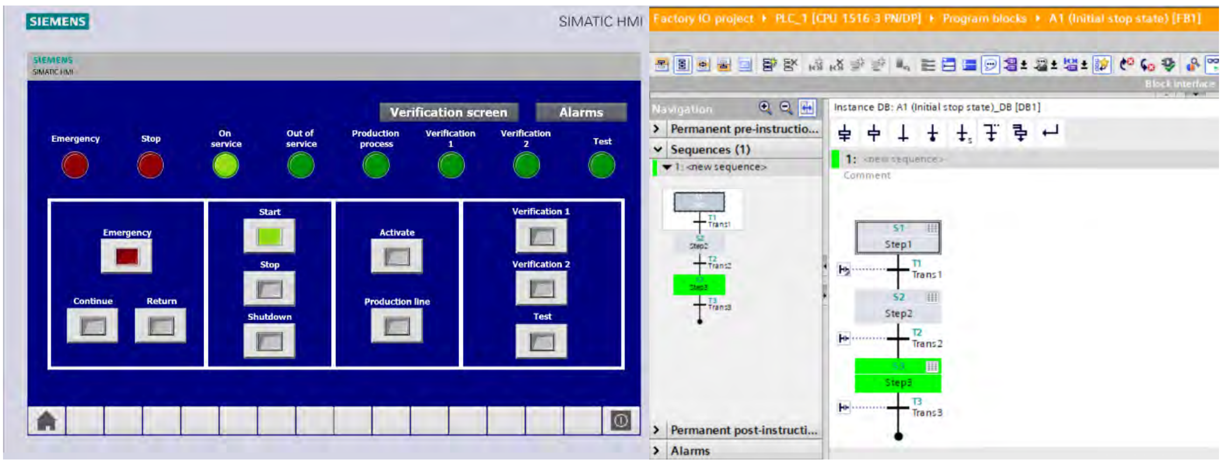
As soon as the reset process finishes, the intelligent algorithm switches off the reset to initial state (A6) (figure 6.299) and places the program at the initial stop state (A1) (figure 6.300). At this situation, the production line is ready for the next required production, and the program is prepared for the next request of the operator.



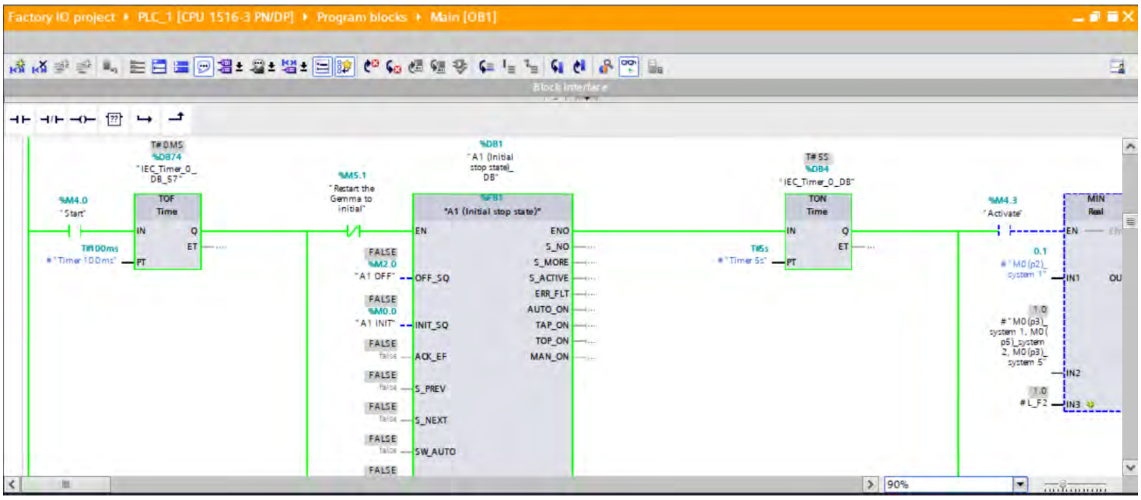
(a) (b)

(c)

Figure 6.299: The reset to initial state mode (A6) of GEMMA is off, while the reset process has finished. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm



(a) (b)

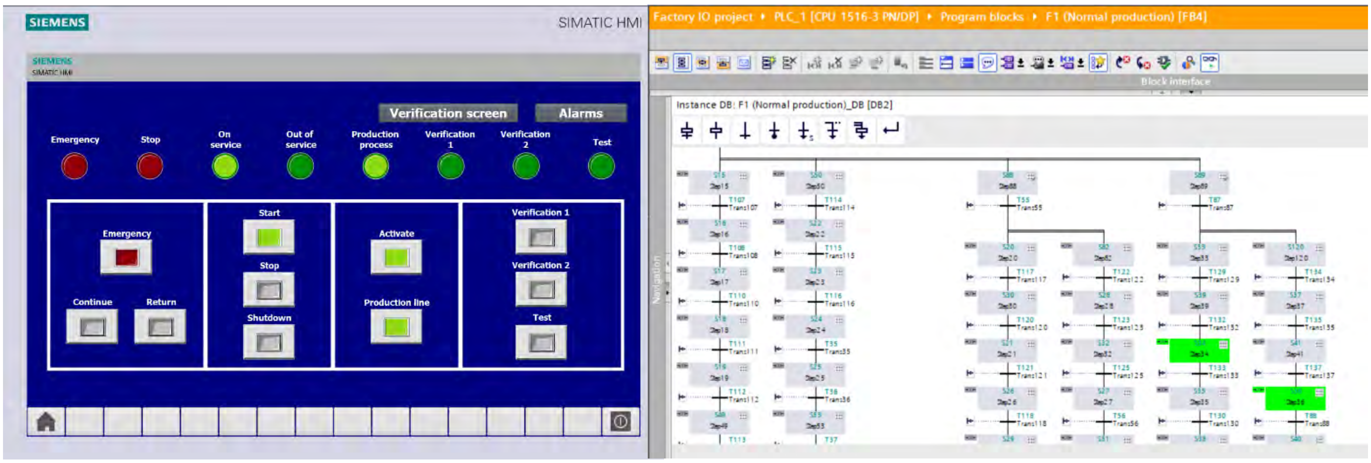


(c)

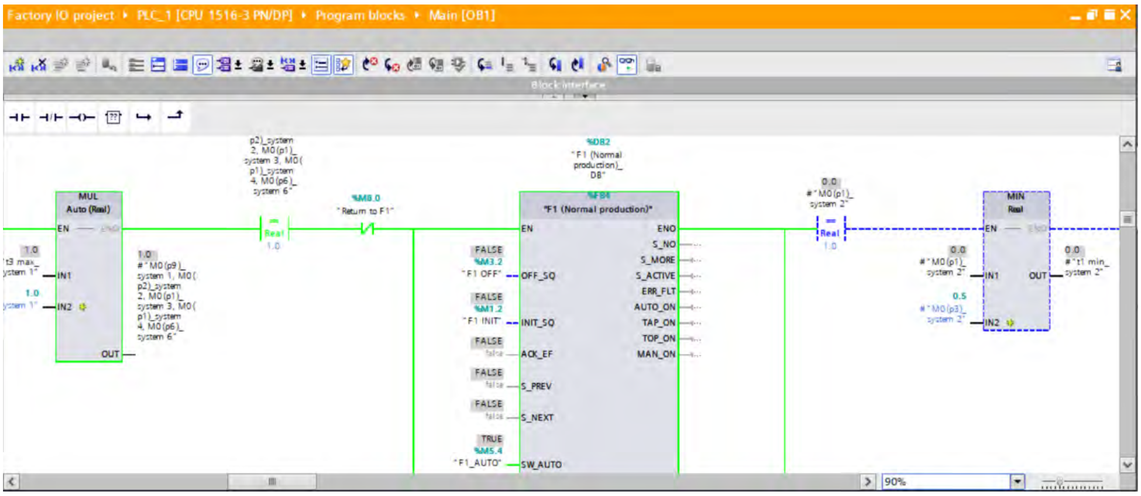
Figure 6.300: The program is placed at the initial stop state (A1) of GEMMA. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

The second type of transitions between the operation procedure and failure procedure is automatically. That is to say, at the moment that some failure is occurred, the algorithm stops the production line immediately and places the program at the appropriate mode according to the level of the failure.

The first failure level that it is presented is the critical failure. In the figure below, it is possible to see the operation screen, program and Fuzzy Petri Nets intelligent algorithm while the third lid and base are produced, and there is no failure in the production line.



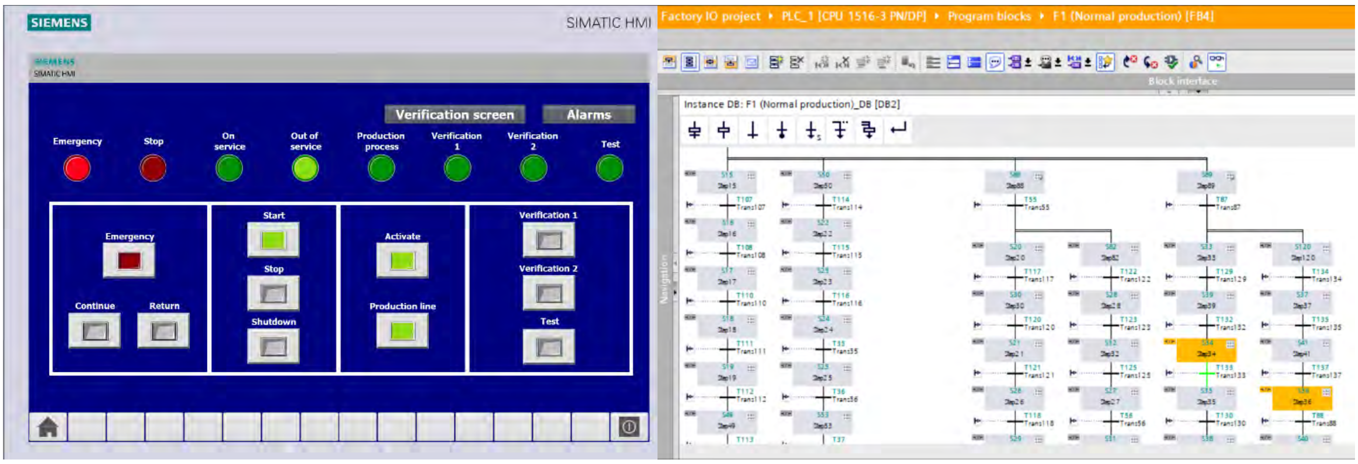
(a) (b)



(c)

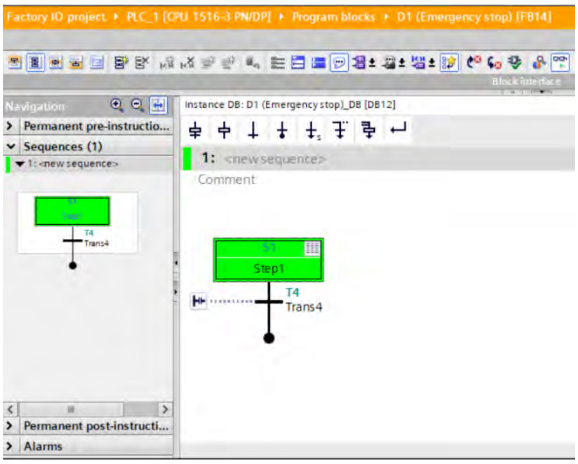
Figure 6.301: The program is placed at the normal production mode (F1) of GEMMA, while the third base and lid are produced. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

At the moment that a critical failure occurs, the intelligent algorithm stops the production line, and freezes the normal production mode (the color of the activated steps has changed from green to orange) as it is presented in figure 6.302. At the same moment, the program is placed at the emergency stop mode (D1) on order to be at the safe mode and memorize the production point. Figure 6.303 shows the program and Fuzzy Petri Nets intelligent algorithm while it is placed at D1.

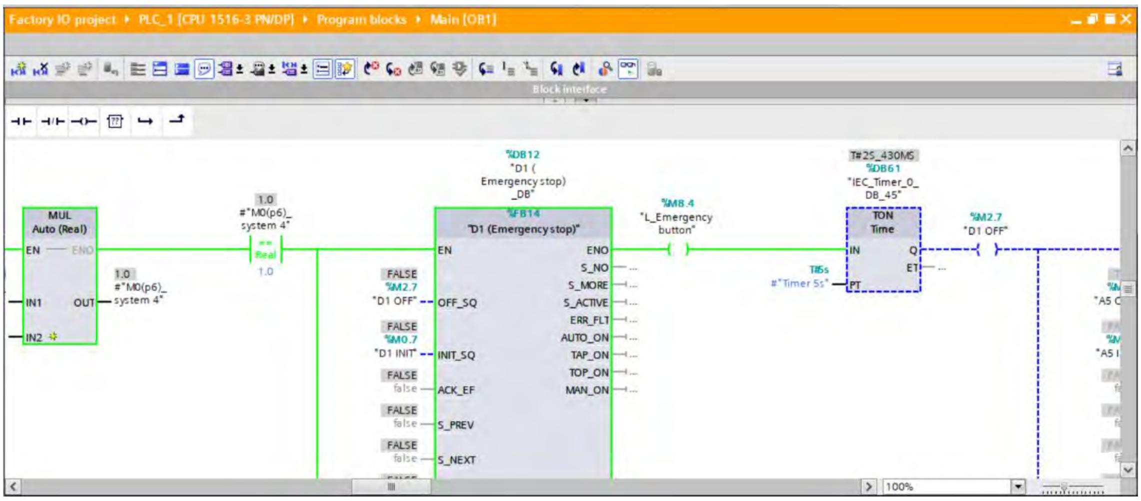


(a) (b)

Figure 6.302: The normal production mode (F1) of GEMMA is frozen while a critical failure is detected. (a) the screen, (b) the program



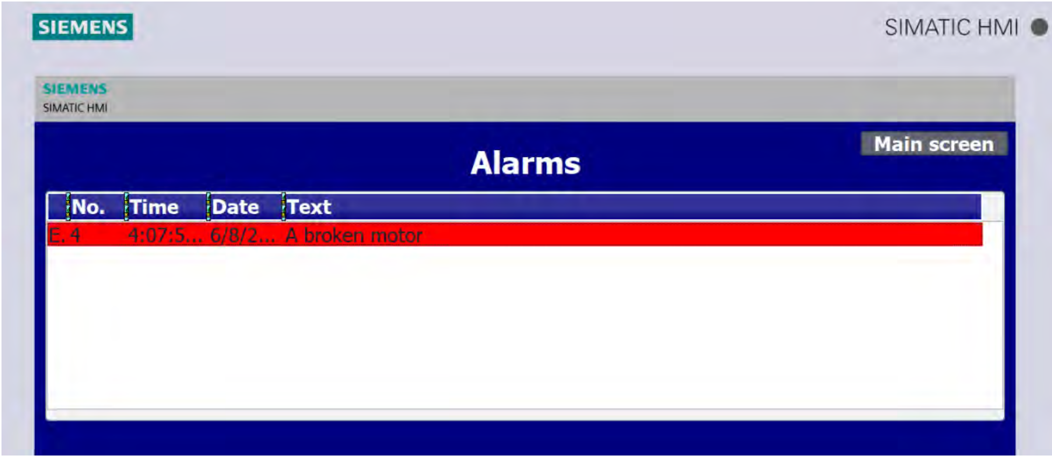
(a)



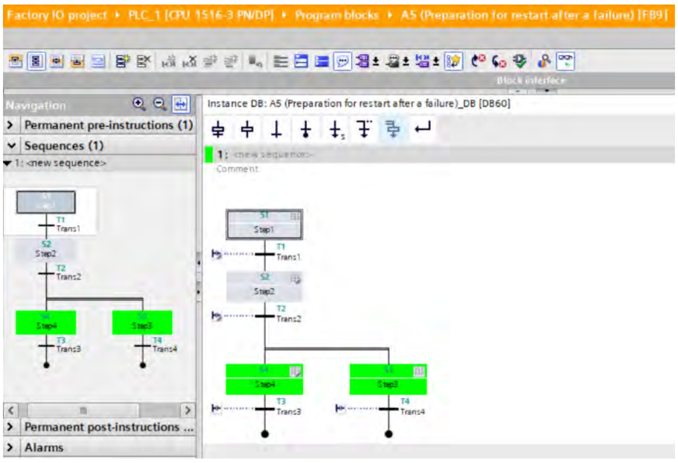
(b)

Figure 6.303: The program is placed at the emergency stop mode (D1) of GEMMA. (a) the screen, (b) the Fuzzy Petri Nets intelligent algorithm

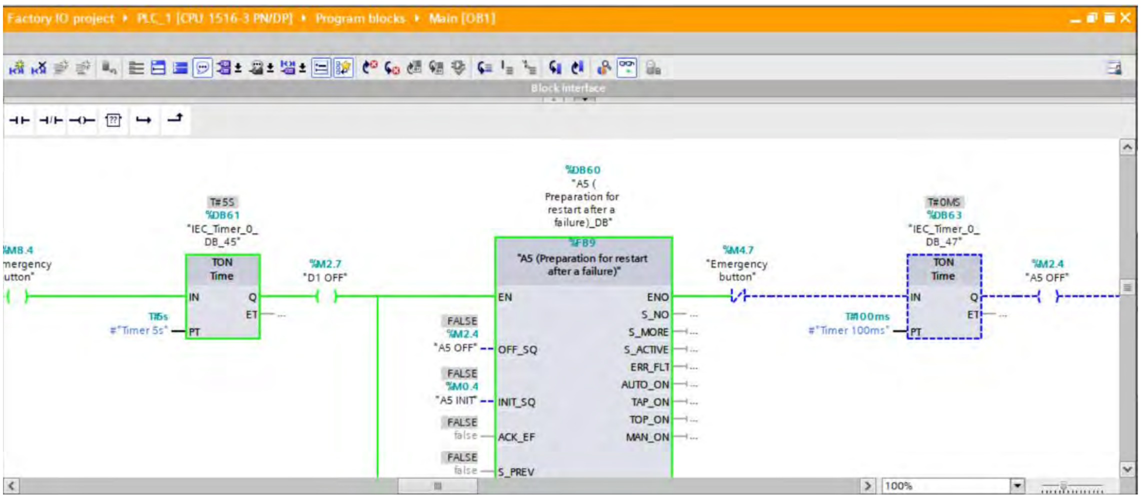
At the next step, the program is placed at the preparation for startup after a failure (A5) in order to detect the failure and present it in the alarms screen. Figure 6.304 shows the alarms screen, program and Fuzzy Petri Nets intelligent algorithm at this moment. It is possible to see the failure that has been detected on the screen, in this case ”A broken motor”. Moreover, the screen presents the details of the failure.



(a)



(b)

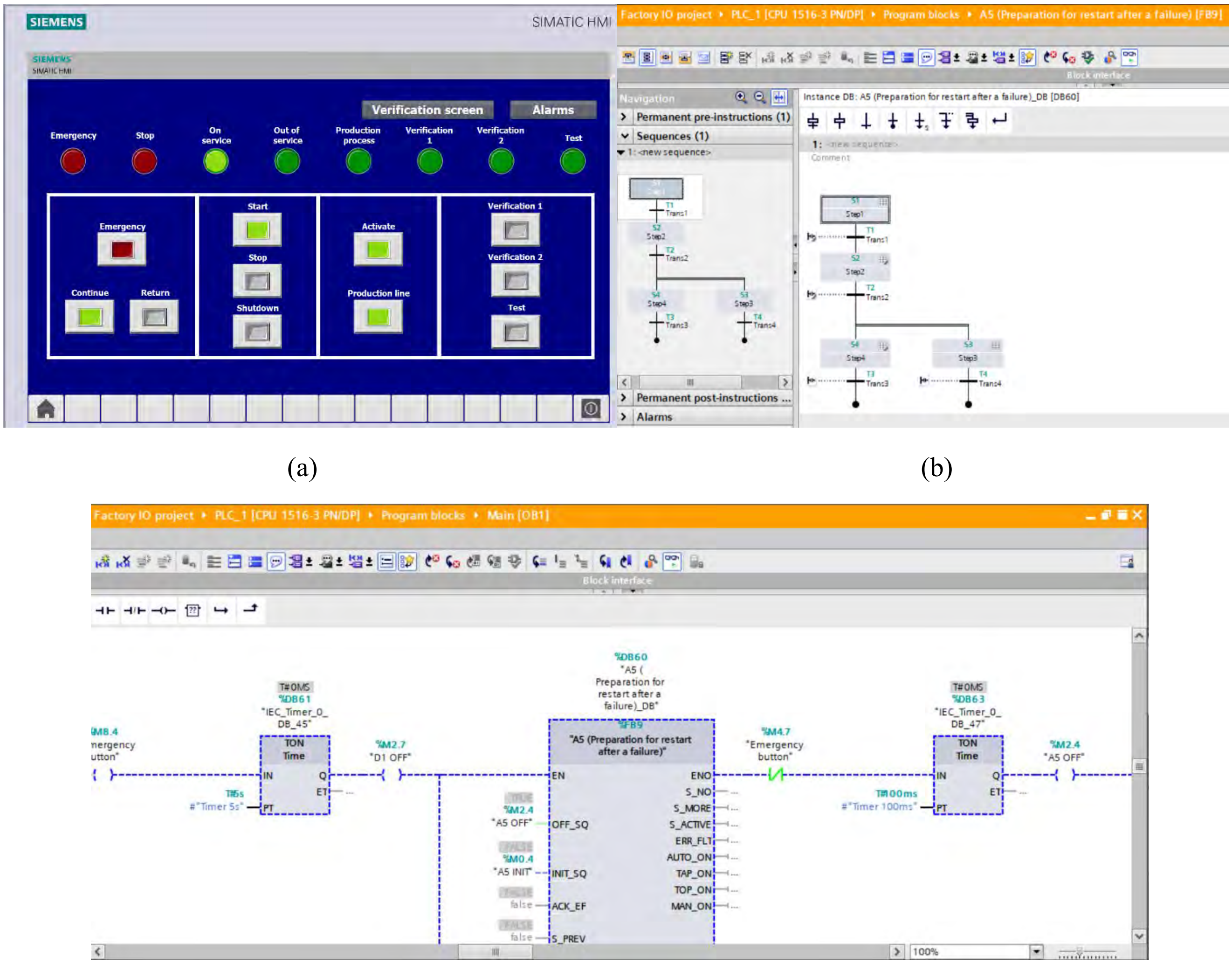


(c)

Figure 6.304: The program is placed at preparation for startup after a failure mode (A5) of GEMMA. (a) alarm screen including the failure presentation, (b) program, (c) the Fuzzy Petri Nets intelligent algorithm

As soon as the failure has fixed, the operator is able to choose the next step, similarly to the first type of the production to failure transitions. The operator is able whether continue the production at the same point that it was stopped or reset the production line and start over the program.

The first case that it is shown presents the situation that the operator desires to continue the production at the same point that it stopped when the failure occurred. The operator is able to do it by pressing the continue button. The figure below shows the operation screen, program and Fuzzy Petri Nets intelligent algorithm at the moment that the operator has pressed the continue button. It is possible to notice that at this moment the preparation for startup after a failure mode (A5) has switched off.

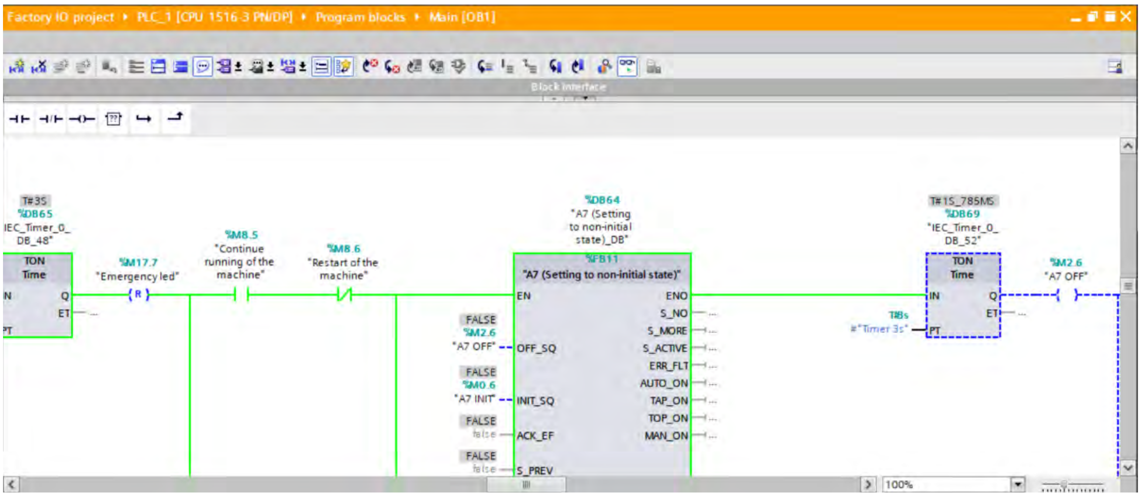


(a) (b)

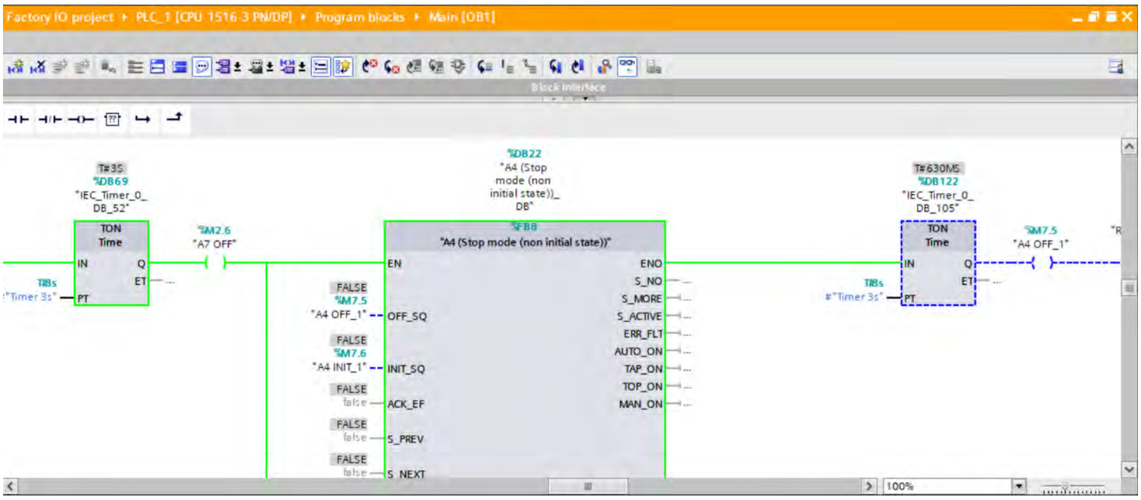
(c)

Figure 6.305: The preparation for startup after a failure mode (A5) of GEMMA is off, while the continue button has pressed. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

At the same moment, the intelligent algorithm places the program at the setting to non-initial state (A7) in order to prepare the program to continue the operation in the correct point of the production. When the program is ready, it is placed at the stop mode (non-initial state) (A4) in order to continue the production. Figure 6.306 presents the Fuzzy Petri Nets intelligent algorithm of these steps.



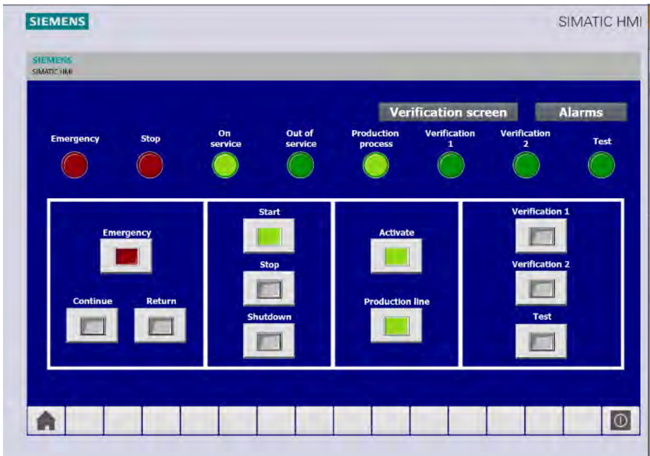
(a)



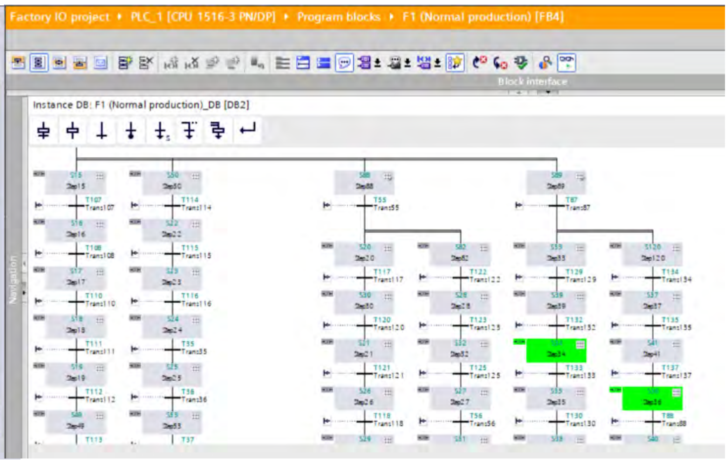
(b)

Figure 6.306: The preparation for startup after a failure mode, the Fuzzy Petri Nets intelligent algorithm. (a) setting to noninitial state (A7), (b) stop mode (non-initial state) (A4)

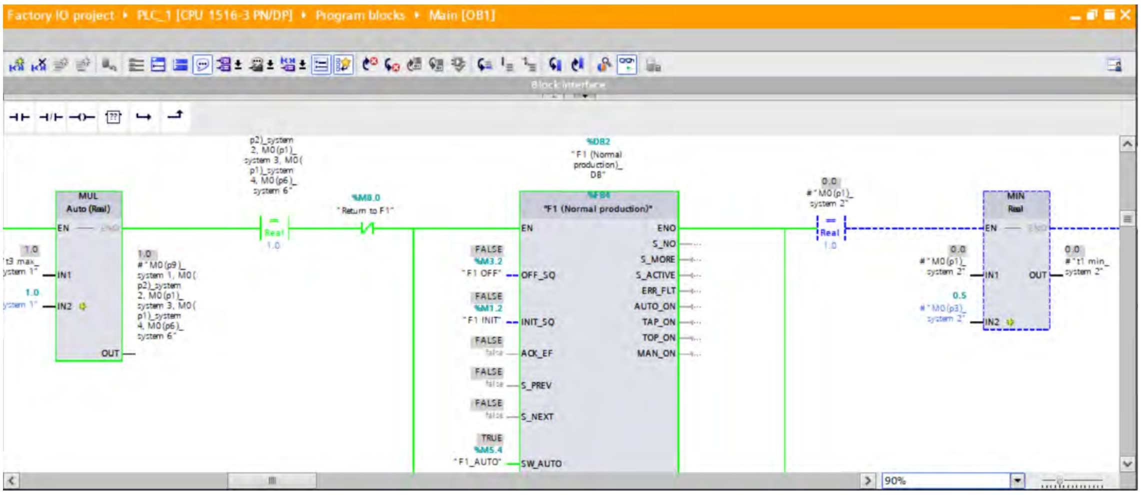
At the next step, the intelligent algorithm places the program at the normal production mode (F1) at the exact point of the production that it was when it stopped. The figure below shows the operation screen, program and Fuzzy Petri Nets at this situation. It is possible to see that the production line continues to produce the third base and lid.



(a)



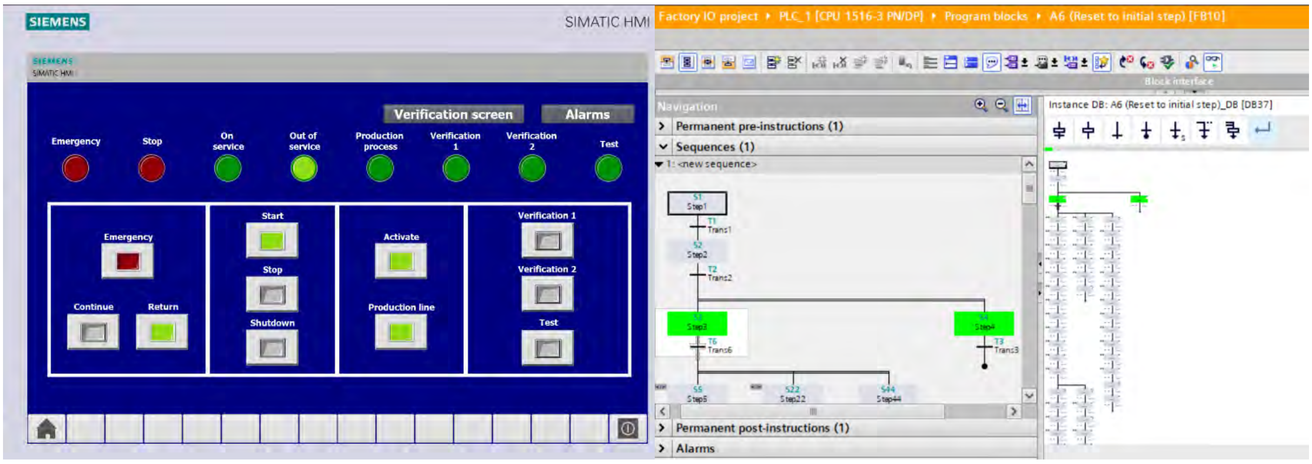
(b)



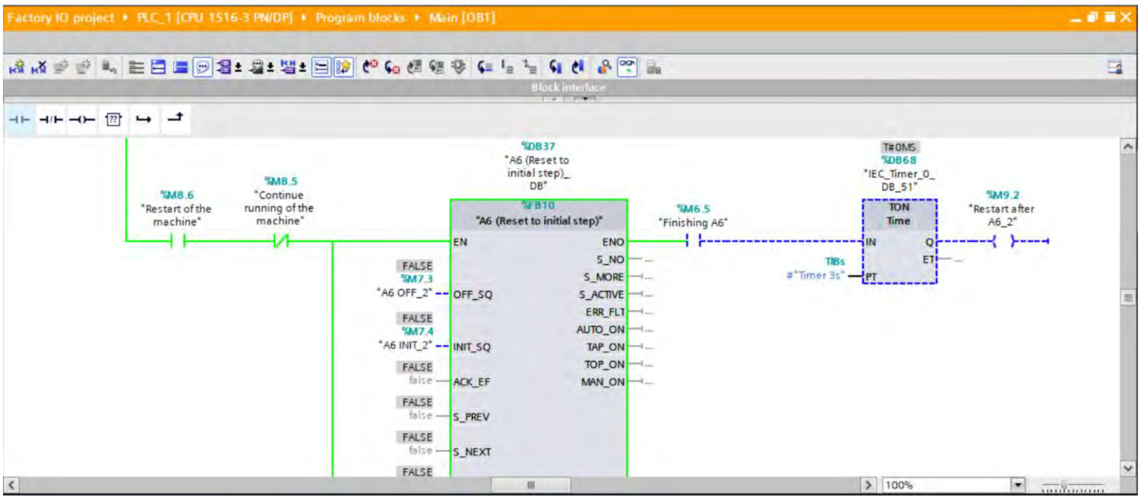
(c)

Figure 6.307: The program is placed at the normal production mode (F1) of GEMMA, while the third base and lid are produced. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

At the situation that the operator desires to reset the production line after the failure has fixed, he is able to do it by pressing the return button. At that moment, the intelligent algorithm switches off the preparation for startup after a failure mode (A5) and places the program at the reset to initial state mode (A6). At this mode, the program prepares the production line for the next desired production. Figure 6.308 shows the operation screen, program and Fuzzy Petri Nets intelligent algorithm at this situation.



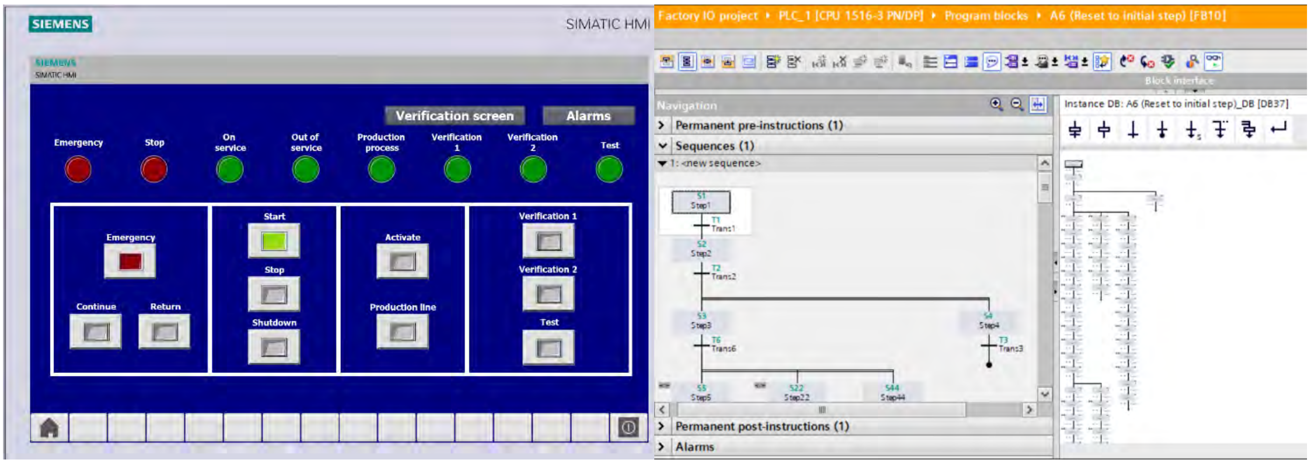
(a) (b)



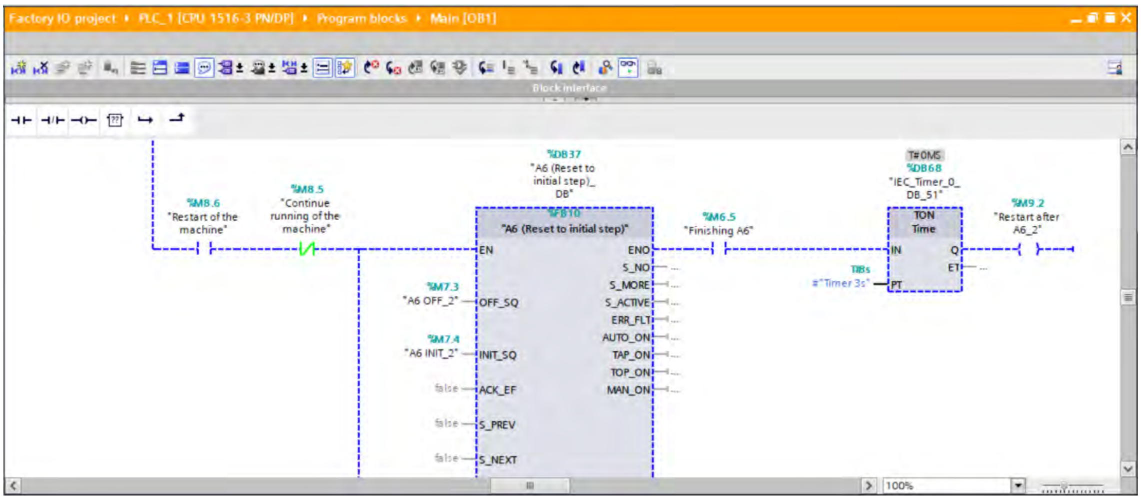
(c)

Figure 6.308: The program is placed at reset to initial state mode (A6) of GEMMA, while the return button has pressed. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

As soon as the reset process finishes, the intelligent algorithm switches off the reset to initial state mode (A6) as it is shown in figure 6.309. At the same moment, it places the program at the initial stop state (A1) as it is presented in figure 6.310. This means that both the production line and program are ready for the next desired action.

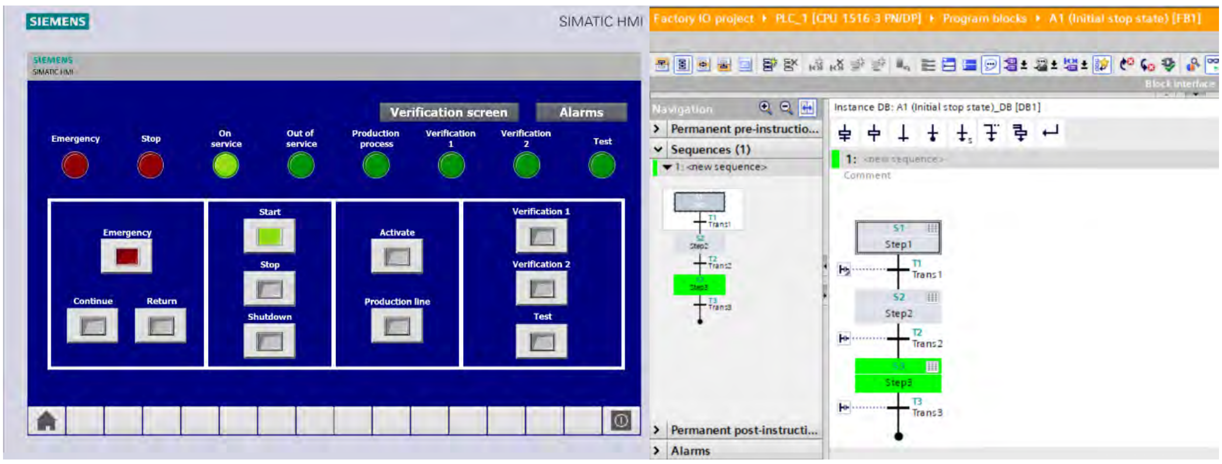


(a) (b)

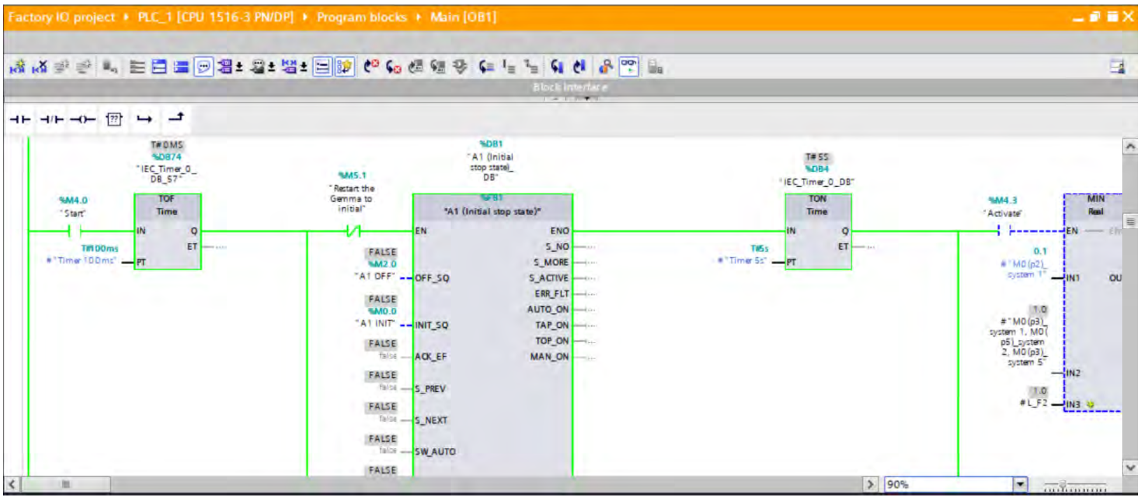


(c)

Figure 6.309: The reset to initial state mode (A6) of GEMMA is off, while the reset process has been finished. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm



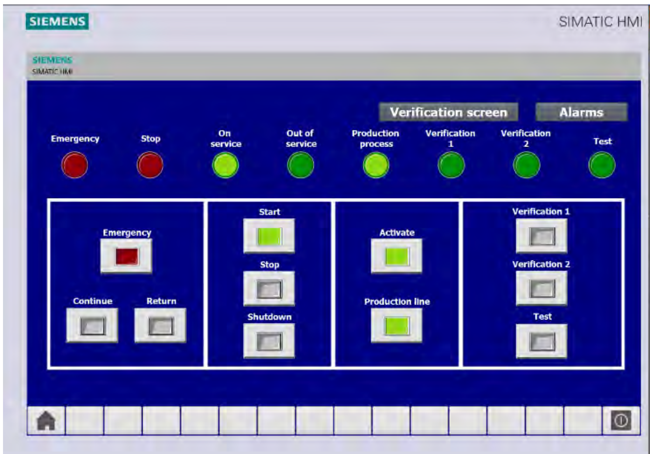
(a) (b)



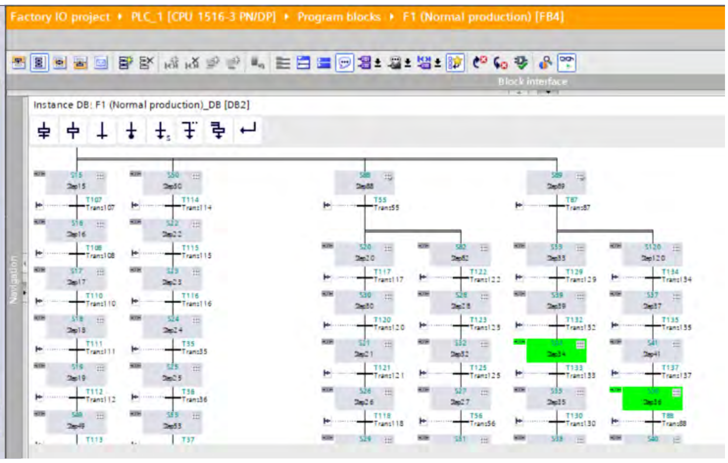
(c)

Figure 6.310: The program is placed at the initial stop state (A1) of GEMMA. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

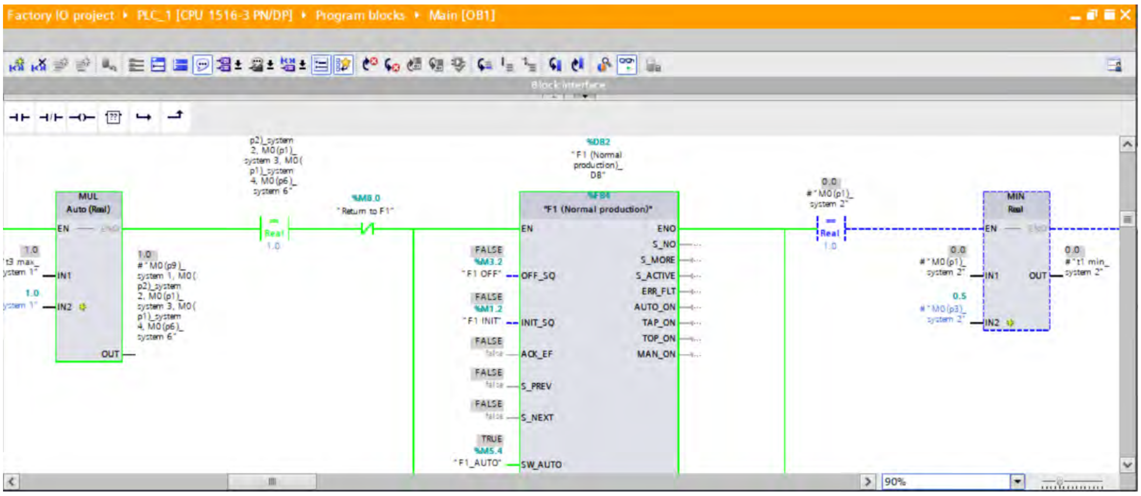
The second failure level is the medium critical failure. When this failure level occurs, the intelligent algorithm stops the production line immediately and places the program at the diagnosis and/or treatment of the failure (D2) in order to make a diagnosis of the failure and help the maintenance worker to fix it. In the figure below, it is possible to see the operation screen, program and Fuzzy Petri Nets intelligent algorithm while the program is placed at the normal production mode (F1), the third base and lid are produced and there is no failure.



(a)



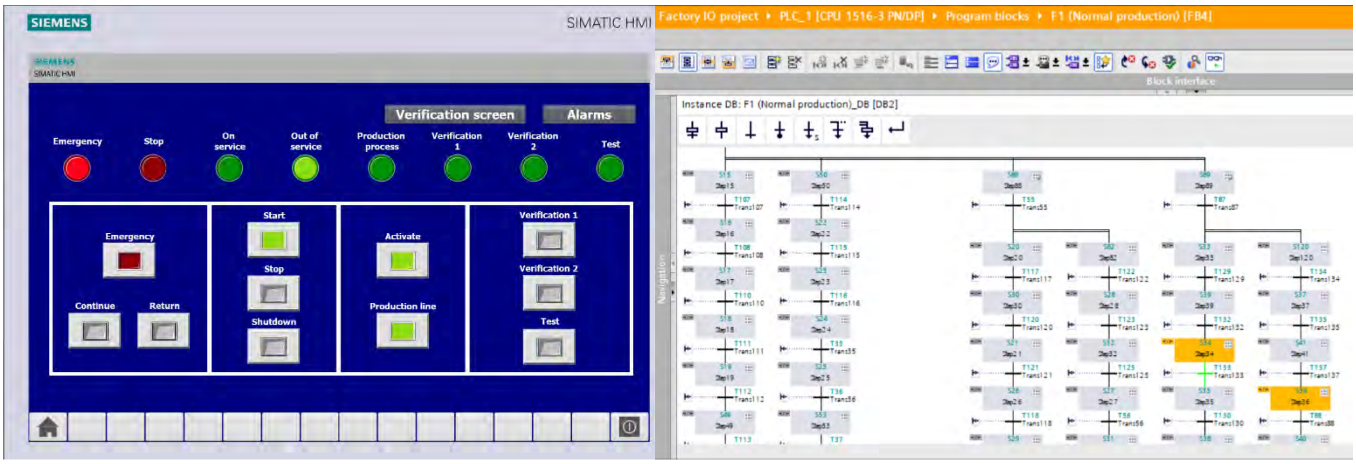
(b)



(c)

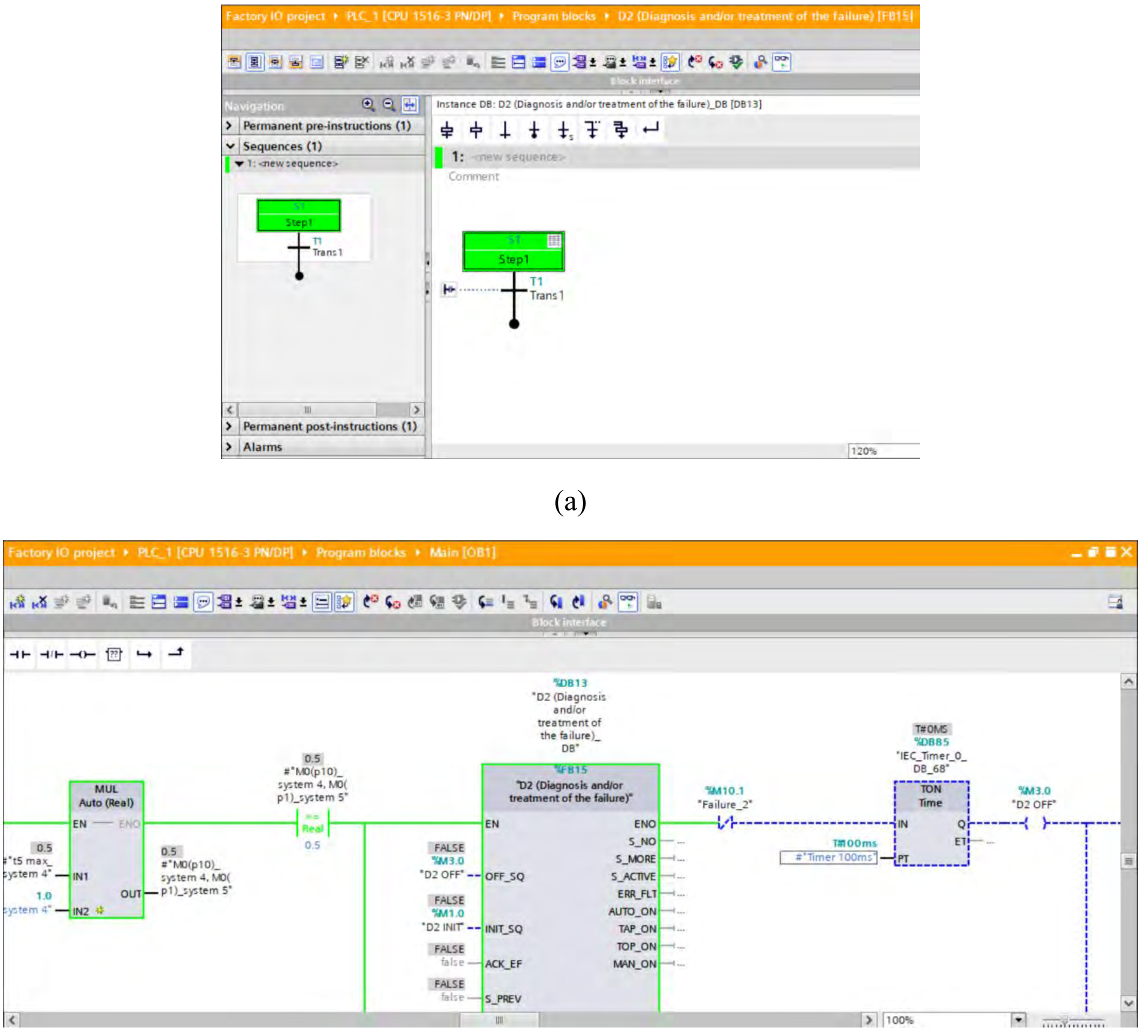
Figure 6.311: The program is placed at the normal production mode (F1) of GEMMA, while the third base and lid are produced. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

At the moment that a medium failure occurs, the intelligent algorithm stops the production line immediately and freezes the normal production mode (F1) as it is shown in figure 6.312. At the same moment, the intelligent algorithm places the program at the diagnosis and/or treatment of the failure (D2) as it is presented in figure 6.313. At this mode, the program guides the operator to find the defect as it is explained in Subsection 3.3.1.



(a) (b)

Figure 6.312: The normal production mode (F1) of GEMMA is frozen while a medium critical failure has detected. (a) the screen, (b) the program

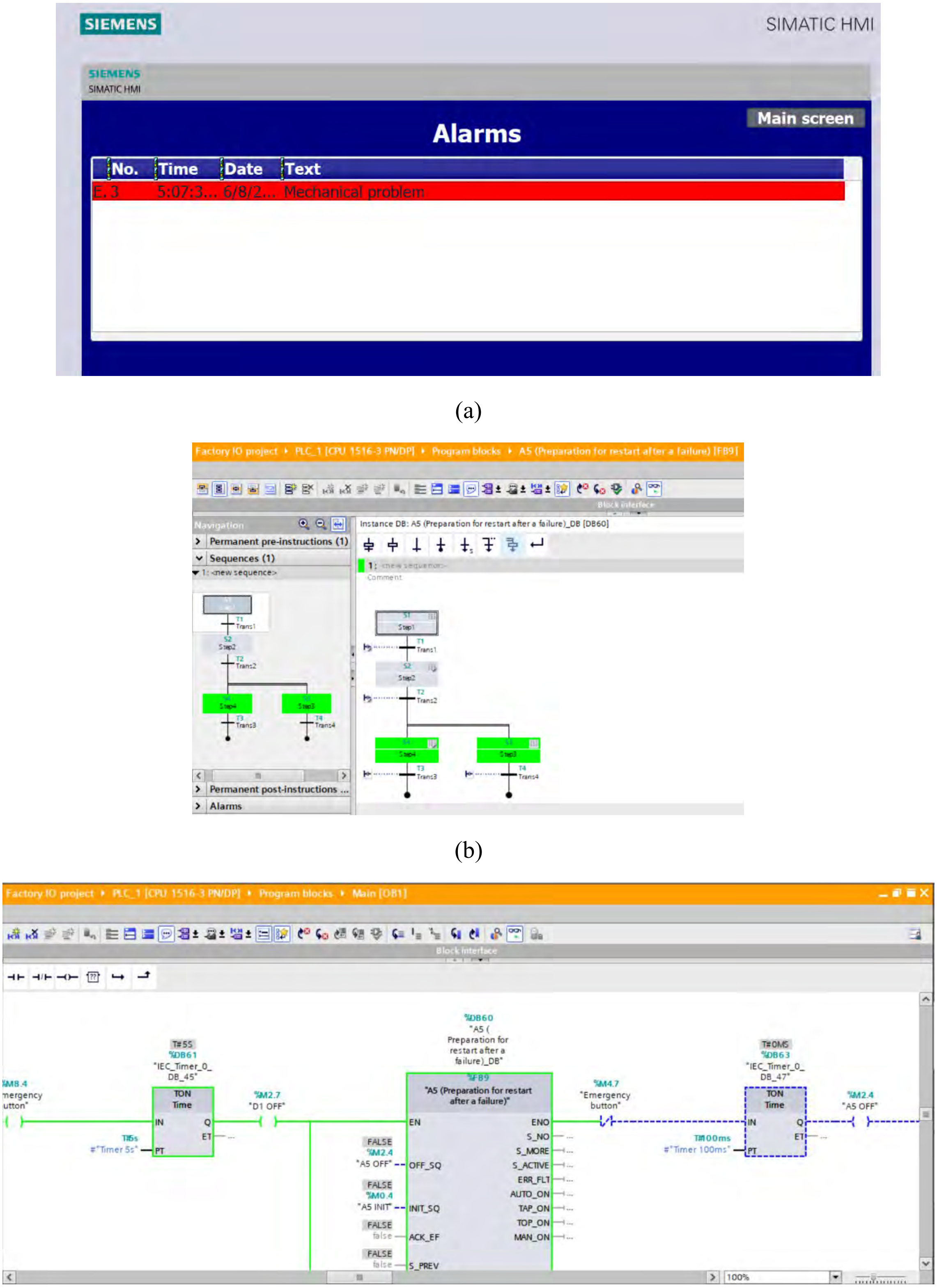


(a)

(b)

Figure 6.313: The program is placed at the diagnosis and/or treatment of the failure mode (D2) of GEMMA. (a) the screen, (b) the Fuzzy Petri Nets intelligent algorithm

As soon as the diagnosis of the failure finishes, the intelligent algorithm places the program at the preparation for startup after a failure (A5). At this mode, the program presents where the failure is in order to help the maintenance worker to take the necessary actions and fix it. The figure below shows the alarms screen including the failure presentation, program and Fuzzy Petri Nets intelligent algorithm.



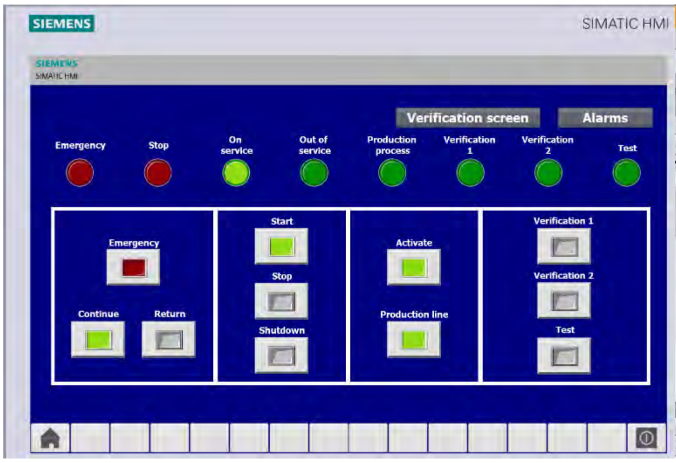
(a)

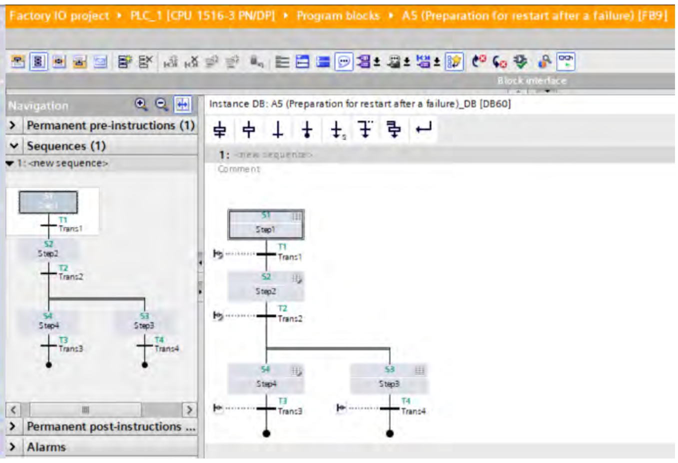
(b)

(c)

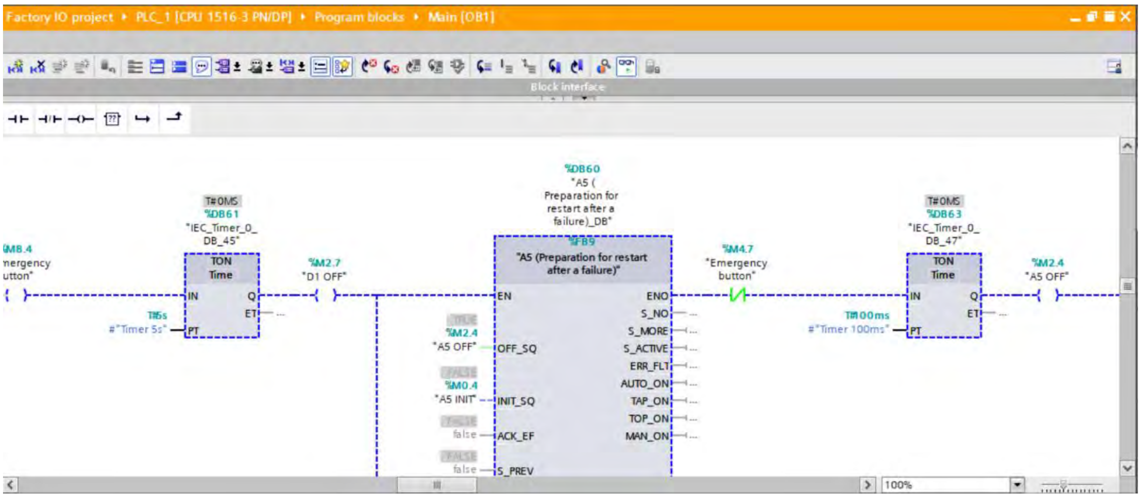
Figure 6.314: The program is placed at preparation for startup after a failure mode (A5) of GEMMA. (a) alarm screen including the failure presentation, (b) program, (c) the Fuzzy Petri Nets intelligent algorithm

After the maintenance worker has finished to fix the failure, the operator has two option for the next step similarly to the previous failure level. He is able whether continue the production or reset the production line and start over the program. In a situation that the operator desires to continue the production at the same point that it was before it stopped, he is able to do it by pressing the continue button. At this moment, the intelligent algorithm switches off the preparation for startup after a failure (A5) as it is shown in figure 6.315. Moreover, it places the program at the in the setting to non-initial state (A7) in order to set the program to the exact point of the production. As soon as the program is ready, the intelligent algorithm places the program at the stop mode (non-initial state) (A4) for allowing to continue the production. It is possible to see the transitions between A5 and A7, A7 and A4 in figure 6.316 which presents the Fuzzy Petri Nets intelligent algorithm.



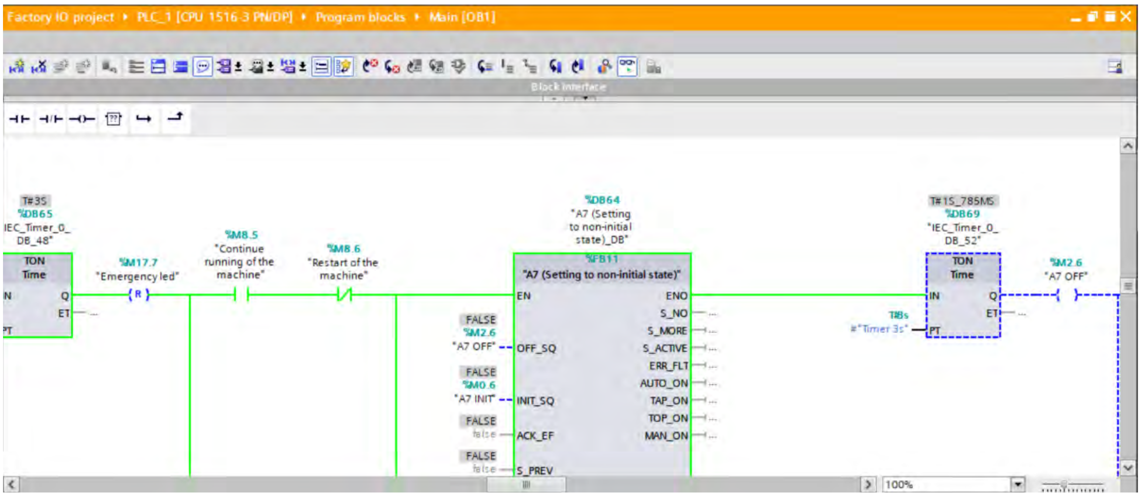


(a) (b)

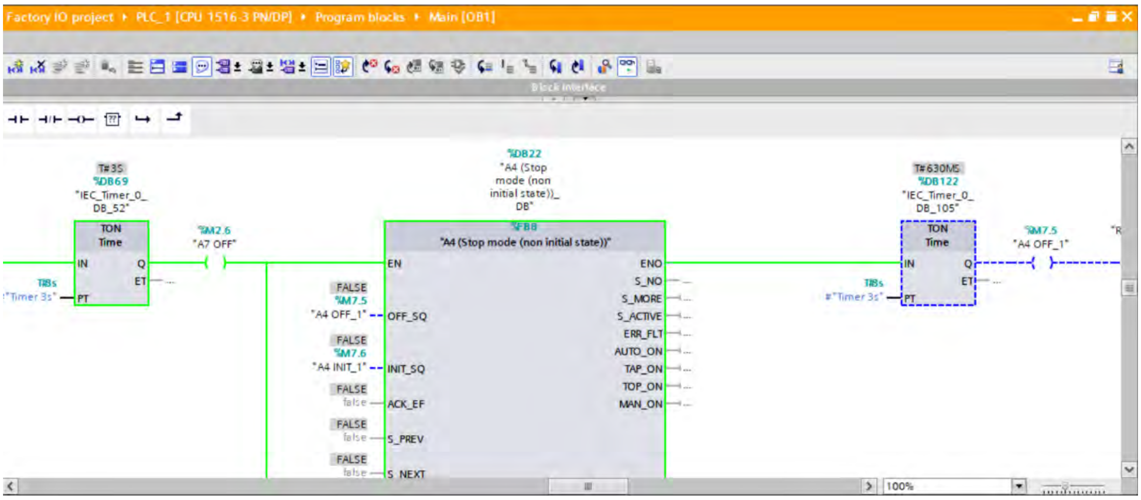


(c)

Figure 6.315: The preparation for startup after a failure mode (A5) of GEMMA is off, while the continue button is pressed. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm



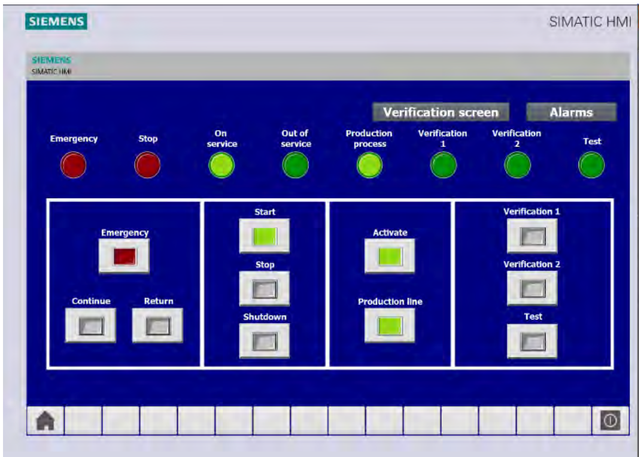
(a)



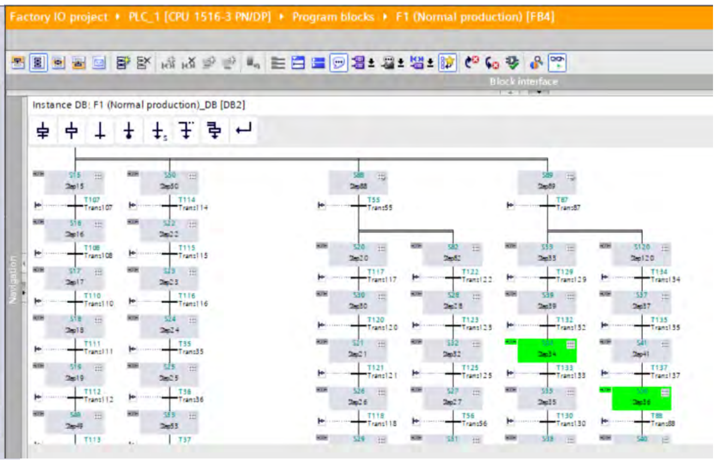
(b)

Figure 6.316: The preparation for startup after a failure mode, the Fuzzy Petri Nets intelligent algorithm. (a) setting to noninitial state (A7), (b) stop mode (non-initial state) (A4)

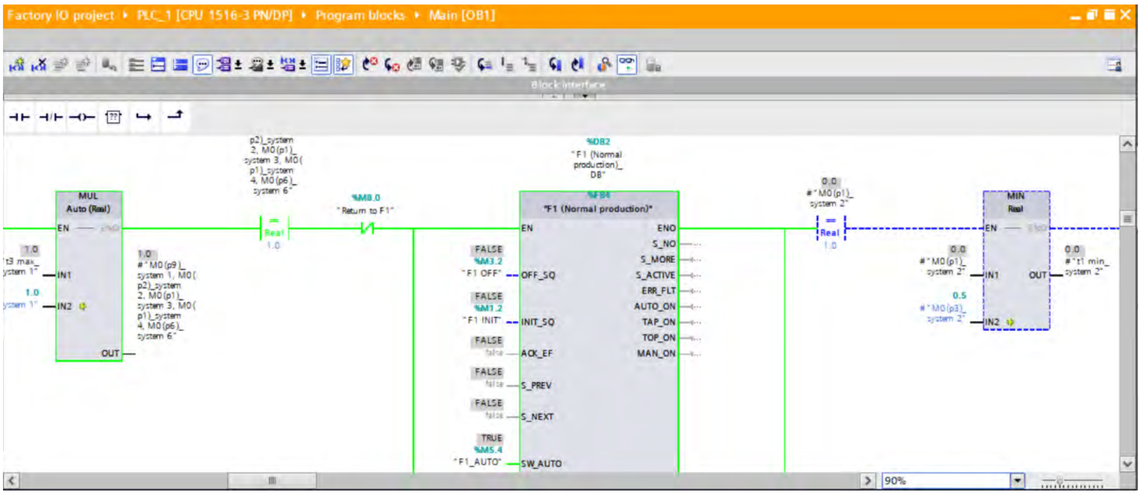
At the moment that the program is ready to continue the production, the intelligent algorithm places the program at the normal production mode (F1). It is possible to see in the figure below the operation screen, program and Fuzzy Petri Nets intelligent algorithm while it is placed at F1 and the production of the third base and lid continue.



(a)



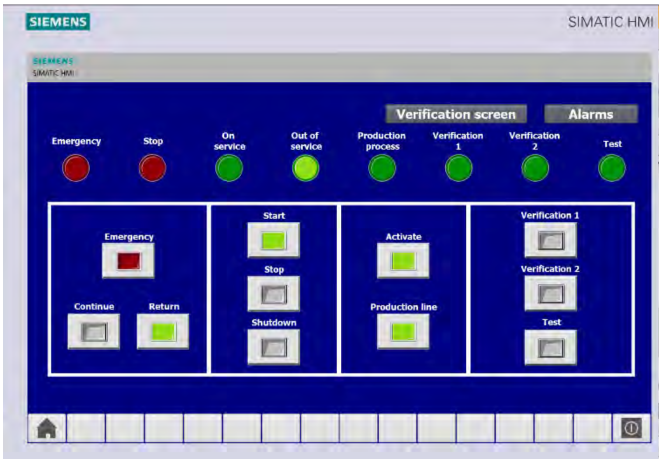
(b)



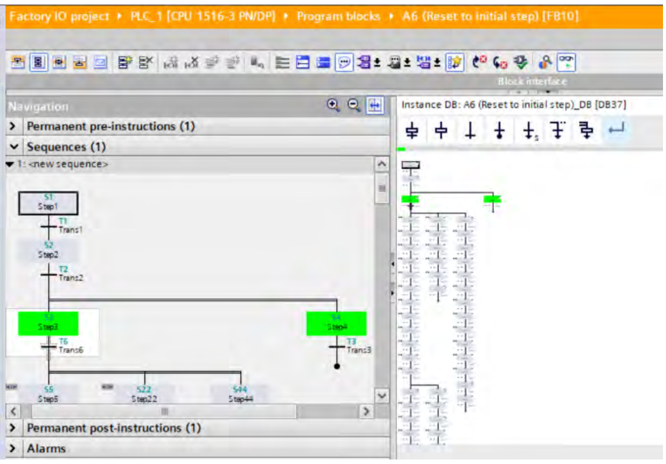
(c)

Figure 6.317: The program is placed at the normal production mode (F1) of GEMMA, while the third base and lid are produced. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

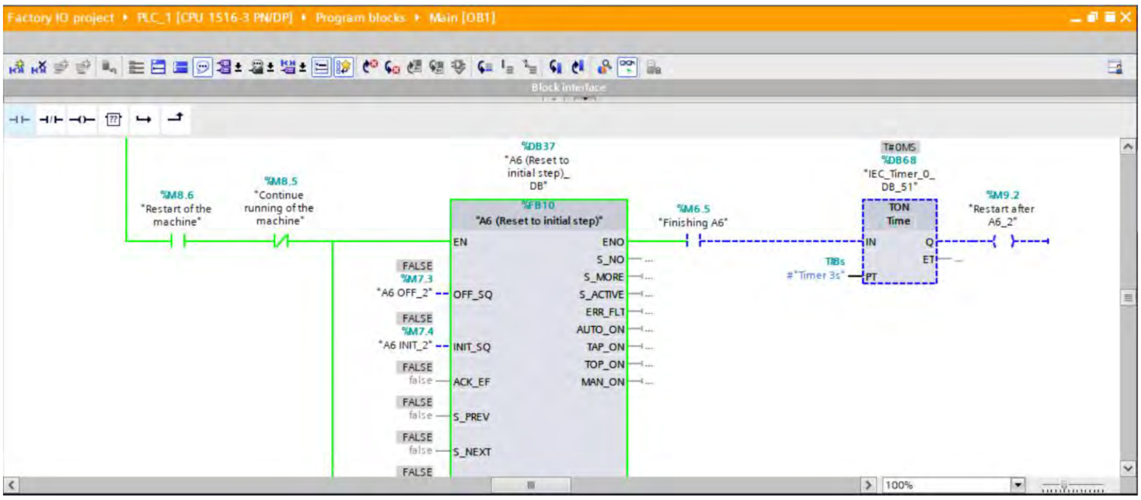
The second case allows the operator to reset the production line to its initial state and start over the program. At the moment that the operator presses the return button, the intelligent algorithm switches off the preparation for startup after a failure (A5) and places the program at the reset to initial state mode (A6) as it is shown in figure 6.318. At this mode, the program resets the production line to its initial state.



(a)



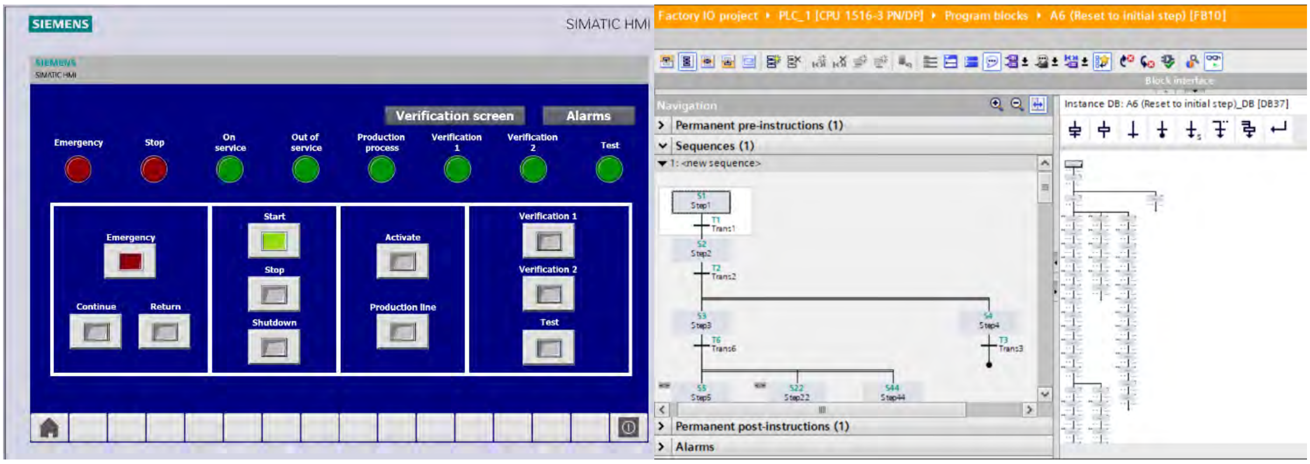
(b)



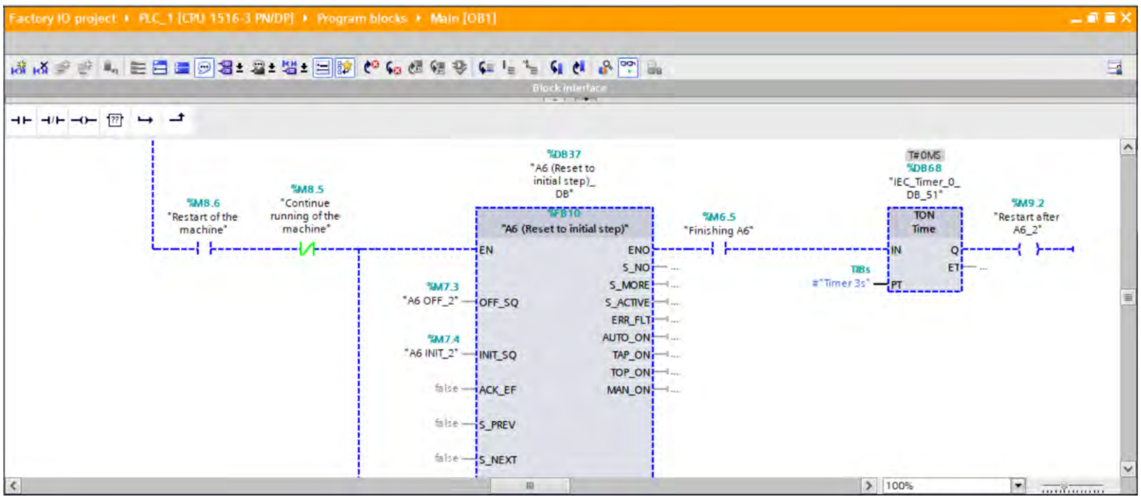
(c)

Figure 6.318: The program is placed at reset to initial state mode (A6) of GEMMA, while the return button has pressed. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

As soon as the reset process finishes, the intelligent algorithm switches off the reset to initial state mode (A6) and places the program at the initial stop state (A1). At this moment, both the production line and program are ready for the next action. Figures 6.319 and 6.320 show these situations.

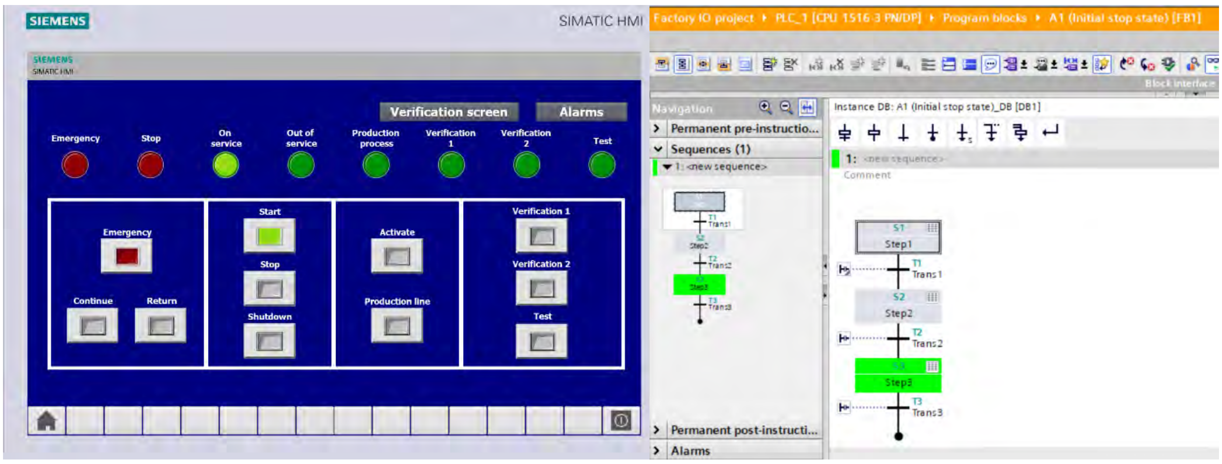


(a) (b)

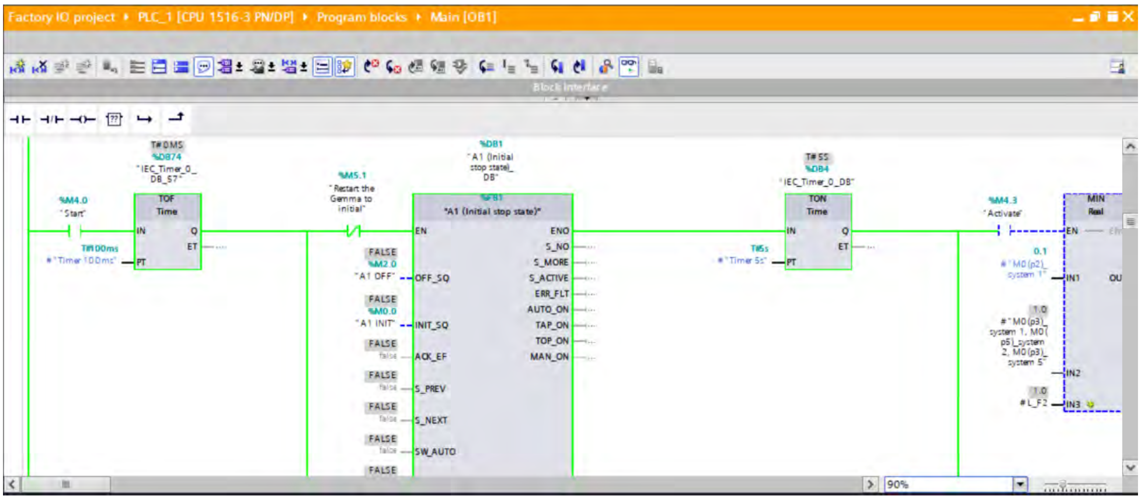


(c)

Figure 6.319: The reset to initial state mode (A6) of GEMMA is off, while the reset process has been finished. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm



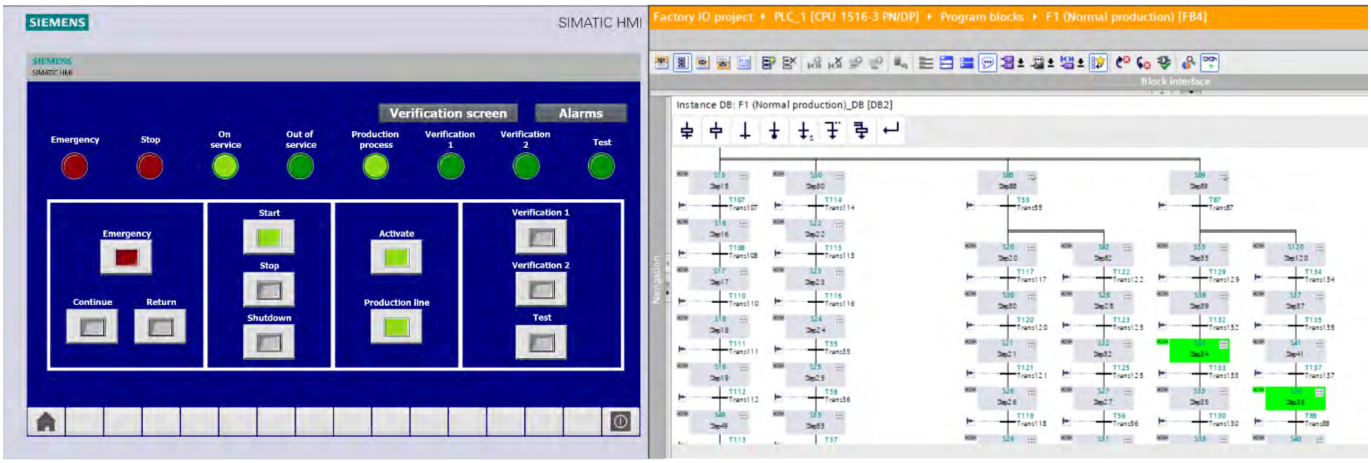
(a) (b)



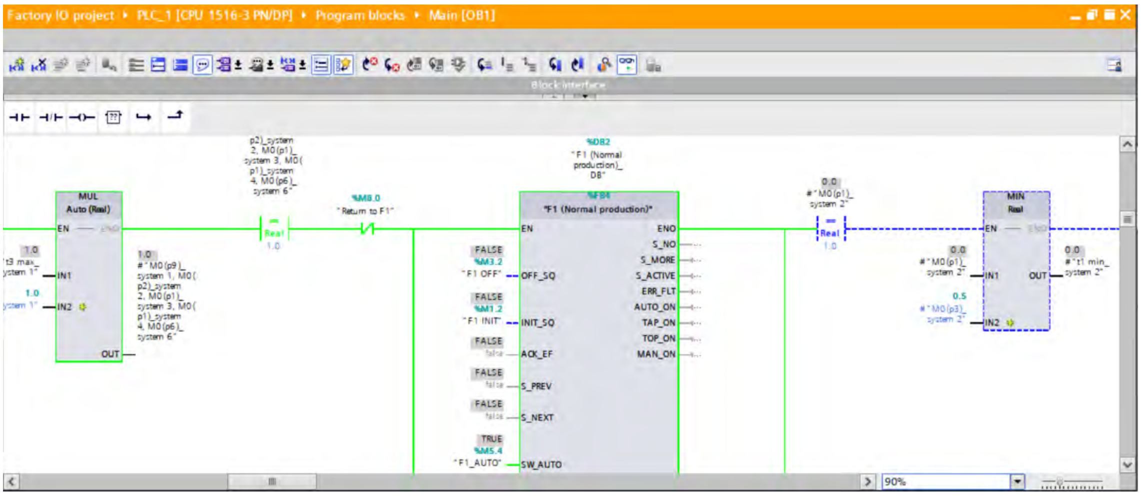
(c)

Figure 6.320: The program is placed at the initial stop state (A1) of GEMMA. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

The last failure's level is noncritical failure. This is a case of a failure that the production line is able to continue the production despite the failure. In other words, this failure level cannot put the human life in danger, and neither make damage to the production line. The figure below presents the production line while the third base and lid are produced and there is no failure.



(a) (b)



(c)

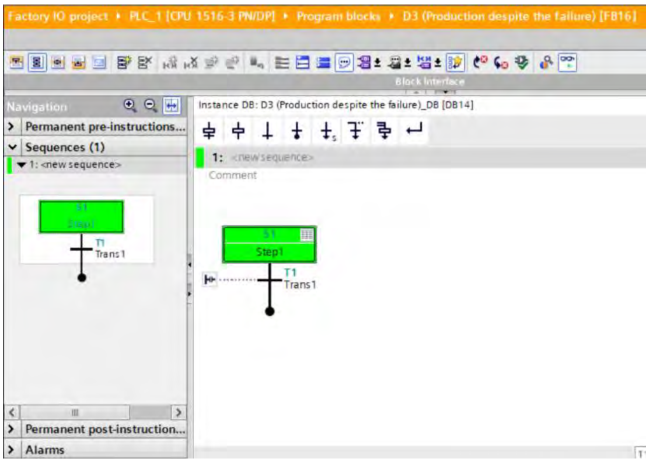
Figure 6.321: The program is placed at the normal production mode (F1) of GEMMA, while the third base and lid are produced. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm.

At the moment that a noncritical failure occurs, the intelligent algorithm stops immediately the production line and freezes the normal production mode (F1), it is presented in figure 6.322. Moreover, the program is placed at the production despite the failure (D3) as it is shown in figure 6.323. This mode allows the operator to continue the production despite the failure in a situation that there is no danger and indicates the failure on the alarms screen. Moreover, the intelligent algorithm places the program automatically at the initial stop state in a situation that the failure occurs while the production line is in its initial state. This situation is explained deeper in the next Subsection (Failure procedure to stop procedure transitions).

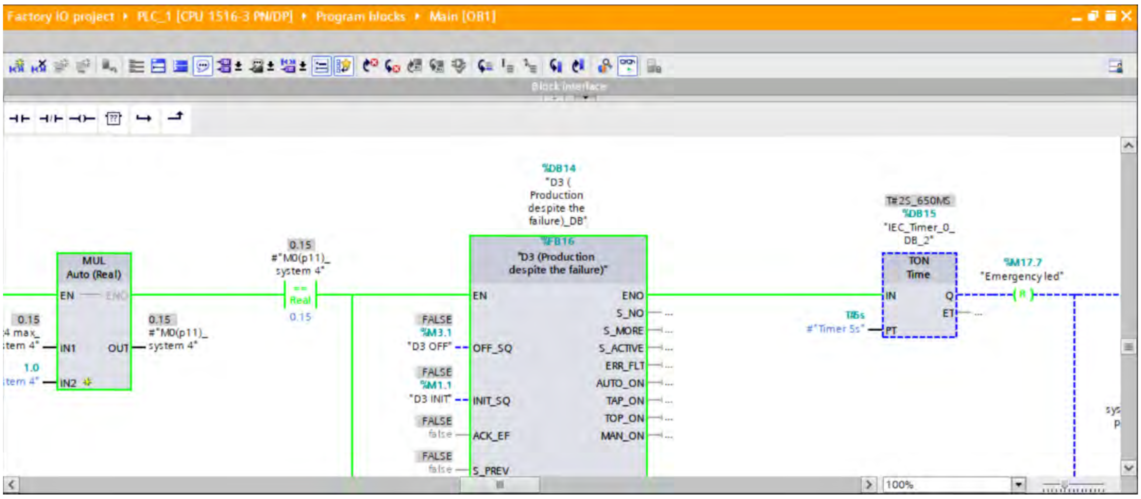
(a) (b)

Figure 6.322: The normal production mode (F1) of GEMMA is frozen while a noncritical failure is detected. (a) the screen, (b) the program

(a)



(b)



(c)

Figure 6.323: The program is placed production despite the failure mode (D3) of GEMMA. (a) alarm screen including the failure presentation, (b) program, (c) the Fuzzy Petri Nets intelligent algorithm

6.2.4.5. Failure Procedure to Stop Procedure

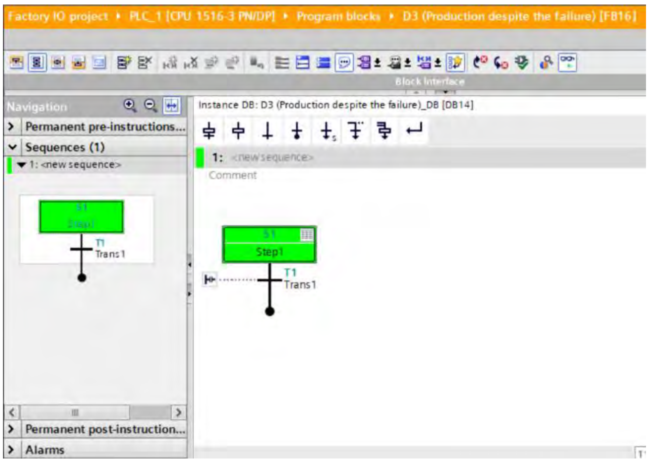
The failure procedure to stop procedure transitions are the next step of the last subsection. That is to say, the intelligent algorithm detects a noncritical failure, immediately stops the production line and places the program at the production despite the failure (D3). At that moment, the algorithm has to make the best decision for the next step according to the production line situation. In other word, the intelligent algorithm will place the program at either requested stop (non-initial state) (A3) in order to continue the production if the production line was at some point of the production or requested stop at the end of the cycle (A2) in order to start over the program in a situation that the production line is in its initial state.

Figures 6.324 and 6.325 present a situation that a noncritical failure has occurred, and the intelligent algorithm has stopped the production line and placed the program at the production despite the failure (D3). Figure 6.324 shows the first step of this process, the normal production mode (F1) is frozen. Moreover, figure 6.325 shows the second step, the intelligent algorithm has placed the program at the D3 mode and indicates the failure that has occurred.

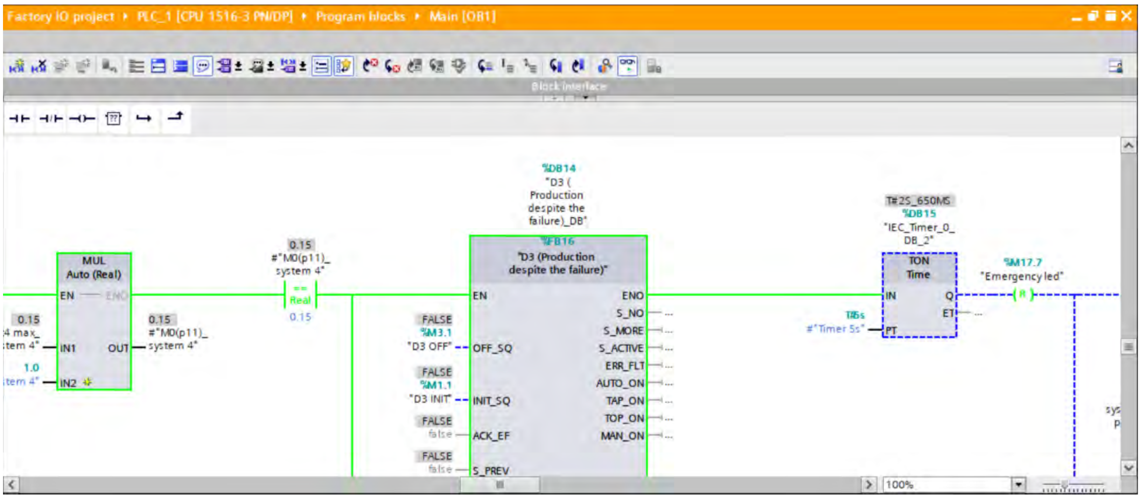
(a) (b)

Figure 6.324: The normal production mode (F1) of GEMMA is frozen while a noncritical failure is detected. (a) the screen, (b) the program

(a)



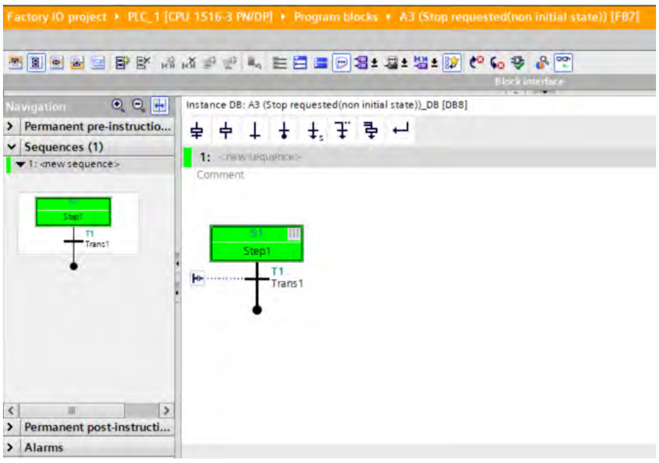
(b)



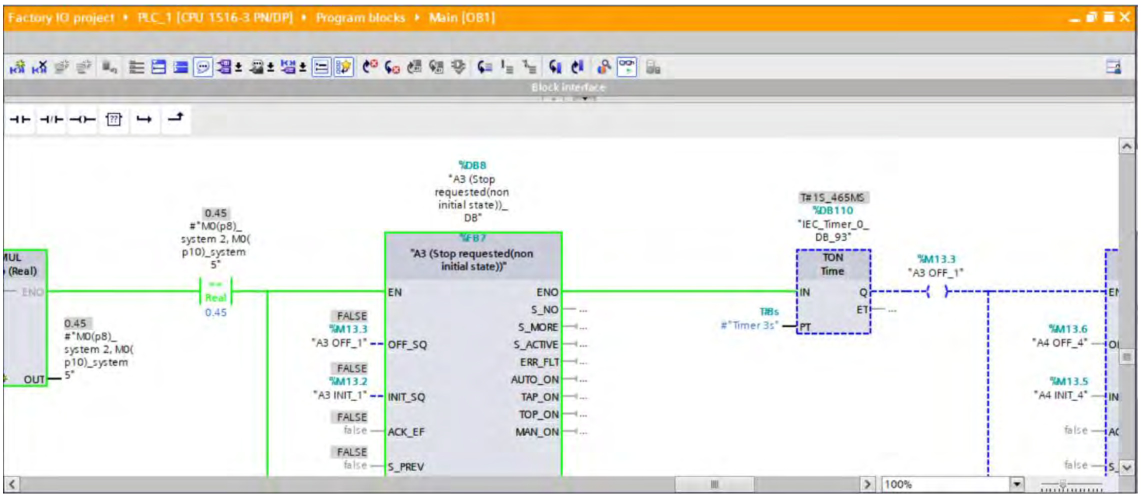
(c)

Figure 6.325: The program is placed production despite the failure mode (D3) of GEMMA. (a) alarm screen including the failure presentation, (b) program, (c) the Fuzzy Petri Nets intelligent algorithm

As it is mentioned before, these transitions are divided into two categories according the production line situation. The first category refers to a situation that the production line was at some point of the production and it is needed to be continued. That is to say, the production line has to finish the production and due to the fact that it is a noncritical failure it could be done despite the failure. In this case, the intelligent algorithm places the program at the requested stop (non-initial state) (A3). At this mode, the program prepares to continue the production at the same point that it was stopped. Figure 6.326 presents the program and Fuzzy Petri Nets intelligent algorithm while the program is at the preparation mode.



(a)



(b)

Figure 6.326: The program is placed at the requested stop (non-initial state) mode (A3) of GEMMA. (a) program, (b) the Fuzzy Petri Nets intelligent algorithm

As soon as the program is ready, the intelligent algorithm places it in the stop mode (non-initial state) (A4). This mode is an intermediate mode, and it is similar to the initial stop state (A1). In other words, while the program is placed at this mode, it is ready to continue the production. Figure 6.327 presents the Fuzzy Petri Nets intelligent algorithm at this mode. Then, the intelligent algorithm places the program back at the normal production mode (F1) at the same point of the production as it is presented in figure 6.328.

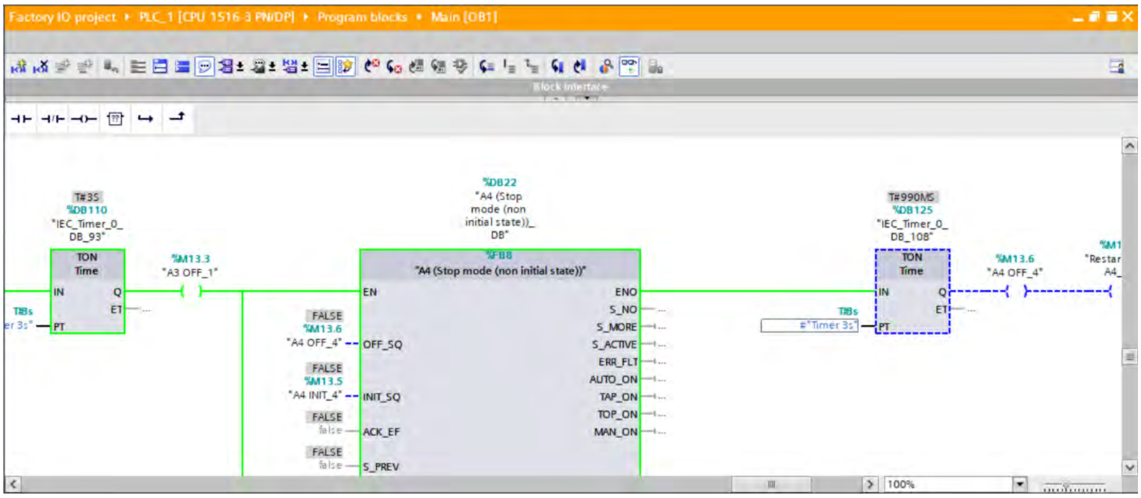
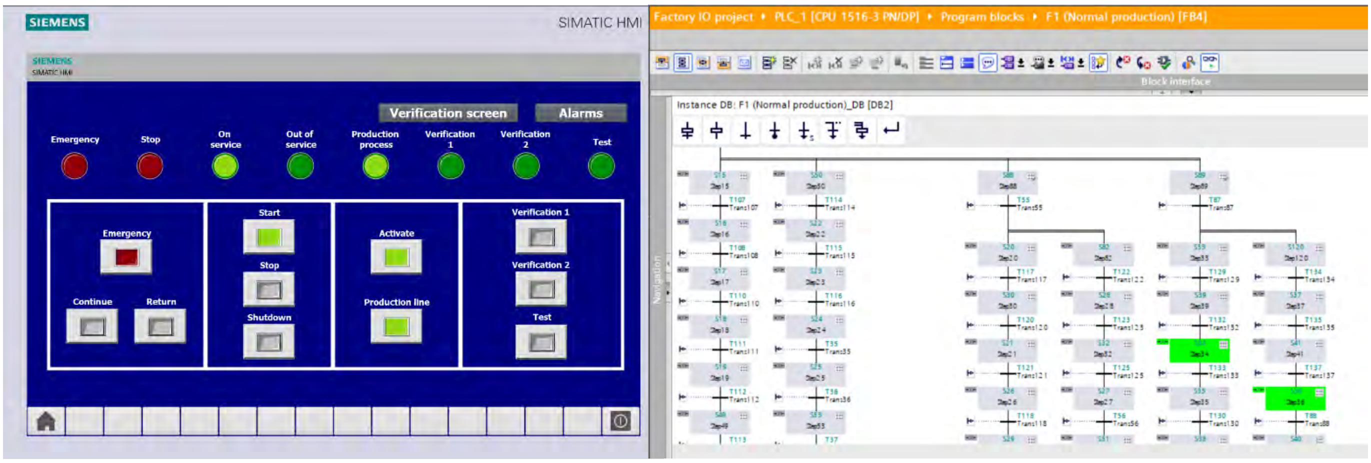
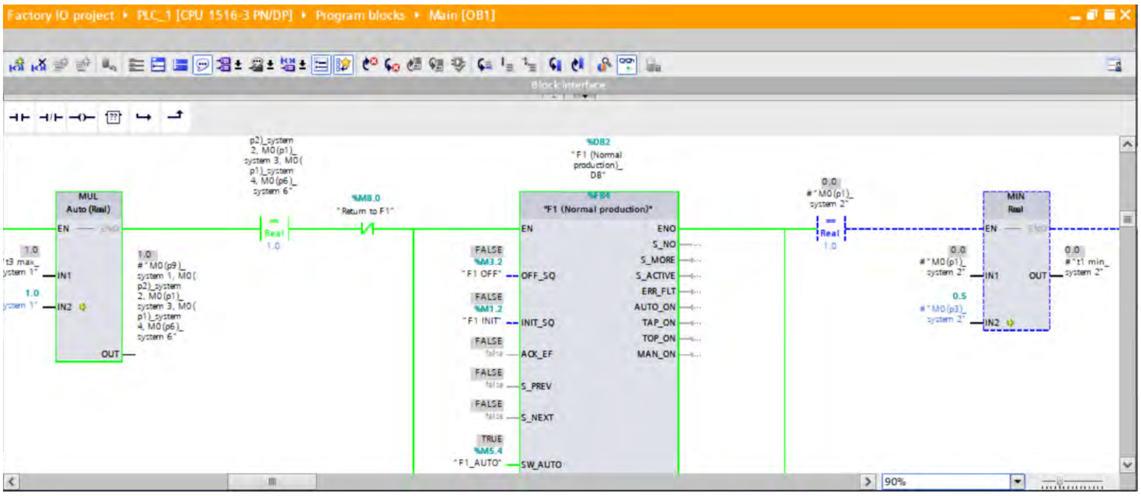


Figure 6.327: The program is placed at the stop mode (non-initial state) (A4), Fuzzy Petri Nets intelligent algorithm



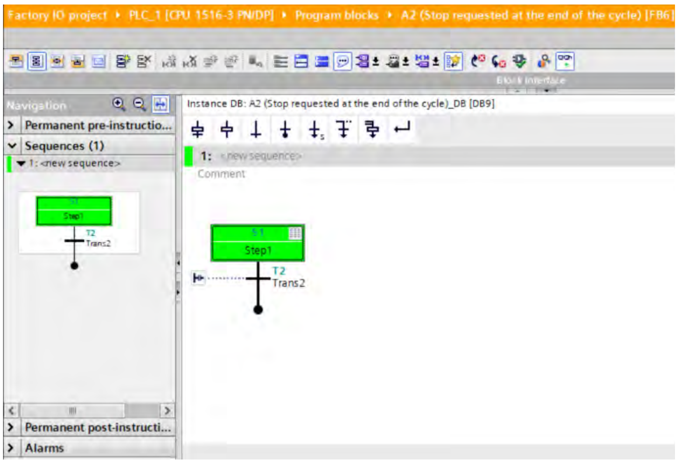
(a) (b)



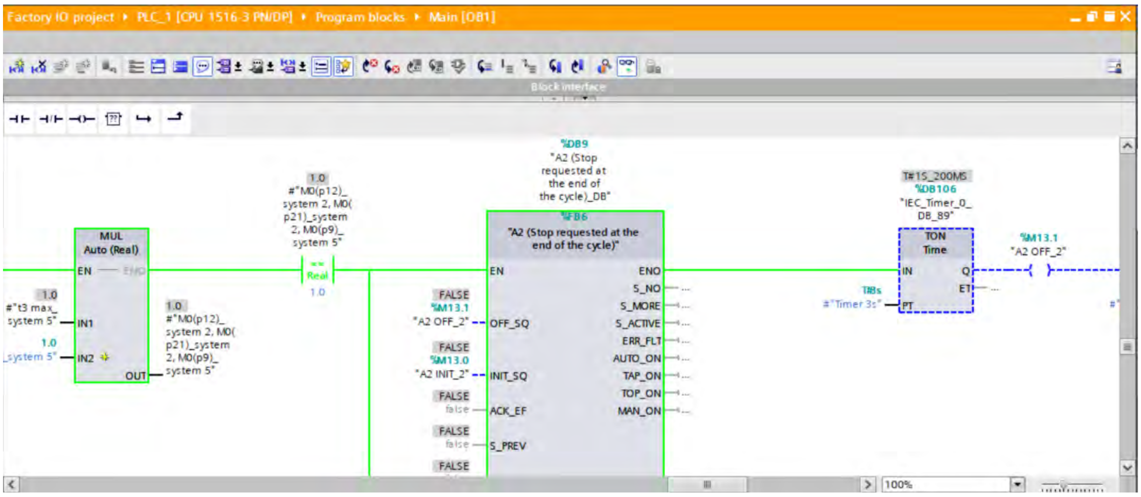
(c)

Figure 6.328: The program is placed at the normal production mode (F1) of GEMMA, while the third base and lid are produced. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

The second category refers to a situation that the production is either did not start yet or has finished already. At this situation, the intelligent algorithm places the program at the requested stop at the end of the cycle (A2). This is a temporal mode that prepares the program for the initial stop state (A1). Figure 6.329 shows the program and Fuzzy Petri Nets intelligent algorithm while the program is placed at this mode. As soon as the program is ready, the intelligent algorithm places the program at the initial stop state (A1) as it is presented in figure 6.330. The figure presents the operation screen, program and Fuzzy Petri Nets intelligent algorithm.

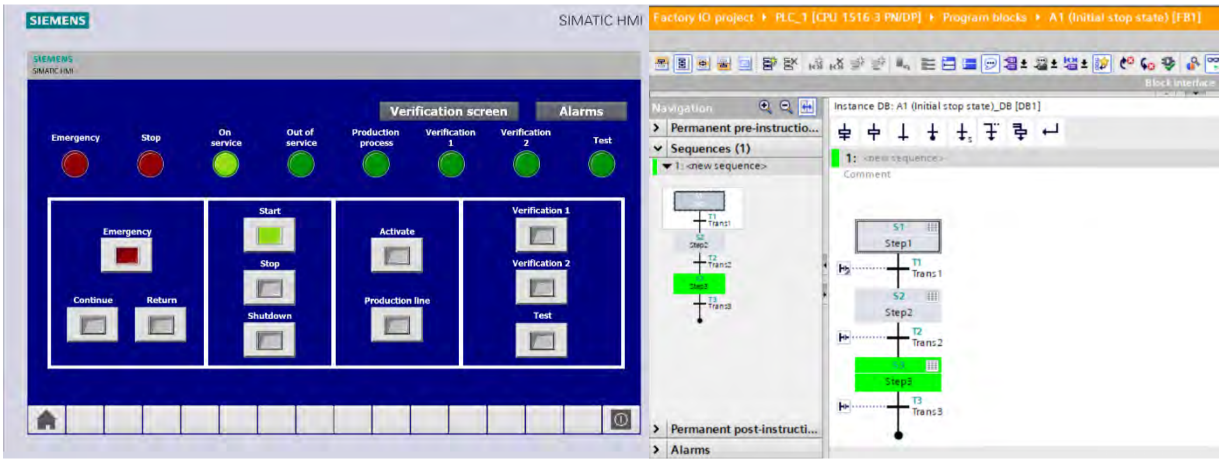


(a)

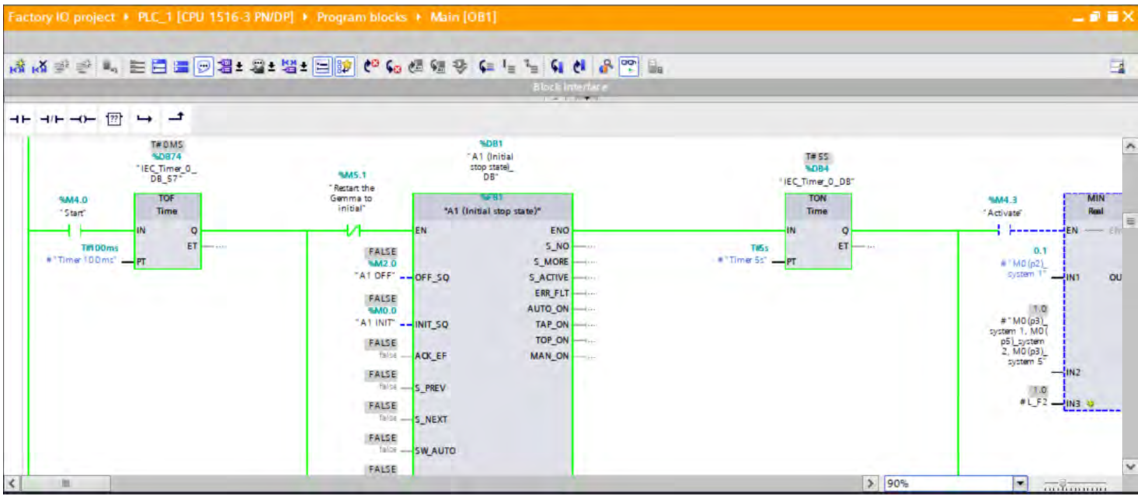


(b)

Figure 6.329: The program is placed at the requested stop at the end of the cycle mode (A2) of GEMMA, (a) the program, (b) the Fuzzy Petri Nets intelligent algorithm



(a) (b)



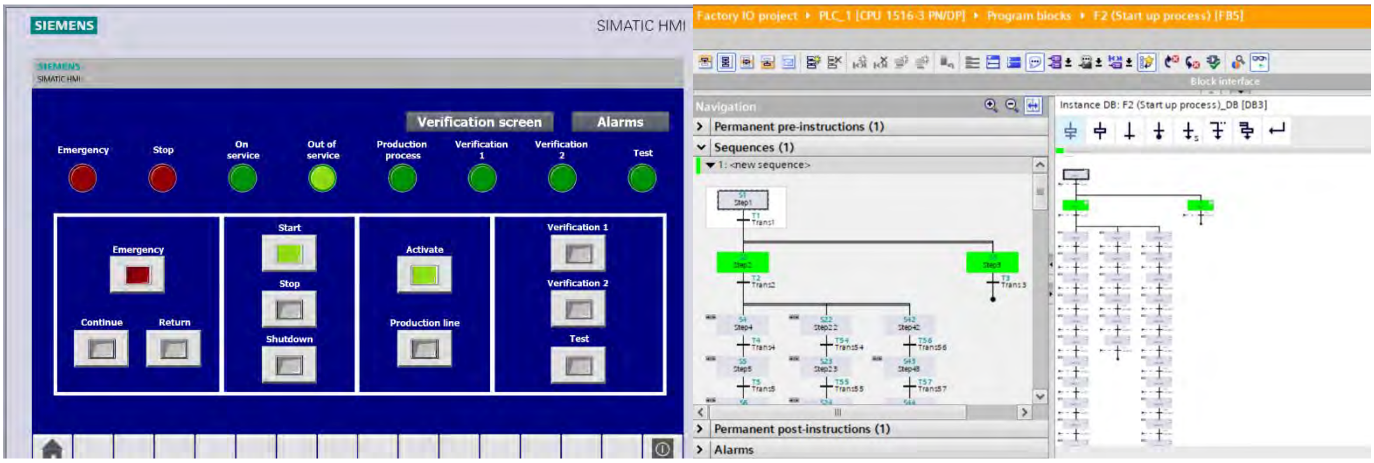
(c)

Figure 6.330: program is placed at the initial stop state (A1) of GEMMA. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

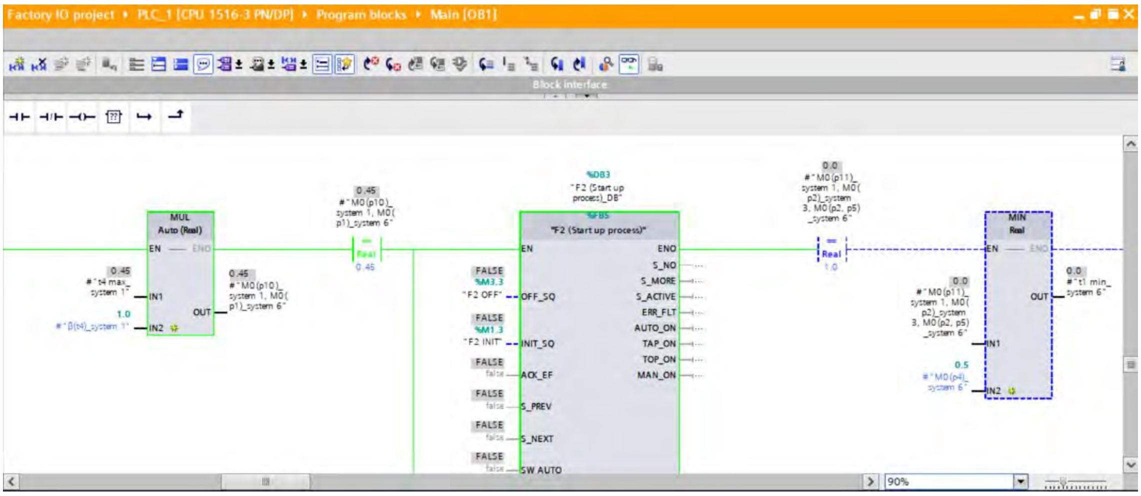
6.2.4.6. The Intelligent Algorithm for Scenario A

The intelligent algorithm for scenario A is already explained in the Section 5.2. This algorithm is very significant for the safety of the human life and production line integrity. It allows the operator to place the program at the running in verification mode disorderly (F4) directly from the startup process mode (F2) at any point of the startup process. In this way, the operator is able to prevent either a danger to the human life or a damage to the production line in a situation that he sees something that may happen. Moreover, it allows him to place the program at the F4 mode depending on his needs, for example when he desires to do some action at some point of the startup process.

The figure below presents the operation screen, program and Fuzzy Petri Nets intelligent algorithm while the program is placed at the startup process mode (F2). It is possible to see that in this situation the program is in the initial state of the startup process.



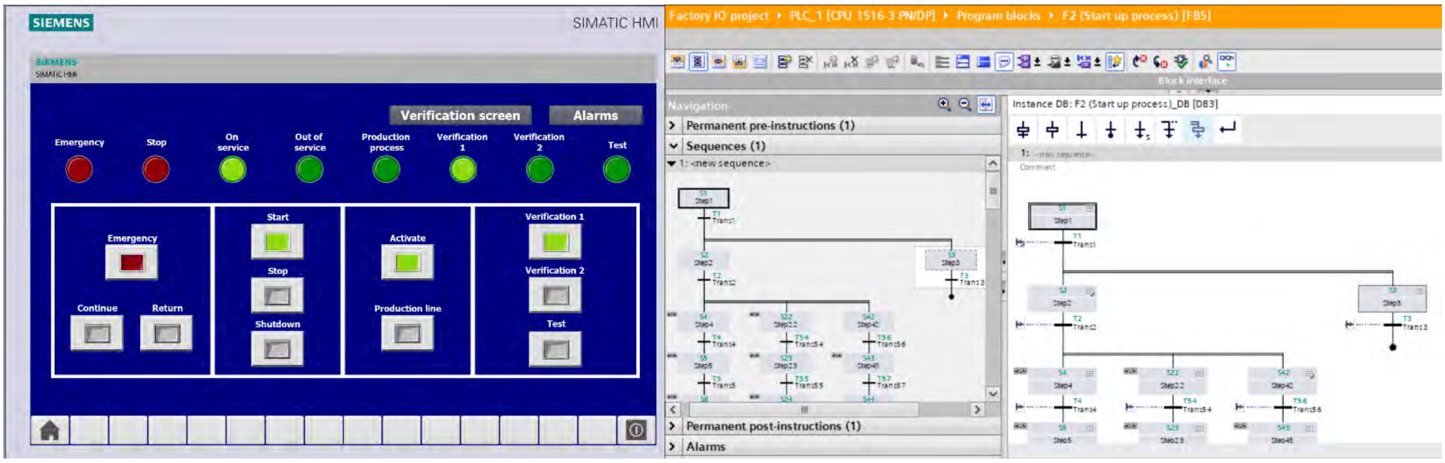
(a) (b)



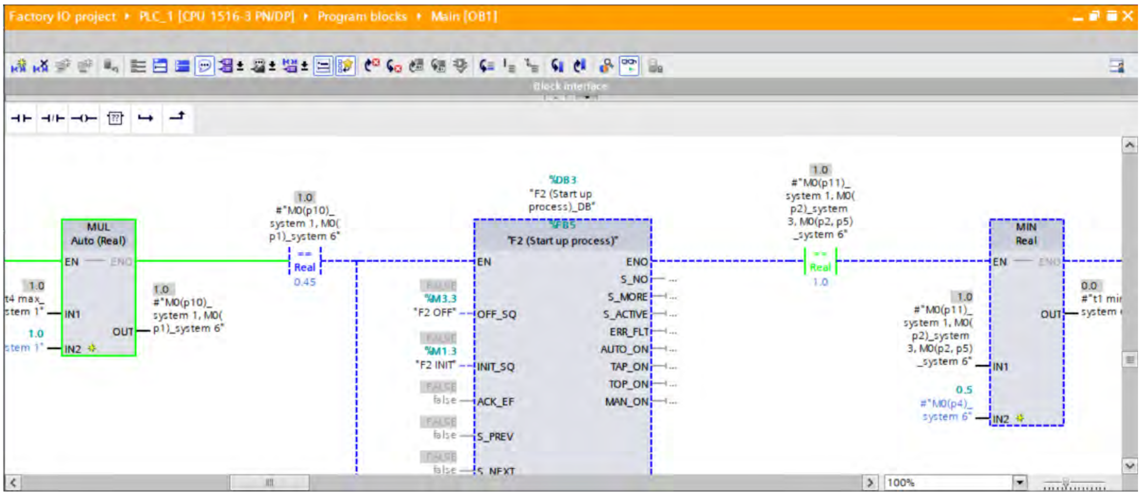
(c)

Figure 6.331: The program is placed at the startup process mode (F2) of GEMMA. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

As soon as the operator desires to stop the startup process and place the program at the running in verification mode disorderly (F4), he is able to do it by pressing the verification 1 button. At this moment, the intelligent algorithm stops the startup process immediately and switches off the startup process mode (F2) as it is presented in the figure below. The figure shows the operation screen, program and Fuzzy Petri Nets intelligent algorithm at this moment.



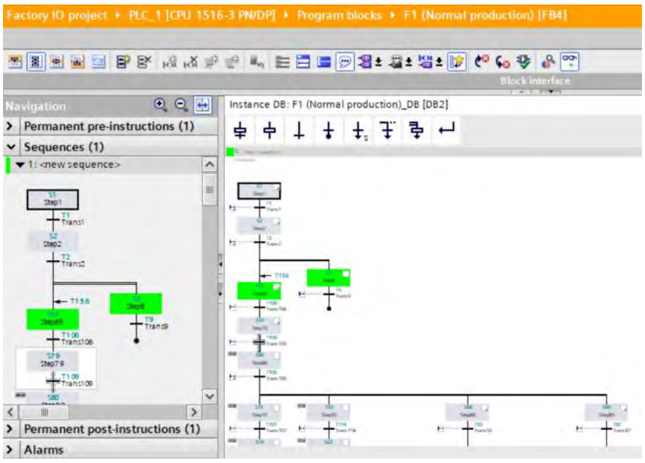
(a) (b)



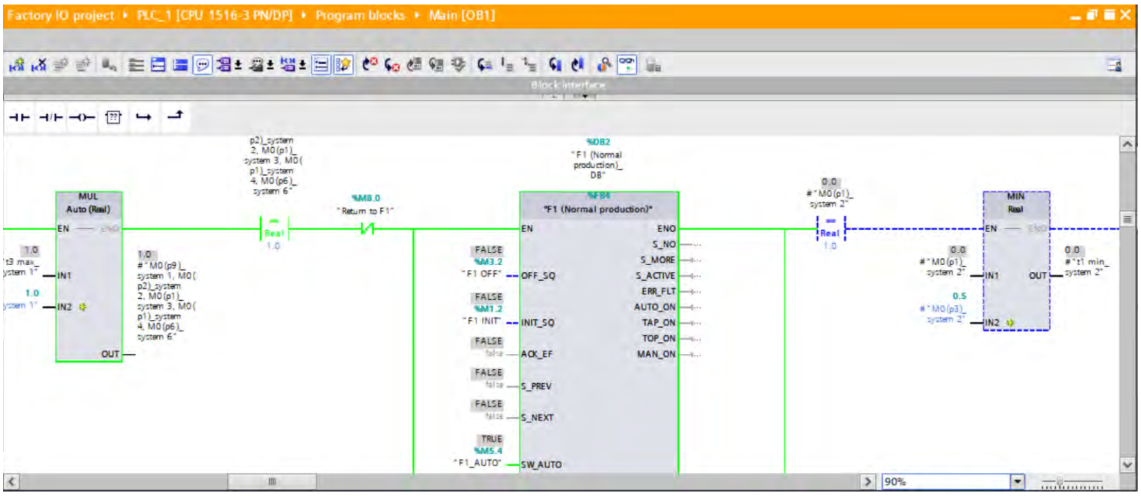
(c)

Figure 6.332: The startup process mode (F2) of GEMMA is off, while the verification button 1 has been pressed. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent transition

At the next step, according to the GEMMA rules, the intelligent algorithm places the program first at the normal production mode (F1) as it is show in figure 6.333. This allows the operator either to operate the production line from the F1 mode or to wait for the delay time of the algorithm for the verification mode disorderly (F4).



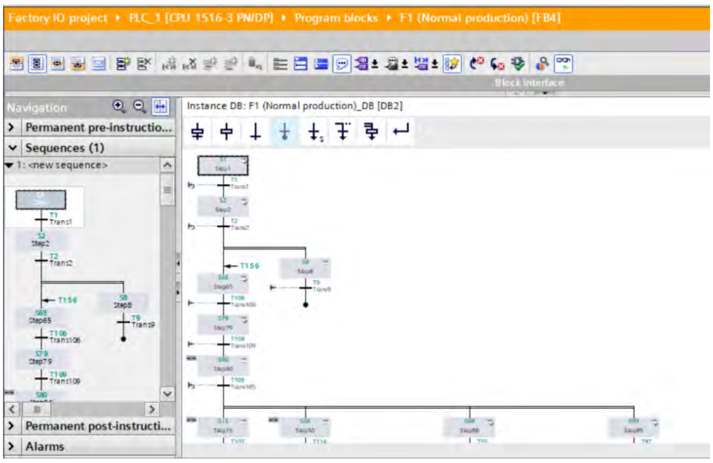
(a)



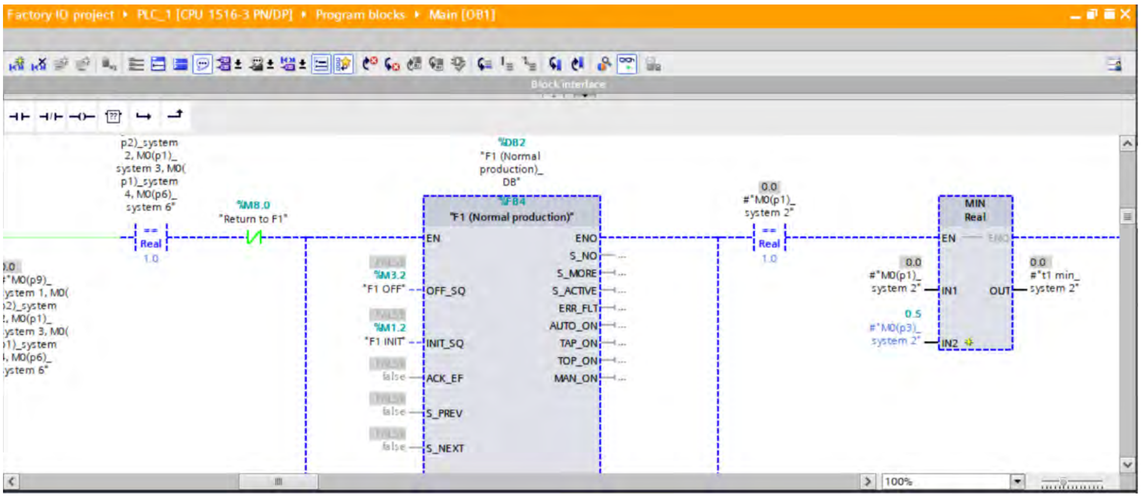
(b)

Figure 6.333: The program is placed at the normal production mode (F1) of GEMMA, after the verification button 1 has been pressed. (a) the program, (c) the Fuzzy Petri Nets intelligent algorithm

In a situation that the operator desires to operate the production line from the verification mode disorderly (F4), the intelligent algorithm switches off the normal production mode (F1) as it is shown in figure 6.334. Afterwards, it places the program at the F4 mode as it is presented in figure 6.335. It is possible to see that the program is placed at the F4 mode and it is ready for the desired actions. The figures below show the program and Fuzzy Petri Nets intelligent algorithm at each situation.

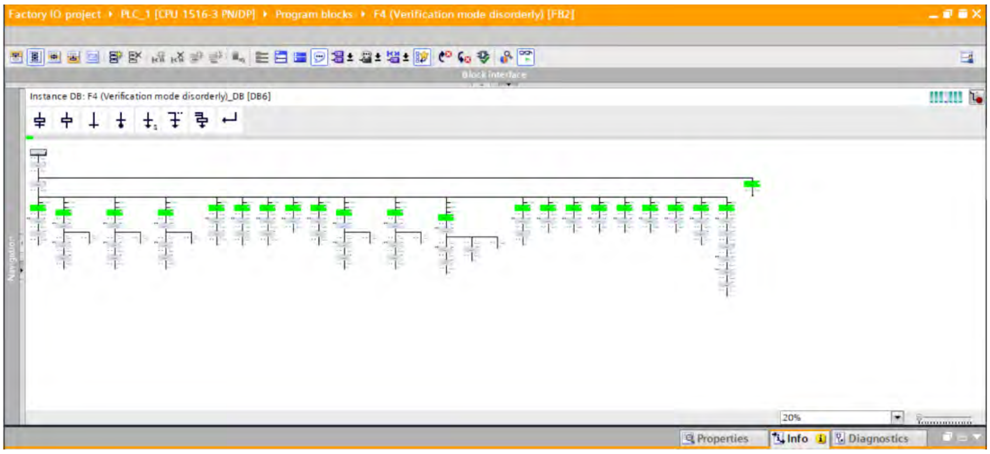


(a)

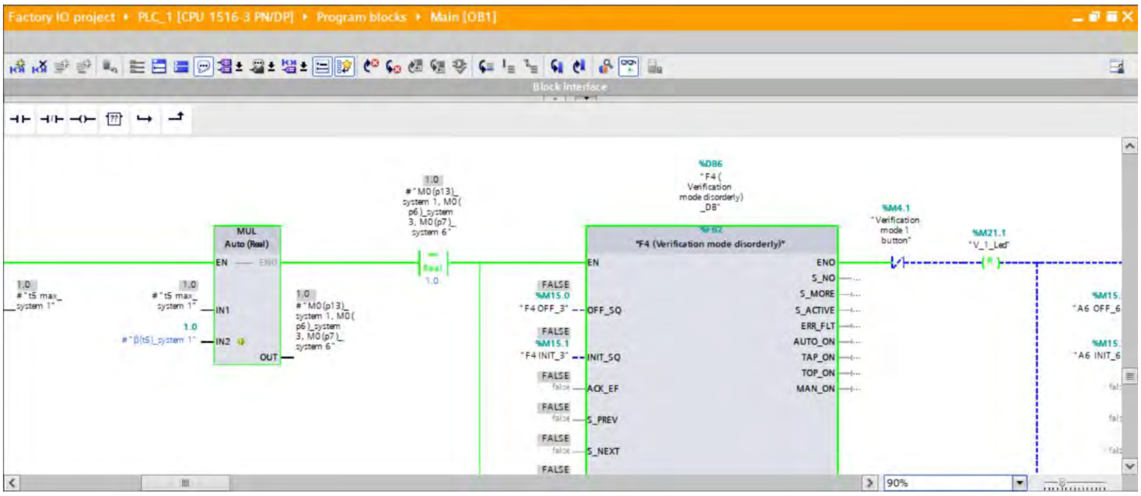


(b)

Figure 6.334: The normal production mode (F1) of GEMMA is off. (a) the program, (b) the Fuzzy Petri Nets intelligent algorithm



(a)



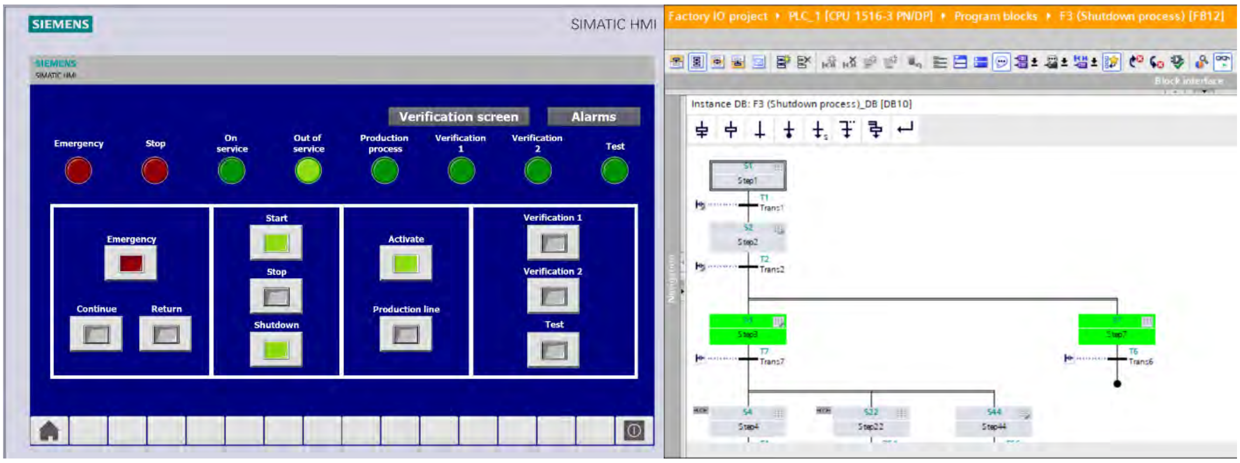
(b)

Figure 6.335: The program is placed at the running in verification mode disorderly (F4) of GEMMA, and it is ready for the different verification actions. (a) the program, (b) the Fuzzy Petri Nets intelligent algorithm

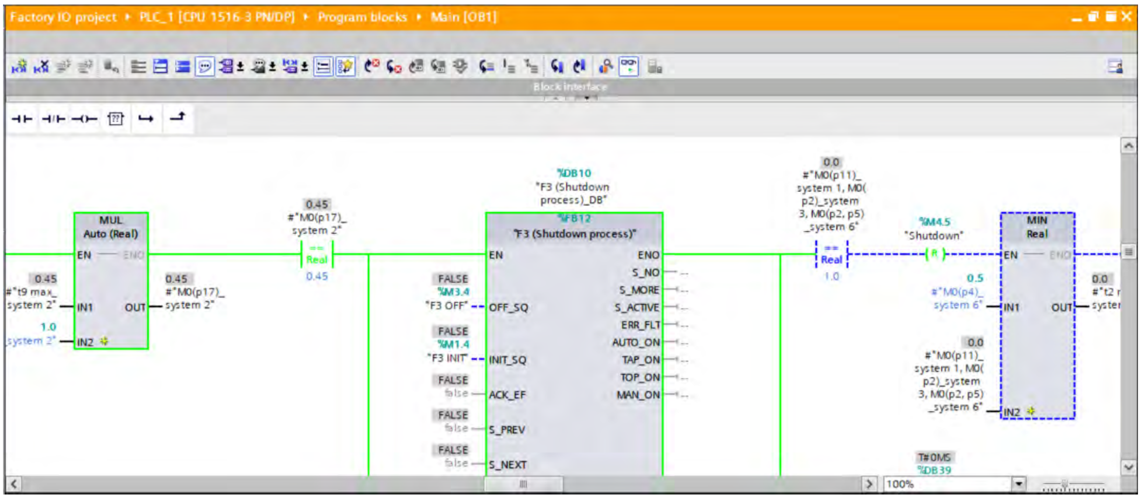
6.2.4.7. The Intelligent Algorithm for Scenario B

The intelligent algorithm for scenario B is very important for both the human life safety and production line integrity. As it is explained in the Section 5.3, this algorithm allows to place the program at the normal production mode (F1) verification mode disorderly (F4) directly at any point of the shutdown process. That is to say, the operator is able to stop the shutdown process at any moment and to place the program at the F1/F4 mode in order to do the desired actions. In this way, he is able as well to prevent either failure or danger that may occur.

The figure below presents the operation screen, program and Fuzzy Petri Nets while the program is placed at the shutdown process mode (F3). It is possible to notice that in this case the program is in the initial state of the process. However, the operator allows to place the program at the F4 mode at any moment of the shutdown process as it is mentioned before.



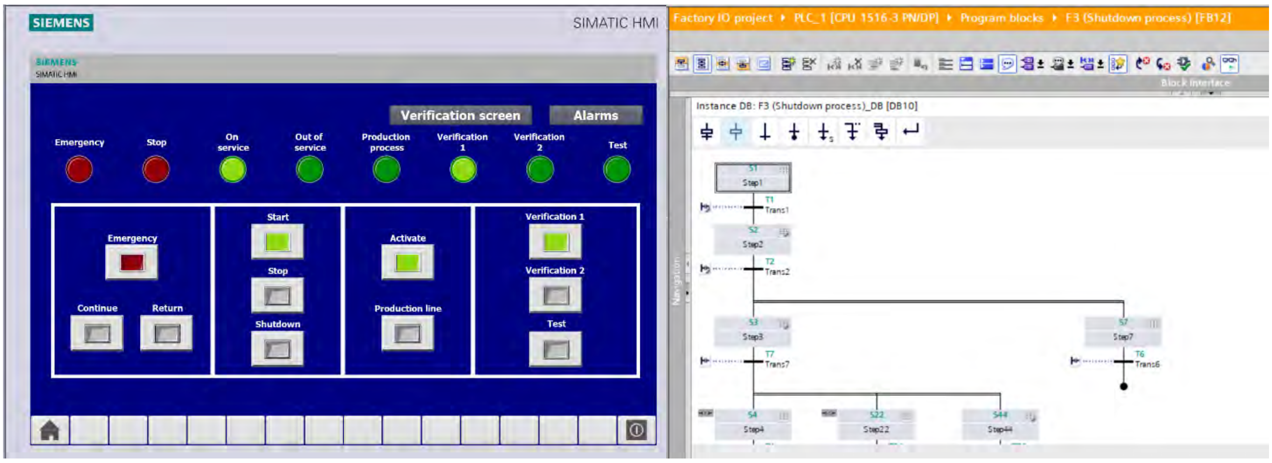
(a) (b)



(c)

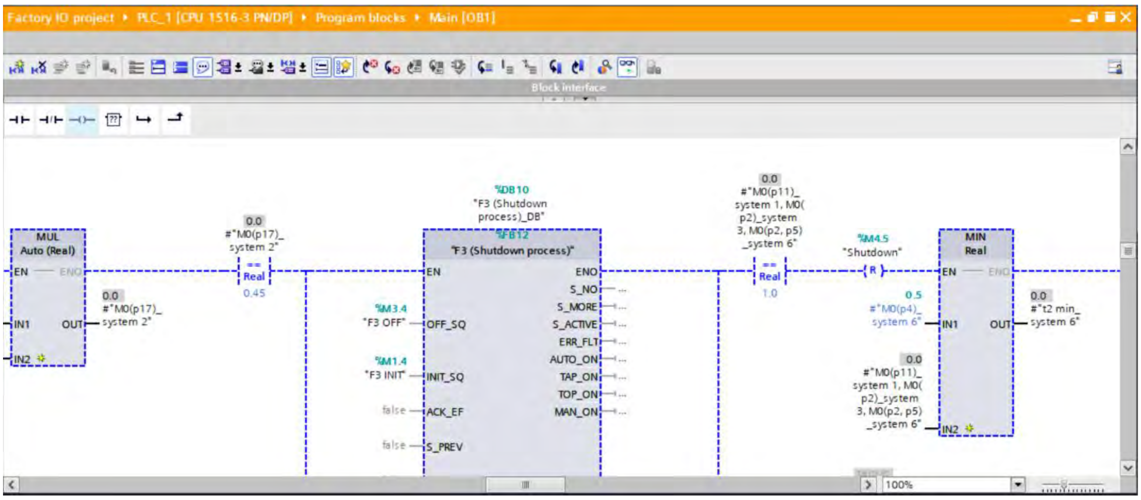
Figure 6.336: The program is placed at the shutdown process mode (F3) of GEMMA. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

At the moment that the operator desires or has the need to do some action while the shutdown process is operated, he is able to do it by pressing the verification 1 button. As soon as he presses the button, the algorithm stops immediately the shutdown process, and switches off the shutdown process mode (F3) as it is presented in figure 6.337. The figure shows the operation screen, program and Fuzzy Petri Nets intelligent algorithm at this moment.



(a)

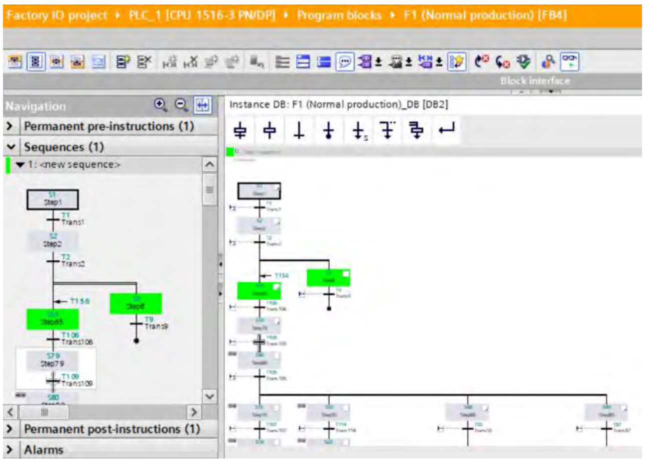
(b)



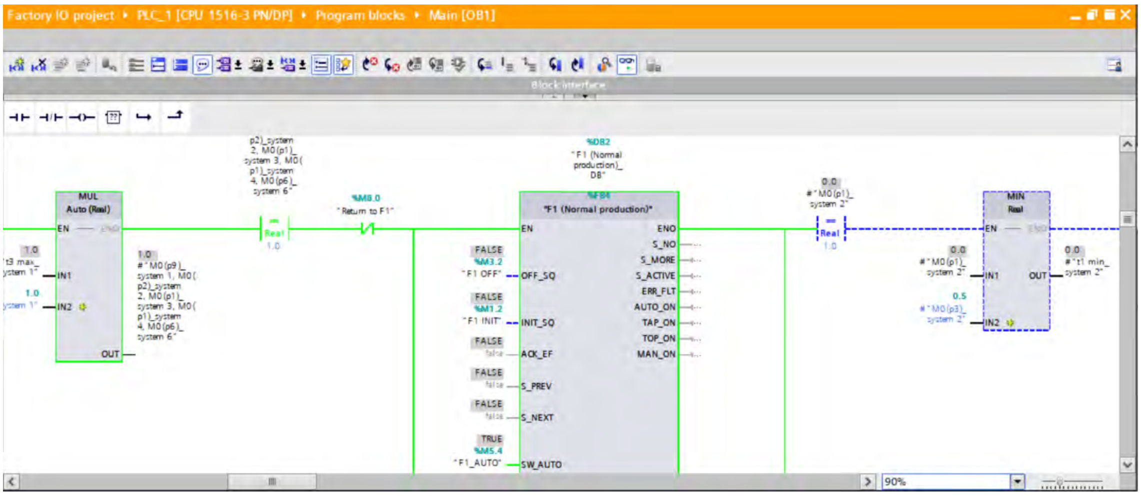
(c)

Figure 6.337: The shutdown process mode (F3) of GEMMA is off, while the verification button 1 has been pressed. (a) the screen, (b) the program, (c) the Fuzzy Petri Nets intelligent algorithm

Similarly to scenario A, the intelligent algorithm has to follow the GEMMA rules, for this reason the program is placed first in the normal production mode (F1). It provides the operator the opportunity either making the desired action at the F1 mode or F4 by waiting the transition's delay. Figure 6.337 shows the program and Fuzzy Petri Nets intelligent algorithm while the program is placed at the F1 mode.



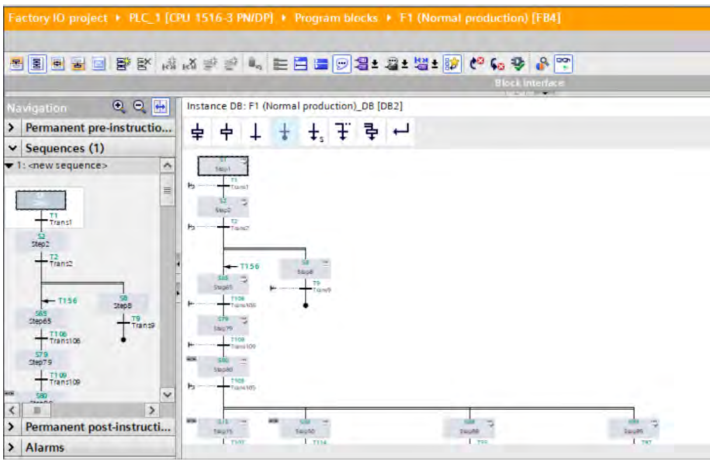
(a)



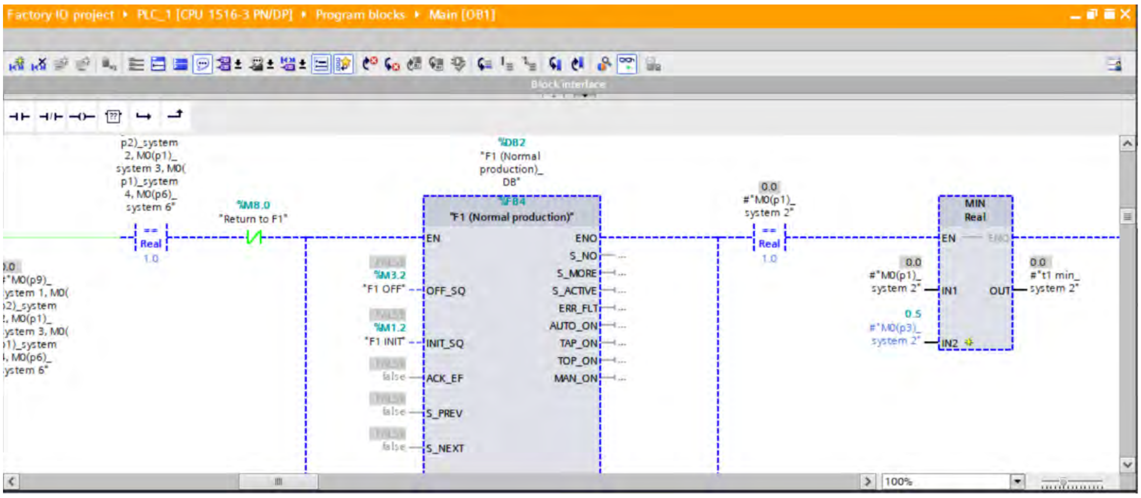
(b)

Figure 6.337: The program is placed at the normal production mode (F1) of GEMMA, after the verification button 1 has been pressed. (a) the program, (c) the Fuzzy Petri Nets intelligent algorithm

In a situation that the operator desires to make the needed actions at the verification mode disorderly (F4), the normal production mode (F1) become to be a temporary mode and the intelligent algorithm switches it off as it is presented in figure below 6.338. It is possible to see the program and Fuzzy Petri Nets intelligent algorithm at this moment. In the next step, the intelligent algorithm places the program at the F4 mode as it is presented in figure 6.339. The figure shows the program and Fuzzy Petri Nets intelligent algorithm at this moment. It is possible to see that the program is ready for the different actions.

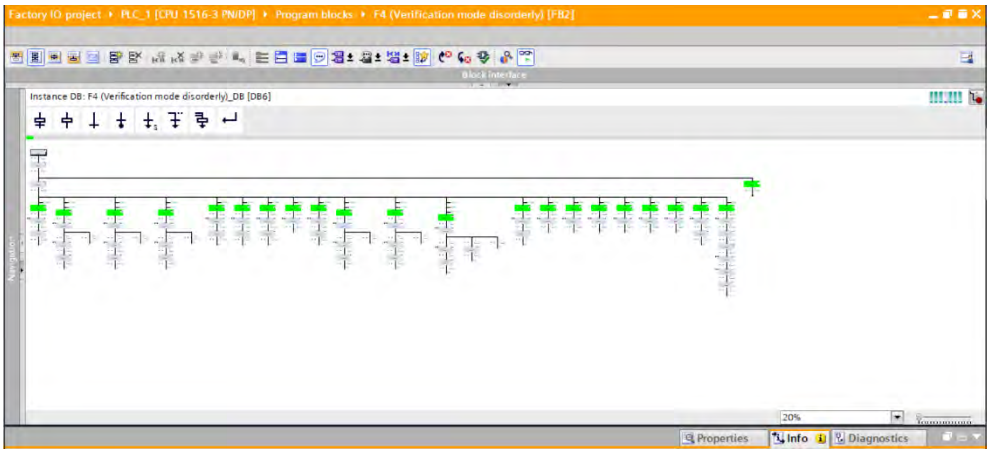


(a)

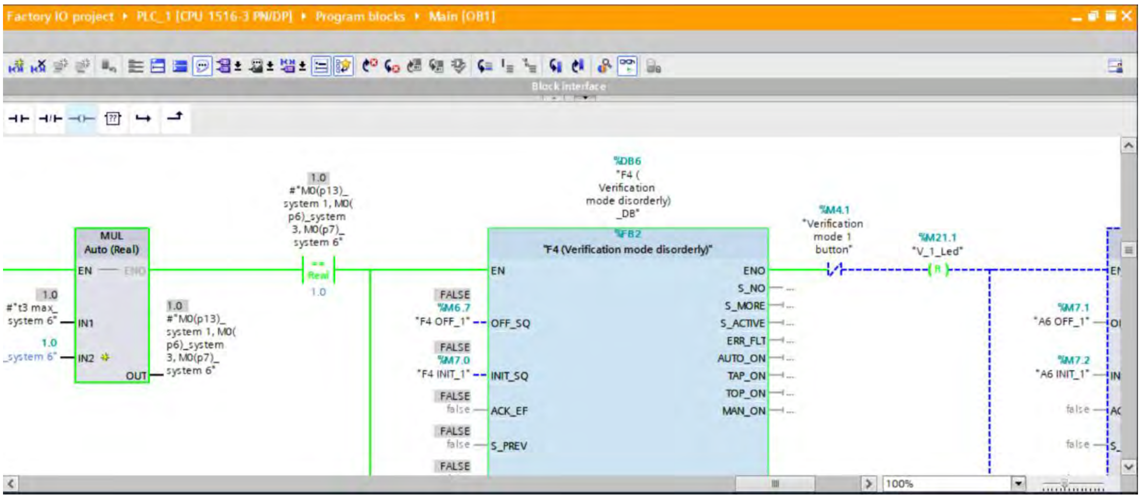


(b)

Figure 6.338: The normal production mode (F1) of GEMMA is off. (a) the program, (b) the Fuzzy Petri Nets intelligent algorithm



(a)



(b)

Figure 6.339: The program is placed at the running in verification mode disorderly (F4) of GEMMA, and it is ready for the different actions. (a) the program, (b) the Fuzzy Petri Nets intelligent algorithm

6.2.5. Conclusion

In this subchapter the virtual factory was designed. The virtual factory is a production line that produced a plastic base and lid, assemblies them to the desired product and pucks it. The virtual factory was designed by the 3D software Factory I/O which provides industrial devices and allows to simulate the automation technologies of a factory. This software provides the connection of the virtual factory with Siemens TIA Portal in order to implement the control, test it and simulate it with the industrial applications. After the virtual factory was designed, the operation of the factory was explained step by step including figures and the different stages of the production line.

The main aim of this subchapter was to implement and test the intelligent algorithms that were developed in Chapter 4 in order to validate that the algorithms and provide good control and decision-making system to the industrial applications, and to ensure safety for production process. Each subsection was testing another intelligent algorithm including all its stages and situations. It was shown that the intelligent algorithms provide good control and decision-making system for the production line. That is to say, by testing these algorithms, it proved the appropriate transitions between the different modes of the GEMMA Guide Paradigm according the situation of the machine. Additionally, by making different types of failures, it was shown that the intelligent algorithms provide a safety control and makes the properly transition for each failure type which keeps the human life safety and prevents damage to the production line. At last, the intelligent algorithm for scenarios A and B were tested, it was shown that these algorithms provide the operator the best option to make the needed action at any urgent situation while the program is at some point of the startup/shutdown process. In this way, when an urgent action is needed, the operator is able to stop the startup/shutdown at any moment of the process and to place the program at either normal production mode (F1) or running in verification mode disorderly (F4) and to make the needed action. The tests of these intelligent algorithms showed that the operator is able to stop the startup/shutdown process properly at any moment, to place the program in either F1 of F4 and to make the needed action in the production line.

6.3. Discussion

Along this chapter several experiments concerning the performance of the Fuzzy Petri Nets intelligent algorithms implementations on the GEMMA Guide Paradigm for the control and decision-making system of industrial applications.

According to the obtained results the intelligent algorithms based on the GEMMA Guide Paradigm provides an appropriate control and decision-making system for industrial applications. That is to say, it has the capability to make the transitions between the different GEMMA modes and states according the situation of the machine and operator needs. The intelligent algorithms were developed based on the approaches that presented in Chapter 2. These approaches aided to understand the base principals of artificial intelligent for control and decision-making system.

In general terms, the correct execution of these trials reflects the fact that the developed intelligent algorithms based on Fuzzy Petri Nets that is presented in Chapter 3 have been correctly developed. They prove a complete control and decision-making system for any situation that may occur and more importantly a safety operation.

This chapter was divided into two parts in order to make the experiments of the intelligent algorithms and to ensure that they can provide a good control and decision-making system for any industrial application. The first part included the design of OPS (onshore power supply) carne and the experiments of the intelligent algorithms for controlling the crane operation. In the second part, a production line was designed, and the intelligent algorithms were experimented on it. The experiments on these two projects allow to validate that the intelligent algorithms that were developed by Fuzzy Petri Nets based on GEMMA Guide Paradigm will provide a good control and decision-making system for any industrial application and can improve their operations and safety. These experiments made by TIA Portal and programmable logic controller (PLC) SIMATIC S7-1500 Siemens for OPS crane, and by PLCSIM for the production line. However, they can be implemented on any automation portal and PLC.

7. CONCLUSION

This thesis has focused on the research and development of intelligent algorithms for revisiting the GEMMA Guide Paradigm in order to provide an intelligent control and decision-making system based on GEMMA. Chapter 2 provides the necessary tools for this work. First, the decision-making and artificial intelligence were explained which provides a general idea of it, where it is used, how and why it is so important. Then, the intelligent control was presented including the main approach and mathematical model that were used for this work, Fuzzy Logic and Petri Nets. Fuzzy logic is an approach to compute based on degree of truth which the truth value may be any number between 0 and 1 both included. Petri Nets is a mathematical model tool for control systems which has two types of elements, place and transition that are connected by arcs. By this tool it is possible to model and simulate controls systems in an effective and reliable way. These tools and expertise that were explained in Chapter 2 are the base for this thesis and for the intelligent algorithms' development.

Chapter 3 presents the GEMMA Guide Paradigm including its modes, states and uses. Moreover, the general development of the intelligent algorithm for GEMMA was developed. The development of the intelligent algorithm is based on the Fuzzy Petri Nets approach that was clarified in this chapter. A combination of Fuzzy Logic and Petri Nets makes a graphical model with significant abilities for representing and reasoning the decision making of systems that calls Fuzzy Petri Nets. At last, the conversion of the algorithm to a control system was explained. In other words, in order to use the intelligent algorithms for the GEMMA Guide paradigm it is necessary to convert it to a programming language that will supply the control and decision-making system of the algorithms. The best way to convert the Fuzzy Petri Nets algorithm to a control system is by Ladder Logic Diagram due to its good capabilities for control systems.

Chapter 4 presented the development of each intelligent algorithm of the GEMMA Guide Paradigm including their mathematical calculations and graphical presentation. The intelligent algorithm for the control and decision-making of GEMMA are divided into five different algorithms that allow together to cover all the necessary transitions of GEMMA and to handle the different states and situations in which the machine may be. In order to provide this perfect and complete system, the following transitions were developed: Stop to Operation procedure, Operation procedure, Operation to Stop procedure, Operation to Failure procedure and Failure to Stop procedure. These algorithms provide the complete system in order to have an intelligent and safe control, and to make the appropriate decision according the certain situation in order to place the program at the right mode. Moreover, in Chapter 4 two additional intelligent algorithms were developed, there are particular situations that may happen during an operation that GEMMA Guide Paradigm does not cover them, such as the transition between Startup process (F2)/Shutdown process (F3) and Normal production (F1)/Running in verification mode disorderly (F4). These two intelligent algorithms are very important for the control system due to their capabilities. They provide a safer control due to the flexibility of making the needed action at any moment of the startup/shutdown process. Also, they could save lot of time and money.

At last chapter 6 showed the experimental results concerning the performance of the intelligent algorithm for the GEMMA Guide Paradigm. First, in order to test the algorithms, two different industrial projects were designed. These two projects provide different types of operations which prove the control and decision-making system of the intelligent algorithm for any industrial project. The first project that was designed in this chapter is an OPS (Onshore power supply) carne. The OPS crane has to supply the electric cable to the ship while the ship is moored at the port in order to supply the ship an onshore power. The design of the crane was included all the different stages, and the prototype operation. The second project is a factory that produces bases and lids, assemblies them to a finished product, packs the products and delivers them. This design of the factory was made by Factory I/O, and it includs all the different devices and machines. The control and decision-making system of the intelligent algorithms were applied on these two projects and showed very good results. In other words, the operation of the projects was safe, and it proved a very good control. Additionally, it proved its decision-making system for each situation according the operation situation, and found as user-friendly operator interface. Accordingly, the intelligent algorithms for the GEMMA Guide Paradigm were correctly developed, otherwise the experiments would not be possible to control the production process of the factory, and the operation of the crane.

7.1. Future work

The development of the Fuzzy Petri Nets intelligent algorithms based on the GEMMA Guide Paradigm constitutes of a first step towards future control and decision-making systems for the industrial applications. However, there is a pending work to improve the performance and usability of such intelligent control and decision-making system. In this regard, the intelligent algorithms that were developed in this thesis for controlling any type of industrial application provide a starting point for further research.

Multiple improvements can be suggested for the Fuzzy Petri Nets intelligent algorithms, and several future projects could bring added value to the intelligent control systems. Future work concerns deeper analysis, new proposals to try different methods, or simply curiosity. When the complexity of the task increases, the use of other approaches could be advantageous.

This thesis has been focused on the use of Fuzzy Petri Nets approach for developing the intelligent algorithms for revisiting the GEMMA Guide Paradigm. However, different approach can be used in order to have a powerfuller control and decision-making system that will allow to deal with more complex tasks and provide a control system for more types of applications. Artificial neural network (ANN) approaches can be used to improve the intelligent algorithms. ANN approaches combine some complexity techniques from statistics with machine learning that is mimicking the human intelligence. One ANN approach is Threshold Logic Units (TLU), it is a form of machine learning model that consist of a single input unit, corresponding weights and activation function. It is able to mimic the functionality of a biological neuron at high level. By this approach, the control and decision-making can be improved due to its deep learning capability and to deal with more complex tasks and applications. Obviously, the use of other types of approaches could be investigated since they have an important influence on the results obtained at the end.

The intelligent algorithms were developed mainly for control and decision-making system of industrial applications, such as operation of machines and production lines. Nevertheless, they could provide a good control and decision-making system for different type of application, such as autonomous mobile robots. Autonomous mobile robots require a very complex control due to their needs to deal with unexpected situations during the tasks that they should perform. The intelligent algorithms based on the GEMMA Guide Paradigm could be integrate with the autonomous mobile robot in order to provide them a powerful control and an appropriate decision-making system, and to deal with their needs by their learning ability. Moreover, the learning capability of these algorithm can deal better with the unexpected situation that may occur during the autonomous mobile robot's navigation. The modern automatization applications become more complex due to the need of several autonomous mobile robots that have to work in parallel in order to perform complex tasks. For this reason, the communication between the autonomous mobile robots is critical in order to be able to perform the required task together. The implementation of the intelligent algorithms based on GEMMA Guide Paradigm could improve the robots' communication and provide a better control and decision-making system for each robot, and robots' group.

Appendix

A Publications

The contributions of this thesis along with other activities developed during the Ph.D. program had led to the following scientific publications.

Articles:

- Oz Yakrangi, Roque J. Saltarén Pazmiño, Juan S. Cely, Alejandro Rodríguez, Cecilia E. García Cena, Pablo San Segundo Carrillo, Julio De La Cueva and Amir Shapiro. *An Intelligent Algorithm for Decision-Making System and Control of the GEMMA Guide Paradigm Using the Fuzzy Petri Nets Approach*. Electronics 2021, 10, 489. https://doi.org/10.3390/electronics10040489
- Juan S.Cely, Roque Saltaren, Gerardo Portilla, Oz Yakrangi, and Alejandro Rodríguez-Barroso. *Experimental and Computational Methodology for the Determination of Hydrodynamic Coefficients Based on Free Decay Test: Application to Conception and Control of Underwater Robots.* Sensors 2019, 19(17), 3631; https://doi.org/10.3390/s19173631
- Gerardo Portilla, Roque Saltaren, Francisco Montero de Espinosa, Alejandro R.Barroso, Juan Cely, and Oz Yakrangi. Dynamic Walking of a Legged Robot in Underwater Environments. Sensors 2019, 19(16), 3588; https://doi.org/10.3390/s19163588
- Alejandro Rodríguez-Barroso, Roque Saltaren, Gerardo A.Portilla, Juan S.Cely, and Oz Yakrangi. *Potential Energy Distribution of Redundant Cable-Driven Robot Applied to Compliant Grippers: Method and Computational Analysis*. Sensors 2019, 19(15), 3403; https://doi.org/10.3390/s19153403
- Gerardo Portilla, Roque Saltaren, Alejandro Rodríguez Barroso, Juan Cely, and Oz Yakrangi. A Sensor Based on a Spherical Parallel Mechanism for the Measurement of Fluid Velocity: Experimental Development. VOLUME 7, 2019; 10.1109/ACCESS.2019.2892819
- Roque Saltaren, Alejandro Rodríguez Barroso, and Oz Yakrangi. *Robotics for Seabed Teleoperation: Part-1—Conception and Practical Implementation of a Hybrid Seabed Robot*. VOLUME 6, 2018; 10.1109/ACCESS.2018.2876040

Patents

- Saltaren Pazmiño, Roque Jacinto; Cely Gutierrez, Juan Sebastian; Rodriguez Barroso, Alejandro; Portilla Tuesta, Gerardo Alejandro and Yakrangi, Oz. *Sistema subacuático para labores de acuicultura.* Patent No. ES-2729816-A1, Universidad politécnica de Madrid, Spanish Patents and Trademarks Office, Nov 2019.

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