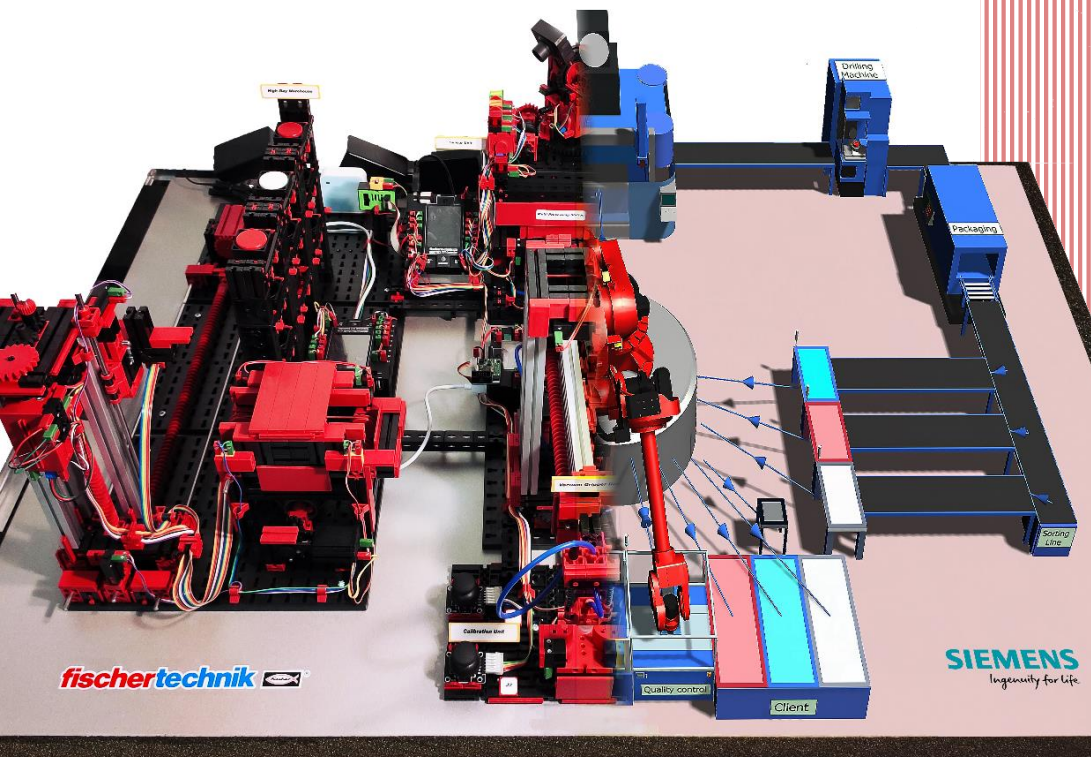# Industry 4.0 through Fischertechnik and a Digital Twin

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Title   **Industry 4.0 Through Fischertechnik and a Digital twin**

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Abstract German

Die Hochschule Luzern - Technik & Architektur hat ein Modell der Fischertechnik 4.0 Training Factory für Schulungszwecke erworben. Dieses Bachelorarbeitsprojekt zielt darauf ab, das Simulationsmodell der Fischertechnik 4.0 Training Factory im Kontext der 4.0-Industrie zu analysieren. Die 4.0 Training Factory ist eine Smart Factory, die eine automatisierte Produktionslinie emuliert und verschiedene 4.0 Industry-Funktionen einführt. Zusätzlich und im Zusammenhang mit dem Thema 4.0-Industrie wird das Fischertechnik-Modell durch einen Digital Twin oder eine digitale Replik ergänzt, die mit der Siemens Tecnomatix Plant Simulation-Software für die Analyse erstellt wurde. Begleitend zum Digital Twin werden ein Anfangsszenario und ein To-Be-Szenario des Fischertechnik-Modells erstellt, um die Analyse im selben Kontext zu ergänzen.

Die Analyse basiert auf den drei erstellten Szenarien und zielt darauf ab, das Potenzial beider Tools für Schulungszwecke aus akademischer Sicht aufzuzeigen.

Die Fischertechnik 4.0 Training Factory ist aufgrund der verwendeten neuen C ++ - Software äußerst vielseitig, da hierdurch verschiedene 4.0-Funktionen und ergänzende Geräte zur Verbesserung des Tools eingeführt werden können, z. B. Node-RED, indem das MQTT-Netzwerk und ein Raspberry Pi-Gerät verwendet werden. Aufgrund des Mangels an C ++ - Code-Programmierkenntnissen und der Verwendung von Raspberry Pi konnten diese Aspekte jedoch nicht weiterentwickelt werden.

Im Gegensatz dazu wurde die Siemens Tecnomatix-Software anhand der drei Szenarien als Digital Twin-Software analysiert. Der Digital Twin-Zyklus und sein Potenzial werden anhand dieser Szenarien dargestellt, in denen Implementierungen durchgeführt und Verbesserungen anhand verschiedener KPIs visualisiert werden.

Als Ergebnis der Untersuchung, die das folgende Dokument realisiert und ergänzt, wurden zwei Handbücher erstellt, um beide Tools zu verstehen und ihre Verwendung zu vereinfachen.

Abstract English

The Hochschule Luzern – Technik & Architektur has acquired a Fischertechnik 4.0 Training Factory model for training purposes. This Bachelor Thesis project aims to analyse the Fischertechnik 4.0 Training Factory simulation model within the 4.0 Industry context. The 4.0 Training Factory is a Smart Factory which emulates an automated production line and introduces several 4.0 Industry features in it. Additionally, and related to the 4.0 Industry topic, the Fischertechnik model is complemented with a Digital Twin, or digital replica, created through the Siemens Tecnomatix Plant Simulation software for the analysis. Accompanying the Digital Twin, an Initial scenario and a To-Be scenario of the Fischertechnik model are also created to complement the analysis within the same context.

The analysis is based on the three scenarios created and aims to show the potential of both tools for training purposes through an academic perspective.

The Fischertechnik 4.0 Training Factory is highly versatile due the new C++ software used, as this allows to introduce different 4.0 features and complementary devices to enhance the tool, like Node-RED by making use of the MQTT network and a Raspberry Pi device. However, due the lack of C++ code-programming knowledge and Raspberry Pi use, these aspects could not be further developed.

By contrast, the Siemens Tecnomatix software has been analysed as a Digital Twin software by using the three scenarios. The Digital Twin cycle and its potential is presented through these scenarios, where implementations are materialized, and improvements visualized through different KPIs.

As a result of the investigation realized and complementing the following document, two manuals have been made to understand and make use of both tools easier.

Place, date   Horw, 08 of June, 2020

Glossary

API	**Application Programming Interface**
CPS	**Cyber-Physical System**
DPS	**Delivery and Pickup Station**
FIFO	**First In First Out**
HBW	**High-Bay Warehouse**
HSLU	**Hochschule Luzern**
IoT	**Internet of Things**
KPI	**Key Performance Indicator**
MPO	**Multi-Processing Station**
MQTT	**Message Queuing Telemetry Transport**
PLC	**Programmable Logic Controller**
PLM	**Product Lifecycle Management**
SLD	**Sorting Line**
SSC	**Environmental and Surveillance Station**
VDI	**Verein Deutscher Ingenieure**
VGR	**Vacuum Gripper Robot**
VSM	**Value Stream Mapping**

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1. Introduction

This chapter serves as an introduction to the thesis. The necessary background information is going to be presented, followed by a complete problem description, the expected results and the scope given to the problem at issue. The chapter concludes with a description of the document's structure.

1.1. Starting Situation

A simulation model has been acquired by the Lucerne University of Applied Science - Technik & Architektur (HSLU - TA) for training purposes. This simulation model replicates in a small and comprehensive scale a generic industrial production line, integrating up-to-date digital features. The model, called *Training Factory Industry 4.0* is provided by the company Fischertechnik GmbH, based in Germany.

1.2. Project context

The context of the project is strongly related to the fourth industrial revolution.

It is a fact that the 4.0 Industry is changing industries significantly. These changes introduce new concepts, characteristics and behaviours within machineries, production lines and complete supply chains. As the industrial environment changes, there is a need to train the future engineers and prepare them for the immediate future. Therefore, the HSLU has acquired the *Training Factory Industry 4.0*, which could be ideal for learning these concepts.

1.3. Aim of the Thesis

The aim of the thesis is to analyse and prepare the Fischertechnik 4.0 Training Factory for academic usage. Since different modules of the HSLU have the intention to introduce the factory to the lessons, a wide perspective is going to be given for its usage.

Furthermore, a Digital Twin of the Fischertechnik 4.0 Training Factory is going to be created as a counterpart to the mentioned tool, for the same academic usage. The Digital Twin is specifically built for the Operations Management module or related modules.

The project objectives are the following:

- Provide a manual of Fischertechnik 4.0 Training Factory for academic purposes in order to explain how to configurate the model, how to simulate its basic scenario and how to extract data from this model.
- Fulfil an analysis of the Fischertechnik 4.0 Training Factory for an academic purpose.
- Introduce Node-RED as a complementary tool for Fischertechnik 4.0 Training Factory.
- Provide a manual in order to use Siemens Tecnomatix Plant Simulation for academic purposes. How to modify different scenarios and extract relevant data from these scenarios to facilitate further analysis.
- Provide a basic Digital Twin of Fischertechnik 4.0 Training Factory, as well as an antecedent and a future scenario related to the Digital Twin with their applicable analysis.

1.4. Project deliverables

The Bachelor Thesis deliveries consist of the thesis document, the handout of two booklets, a booklet for the Fischertechnik 4.0 Training Factory model usage and a booklet for the Siemens Tecnomatix usage. Both for academic use. Plus, a proper analysis for both tools, as commented on the previous subchapter, and the three different Siemens Tecnomatix Plant Simulation scenarios created.

The handout is done before 08/06/2020.

1.5. Thesis structure

This thesis follows a conventional structure through the document, commonly used in this kind of dissertations. Starting with the presentation of materials and methods used, the research and analysis of the research question, and finally presenting results and comments on the results.

Chapter 2 is the chapter where information sources, methodology, and explanation of the tools used are showed. This chapter contains essential information for the comprehension of the following chapters.

Chapter 3 is the chapter where the insides of the Fischertechnik simulation model are going to be presented. Starting from an introduction and general perspective to a technical aspect. Additionally, an analysis for academic use is going to be provided.

Following chapter 3, Chapter 4 is going to provide the Siemens Tecnomatix Plant Simulation insides. Again, from an introduction perspective to a more technical aspects overview. Furthermore, as the project contains a Digital Twin creation of the physical simulation model, this chapter is going to show the Digital Twin of the Fischertechnik model, also including a previous scenario and a future scenario. The Digital Twin corresponds to the *As-Is* scenario as it represents the current state of the simulated object, the previous scenario is an initial and early version of the Fischertechnik 4.0 Training Factory, and the future scenario represents a *To-Be* version of the physical simulation model.

The Figure 1.1 illustrates the different scenarios in the project, separating the physical tool with the simulation software. The arrows reflect a theoretical timeline, as the starting point of the Fischertechnik model is a theoretical initial scenario. Then, from the Fischertechnik model, a Digital Twin is created, who serves for simulating and applying several changes in parameters in a To-Be version of the Digital Twin. These changes should be applied to the Fischertechnik model at the end to finish the improvement cycle to visually observe the improvements made in the virtual model into the real-world production line.

Then, the results of different simulations on the virtual scenarios and the Fischertechnik model are provided in Chapter 5, according to several KPIs selected for the comparison. This allows an analysis of the scenarios. More information is given in the according chapter.

Chapter 6 is a chapter which explains the booklets provided and gives a better comprehension for a better usage in the future.

Finally, Chapter 7 is going to show a discussion on the results given, the usage of both tools for academic usage, recommendations, and personal experiences, as a final summary of the project.
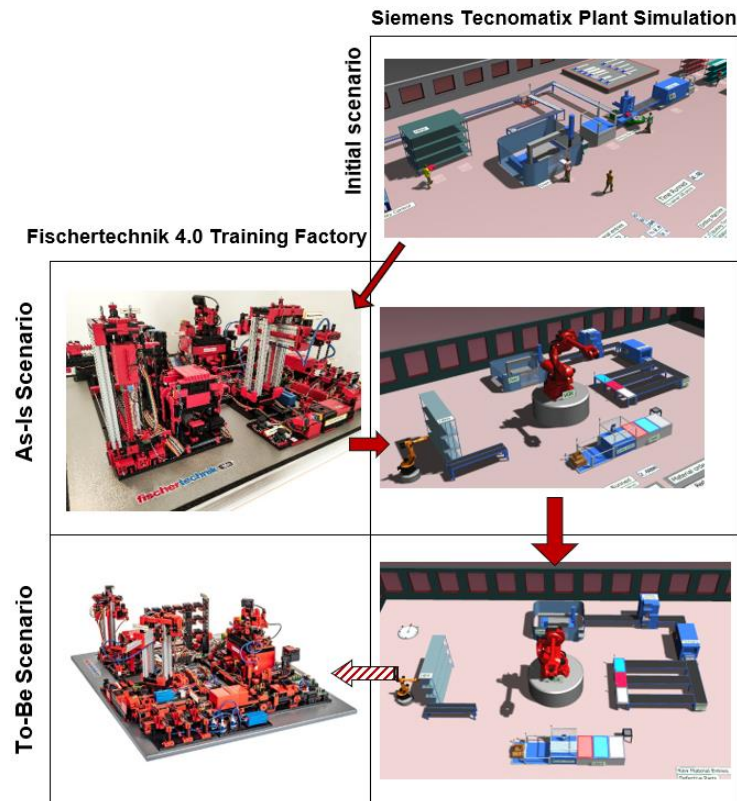
Figure 1.1: Scenario simulation according to the Fischertechnik 4.0 Training Factory[1]

- The project aims to analyse Fischertechnik 4.0 Training Factory combined with a Digital Twin software in the context of the Industry 4.0

- The structure of the Thesis is the following:
    - Chapter 2: Method and Material
    - Chapter 3: Fischertechnik 4.0 Training Factory
    - Chapter 4: Siemens Tecnomatix Plant Simulation
    - Chapter 5: Results
    - Chapter 6: Academic Booklets
    - Chapter 7: Discussion

- Two manuals are provided for the better comprehension and usage of both tools

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[1] Figure 1.1: Graphical overview to locate the different scenarios in a timeline according Fischertechnik 4.0 Training Factory. Columns represent the tool used; the rows represent the status. Source: Own pictures and Fischertechnik webpage.

2. Materials and Methods

The Materials and Methods chapter is focused on the methods used to achieve the targets and objectives of this project. Additionally, this chapter is going to focus in providing important information and specifications needed in future chapters.

2.1. Methodology overview

The methodology overview shows the gradual process followed during the duration of the project in a generic perspective. Figure 2.1 allows to have a graphical view of this process for better comprehension.
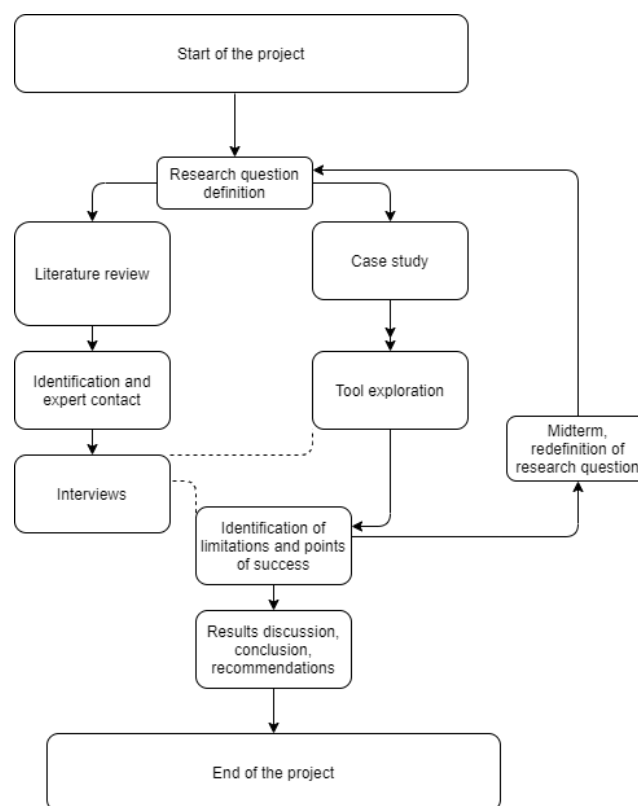
Figure 2.1: Procedure structure[2]

At the start of the project the research question is defined, including the aim of the thesis and proposed objectives. This initial part forms the basis for the next steps, which are literature review and study case. The literature review consists of a research to gather information related to the research question. This part generally begins with a generic overview and deeps in with the progress of the project. On the other hand, the part of the case study intends to examine the tool through research and exploration of its functionalities. In this particular case, the tool represents both the 4.0 Training Factory and the Siemens Tecnomatix software.

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[2] Figure 2.1: Graphical overview of the methodology applied during the project. Own source

Following the previous stages, after the case study, a deeper tool exploration is needed. Simultaneously, after literature review, experts in field are identified and first contacted[3]. This leads us to the interview realization section, where interviews are hold with identified experts. Interviews are commonly made in this project around the topic of the tool at issue, as there is a need to understand the tool deeply to use and analyse it. Therefore, the interview stage and the tool exploration stage are closely related.

The deep tool exploration, added with the output given by the expert interview, provide a solid basis to determine limitations and success points related to the initial research question and aim. At this point, a midterm discussion was made related to the previous output, where a discussion lead to a redefinition of the aim of the thesis and readjust of research question. This change provoked the need to return to the initial section of the diagram and repeat the process.

Finally, with the new identified limitations and points of success, results are provided, as well as a conclusion and recommendations. This leads to the end of the project.

The coming subchapters are going to provide initial concepts and definitions related to the research question[4] and further details on the methodology process for a better understanding of the diagram.

2.2. Research

2.2.1. Literature research

Literature research is an essential method for this project, as an important part of research aim is analysis. A legitimate analysis must be made with a solid basis of information. Different literature research sources can be used in order to obtain data and information. Some of the most common sources, used in this project are:

- Search engines. This widely used tool is helpful with providing initial information on the different topics and gaining a general knowledge and context about these topics. Search engines are also additional links to experts for later interviews. A disadvantage of this tool is the risk of using fake or manipulated sources and references. Through this specific tool, projects related to Fischertechnik made in prestigious companies such as SAP, IBM, or Siemens, have been found. These projects have been used as guidelines for the thesis and have been useful for the expert interviews.

- Libraries and electronic databases. This methodology of research is a common approach for research, as it provides specific and contrasted information related to a concrete topic. This source of information has been limited to electronic databases, as due the Covid-19 situation, libraries have been closed. For this type of research, *Iluplus.ch* and *Scribd* has been used to gather different information.

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[3] Identification and expert contact need to be on separate sections with the interview realization in the Thesis structure diagram, as only a small portion of experts were willing to undertake interviews.
[4] See chapter 1.2: Research question

2.2.2. Interviews

An interview is a common approach used to gather specific information regarding a research topic from an expert. This approach consists of a primary source of qualitive data (Kvale, S. 1996) and has been therefore used numerous times during the duration of this project. It is important to comment that the unprecedented Covid-19 situation has not affected the interview normal procedure as the interviewed experts were located in different regions or countries, making face-to-face interviews unfeasible.

Interview guidelines offered by different subjects in the HSLU, as *International Project* (imparted by Christine Grimm) or *Product Management* (imparted by Christoph Imboden) have been followed for this task.

The most common procedure taken for these interviews were online emails, as it is practical when schedules do not match, and it allows the expertise to answer calmly and correctly. However, online video conference has been made when the research topic needed an immediately feedback. This mainly corresponds to the Fischertechnik 4.0 Training Factory as the expertise had to evaluate the response of the tool.

The research question of the interviews was mainly focused on the functionality and comprehension of both tools used, Fischertechnik's 4.0 Training Factory and Siemens Tecnomatix Plant Simulation 15.

The experts that were interviewed were Mr. Steiger (Fischertechnik Development department), Mr. Schubert (Fischertechnik Sales Director), Mr. Wunderli (Siemens Digital Operations), Mrs. Watson (Lanner Simulation), Mr. Rundholz (SAP Innovation Expert) and Mr. Bangsow (Siemens Tecnomatix expert).

The interviews are transcribed in the Appendix.

2.2.3. Other sources of information

A recommendable and useful information source that has been used in this project for a better comprehension and understanding of Fischertechnik 4.0 Training Factory and the Digital Twin software have been the official forums and communities of the companies.

These official forums act as a large know-how database for both tools, as they record common issues, solutions, examples, and tips. Another advantage of this information source is the presence of several experts and advanced users, who give feedback and discuss the issue. The consequence of this is a contrasted information source as several experts can give different approaches on a problem or issue. These forums also act as and replicate a technical support related to the know-how of these tools, being more efficient than the conventional technical support, as problem solving is done in less time, and sometimes, more efficiently.

2.3. Industry 4.0 Concepts

This subchapter serves to understand the importance and usefulness of the 4.0 Training Factory model within the Industry 4.0 and the current industrial context. It represents the summary of the initial research made in the Literature review[5].

2.3.1. Industry 4.0

Industry is at present immerse in a significant technological change called *4.0 Industry*. This term, first mentioned by the German Federal Government in 2011 (Hermann et al. 2015), has no consensus in its complete definition, but in essence it represents the global trend in industrial processes towards data exchange in manufacturing processes and complete machine automation. This terms also involves four key aspects: *Cyber-Physical Systems* (CPS), *Internet of Things* (IoT), *Internet of Services* (IoS) and *Smart factories*. However, Porter (2014) stated that the most important aspect is the CPS, as IoT, IoS and Smart Factories derive and are possible thanks to this first concept.

Cyber-Physical Systems are engineered systems which integrate computation, networking, and physical processes. This includes feedback and reaction loops where computations affect physical processes and vice versa. Currently, CPS are becoming autonomous in higher degrees thanks to the large amount of data that is been recollected in different fields and activities in recent years and here is where the potential of the concepts of CPS relies on, data. Further, higher degrees of automation in industrial production calls for stronger networking and smarter information at all levels of production and is briefly exposed throughout the thesis.

2.3.2. Simulation concept

The definition of simulation, in its shortest version, is defined as the emulation of a system. This emulation includes dynamic processes that are represented in a model or scenario where a person can experiment with. It aims to achieve results that can be transferred at a certain degree to a real situation (VDI, Association of German Engineers). In addition, simulation defines the preparation, execution, and evaluation of carefully directed experiments within a simulation model.

The VDI also include common and essential steps that need to be done to execute a simulation study and are followed throughout the project:

Firstly, a data recollection is needed from a real scenario or situation. After, the creation of the simulation model is done according to the aims of the simulation studies and the initial data recollected. Then, execution of the simulation needs to be done. This will produce results and provide information. Therefore, the next step is an interpretation of the information, transforming it to relevant data, that is needed as a base for decisions, which is the last step of the simulation study.

Simulation gains importance in the fourth industrial revolution, since two key aspects are provided: The need for simulation, as complex systems need to be tested beforehand to avoid complications, and the simulation possibility, as advanced technology makes complex simulation possible. A simulation software is going to be used during the project to simulate a Digital Twin, and consequently, expose an interesting 4.0 Industry feature.

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[5] See Figure 2.1: Procedure structure

However, the Digital Twin concept is strongly related to the simulation concept and is key in the realization of this project. Therefore, there is a need further explanation. See the next section.

2.3.3. Digital Twin concept

Conceptually, a Digital Twin is a dynamic virtual representation of a physical object or system. The Digital Twin uses real-world data, simulation or machine learning models and is combined with data analysis. This enables understanding, learning, and reasoning of the physical object or system represented (IBM TCG, 2019).

As a concept, Digital Twin first appears in 2002, referred as the Mirrored Spaces Model, in executive PLM courses at the University of Michigan. With no relevance in early years, its importance has increased exponentially due to the technology outbreak, and it has become imperative to business today. So it is that it has been named in Gartner's Top 10 Strategic Technology Trends in 2017, 2018 and 2019.

Current Digital Twins are not only dynamic virtual representations, they are also an instrument which incorporate the most known 4.0 Industry concepts, such as intelligent data, machine learning and the Internet of Things (IoT).

There is an important difference between a Digital Twin and a simulation. Both are virtual representations, who try to emulate real-world scenarios. The key aspect that distinct them is the interaction with the physical world. Commonly, Digital Twins are imagined as highly detailed simulations, which include countless parameters and provide exceptional results, they are imagined as sophisticated simulations. However, the difference relies on the real-time data feedback, as these representations measure constantly real-time data, which simultaneously feed the system to improve their performance and allow them to provide more reliable results.

These two concepts are not identical, neither antagonistic. Further discussion is going to appear in next chapters.
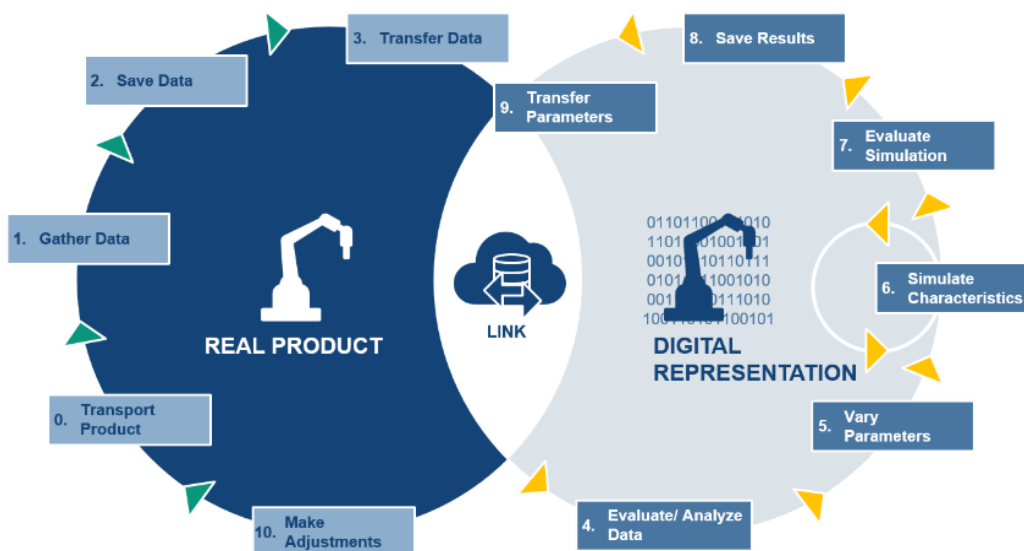
Figure 2.2: The Digital Twin Cycle[6]

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[6]Figure 2.2: Visual representation of the interaction between the Digital Twin and the physical world. Source: HCL Technologies

Table 2.1 shows the main differences between *simulation* and *Digital Twin* in a more visual approach for better understanding.

Simulation	Digital Twin
Static Need manual change in parameters	Active Changes through real-time data feedback
Answers the question: What can happen? (What-if scenario)	Answers the questions: What may happen, and what is happening? (What-is scenario)
Generally used for design and optimization, separately.	Used for the complete lifecycle: design, execute, change, decommission.
Product-focused	Business-focused
Lower level of detail	Higher level of detail

Table 2.1: Simulation and Digital Twin differences[7]

The concepts related to the project have been explained. The next subchapters are focused on the tools used for the fulfilment of the project.

2.4. Fischertechnik 4.0 Training Factory

Fischertechnik is a German company based in Stuttgart. This company provides, among other products, physical simulation factories used for learning purposes and scenario simulations. The most advanced model so far is Fischertechnik *4.0 Training Factory,* which integrates multiple Industry 4.0 features used in real-world industrial plants.

The simulation model, perhaps of not being virtual, has the availability to simulate a standard production plant. The production plant is completely automated and digitised with the help of 20 sensors (colour recognition, position detection and environmental sensors). Different inputs can be given to the factory, and with the help of the sensors, diverse outputs can be measured or recorded.

The model is composed by different sections or modules which are interconnected. These modules contain and make use of the sensors, 12 different motors, 2 conveyor belts, different pneumatic systems, 3-D coordinates, ejectors, machine status lightening, and a NFC reader, among different specifications. The size of the model is 110x80x40 cm.

As mentioned, the Fischertechnik 4.0 Training Factory has been acquired by the HSLU for training purposes. The simulation model is indispensable in the elaboration of the thesis, as it consists of the main precondition and premise.

Chapter 3 is going to provide more information related to this tool

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[7] Table 2.1: Differences between "Simulation" and "Digital Twin". Own creation.
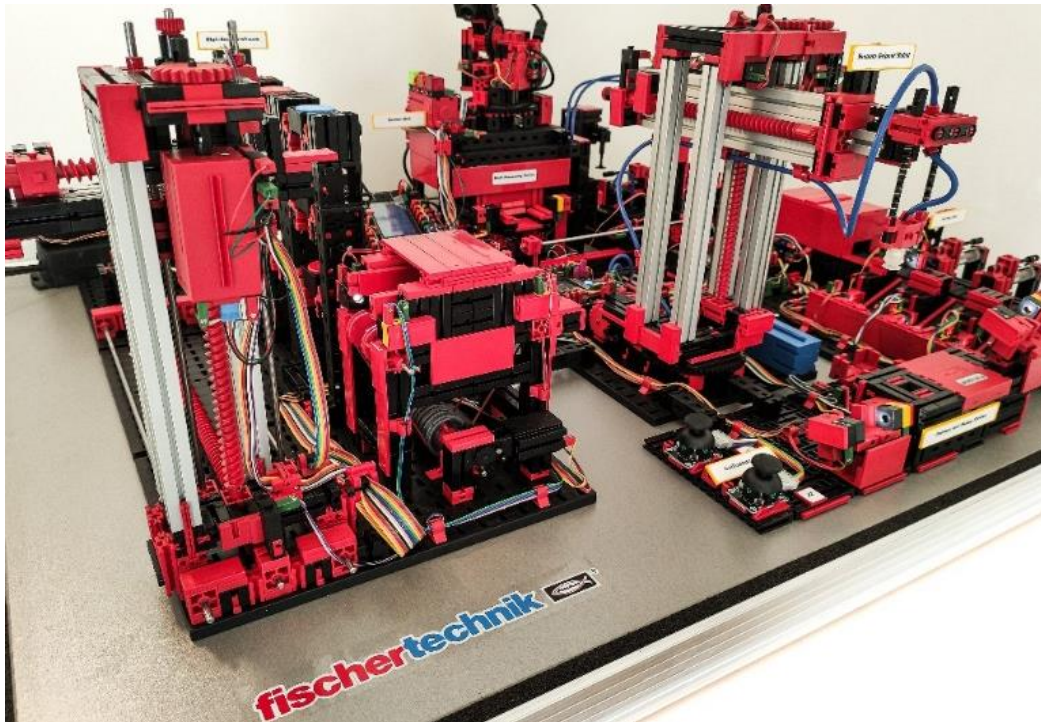
Figure 2.3: Fischertechnik 4.0 Training Factory[8]

2.5. Selection of the Digital Twin Software

A key aspect of the project, besides the Fischertechnik simulation model, is the Digital Twin representation of the Fischertechnik 4.0 Training Factory. This Digital Twin needs to be done in a specialized software which allows the recreation of the physical simulation model.

As there was no software specifically provided for the completion of this task, it required a market analysis. The market analysis aim was to explore different solutions in the market regarding Digital Twin possibilities in order to complete the task of replicate and emulate the 4.0 Training Factory accurately. The inside of this market analysis is explained in the next section.

2.5.1. Digital Twin options

A first generic market approach for Digital Twin software has been made through research. This market research provided several software, each solution with different characteristics. Continuing then with a deeper analysis, direct contact with the companies was intended to make for the search of viable solutions for the usage of their software.

The different possibilities that were found through research are represented in Table 2.1. These are examples of the multiple solutions available in the market. The table includes the most important advantages and disadvantages from an academic and training perspective of the solutions found after the corresponding market research and company contact.

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[8] Figure 2.3: Fischertechnik 4.0 Training Factory acquired by the HSLU. Own picture.

Digital Twin	Advantage	Disadvantage
Microsoft Azure Digital Twin	Robust, well-established in the market, professional use	Professional use limits the academic use, due complexity, and pricing. Demo version is not useful.
Bentley iTwin	Robust, professional use. Combined know-how with Siemens.	Its professional use limits the academic use, due to complexity and pricing.
IBM Watson IoT	Robust, well-established in the market, professional use. Market leader.	Its professional use limits the academic use, due to complexity and pricing.
Lanner Simulation Witness	More personalized, open to talk. Useful and representative Digital Twin.	Pricing.
Siemens Simcenter	Robust, for professional use. Siemens provides multiple solutions to IT topics.	No academic license available.
Siemens Tecnomatix Plant Simulation	Simple and effective. In the borderline between Digital Twin and simulation.	Student license available at the HSLU.
SIMIO	Simple. Easy for learning. Provides student license.	Not Digital Twin. Simulation with a poor 3D modelling.
JaamSim	Simple. Easy for learning. Free usage.	Not Digital Twin. Simulation with a poor 3D modelling.

Table 2.1: Digital Twin market search[9]

With these results, the definition of important aspects or criteria need to be defined for a proper decision making, as the selection of the software is essential for the output of the project.

2.5.2. Criteria for selection

The criteria used for the selection of the Digital Twin software is various, as different aspects are considered. Simultaneously, the attributes or specific criteria have a different degree of importance within the project, and this importance is also going to be reflected.

Table 2.2 recollects the results for the decision making. The top row of the table represents the points or criteria that are analysed during the process. These points include a multiplier factor, or weight, of 0.6, 0.8, 1, 1.2 or 1.4 according the importance given to the point. On the other hand, the left column represents the selection made of the Digital Twin software.

The result is a matrix where the software is analysed according to the criteria with a score from 1 to 10, using integer numbers.

After the different scores given in the matrix, according to the software and the aspect analysed, total punctuations are calculated in Table 2.3. The results are shown with and without the weights and ordered according the score obtained.

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[9] Table 2.1: Digital Twin market options found with the market research. Own source.

	1.Interface design (x0.8)	2.Interface simplicity (x1.4)	3.Pricing (x1.2)	4.Fast integration (x1.2)	5.Community development (x1.4)	6. Professional use (x0.6)	7.Ease contact (x0.8)	8.Public database (x1)	9. Compatibility (x0.8)
Microsoft Azure	7	7	1	6	6	9	2	2	8
Bentley iTwin	3	3	1	4	3	8	4	1	6
IBM Watson IoT	7	6	1	6	3	9	4	2	7
Lanner Simulation	6	5	3	7	1	7	6	4	4
Siemens Simcenter	7	5	3	6	8	8	8	5	7
Siemens Tecnomatix	7	7	10	8	8	8	8	5	7
SIMIO	6	9	9	8	6	5	6	9	3
JaamSim	2	9	10	9	2	3	5	9	3

Table 2.2: Digital Twin software selection[10]

	Results without weights	Results including weights
Siemens Tecnomatix	68	70
SIMIO	61	65.4
JaamSim	52	57
Siemens Simcenter	57	56.4
Microsoft Azure	48	47.6
IBM Watson IoT	45	42.8
Lanner Simulation	43	41.4
Bentley iTwin	33	30.6

Table 2.3: Digital Twin selection result[11]

With the resulting table, *Siemens Tecnomatix Plant Simulation* has been selected for the elaboration of the Digital Twin. The main factors that lead into the decision where:

- Siemens Tecnomatix has got higher 3D modelling flexibility and a wider range of tools that can be used in the simulation in comparison with SIMIO and JaamSim.
- The free usage through the student license provided.
- Well-established in the professional market, perhaps still ideal for academic use.
- Customizable in terms of simulation creation, this means not only an improved scenario could be created, but also a previous one.

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[10] Table 2.2: The numbers represent results of a qualitative analysis according to perceptions after the research made and do not include the factor. For priced software, demo versions have been used, if available. For more information, see in the Appendix. Own source.

[11] Table 2.3: Shows the results of Table 2.2. Own source.

After having presented the methods used to achieve the targets and the materials used for these targets, Chapter 3 is going to be focused on the simulation model of Fischertechnik, while Chapter 4 is going to be focused on the Digital Twin software selected. Both chapters are strongly related.

SYNOPSIS

- Research has been done mainly through three different tools: Search engines, expert interviews, and official forums or community webpages.

- The main difference between a Simulation software and a Digital Twin is the real-time feedback and the interaction between the physical and the virtual situation.

- Fischertechnik 4.0 Training Factory is a physical simulation tool that emulates automated production plants.

- Siemens Tecnomatix Plant Simulation has been selected for the creation of the Digital Twin among different market solutions.

3. Fischertechnik 4.0 Training Factory

Fischertechnik 4.0 Training Factory is a physical simulation model used for research, training and learning for high education levels and companies. This model is a small-scale representation of a so-called *Smart Factory*.

There are three versions of the Fischertechnik Simulation Factory: The Factory Simulation 9V (volts) and the Factory Simulation 24V and the 4.0 Training Factory. The first and second factory models are focused in industrial automation, being the second one powered by a PLC, and the third model is a 9V version (without PLC control) that includes the 4.0 Industry features. This last model is the model acquired by the HSLU.
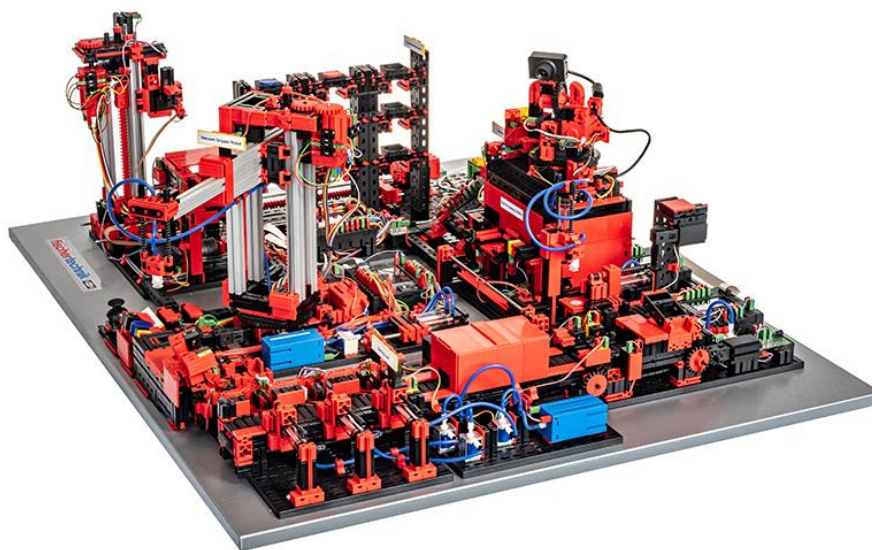
Figure 3.1: Fischertechnik Training Factory Industry 4.0.[12]

Firstly, the chapter starts with an introduction to the simulation model which explains the Fischertechnik 4.0 Training Factory for a better comprehension of this tool. Secondly, the insides are going to be explained, including an introduction to a complementary tool, and finally, the physical simulation model is going to be analysed according to an academic perspective, as the tool is going to be used for different modules.

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[12] Figure 3.1: The 4.0 Training Factory model. Source: official Fischertechnik website.

3.1. Introduction to the Training Factory Industry 4.0

With Fischertechnik 4.0 Training Factory 4.0, the automated industrial activities can be simulated, comprehend, and applied on a small scale before they are implemented on a larger scale as well as test the 4.0 Industry features previous to a larger implementation. This Fischertechnik model is a highly flexible, modular, and simultaneously a robust training and simulation model that can be used to carry out highly technical logistical processes.

Some of the features introduced in the newest version are:

- Connected and networked TXT controllers
- Fischertechnik Cloud integration using WLAN router (TP-Link)
- Environmental station with integrated camera
- NFC technology for workpieces identification
- C++ based software for better integration of additional 4.0 Industry features

The model has different distinctive parts or modules: The High-Bay Warehouse (HBW), Vacuum Gripper Station (VGR), the Multi-Processing Station (MPO), the Sorting Line (SLD), the Environmental Sensors (SSC) and, the Delivery and Pickup Station (DPS), as showed in Figure 3.2. Each section is controlled by at least one TXT controller who receives an executable file from a compiled C++ code. These files are uploaded manually or through the Fischertechnik Cloud. The TXT controller activates several functions inside the section according to this previous file and make the factory run.
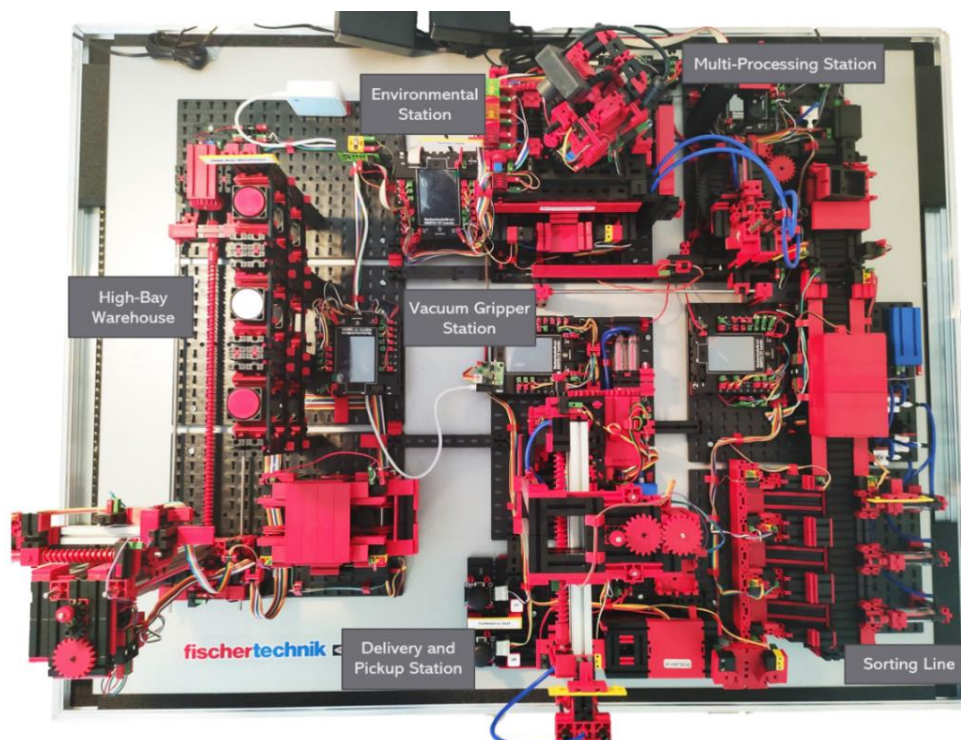
Figure 3.2: Fischertechnik 4.0 Training Factory layout[13]

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[13] Figure 3.2: Picture from above the Fischertechnik 4.0 Training Factory to visualize the layout. Own picture.

3.1.1.Production Process

The process followed by a workpiece from being supplied to being delivered to client is going to be explained. The collage made by specific pictures of the process helps to visualize it.

Figure 3.3: The Fischertechnik process[14]

1. To start the process, a workpiece needs to be supplied manually in the special location provided for it. The VGR crane detects the piece and grabs it to transfer it to the quality station.
2. The piece is checked in the quality station and its colour is detected through a sensor.

---

[14] Figure 3.3: shows with a collage made by pictures of the standard scenario the process followed by the Fischertechnik 4.0 Training Factory to deliver pieces to the client. Own pictures are used.

3. After the quality control, the piece is transferred to the HBW entrance conveyor. Simultaneously, the HBW crane takes an empty container from the store and moves it to the same conveyor. The piece is loaded into the container and the container with the loaded piece is stored again. After this process, the client can make an order through the cloud, and if so, the specific piece is unloaded from the container and transferred with the VGR crane to the Multi-Processing Station.
4. The piece is loaded in the entrance of the Multi-Processing Station. It is processed within a station that emulates a kin or oven, and then it is transferred to the next process station.
5. The next process station emulates a polish or drilling machine. After this process, the piece is ejected to a conveyor belt and transferred to the next module by passing through a colour sensor that could emulate a final packaging machine.
6. After passing through the colour sensor, the piece is ejected of the conveyor belt depending on its colour and stored waiting to be picked up.
7. The VGR crane picks this processed piece up from its location. Then, the piece passes through a final quality control, which is the same station as the initial quality control.
8. Finally, the piece is transferred to the specific location for the client deliveries.

For a better understanding of the Fischertechnik simulation model and the processed followed see the Fischertechnik Booklet.

3.1.2. TXT controller overview

The workpiece process and the complete factory is controlled by TXT controllers, which are located in every section and are responsible for executing the files uploaded which contain the specific instructions. These files are executable files originated in the C++ compilation. The main TXT controller is located between the SSC and the WLAN router, this TXT controller is the only controller connected to the router, and consequently, to the Fischertechnik Cloud. In addition, this involves that the main code-programming file of the factory is also situated in this controller.
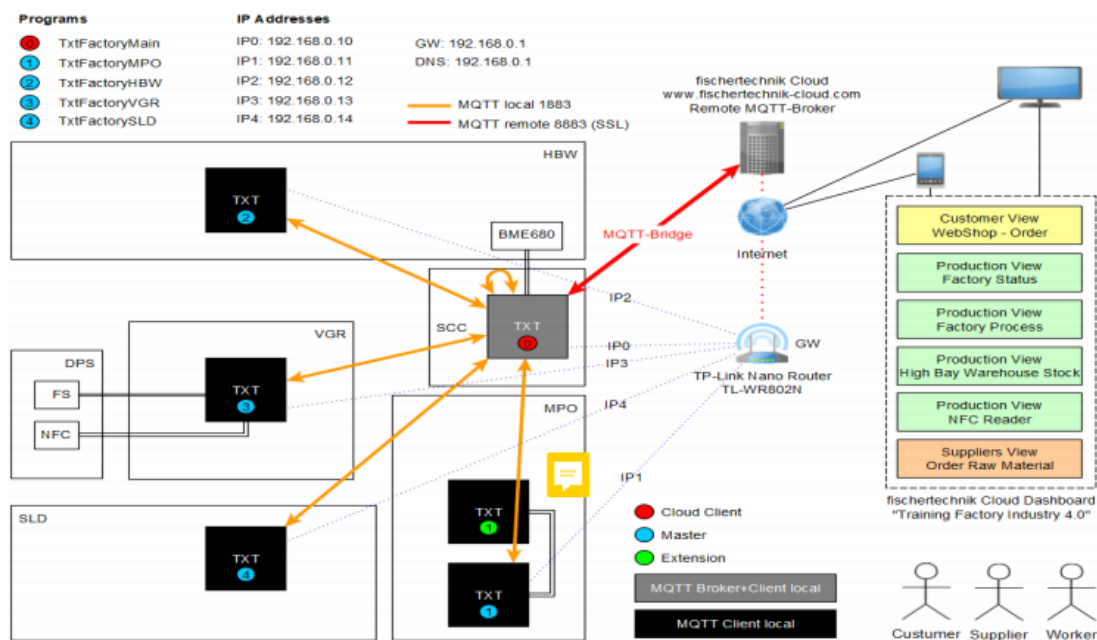

Figure 3.4: TXT controller diagram[15]

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[15]Figure 3.4: Explains the internal connection, with the Fischertechnik Cloud and between TXT controllers. Source: Fischertechnik Manual

The internal TXT controller diagram connection is viewable in Figure 3.4. The main TXT controller is remarked with the red colour, the other TXT controllers are the controllers from the other sections. Notice that the DPS section is the only section without TXT controller as it is connected to the VGR TXT controller, and the MPO module, because of having two different processes (oven and drilling machine), it requires two TXT controllers.

Once a device is connected to the TP-Link router of the Fischertechnik model it is possible to connect to each TXT controller of the model through webservers. These webservers have IP addresses, visible at the top of the image, and correspond to a TXT controller. Introducing the IP addresses to the browser and connecting to the TXT controller, allow you to upload executable files to the TXT controller.[16]

The TXT controllers are networked using MQTT (Message Queuing Telemetry Transport)[17].The information flows with the MQTT to the TXT main controller, and this sends it to the Fischertechnik Cloud. This messaging protocol is specific for machine-to-machine (M2M) communication and it enables to transfer data in messages form, this makes this M2M connection simple and reliable.

Finally, both TP-Link router and Fischertechnik Cloud are connected to the Internet, which enables to display the Fischertechnik Cloud Dashboard through several devices remotely to visualize real-time factory status, client order, inventory, or environmental information, among several options.

For more information, see the Fischertechnik Booklet provided with the thesis.

3.1.3. Fischertechnik Cloud

The Fischertechnik Cloud is the standard Cloud service offered with the Fischertechnik 4.0 Training Factory. It can be entered by connecting to the simulation model router and entering the Fischertechnik Cloud website. From the Fischertechnik Cloud, different windows can be displayed: The *Customer View*, *Production View* (factory status, stock, NFC read, factory process), the *Supplier View* and the environmental values.

The usability of the Fischertechnik Cloud is basic and considerably limited, as it only displays direct and generic information. The interface is simple, easy understandable; therefore it sacrifices interesting Key Performance Indicators (KPI), or features that could improve the factory. See Figure 3.5 to visualize the Fischertechnik Cloud Dashboard.

---

[16] See Fischertechnik Booklet for more information regarding this topic.
[17] MQTT is a M2M communication that stands out due to the easy implementation, low resource usage, high versatility, and guaranteed information transmission even in unstable networks. For its usage, a MQTT broker is needed who communicates with the different MQTT clients.
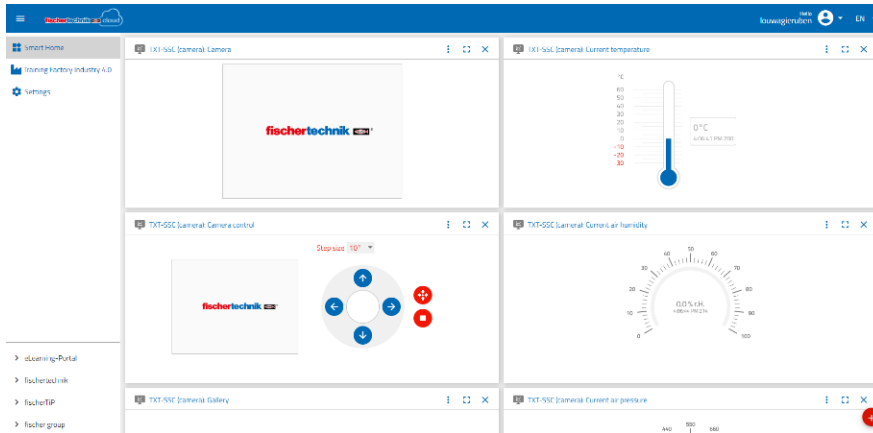
Figure 3.5: Fischertechnik Cloud example[18]

Contrasting with the Fischertechnik Cloud, the programming codes used internally during the process, for the simulation, are complex and for advanced users. The next subchapter is going to show the code-programming insides of the model.

3.2. Internal code-programming

As already commented, the internal code-programming is made with the C++ programming language. While the previous simulation models used the RoboPro software, which is an own software created by Fischertechnik, the newest version of the 4.0 Training Factory uses the C++ programming language internally due to several reasons.

The RoboPro software is a simple software created to control the different Fischertechnik models using intuitive flow charts. The software allowed to build personalized flows considering different variables and charts and is specially made for beginners who do not have experience with code-programming. Perhaps of having limited capabilities, it offered for beginner users easiness in terms of using and experimenting with the model.

Figure 3.6: RoboPro software example[19]

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[18]Figure 3.5: Screenshot of the Fischertechnik Cloud Dashboard. Own source.
[19]Figure 3.6: Displays an example of the interface used by RoboPro, following flow charts intuitively. Source: Fischertechnik WordPress.

Despite the easy and intuitive software used for previous versions, the software has been changed to C++. This is due the versatility offered by the C++ programming language, as this language, if it is known, offers more flexibility in terms of the factory usage. Additionally, C++ is suitable for the majority of 4.0 technology, allowing this technology being incorporated into the factory easily. An example is the use of MQTT, this feature allows data transfer of C++ executable files. Plus, the change to other programming languages such as Python can also be done through this new software.

The internal structure of the code-programming is complex and for advanced C++ users. The main folder is called *Txt Training Factory* and it includes C++ files, C Header files, C Source files and A files, organized in several different folders, which are explained in the Fischertechnik Booklet. There are 581 different files used in the software.

```
main.cpp

31   int hbw_lastCode = -1;
32   int mpo_lastCode = -1;
33   int sld_lastCode = -1;
34   int dsi_lastCode = -1;
35   int dso_lastCode = -1;
36
37   std::string sts_mpo;
38   std::string sts_hbw;
39   std::string sts_vgr;
40   std::string sts_sld;
41
42   // Version info
43   #define VERSION_HEX ((0<<16)|(8<<8)|(1<<0))
44   char TxtAppVer[32];
45
46   unsigned int DebugFlags;
47   FILE *DebugFile;
48
49   FISH_X1_TRANSFER* pTArea = NULL;
50
51   ft::TxtJoystickXYBController* pJoy = NULL;
52
53   ft::TxtPanTiltUnitController* pPtuControl = NULL;
54   float panpos_last = -100.f; //invalid
55   float tiltpos_last = -100.f;
56   float panpos_published_last = -200.f;
57   float tiltpos_published_last = -200.f;
58
59   ft::TxtMqttFactoryClient* pcli = NULL;
60   ft::TxtBME680* pBme680 = NULL; // extern in TxtBME680.cpp
61   ft::TxtCamera* pCam = NULL;
62
63   //uint16_t u16CountState1000ms = 0;
64   int16_t ldr_last = 0;
65   int mleds = 0;
```
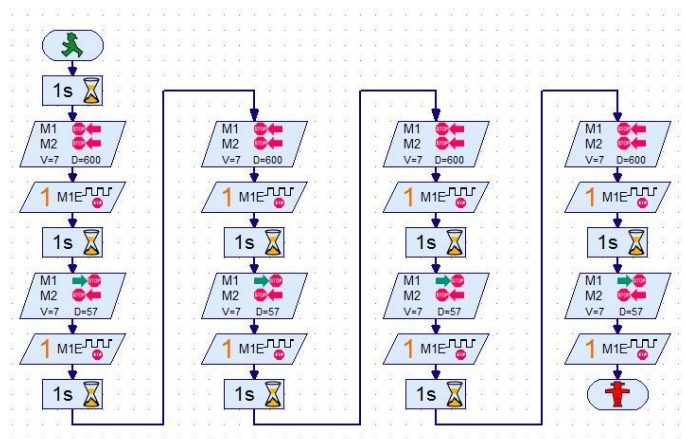
Figure 3.7: C++ example of the Fischertechnik model[20]

The recommended C++ program to visualize and modify the C++ files is *Eclipse for CDT*.

A useful tool for a better comprehension of the internal software is Github, which is a webpage where Fischertechnik has got an official section. This webpage acts as an open-source database, and Fischertechnik use it to upload changes and updates of the different C++ programs. The standard C++ files are provided through this website, Github, or a USB stick.

---

[20] Figure 3.7Figure 3.7 : Shows the initial lines of the Main C++ program used in the main TXT controller, the SSC station. Own source.

3.2.1. Github

As just mentioned, Fischertechnik has got an official section in Github[21]. This section is used to share with the Fischertechnik community updated files. The files are specifically related with the newest simulation model acquired by the HSLU. This section includes demo files for testing specific features of the Smart Factory such as a specific motor, or the 581 files used in the internal software, including the executable files for each TXT controllers.

Github is not only useful to check updates in the internal software, but it also allows to comprehend the internal structure of the software more easily as it includes different notations and comments. An important section is the *API Reference C/C++ Library* which helps to visualize the variables of the factory used in each specific file (like speed or coordinates).

An important section in Github Fischertechnik is the *Node-Red* folder, which is explained in the next subchapter as it allows to introduce a new feature within the factory and makes the factory more versatile.

3.3. Node-RED

Node-RED is a programming tool for wiring hardware devices, APIs (Application Programming Interfaces) and online services together under one tool. Node-RED makes use of *Node.js*[22] and is considered a low-code programming tool specifically created for event-driven applications. Its interface is similar to the interface used in Fischertechnik's RoboPro software.

Node-RED interacts with the factory through MQTT and can create intuitive flow charts using different variables of the factory. Essentially, as the Fischertechnik Cloud is basic and inflexible, it substitutes the Fischertechnik Cloud in the MQTT diagram (See Figure 3.4 in page 19) in order to personalize your own interface and extract personalized data.

The following pictures show the two interfaces provided by the Node-RED tool: The inside flowcharts build with different variables, and the result of the flowcharts displayed on a personalized dashboard. The dashboard shown is the standard dashboard provided by Fischertechnik with Node-RED.

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[21] Official Fischertechnik section in Github: https://github.com/fischertechnik
[22] Node.js is a JavaScript runtime designed to build scalable network applications. Node-RED is installed and run through this software.

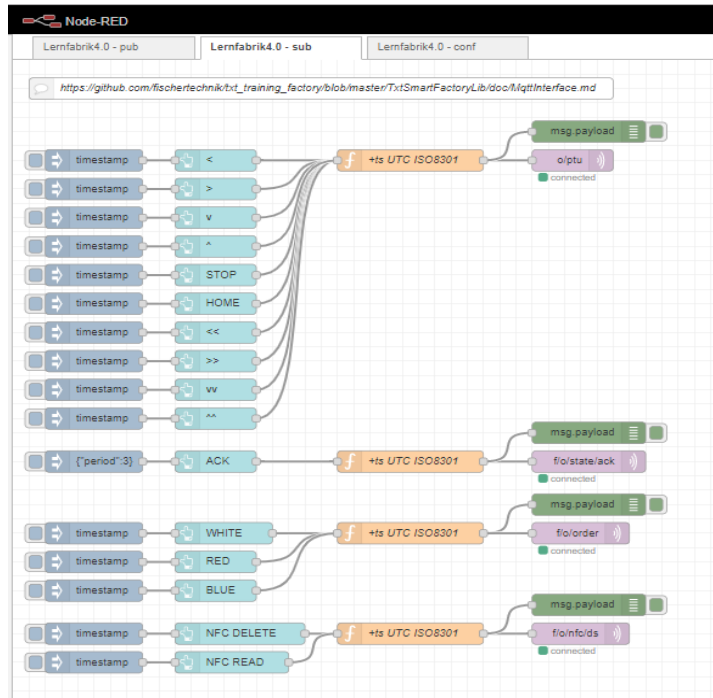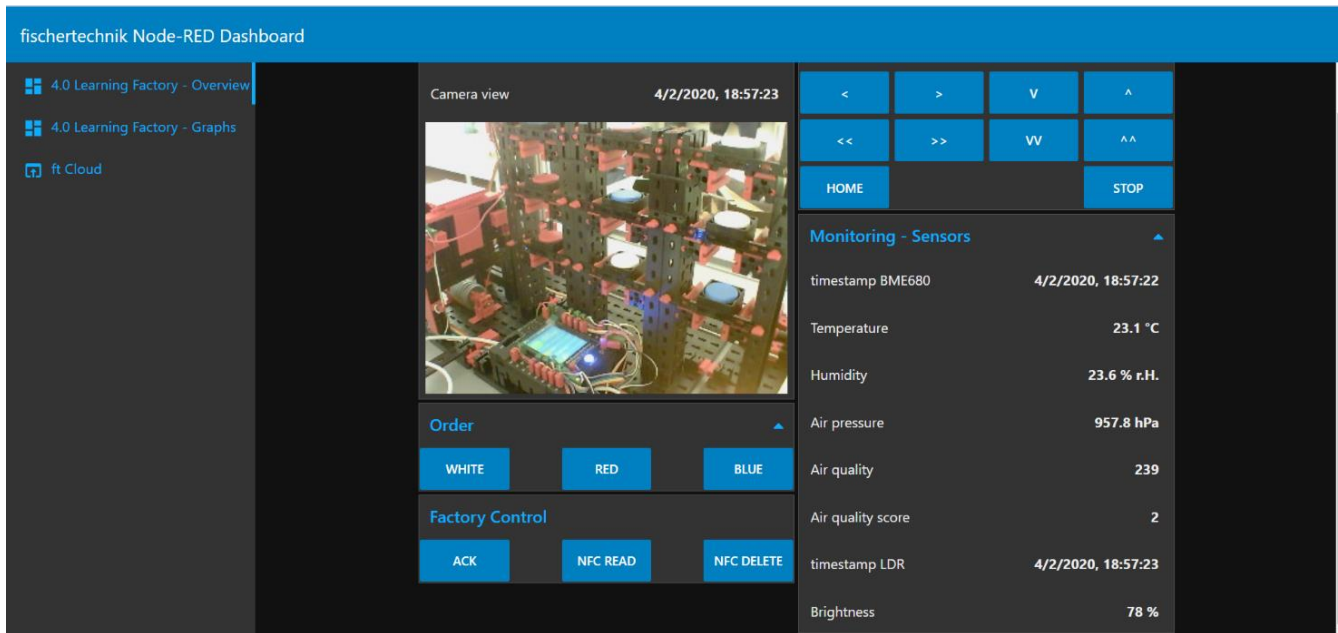Figure 3.8: Node-RED flow chart example[23]

Figure 3.9: Node-RED dashboard[24]

This complementary and free tool enables to exploit some of the Fischertechnik 4.0 Training Factory potentials that are not able to exploit throughout the standard Fischertechnik Cloud, as it is possible to make use of sensors that are not used in the standard scenario of the simulation model. Different examples are provided of how to improve the 4.0 Training Factory by combining the Node-RED tool with unused sensors, these examples are explained in the following subchapter.

Node-RED can be used through a browser like Google Chrome or Firefox. Additionally, it can also be used through devices like Raspberry Pi, Arduino, Android or through Cloud services like Amazon Web Services, IBM Cloud or Microsoft Azure, making Node-RED versatile and recommended for its usage.

Specifically, Raspberry Pi is widely used at the HSLU, and concretely, in the Business Engineering and Innovation degree and makes Node-RED even more useful. This aspect could not be tested as there is no Raspberry Pi available due the closure of the university and because of the lack of knowledge on how to use a Raspberry Pi device, as my home university does not make use of this tool.

For more information on how to get started on Node-RED, read the Fischertechnik Booklet and visit the official Node-RED website[25].

3.4. Implementations for the Fischertechnik simulation model

This subchapter is focused on explaining and showing some examples on how to further exploit the potential of the 4.0 Training Factory and it could be used as a guide for future users with the willingness to create different scenarios and improving the simulation model performance. These examples of possible improvements are listed:

- Speed increase. During the standard scenario it is clearly visible that speed needs to be increased, as it can be even irritating watching the movements of the cranes. Speed can be changed through a specific C++ code-program in an internal file.

- Making use of unused sensors. Different sensors at the factory does not seem to have a clear utility or direct impact on the standard workpiece flow. For example, the use of the light sensors at the entrance/exit conveyor of the HBW module is not clear (see **Error! Reference source not found.** in the next page). When a container with a workpiece loaded is manually removed from the HBW (so that the workpiece still appears in the Cloud as available because the removal has not been detected), and that same workpiece is ordered through the Cloud, the HBW crane makes the intent to grab that workpiece from the HBW and place the non-existent container on the conveyor. The conveyor makes the movement acting like there is a container on it, and the VGR pretends to grab the selected workpiece. This shows that the light sensor of the conveyor, even it does not detect a workpiece, do not act on the system, because the conveyor still acts as there is a workpiece on it.

[25] The official Node-RED website is: nodered.org (without www.)
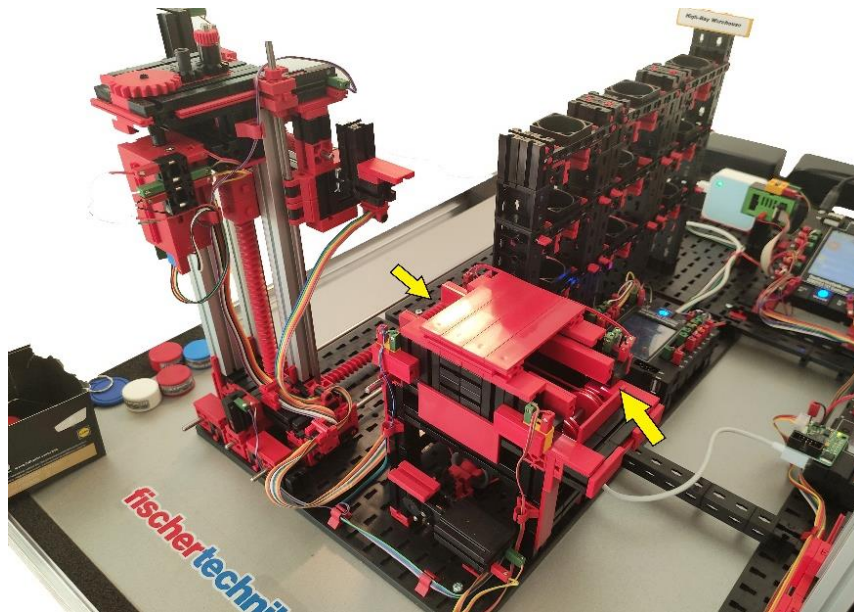
Figure 3.10: The light sensors location of the conveyor of the HBW[26]

- Storage by colour. Currently storage of workpieces is done according to the order of entrance, mixing the colours in the warehouse. Through C++ programming, storage could be ordered by colour.

- Storage of processed pieces and infinitive cycle. With the standard scenario, processed workpieces are deployed in the DPS section. It is possible to change that and instead of deploying the workpieces in the DPS section, send them back to the HBW. This can make the production line an infinitive cycle because the storage is automatically filled back, so workpieces can be ordered continuously, and this avoids adding and removing workpieces from the factory manually.

- Workpiece delivery to client. As an alternative for the previous implementation, the finished workpieces can be also deployed on the "defective storage". This will replace the functionality of the defective storage and replace it for a finished-product storage. This is because the current inconvenience of the production line is that it is blocked when you do not remove manually the delivered piece from the system. With this, the processed workpieces can be stored in the place provided for defective parts, without blocking the production line (See Figure 3.11)

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[26]Figure 3.10: Indication of where the light sensors are located in the HBW module. Own source.
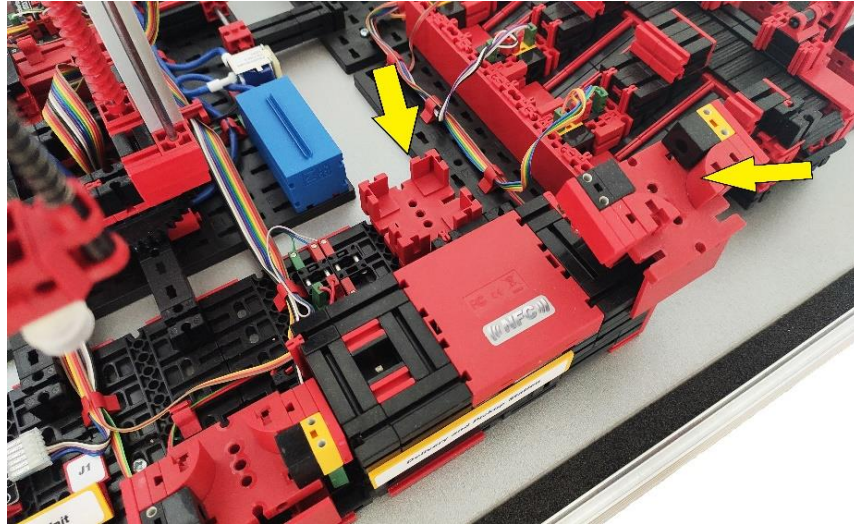
Figure 3.11: DPS Section. Left arrow - Defective storage. Right arrow - Client storage[27]

- Enable parallel jobs. Currently, the production line does not allow to process more than one piece at the time. This means that when an order is placed, it not possible to place another order until the previous workpiece has been completely processed. By enabling this feature, there will not be a need to wait until the end of the complete process to order a new workpiece, making it possible to make several orders at the time or consecutively.

- Finally, Node-RED could be used to record different KPIs of the production line. As the Smart Factory is able to get the current time measure, time related KPIs can be analysed and displayed, such as lead time, cycle time or TAKT time by using different flowcharts in this tool. Or measures like average inventory.

These measures are examples of implementations that could be done to make use of the potential of the Fischertechnik model. A deeper knowledge of C++ programming language, or a deep knowledge of Node-RED flowcharts are needed for these implementations. However, these implementations are just examples and more can be introduced. The limitations of these implementations are related to the limitations of C++ programming and Node-RED, plus the persons creativity.

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[27]Figure 3.11: Shows the defective storage and the final delivery location at the Fischertechnik model. Own picture.

3.5. Fischertechnik analysis for academic use

The Fischertechnik 4.0 Training Factory represents an automated 4.0 production line, and according to what it represents, it is a complex tool. This means a deep knowledge of programming and automation is needed. Comparable to when you have a real and complete automated production line, experts among your employees are required. The level of complexity of a real production line and Fischertechnik 4.0 Training Factory is clearly not comparable in terms of programming, but it is as said, at least representative.

The 4.0 Training Factory, because of using a complete software based on C++, could be a perfect tool to learn on a practical way this programming language, as changes in the files can be visualized directly. Additionally, due to the versatility, Phyton can also be used for implementing complementary features.

As the Node-RED tool is easy to use if a basis is provided previously, plus the possibility to combine it with a Raspberry Pi device used in the HSLU, the 4.0 Training Factory can be used to learn about MQTT (M2M data transfer protocol) easier and with a practical focus.

It is also ideal to show different 4.0 Industry features within production lines, such as Cloud connection, M2M communication, the use of sensors, etc. Complementary features can be introduced in the model, making this even better for showing.

The 4.0 Training Factory can also be used to represent different productive scenarios. This tool will be used as a tangible simulation model of an automated production line. Through it, different consequences could be visualized, representing accurately real consequences. This could be done through predefined scenarios and with already indicated steps to implement the scenarios correctly, meaning a previous programming work needs to be done.

Finally, the Fischertechnik model is able to complete the cycle showed in Figure 1.1 and Figure 2.2 by providing real-time feedback to the Digital Twin as the model includes everything needed for it (sensors, Cloud connection, automation) enabling a proper use of the Digital Twin and creating a synergy to represent in a simple way the main concepts and features of the 4.0 Industry revolution: Smart Factory, CPS, IoT, Digital Twin, Cloud connection, etc.

SYNOPSIS

- The Fischertechnik 4.0 Training Factory serves as an introductory tool for the 4.0 Industry concepts. It shows basic and general features and has the possibility to incorporate more features in it.
- The new software made with C++ is complex, but more versatile. To create and modify scenarios in the model, deeper knowledge of C++ is needed.
- Node-RED is a perfect tool to complement the Fischertechnik, and it is possible to use it with a Raspberry Pi device.

The Fischertechnik model has potential, despite its complexity.

4. Siemens Tecnomatix Plant Simulation

Siemens Tecnomatix Plant Simulation is the software selected for the creation of the Digital Twin[28], the virtual replica of the Fischertechnik 4.0 Training Factory. This specific software solution from Siemens digitizes production processes and allows to implement innovations in a fast and direct approach.

The software focuses on material flow, resource utilization and logistics through production plants or specific production lines and it allows to explore the characteristics of the systems as well as to optimize their performance.

This tool has a medium degree of complexity and implementations do not require advanced knowledge of programming or deep understanding of production or logistics. This contrasts with the code-programming of Fischertechnik 4.0 Training Factory.

First, an introduction to the tool is going to be presented through an example built for the Operations Management module at the HSLU. Next, the relation between the Fischertechnik model and Siemens Tecnomatix software is going to be showed: How the Digital Twin is made, the explanation of the previous and *To-Be* scenario, and finally, the limitations of Siemens Tecnomatix in terms of emulating Fischertechnik as a Digital Twin.

4.1. Introduction to Siemens Tecnomatix Plant Simulation

Siemens Tecnomatix is at a certain point, built with an intuitive approach, as they tried to balance the complex aspects of a production plant with intuition, trying not to sacrifice neither of these.

The code-programming used in the software is a special language created for this tool by Siemens, called *Simtalk 2.0.* This code has got similarities with C++ and Phyton but is specially adapted for the software and reduces complexity for a faster learning. The code is particularly used to create more complex systems in the software, as the code is needed if specific characteristics or behaviours want to be added.

A basic explanation of the software interface and modelling is explained in the Siemens Tecnomatix Booklet provided with the Bachelor Thesis. The read is recommended for a better comprehension of the following subchapters.

4.1.1. Example scenario for Operations Management

To represent the interface, functionality and advantage of Siemens Tecnomatix, a simulation model has been created for the Operations Management module. This example aims to show how Siemens Tecnomatix can be used to simulate production lines and how different parameters can be used to visualize different scenarios. The example consists of three practically identical lines that discern in some specific parameters.

---

[28] See section 2.5: Selection of the Digital Twin

Every line is based on a one-piece flow system and consists of the elements showed in Table 4.1. These elements have the same parameters in every line, the most important parameters are presented in the same table. The three lines have a clear bottleneck, Station 2 (S2), due to the longer processing time.

Element	Source	Store	PickAndPlace[29] (x2)	Buffer	Stations (x3)	Drain	Conveyor
Relevant parameter	Produces each 10s	9-piece capacity	4s for rotation 3s for load/unload	Infinitive capacity	Proc time S1: 11s S2: 20s S3: 7s	-	1 m/s speed

Table 4.1: Elements of the example lines in Siemens Tecnomatix[30]
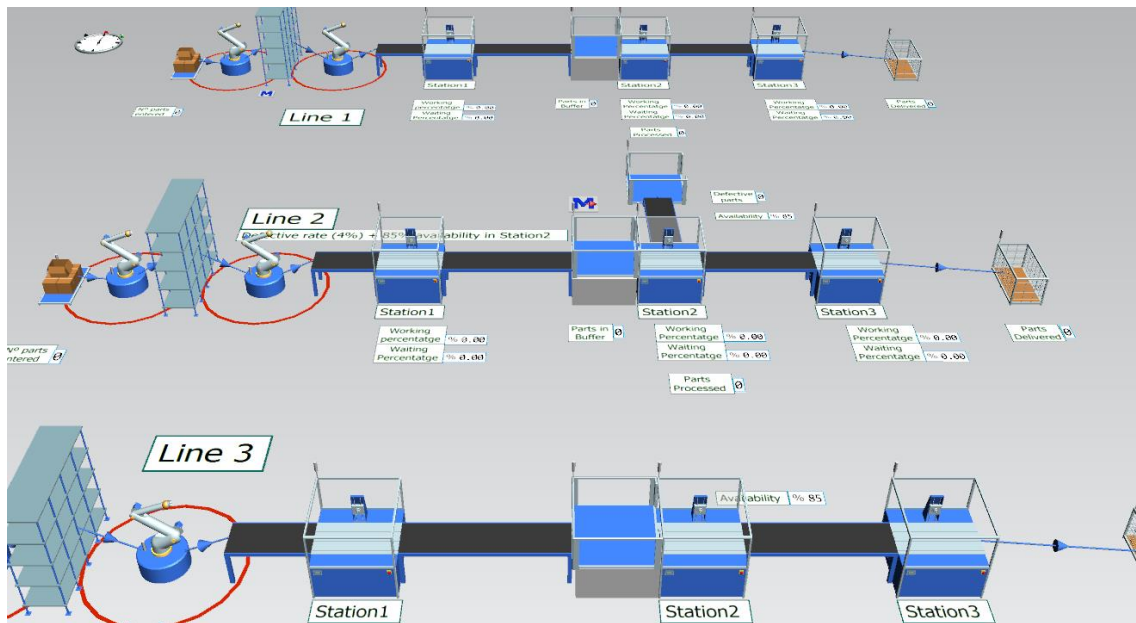
Figure 4.1: Siemens Tecnomatix example[31]

The difference between the three lines lies on a specific parameter introduced in the second and third line, showed in Table 4.2. These changes are going to lead to different consequences within the production line.

Line 1	S2[32] Bottleneck.
Line 2	S2 Bottleneck + 4% Defective rate + 15% Machine Failure with a MTTR[33] of 15s, in S2.
Line 3	S2 Bottleneck + 15% Failure with a MTTR of 15s in S2

---

[29] The PickAndPlace robot are the articulated robots in the production line.

[30] Table 4.1: The basic elements of the Siemens Tecnomatix example with the parameters used. Own source.

[31] **Error! Reference source not found.**: Example made to visualize common production line problems. Own source.

[32] S1, S2 and S3 represent Station1, Station2, Station3.

[33] MTTR: Mean Time To Repair. Uses an Erlang-distribution to calculate times between failures.

Table 4.2: Characteristics of the example lines in Siemens Tecnomatix[34]

---

[34] Table 4.2: Explanation of the different problems introduced in each example line. Own source.

The KPIs used in this simulation are:

Nº parts delivered	Nº of parts in buffer	Working percentages	Nº of defective parts

Table 4.3: KPIs of the example[35]

After 7'5 hour of simulation, representing a normal shift, 2250 pieces have entered the system, however, different results are recorded. The results are represented in Table 4.4:

	Deliveries	Queuing parts in the Buffer	Working percentages			Defective
			S1	S2	S3	
Line 1	1347	899	91.57%	99.84%	34.92%	0
Line 2	1096	1103	91.57%	84.67%	28.41%	46
Line 3	1151	1095	91.57%	85.32%	29.84%	0

Table 4.4: Results of the example[36]
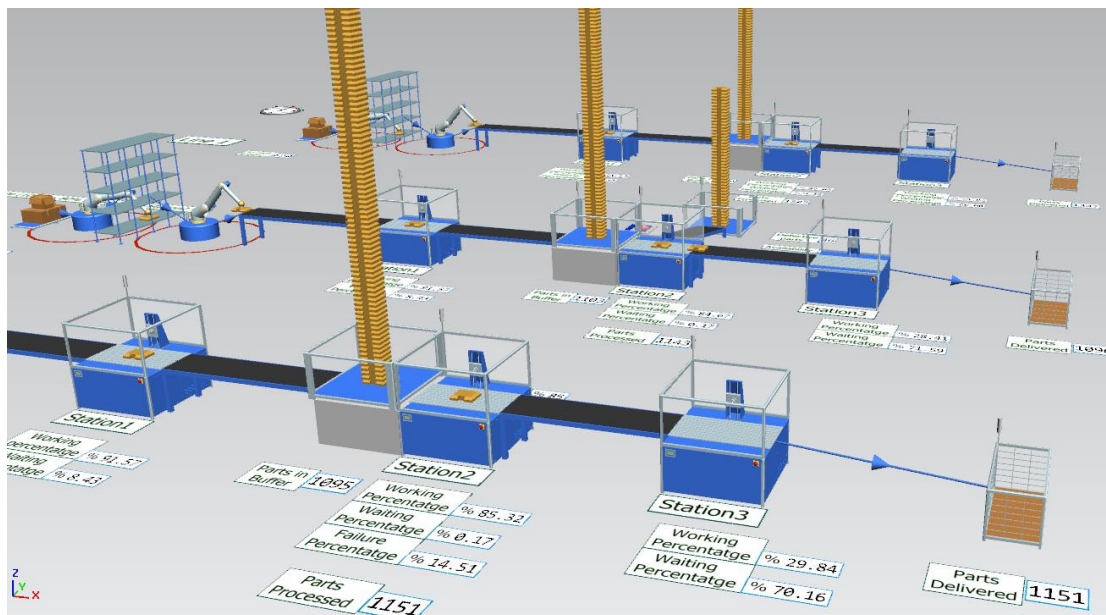
Figure 4.2: Results of the example[37]

While the first section of the line is identical in every line (entries and S1 percentages are the same), differences can be visualized starting from the Buffer:

- The bottleneck is clearly visible through the Buffer; the S2 accumulates an exaggerated number of workpieces due the processing time (899, 1103 or 1095 depending on the line).
- In Line 3, due to the machine failure rate of 15%, the output is reduced by 14.55% (196 workpieces less in comparison with Line 1). The failure rate limits the working percentage of S2 to 84'7% instead of the exaggerated 99'8% in Line 1.
- In Line 2, the change in the output of the line is clearly observable, due the combination of both failure and defective rate, it has been reduced by 18.63% (251 workpieces less comparing with Line 1).

---

[35] Table 4.3: KPIs used to visualize the change in the results of each line in the example. Own source.

[36] Table 4.4: Results of each line according the KPIs selected of the simulation of the example. Own source.

[37] Figure 4.2: visualization of the example simulation model after the simulation. Own source.

The direct consequences of both machine failure and defective rate are visible through the KPIs, as the output is considerably reduced, and the working percentage of S3 decreases with the additional problems introduced in each line, being empty a considerably portion of the time.

This example serves as an example of how Siemens Tecnomatix simulates, and visualizes the consequences of having an unbalanced production line. As an unbalanced line provokes the appearance of a bottleneck, which leads to higher working percentages, which leads to higher machine failure probability and, presumably, higher defective rates.

4.1.2. Internal code-programming

When the production lines are more complex and need to have specific characteristics, code-programming is needed to implement these characteristics. The programming is done in *Methods* and each method is attached to a component of the simulation model. Every production line created makes use of similar methods, modified depending on the specific necessities.

Figure 4.3: Method icon[38]

For the understanding of the internal code-programming within the Methods, an intermediate understanding of *Simtalk 2.0* is needed, as well as a basic understanding of C++ or Python programming language. The Siemens Tecnomatix Booklet provided with the project helps for the *Simtalk 2.0* understanding. These methods are used in the creation of the three scenarios created in Siemens Tecnomatix and explained further on in this chapter. Additionally, to facilitate their comprehension, comments are introduced in each Method as small explanations.

4.2. Fischertechnik and Siemens Tecnomatix

Siemens Tecnomatix software is used for the Digital Twin creation of the Fischertechnik 4.0 Training Factory. This subchapter aims to explain the relation between both tools in the project, while the next subchapters are going to discuss and show the process of the creation of the Digital Twin, including the previous and *To-Be* scenarios.

Firstly, it is important to comment the sequence followed for the creation of the scenarios. The first scenario created, and explained, corresponds to the Initial scenario and not to the As-Is scenario (Digital Twin). The reason of this decision is because the willingness of following the factory timeline, from the initial version to the improved version. With this sequence, improvements are done and visualized gradually. In addition, by using this sequence, the Initial scenario was created based only on the physical Fischertechnik model and not on an already-digital version, making the initial version possibly more realistic and according to the physical model.

The Initial scenario represents a possible initial scenario among different possibilities, and it serves as an example to show the advantages of a simulation software. Equally for the *To-Be* scenario. Both scenarios are examples having as starting point the Fischertechnik 4.0 Training Factory.

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[38]Figure 4.3: Represents the Method icon of Siemens Tecnomatix. Own source.

4.2.1. Limitations of Siemens Tecnomatix as a Digital Twin

As commented in section 2.5: *Selection of the Digital Twin Software*, every software analysed included advantages and disadvantages, and besides selecting Siemens Tecnomatix software, limitations still appear related to the creation of the Digital Twin.

First of all, there is a need to point out that, while the 3D graphics of Siemens Tecnomatix are flexible and customizable, due to the specific design characteristics of the Fischertechnik model, the visual appearance of the Digital Twin according to the physical Fischertechnik model is limited and vague. Furthermore, due to time limitations, it has not been possible to exactly mimic the Fischertechnik model details. Despite this fact, the parameters used for the Digital Twin emulating the Fischertechnik model are practically identical, so the insides of the Digital Twin are a good representation of the Fischertechnik model. The Fischertechnik CAD files of the model were available for the project but could not be integrated in Siemens Tecnomatix.

Additionally, the Fischertechnik 4.0 Training Factory integrates several features and characteristics that are not possible to replicate in Siemens Tecnomatix, due to limitations of the software or due to time limitations. These features were not added in the Digital Twin, as they are not essential for the workpiece processing. The example could be the SSC module of Fischertechnik (Surveillance camera and environmental sensors), which are represented as merely decoration in the Digital Twin.

Finally, another important aspect is that, while the exact parameters can be simulated in Siemens Tecnomatix according to the physical model, and the parameters of the improved version can be replicate in the physical model with code-programming, there is no direct interaction and real-time feedback of the software with the physical model. This provides a discussion whether it really can be classified as a Digital Twin of Fischertechnik, or it is just a replica made in the software for testing and simulating. This depends on the Digital Twin definition made, as this concept does not have a consensus with its definition. See section 2.3.3: *Digital Twin concept.*

To remind the relation between both tools, Figure 4.4 shows the sequence followed for the scenario creation in Siemens Tecnomatix.
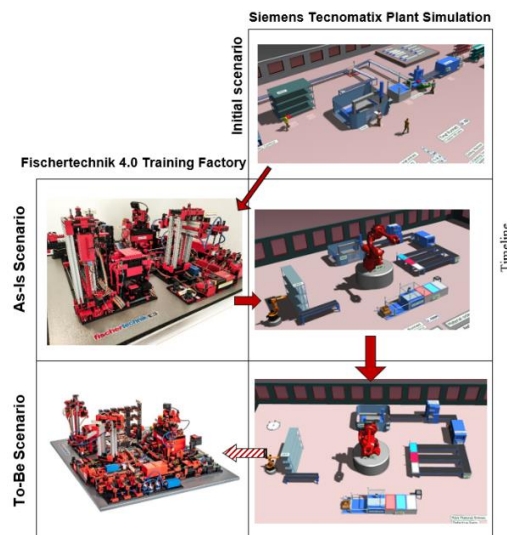
Figure 4.4: The relation between Fischertechnik and Siemens Tecnomatix[39]

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[39]Figure 4.4: The sequence followed for the creation of the digital scenarios in Siemens Tecnomatix. Own source.

Notice that the last arrow of the sequence display is stripped. This is because the last step of the sequence is not going to be done or implemented due to the advance programming skills needed for the implementation into the Fischertechnik. The stripped arrow visualizes the possibility of implementations into the physical factory.

The next subchapters are going to explain the creation of the three digital scenarios. If the Siemens Tecnomatix software is available for usage, the following link provides the three files within a private Google Drive folder to download and use the files:

https://drive.google.com/drive/folders/1buEnyhWHeLLjRDN-

4.3. Initial scenario

The first scenario created is the *Initial scenario*. This scenario represents a previous stage of the factory, a state of the factory in the past before Industry 4.0 implementations and serves as a reference to comprehend the three scenarios as a process of improvements. The initial scenario contains the same sections or modules as the Fischertechnik 4.0 Training Factory except the VGR (three-axis robot crane) and the SSC module, and copies the sequence followed by a workpiece in order to deliver the workpiece to the client. and **Error! Reference source not found.** visualize the Initial scenario:
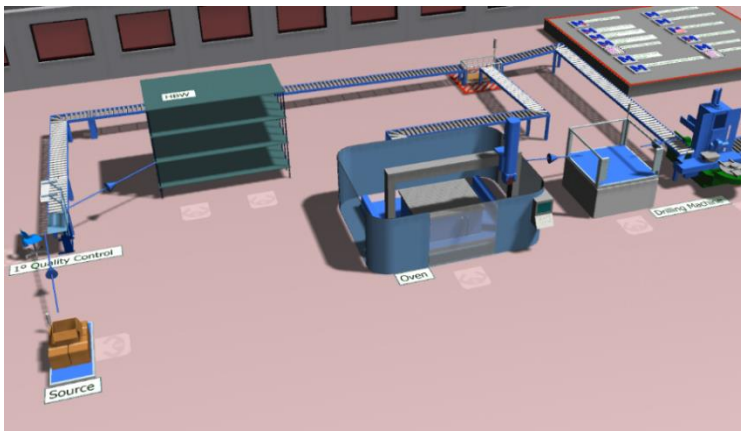
Figure 4.6: Visualization of the initial scenario 1. 40
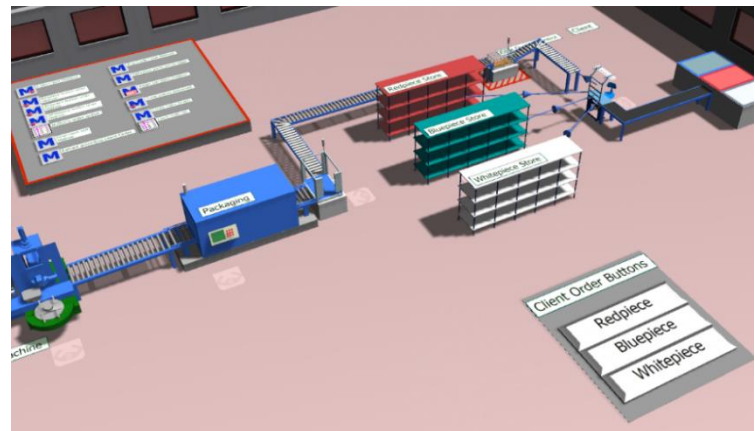
Figure 4.5: Visualization of the initial scenario 2. 41

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[40]: Visualizes the first part of the initial scenario before simulating. Own picture.
[41]**Error! Reference source not found.**: Visualizes the second part of the initial scenario before simulating. Own picture.

4.3.1. Layout of the Initial scenario

The layout of the scenario can be seen in Figure 4.7 and is explained after:
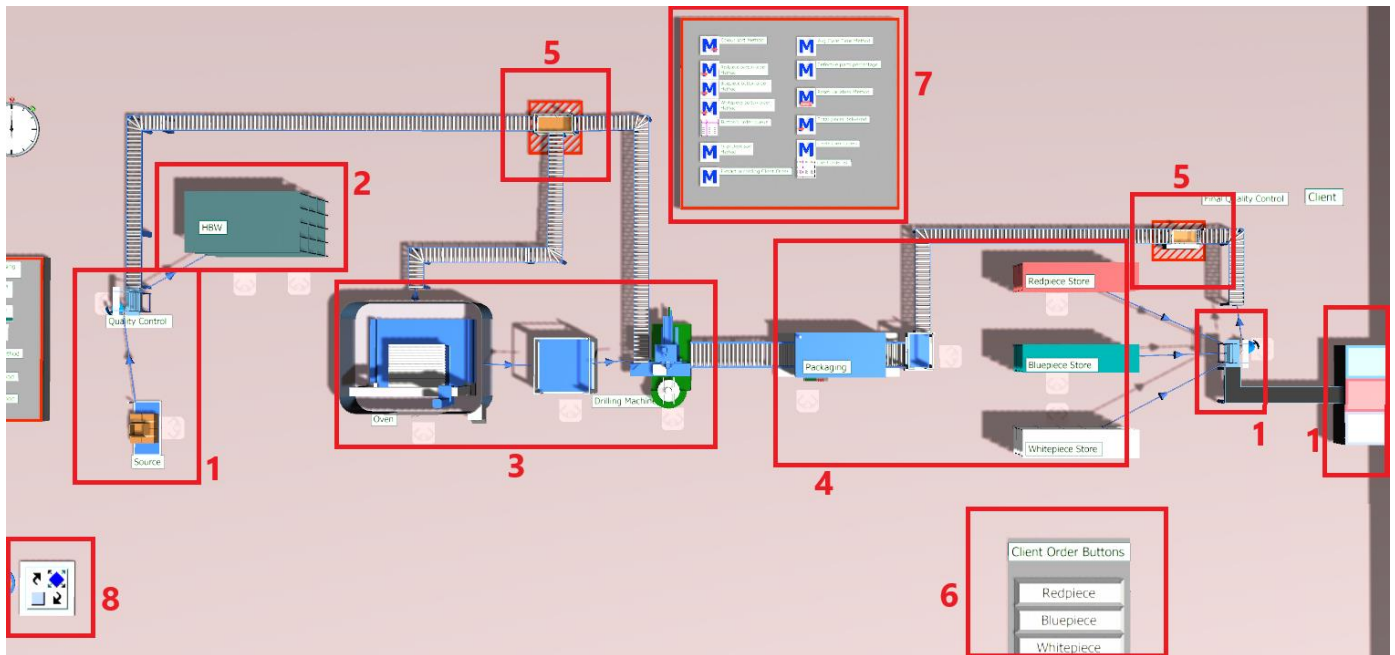
Figure 4.7: Initial scenario layout[42]

1. Represents the Delivery and Pickup Station (DPS). It contains the source for material supply and the first quality control made in the factory (left side), the final quality control and the material delivery (right side). The client is represented with a storage area, sorted by colours. This enables to visualize the number of workpieces delivered to the client.
2. Represents the High-Bay Warehouse (HBW). The storage process is not automated, so the crane is not included in the scenario. The capacity of the warehouse is 12 pieces.
3. Represents the Multi-Processing Station (MPO), starting with a thermal process (oven) followed by a drilling process (drilling machine). A buffer is located between both stations.
4. Represents the Sorting Line module (SLD). It contains a quick packaging process and is followed by a sorting according to colour. The workpieces are sorted into a final product warehouse.
5. Represents the drain component of Siemens Tecnomatix. The drain is used to collect defective workpieces and, if it is the case, overproduction.
6. Represents the client order button displayed in the Fischertechnik Cloud dashboard. This imitates a specific order made by the client and can be catalogued as an urgent order in the scenario.
7. These are the internal code-programs that control the behaviour of the factory.
8. This is a specific component of Siemens Tecnomatix related to the workers of the factory.

4.3.2. Workpiece flow

For a better understanding of the scenario, the workpiece flow throughout the production is explained through Figure 4.8 and Figure 4.9. The first figure as a diagram of the workpiece flow, and the second figure by displaying a collage made by different screenshots of the workers doing the tasks in order to process the workpieces to the client.
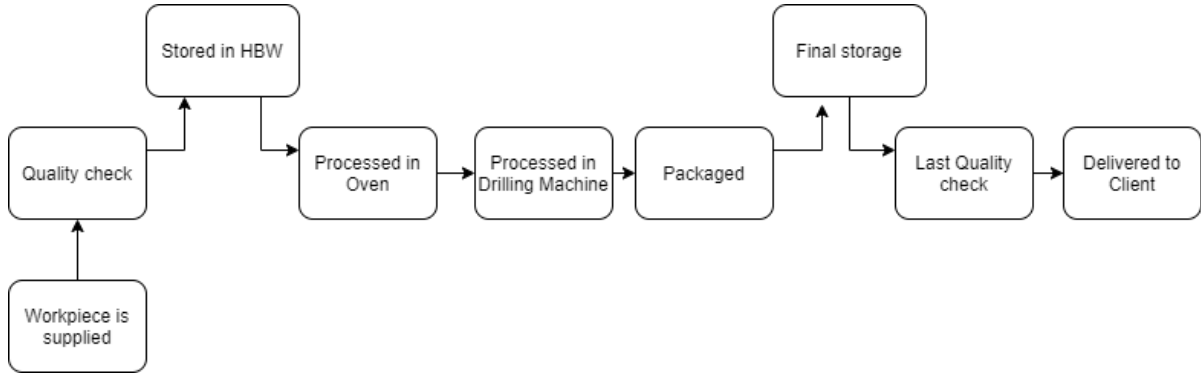
Figure 4.8: Initial scenario workpiece flow diagram[43]
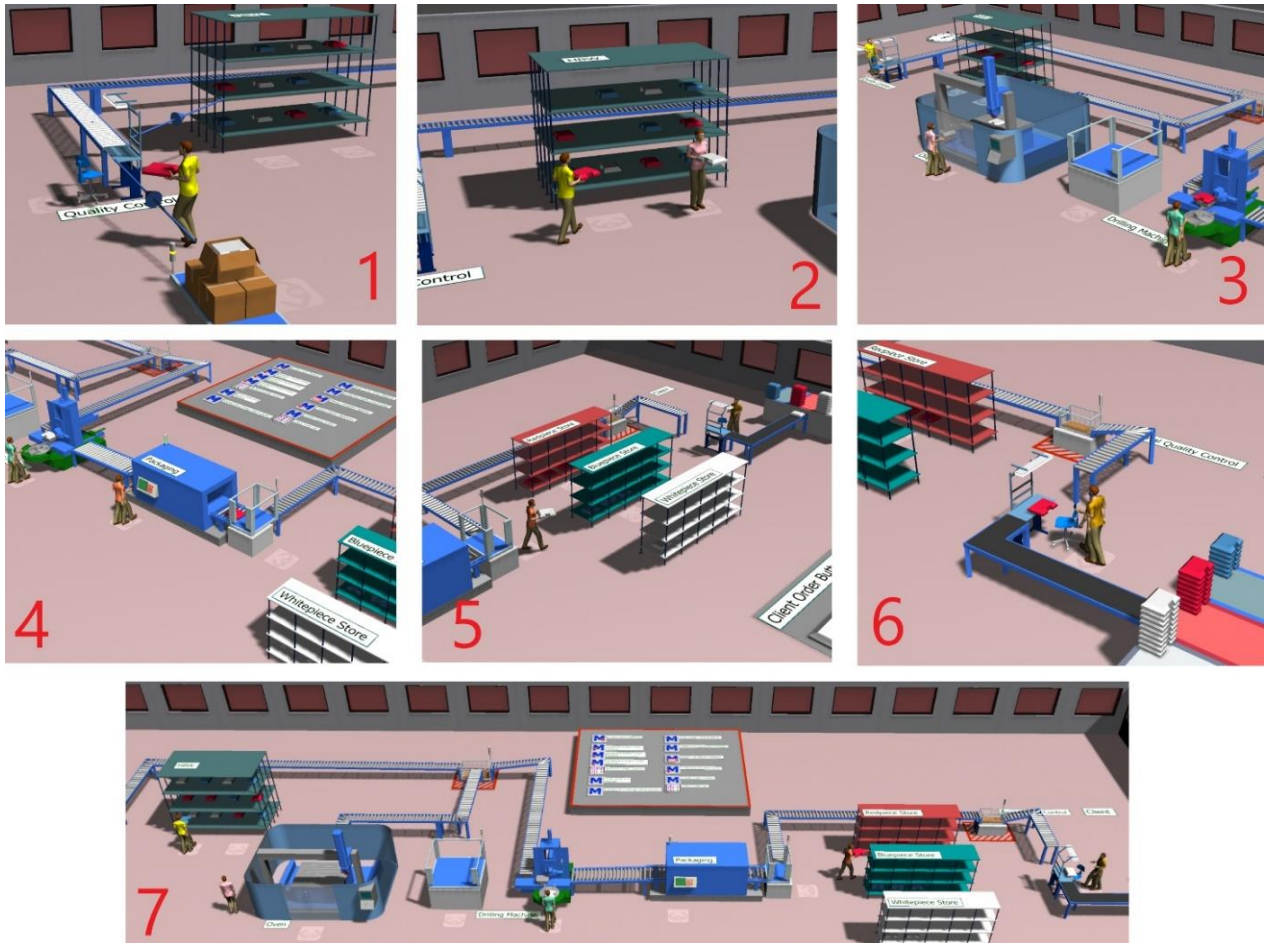
Figure 4.9: Workers collage in the initial scenario[44]

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[43] Figure 4.8: Displays the workpiece flow diagram. Own source.
[44]Figure 4.9: Collage made by screenshots of specific situations within the simulation. Own pictures.

1. The process starts with the material supply in the source. The appeared workpiece is transferred manually to the first quality station and checked before being stored.
2. The raw or unprocessed workpieces are stored into the HBW, who serves workpieces to the next stations. These workpieces are grabbed by another worker and introduced into the Oven.
3. The workpieces are processed firstly in the Oven, and then in the Drilling Machine. To avoid the waiting of the worker and due to different processing times, a Buffer is located between both stations.
4. After the two processes, workpieces are packaged by a different worker.
5. After being packaged, three finished-product warehouses store the different workpieces according to colour.
6. Finally, according to client order, the processed workpieces are delivered to the final quality station and checked before being sent to client (represented as a final storage).
7. Figure nº 7 shows the complete process and process line in one picture.

After the quick overview of how pieces are processed and delivered to client, specific characteristics and parameters are commented hereunder.

4.3.3. Scenario characteristics and parameters

The most important aspects or characteristics of the initial scenario are:

- Like in the Fischertechnik model, three types of workpieces are used: red, blue, and white workpieces.
- The workpieces are transported manually by workers, and the stations where they are processed can only operate with a worker.
- The production line is linear shaped. The workpiece is transferred to the right, where at the end, the client is represented.
- The production line is one-piece flow. This means pieces are processed and transferred one-by-one to the next station or component.
- The production line transfers workpieces with the *Push* strategy. This means that workpieces are processed according to the material supply, the entrance, which projects a future demand of workpieces.
- Material supply is done by percentage: 33,3% red pieces, 33,3% blue pieces, and 33,3% white pieces. However, the colour is randomly selected, within the percentage.
- A client order is created every 35s. The colour of the client order is created randomly with a 33,3% probability for each colour, but independently to the material supply.
- A workpiece is supplied into the production line each 35s, or when there is enough capacity in the initial warehouse to store the entering workpiece. This means that even if 35s have passed, if there is no space free in the warehouse, the piece waits until there is a free space for being supplied.
- Due the variability created between the material supply and the client order; finished-product warehouses are created for each type of workpiece.
- When the capacity of the finished-product warehouse is full, overproduction appears. The pieces that cannot been stored are moved through a conveyor to the drain but are not counted as a defective part in the defective rate (this pieces only count as a useless part).
- Independently to the client order list created, the buttons can place a specific and urgent order of the client.

- There are 5 workers in the production line. Each worker controls a specific section of the factory. The factory is divided according to workers section as:
  1. Material supply pickup, first quality control and warehouse loading.
  2. Warehouse unloading, oven process, and buffer placement.
  3. Buffer unloading and the drilling machine.
  4. Packaging and colour sorting, placing the workpiece into the appropriate warehouse.
  5. Unloading from the colour warehouse according to client order, and final quality control.
- The Drilling Machine, being the bottleneck of the production line, has got a 4% defective rate, and is the only station with a defective rate.

The specific parameters of the stations and components of the production line are showed in Table 4.5 and Table 4.6 for a better understanding. All the parameters are identical in each scenario in order to compare the results in Chapter 5.

Component	Source		1° Quality Station		HBW		Oven		Buffer	
Parameters	Supply interval	35s	Processing time	25s	Capacity	12	Processing time	30s	Capacity	Infinitive
	Supply order	33,3% each colour	Failure	No			Failure	No		
			Set-Up	No	Loading	0s	Set-Up	0:03	Loading t	0s
			Recovery	No	Unloading	0s	Recovery	0:03	Unloading	0s
			Defective	No	Extraction	FIFO	Defective	No	Extraction	FIFO
			Cycle time[45]	3s			Cycle time	1s		

Table 4.5: Initial scenario parameters 1.[46]

Component	Drilling Machine		Packaging Station		Final Warehouse (x3)		Final Quality Station		Client Storage (x3)		Conveyors	
Parameters	Processing time	40s	Processing time	2s	Capacity	30	Processing time	25s	Capacity	144	Speed	1 m/s
	Failure	No	Failure	No			Failure	No				
	Set-Up	0:03	Set-Up	No	Defective	Yes[47]	Set-Up	No	Loading	0s		
	Recovery	0:03	Recovery	No	Loading	0s	Recovery	No	Unloading	0s	Capacity	Depending on length
	Defective	3%	Defective	No	Unloading	0s	Defective	No	Extraction	No		
	Cycle time	10s	Cycle time	3s	Extraction	FIFO	Cycle time	0s				

Table 4.6: Initial scenario parameters 2.[48]

These are the default parameters set for the simulation of the scenario. These are going to be used in every scenario, for a better comparison between them.

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[45] The Cycle Time parameter in Tecnomatix refers to the interval of time when a piece can enter the station. This means that a piece can enter the station each 3s, and if it arrives at second 1, it needs to wait 2s more.

[46] Table 4.5: First table with the most relevant parameters of each component. Own source.

[47] If there is overproduction, the piece is transferred to the drain and counted as defective (or useless piece).

[48] Table 4.6: Second table with the most relevant parameters of each component. Own source.

4.3.4. Further possible implementations

The default parameters are introduced based on the Fischertechnik model and for the final analysis. However, several parameters can be added or changed easily into the production line in order to make it more realistic and experiment with the simulation. Some examples are:

- Bad quality material supply can be introduced within the percentage in the *Material Supply By Percentage list.*
- Machine failure can be added in each station by opening the machine dialogue and selecting *Failures – Active - OK.*
- Defective parts can be introduced in the *Oven* (MPO_1) by entering the *Oven_Exit* Method and changing the "i < -6" parameter. The defective rate follows a normal distribution (0, 1) so probability of defective depends on the number introduced.
- Defective parts can be introduced in the *Final Quality Station* (FinalQuality) by selecting in the station dialogue *Exit – Open List – 'Change percentage to defective rate' – OK.*

After presenting the insight of the Initial scenario, the As-Is scenario is going to be presented.

4.4. As-Is scenario

The *As-Is scenario* created is the Digital Twin of the Fischertechnik 4.0 Training Factory, or virtual representation. This scenario replicates the Fischertechnik model layout and processes accurately and is also an automated version of the initial scenario.

The Vacuum Gripper Station (VGR) or three-axis robot is implemented in this scenario as an articulated arm robot, or *PickAndPlace* robot in the Siemens Tecnomatix software. This is the most similar automated robot available in the software and is functionally equal to the three-axis robot of Fischertechnik. Plus, this scenario also includes the SSC station, or Environmental Station of the Fischertechnik model, but it is merely decorative (not functional) as it does not affect the production process itself. Figure 4.10 shows the resulting scenario.
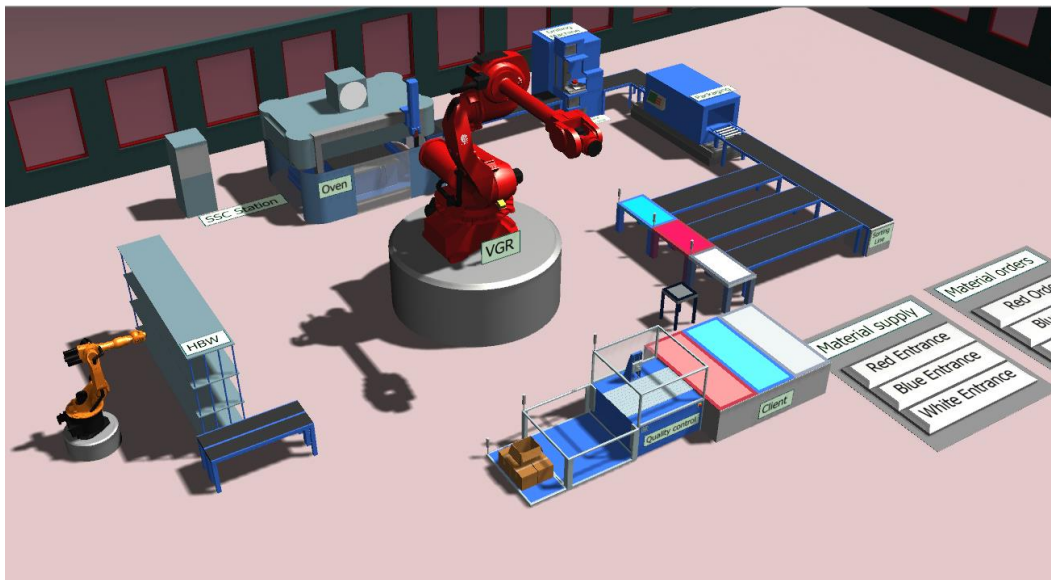
Figure 4.10: As-Is scenario of Fischertechnik 4.0 Training Factory[49]

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[49]Figure 4.10: Screenshot of the As-Is scenario, replicating the Fischertechnik model. Own source.

4.4.1. Layout of the As-Is scenario

The layout of the As-Is scenario is equal to layout of Fischertechnik, as it is the Digital Twin. Figure 4.11 displays the layout, that is quickly explained afterwards. For more details about the layout, read the Fischertechnik Booklet and see Figure 3.2 in page 15.
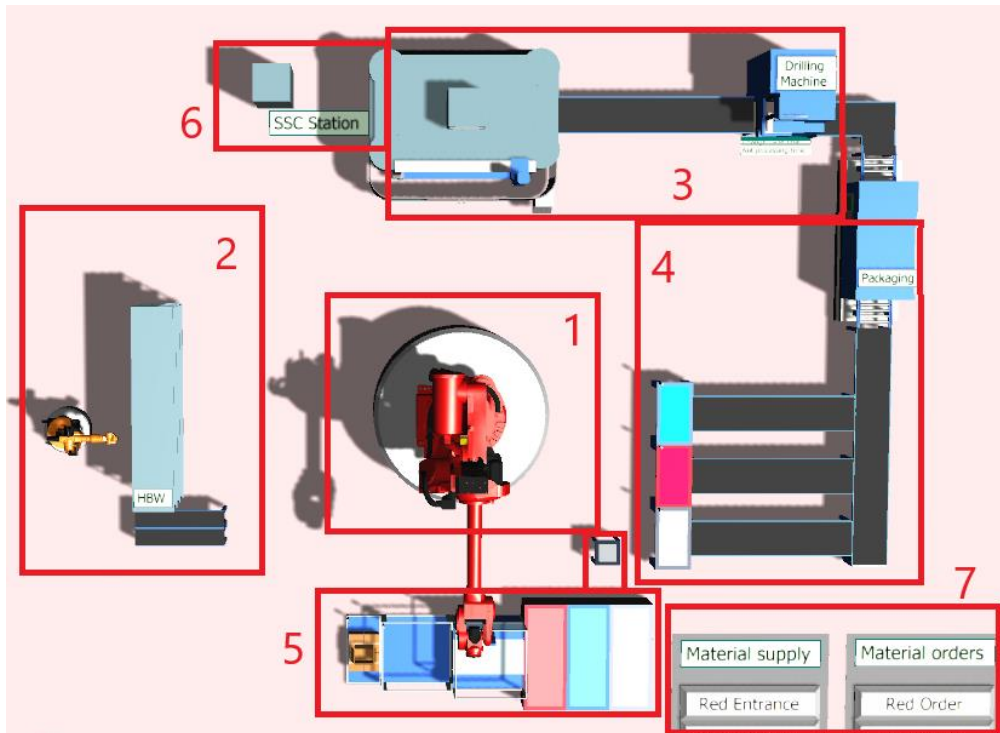
Figure 4.11: As-Is scenario layout[50]

1. Represents the VGR Station. It is the responsible for the transfer between stations and sections of the production line.
2. Represents the HBW section. Includes a 9-workpiece capacity warehouse, a second articulated arm robot substituting the portal crane of the Fischertechnik model and a conveyor that transfers the pieces between the HBW and the VGR module.
3. Represents the MPO section. Includes a thermal process (oven) and a drilling process (drilling machine). In Fischertechnik transport between stations is done through a small vacuum gripper, however, here it is substituted by a common conveyor.
4. Represents the SLD section. The sorting line includes a packaging station, and a sorting by colour line.
5. Represents the DPS section. From left to right: The source and a buffer are used for the material supply entrance. The buffer is to see queue of pieces that are going to enter the line, this is merely decorative and for better visuals. Then the quality station is located. This station makes the quality check for the workpiece entered the system as the workpiece already ready to deliver to client. Then the three storage areas are located, to visualize the delivered pieces to the client.
6. Represents the SSC section. Has no functionality and is purely decorative.
7. Represents the buttons. For material supply and client orders. These represent the Fischertechnik model as in the physical model there is a need to manually supply the production line, and to manually build the client orders.

---

[50]Figure 4.11: Shows the As-Is scenario from above. Own picture.

4.4.2. Workpiece flow

The workpiece in the As-Is scenario goes through the same processes as in the Fischertechnik 4.0 Training Factory. This sequence is simple and is visualized in Figure 4.12. This sequence starts when the workpiece is supplied and ends when it is delivered to client.
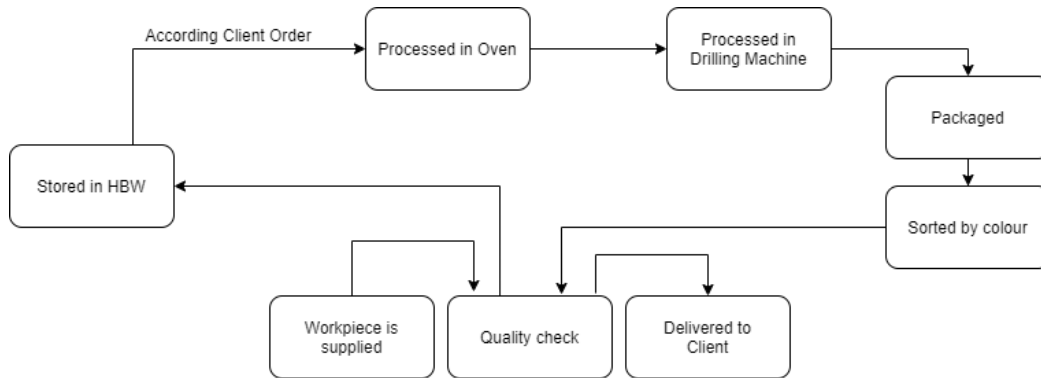
Figure 4.12: As-Is scenario flow diagram[51]
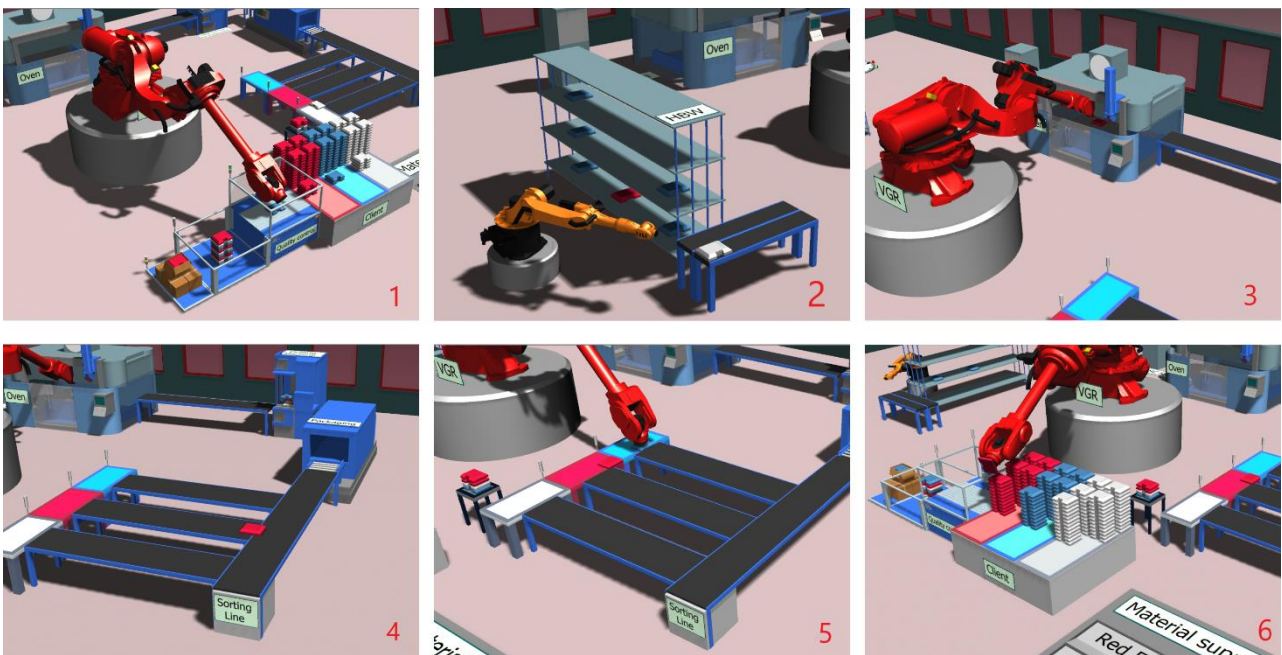
Figure 4.13: Machine collage in the As-Is scenario[52]

The process followed is the identical to the 4.0 Training Factory: the piece is supplied, checked in the quality station (1), transferred to the warehouse (2), it is processed according to the client order in the oven (3), the drilling machine and packaging station, then it is sorted according to colour (4) and transferred to the quality station (5), where it is checked before delivering being delivered to the client (6).

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[51]Figure 4.12: Visualize the flow of the workpiece within the scenario. Own source.
[52]Figure 4.13: Collage of the As-Is scenario made with different screenshots of the process. Own pictures.

4.4.3. Scenario characteristics and parameters

The parameters used in this scenario are similar to the initial scenario.

- Three types of workpieces are used (red, blue, and white)
- The production line is one-piece flow
- Material supply is done by percentage (33.3% for each colour)
- Materials are supplied each 35s and only if the initial buffer is not full
- A client order is created, and a workpiece is supplied each 35s
- Buttons for specific material supply and urgent client orders are provided
- The Drilling Machine is the bottleneck of the line and has got a 4% defective rate

Table 4.7 and Table 4.8 show the exact parameters of the scenario. The main parameters are according to the Fischertechnik model.

Component	Source + Buffer		Quality Station		HBW		Oven		Drilling Machine	
Parameters	Supply interval	35s	Processing time	25s	Capacity	9	Processing time	30s	Processing time	40s
	Supply order	33.3% each colour	Failure Set-Up Recovery Defective Cycle time	No No No No 3s	Loading Unloading Extraction	0s 0s FIFO	Failure Set-Up Recovery Defective Cycle time	No 0:03 0:03 No 1s	Failure Set-Up Recovery Defective Cycle time	No 3s 3s 3% 10s
	Capacity	9								

Table 4.7: As-Is scenario parameters 1.[53]

Component	Packaging		Final Client Storage (x3)		Conveyors		VGR robot		HBW robot	
Parameters	Processing time	2s	Capacity	120	Speed	1 m/s	Capacity	1	Capacity	1
	Failure Set-Up Recovery Defective Cycle time	No No No No 3s	Loading Unloading Extraction	0s - -	Capacity	Depending on length	Loading Unloading Default, Blocking angle	1s 1s 90° 110°	Loading Unloading Default Blocking angle	1s 1s 0° No

Table 4.8: As-Is scenario parameters 2.[54]

The parameters are identical in comparison with the Initial scenario (see Table 4.5 and Table 4.6). However, there are essential internal differences between both scenarios explained in the next subchapter.

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[53] Table 4.7: First table with the most relevant parameters of each component. Own source.
[54] Table 4.8: Second table with the most relevant parameters of each component. Own source

4.4.4. The main differences between the Initial and As-Is scenarios

Perhaps of having the same parameters within the components, there exist significant differences between the first and current scenario, as they not only change visually, but also internally.

Table 4.9 presents the most significant differences between both scenarios.

Initial Scenario	As-Is Scenario
Workpieces transported with workers	Workpieces transported through articulated robots and conveyors
Linear production line	Circular production line
Push strategy	Mixed *Push* and *Pull*[55] strategy
There exists a finished-product warehouse	No finished-product warehouse (due to *Pull)*
Overproduction	No overproduction (due to *Pull* strategy)
Client order buttons	Supply and Client order buttons
Capacity of 12 in HBW warehouse	Capacity of 9 in HBW warehouse
Two quality stations	Quality station are merged in one.
Buffer before drilling machine	No buffers (due to *Pull* strategy)

Table 4.9: Difference between initial and As-Is scenario[56]

As the most significant change is the introduction of the *Pull* strategy, which leads to different consequences such as eliminating buffers or finished-product warehouse, further details are provided.

4.4.5. Push and Pull strategy in the As-Is scenario

As commented, the Digital Twin combines both *Push* and *Pull* strategies in the workpiece flow of the production line.

The workpiece supply continues using *Push* strategy. The workpiece supply is independent with the client order process: the pieces are supplied each 35s, and only when the initial buffer is not full. The workpieces are checked in a quality control and stored in the HBW. However, the difference relies in the workpiece extraction of the HBW, where unprocessed workpieces are stored.

The workpieces are only extracted from the HBW, so consequently, are processed, if the client order demands it (*Pull strategy*). This contrasts with the previous scenario, where a piece had to be extracted from the warehouse as soon as possible.

Having presented the Digital Twin, the To-Be scenario is presented as the next stage of the Digital Twin, after a quick analysis that has led to some improvements.

---

[55] Pull strategy is a production strategy where a piece only flows to the next station if the next station demands that piece. This strategy aims to avoid overproduction and unnecessary inventory.
[56] Table 4.9: Present the main differences between the Initial and the As-Is scenario. Own source.

4.5. To-Be scenario

A Digital Twin aims not only to simulate, but also analyse, and improve a real-world situation. The process followed by a Digital Twin software is easily explained in Figure 4.4, page 31 and needs to be reminded in this subchapter. While the *As-Is* scenario consists of a virtual replica of the Fischertechnik model, the *To-Be* scenario is the result of the analysis made on the virtual replica, by implementing different changes.

As explained in Section 4.2.1: *Limitations of Siemens Tecnomatix as a Digital Twin*, a Digital Twin commonly receives real-time feedback in order to analyse and implement changes, yet that is not possible with the current software used. Consequently, the real-time feedback that a Digital Twin commonly receives is substituted with a virtual feedback, meaning that the *To-Be* scenario implementations are not based on results provided by the Fischertechnik model, but on results provided by the virtual model.

Additionally, due the limitations, the changes applied in the *To-Be* scenario cannot be implemented through the Digital Twin into the physical Smart Factory and need to be implemented manually, which is not possible in this project.
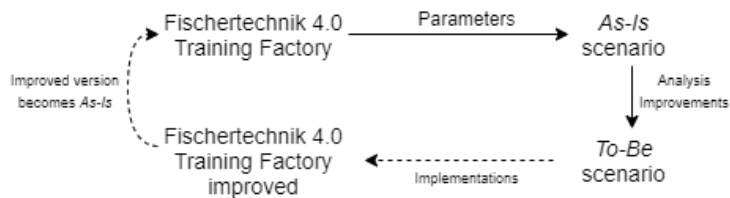
Figure 4.14: Siemens Tecnomatix as a Digital Twin diagram[57]
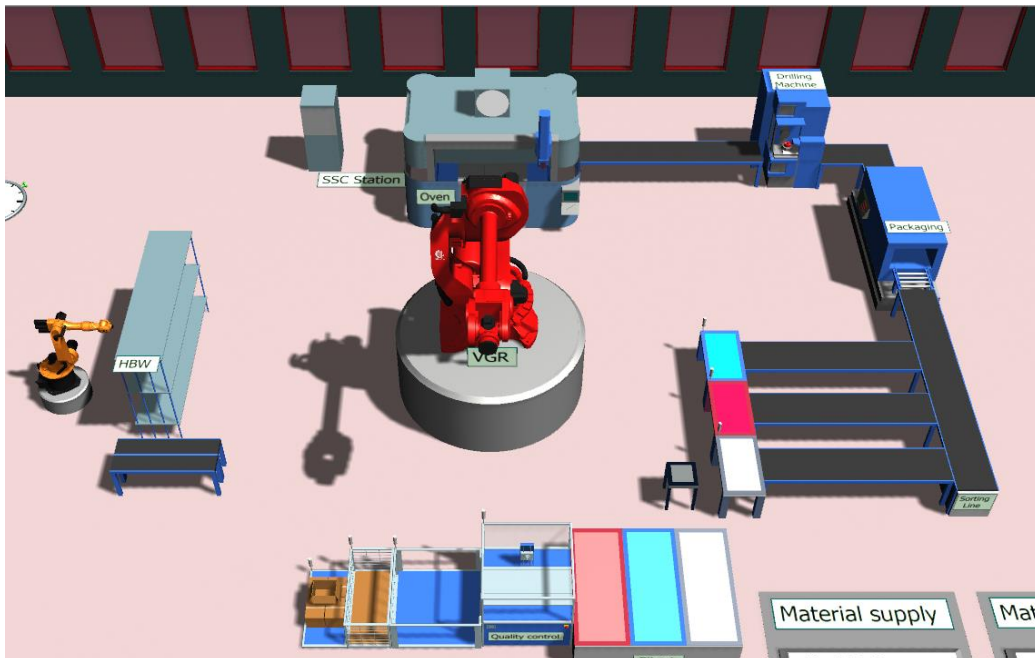
Figure 4.15: To-Be scenario of Fischertechnik 4.0 Training Factory[58]

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[57]Figure 4.14: Simple explanation of how Siemens Tecnomatix can be used as a Digital Twin. Own source.
[58]Figure 4.15: Figure of the *To-Be* scenario, which is visually identical to the Digital Twin. Own source.

The changes and implementations made in the *To-Be* scenario are not layout-based and only affect the internal workpiece flow and code-programming. Consequently, there are no visual differences between the Fischertechnik replica and the improved version. Because of this reason, the explanation of the layout of the scenario is redundant as it has been explained in the previous subchapter (See section 4.4.1: *Layout of the As-Is scenario*).

4.5.1. Workpiece flow

In contrast to the *As-Is* scenario, the workpiece flow through the production line has been changed. The workpieces are processed in the same order; however, slight changes have been introduced internally that affect the flow. These changes can be visualized in Figure 4.16 by comparing this workpiece flow with the flow of the *As-Is* scenario (Figure 4.12, page 39).
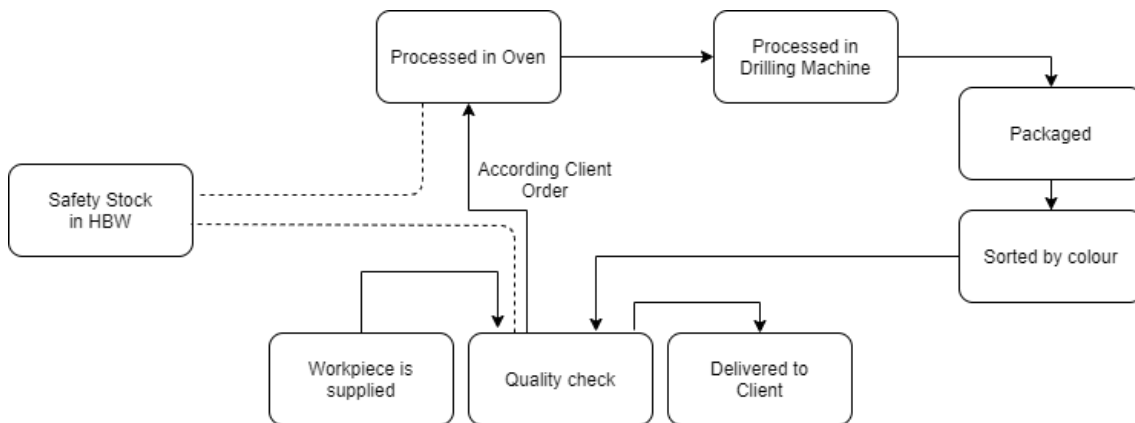
Figure 4.16: To-Be scenario flow diagram[59]

Visually, the difference between both diagrams relies on the first part of the flow. As in the previous commented scenario, the workpieces were mandatory sent to the HBW, but in the new diagram, these pieces are sent directly to the Oven or MPO station. The HBW continues in the production line, however, its connection with the other stations is represented with dotted lines. Further explanations of the diagram are given in the following chapters.

The process followed by the workpieces in order to be delivered to client is identical to the Digital Twin. See the collage (Figure 4.13), in page 39.

4.5.2. Scenario characteristics and parameters

This scenario has got similarities with the other two scenarios, as the basis of the virtual representations are based on the same physical simulation model. Some of the similarities are:

- Three types of workpieces (red, blue, and white)
- One-piece flow production
- Materials are supplied each 35s if the initial buffer allows it
- A client order is created each 35s
- Buttons for specific material supply and urgent client orders are provided
- The Drilling Machine is the bottleneck of the line and has got 4% defective rate

Table 4.10 and Table 4.11 display the parameters used in this scenario.

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[59]Figure 4.16: Displays intuitively the flow followed by the workpieces. Own source.

Component	Source + Buffer		Quality Station		HBW		Oven		Drilling Machine	
Parameters	Supply interval	35s	Processing time	25s	Capacity	6	Processing time	30s	Processing time	40s
	Supply order	33.3% each colour	Failure	No	Loading	0s	Failure	No	Failure	No
			Set-Up	No	Unloading	0s	Set-Up	0:03	Set-Up	3s
			Recovery	No	Extraction	FIFO	Recovery	0:03	Recovery	3s
	Capacity	9	Defective	No			Defective	No	Defective	3%
			Cycle time	3s			Cycle time	1s	Cycle time	10s

Table 4.10: To-Be scenario parameters 1.[60]

Component	Packaging		Final Client Storage (x3)		Conveyors		VGR robot		HBW robot	
Parameters	Processing time	2s	Capacity	120	Speed	1 m/s	Capacity	1	Capacity	1
	Failure	No	Loading	0s			Loading	1s	Loading	1s
	Set-Up	No	Unloading	-	Capacity	Depending on length	Unloading	1s	Unloading	1s
	Recovery	No	Extraction	-			Default,	90°	Default	0°
	Defective	No					Blocking	0°	Blocking	No
	Cycle time	3s					angle		angle	

Table 4.11: To-Be scenario parameters 2.[61]

Despite being the previous characteristics identical to the *As-Is* scenario or Digital Twin, excepting the HBW capacity, reduced to 6 workpieces, still changes have been implemented.

4.5.3. The main differences between the As-Is and To-Be scenario

The changes as commented are internal, within the code-programming. Table 4.12 presents the most significant changes between the *As-Is* and the *To-be* scenario.

As-is Scenario	To-Be Scenario
Mixed *Pull* and *Push* strategy	*Pull* strategy
HBW for unprocessed workpieces storage	HBW for security stock
Workpieces go necessarily to HBW	Workpieces go directly to Oven
HBW capacity of 9	HBW capacity of 6
Material supply by percentage (33.3%)	Material supply according to client order

Table 4.12: Difference between As-Is and To-Be scenario[62]

The most important feature introduced in the *To-Be* scenario consists of implementing a complete *Pull* strategy, and the other differences appear as a consequence of the use of this strategy. The next subchapter explains further this new feature.

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[60] Table 4.10: 1. The most relevant parameters of each component of the *To-Be* scenario. Own source.
[61] Table 4.11: 2. The most relevant parameters of each component of the *To-Be* scenario. Own source.
[62] Table 4.12: The main differences between the As-Is and To-Be scenario. Own source.

4.5.4. Pull strategy in the To-Be scenario

As commented, the Pull strategy is the origin of the other differences between the current and the futuristic scenario. Using Pull strategy in the production line according the client demand implies that only the needed workpieces are supplied into the line, reducing considerably the inventory needed.

In this production line, the Pull strategy is implemented by relating the client order creation with the material supply. The material supply firstly reads the client order, afterwards checks if the supply can be possible, and finally supplies it. The workpiece created is sent after the corresponding quality control to the Oven, where the process starts; when processed, it is delivered to the client.

This seem to be idyllic, however, due to the defective rate in the Drilling Machine, not every order can be delivered correctly. Therefore, a safety stock is set at the start of the simulation. This safety stock (SS) is used when a defective part appears, with the intention to compensate at the earliest the undelivered and defective part. The SS is filled again to the minimum level when possible. Due to the low storage needed for the scenario, the capacity of the HBW is reduced to 6 workpieces.

4.6. Siemens Tecnomatix for academic use

Through this chapter, Siemens Tecnomatix Plant Simulation software has been presented using different simulation scenarios.

Although the scenarios created for the purpose of this project are complex and heavy in terms of contents, it showed that Siemens Tecnomatix is a powerful tool for simulations. Additionally, the tool is not only powerful, but also versatile and adaptable. This is due to features like the possibility of synchronization with real manufacturing processes, import of personalized graphics into the software, the high number of parameters included in every single component and the program language created specifically for this software.

Consequently, this tool is widely used in production plants, in manufacturing, R&D or other departments. However, its usage in the academic field is not established despite its potential.

After the usage of this tool in the project, different aspects have been noticed related for an academic use. The tool is perfect in modules related to Business Engineer, especially for topics related to production or logistics. This software allows the simulation of easy scenarios who can represented from a practical perspective different theoretical concepts such as the Queuing Theory, EOQ, or different algorithms such as the Genetic Algorithm. Due to the possibility to introduce costs in the simulation, almost every production-logistic concept can be visually explained through Siemens Tecnomatix.

Even Value Stream Mapping (VSM), Kanban, or just general Lean Production exercises could be done through Siemens Tecnomatix, with simple and specific scenarios created for these purposes. Siemens Tecnomatix includes a Kanban and a VSM library within the software[63], however, these libraries have not been explored as there were not included in the project scope.

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[63] The Kanban library is included and free in the student license. The VSM library is not included.

The Siemens Tecnomatix is a powerful tool for companies as it can simulated even the most complex production line, but is also powerful for an academic use, as it also can simulate simple but specific scenarios who can complement and visualize the majority of the Operations Management related concepts. Practical exercises or just simple visualizations will help a student to interiorize the concepts provided.

A possible limitation of this tool is the need to learn the basics of the internal programming language if a specific scenario wants to be built. As a consequence of the complexity included by Siemens to represent the most complex production plants, more time and knowledge is needed to pass the so-called learning curve in comparison to simpler software like SIMIO or JaamSim. However, some of the previous concepts mentioned before could not be represented in SIMIO or JaamSim. Plus, the Siemens Tecnomatix Booklet provided aims to help to pass the learning curve, helping the future student to achieve results faster and easier.

SYNOPSIS

- Siemens Tecnomatix is an exceptional tool for simulation.

- The parameters used in each component of the three scenarios are identical and related to the 4.0 Training Factory.

- The Initial scenario is based on manual work and transport while the Digital Twin and To-Be scenario are automated.

- The essential change of the scenarios is the gradual change to a complete Pull strategy in the production line.

5. Results

This chapter is going to focus on the different results provided by the simulation of the Fischertechnik 4.0 Training Factory and the three Siemens Tecnomatix scenarios. These results are provided through different KPIs introduced in the scenarios and are framed in a specific time window.

5.1. Fischertechnik 4.0 Training Factory

Fischertechnik 4.0 Training Factory has been simulated in its standard scenario. The results are mean times calculated by capturing manually different times through the simulation of the scenario.

10 different samples of time recordings have been captured for the calculation of each mean time; individual results are provided in the Appendix. Due to the manual calculation of the time by using a chronometer, results are within a certain variability and not exact, but representative.

The Node-RED tool could have been used for these time measurements by personalizing the dashboard and including different variables. This has already been commented in section 3.3, page 21. Although this could not be implemented due to the lack of comprehension and usage of this tool.

Process	Mean time	Siemens Tecnomatix
Quality control	25.43s	25s
Workpiece supply (from manual supply to HBW storage)	61.86s	50s
Workpiece process (from Oven to Packaging)	72.28s	73s
Production line Lead Time (from Client Order to Delivery)	115.21s	-

Table 5.1: Fischertechnik results[64]

Firstly, due to the fact that the 4.0 Training Factory workpieces supply, the client order creation and the workpiece removal are done manually, limitations are considerable as this means that every sample will be considerably different; plus, long simulations are not possible. Generic KPIs like total output within a time window, production line cycle time, or complete workpiece lead time is not possible to record as they depend on the piece supply and removal, or the client orders.

Despite this fact, times showed on Table 5.1 are independent to these factors and can be recorded. The quality control takes 25.43s to be done, which is similar to the Siemens Tecnomatix time. The workpiece process takes 72.28s in the Fischertechnik model, and in Siemens Tecnomatix, this same process takes less than 1s more. Lead time cannot be compared because it is calculated differently in both tools: while in the Fischertechnik model it is the time taken from the HBW exit to the client delivery, in Siemens Tecnomatix it is calculated from the initial material supply to client delivery. Finally, due to the slowness of the crane movement in Fischertechnik, times for workpiece supply are higher than in Siemens Tecnomatix.

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[64] Table 5.1: Presents the mean time of 10 samples of the processes which are not depending on the manual piece supply, client order or piece removal. Own source.

The simulation of the Fischertechnik model has clear limitations respecting the virtual scenarios. The virtual scenarios have the possibility to simulate a complete production day in 10 seconds, providing more diverse and reliable long-term results. Therefore, the results of the Fischertechnik simulation are considerably basic. Using Node-RED could have helped by providing more diverse results.

5.2. Siemens Tecnomatix Plant simulation

The simulation in Siemens Tecnomatix has been different respecting the Fischertechnik 4.0 Training Factory. This is because Siemens Tecnomatix is more flexible and versatile than the physical model. The software allows to gather data from the different scenarios easier and more intuitively, allowing to use more Key Performance Indicators (KPIs) for the analysis of each scenario. Additionally, as commented, the speed of the simulation can be increased in the software, allowing to simulate a complete production shift in just seconds. With the increase of speed results provided are more reliable as they are based on a longer-term and are not based on one concrete moment or samples.

The simulations realized and the results provided hereafter are done in the same conditions for each scenario. This means that the parameters displayed in the tables in Chapter 4 for each scenario have not been changed, plus the time simulated is identical in the three scenarios: 7'5 h. This allows a proper comparison between the results of each scenario based on predefined KPIs and provides useful information for a further analysis. Furthermore, as the basis in the three scenarios are identical, the changes visualized in each KPI are direct consequences of the implementations introduced.

5.2.1. Predefined Key Performance Indicators

The comparison is going to be made based on predefined Key Performance Indicators, or KPIs. These KPIs are calculated within each scenario using different *Methods* or code-programming tools. The next table lists the KPIs used, includes an explanation each KPI and shows how it is calculated in the simulation, for better comprehension.

KPI	Explanation	Calculation
Raw Material Entries	Shows the nº of unprocessed workpieces that have entered the production line within a certain time.	Nº of workpieces created in the source. *10 pieces* means that 10 pieces have been created and are in the production line.
Defective Parts	Displays the nº of workpieces that have been defective.	Nº of pieces that have entered the drain as defective. *10 pieces* means that 10 pieces have been defective in the production line (drilling machine in this specific case).
Pieces Delivered	Presents the nº of workpieces that have been delivered to client.	Summation of pieces that have entered the three final storage places. *10 pieces* means that 10 pieces have been delivered to the client.

Table 5.2: First KPI table[65]

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[65] Table 5.2: Shows and explains the first three KPIs introduced in the scenario simulation. Own source.

KPI	Explanation	Calculation
Defective Percentage	Presents the % of defective workpieces in the production line compared to the total delivery.	Ratio between defective pieces and pieces delivered. Defective (%) = Nº of defective *100 / Nº Delivered pieces *10%* means that the ratio of defective pieces and pieces delivered is 1:10.
Average Inventory	Shows the average of workpieces that are in the warehouse. This is also applicable for the Sorting Line in the As-Is and To-Be scenario, changing *warehouse* for *buffer*.	Division between the summation of workpieces visualized in different samples and the nº of samples taken. Each time a workpiece is delivered, one sample is taken. Avg Inventory = (SUM of workpieces in warehouse when sample taken) / nº samples taken An average of *4 pieces* with 10 deliveries to client means that with 10 samples, a total of 40 workpieces were stored
Average Cycle Time	Displays the average time taken by the production line to process workpieces and deliver to client.	Division between the current simulation time and the nº of workpieces delivered to client. Each time a workpiece is delivered, one sample is taken. Avg Cycle Time = Simulation Time / Nº Pieces delivered An average of *1 minute* with 10 deliveries to client means that in 10 minutes of simulation time, 10 pieces have been delivered.
Average Lead Time	Visualizes the average time taken by the workpieces from entering the production line, to being delivered to client (lead time).	Division between the summation of lead times of each workpiece delivered, and the nº of pieces delivered. Avg Lead Time = (SUM of lead times) / nº of pieces delivered An average of *10 minutes* with 5 deliveries to client means that the sum of the lead times of the 5 deliveries have taken 50 minutes.
Average Work-in-Progress (WIP)	Shows the average nº of workpieces that are inside the production line.	Division between the summation of workpieces between the source and the client storage each time a sample is taken and the nº of samples taken. Each time a workpiece is delivered, one sample is taken. Avg WIP = (SUM of WIP each time sample is taken) / Nº of samples taken An average of *5 WIP* with 10 deliveries means that the sum of the WIP with 10 samples is equal to 50 workpieces.

Table 5.3: Second KPI table[66]

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[66] Table 5.3: Shows and explains the next KPIs introduced in the scenario simulation. Own source.

KPI	Explanation	Calculation
Service Level	Displays the % of workpieces delivered according to the client order list.	Comparison between the Client Order sequence and the Workpiece delivery sequence. Service Lvl (%) = Nº pieces in correct sequence *100 / Nº pieces delivered *100%* means that the sequence of delivery is exactly as the sequence of client order.
Working Percentage	Visualizes the percentage of time a specific component in the production line is working or processing.	Portion of time given in the statistics of the component. *60%* means the component is being used 60% of the total simulation time.
Waiting Percentage	Visualize the percentage of time a specific component in the production line is not being used or waiting.	Portion of time given in the statistics of the component. *60%* means the component is not being used 60% of the total simulation time.
Blocking Percentage	Visualizes the percentage of time a specific component in the production line is blocking the normal workability of another component.	Portion of time given in the statistics of the component. *60%* means the component is blocking the workpiece flow in another component 60% of the total simulation time.
Setup Percentage	Visualize the percentage of time a specific component in the production line is setting up for the next workpiece.	Portion of time given in the statistics of the component. *6%* means the component is setting up 6% of the total simulation time.
Space Occupied	Siemens Tecnomatix makes use of a grid with predefined squares. These squares are used to measure the occupation of the scenario. 1 square is 1 unit.	Nº of grid squares used by the production line in the simulation. *30x30* means that the production line occupies 30 squares of width, 30 squares of depth.

Table 5.4: Third KPI table[67]

The tables display the most relevant KPIs used within the scenarios, and are the indicators chosen to evaluate the three different simulations. Through Simtalk 2.0, Siemens programming language, many other indicators could have been implemented in addition to the indicators just shown and can be implemented in the future.

The results of the scenarios according the KPIs are provided in the next subchapters.

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[67]Table 5.4: Shows and explains the last KPIs introduced in the scenario simulation. Own source.

5.3. Initial production plant scenario

The initial scenario is the scenario which is used to exemplify a previous stage of the Fischertechnik 4.0 Training Factory. As a reminder, the main characteristic used in this scenario is the usage of workers for processing and material transport, plus the Push strategy in production, meaning that the real-time client demand is not considered, instead a demand based on long-term percentage (33'3%) is used.

The only KPI that differs from the next two scenarios is the *Overproduction* KPI, this KPI is measured due to the result of the Push Strategy and the overcapacity of the production line. The combination of both cause the overproduction of workpieces and leads to full finished-product warehouses, and eventually, wasted workpieces due the non-existing space for storage. This KPI displays the number of workpieces that have been eliminated due this reason.

The results provided by the KPIs after 7'5 h of simulation of the initial scenario using the standard parameters are visualized in Figure 5.1 and Table 5.5: First Initial scenario results:
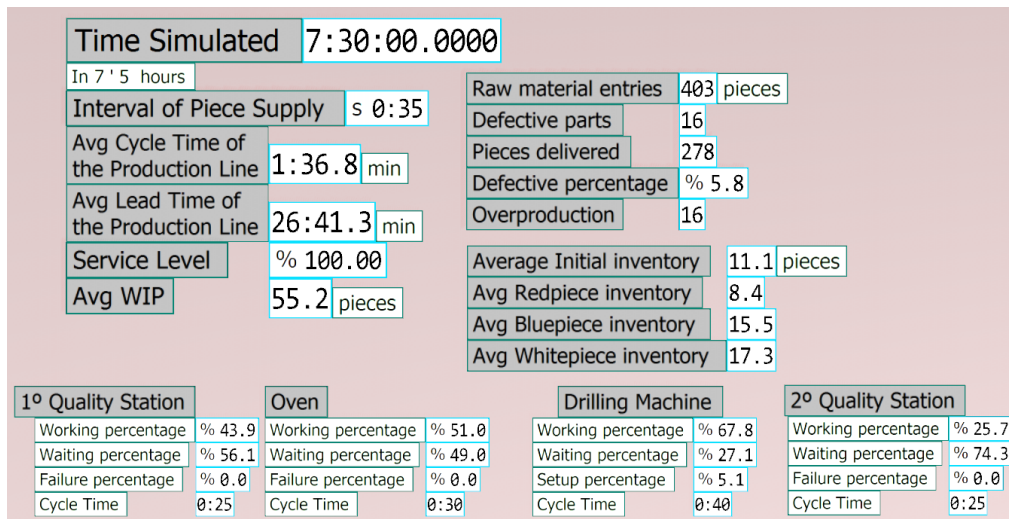
Figure 5.1: Initial scenario results[68]

KPI	Results
Time Simulated	7h 30min
Raw workpiece entries	403 pieces
Workpieces delivered	278 pieces
Defective workpieces	16 pieces
Overproduction	16 pieces
Defective percentage	5'8 %
Service Level	100 %

Table 5.5: First Initial scenario results[69]

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[68] Figure 5.1: The KPIs of the scenario are displayed after 7'5h using the *Display* tool in Siemens Tecnomatix. Own picture.
[69] Table 5.5: Recollects the first KPIs of the Initial scenario simulation after 7'5h. Own source.

KPI	Results
Average Initial inventory	11'1 pieces
Average Red piece inventory	8'4 pieces
Average Blue piece inventory	15'5 pieces
Average White piece inventory	17'3 pieces
Average Cycle Time	1min 37s
Average Lead Time	26min 41s
Average Work-in-Progress	55'2 pieces
1º Quality Station percentages	43'9 % Working 56'1% Waiting
Oven Station percentages	51% Working 49 % Waiting
Drilling Machine Station percentages	67'8% Working 27'1% Waiting 5'1 % Setting Up
Final Quality Station percentages	25'7% Working 74'3 % Waiting
Space Occupied	41x14 units 574 unit^2

Table 5.6: Second Initial scenario results[70]

Explanations and comments of the specific results are given in the subchapter 5.6: Comparison of KPIs. Next, the results of the Digital Twin results are presented.

5.4. As-Is production plant scenario

The As-Is scenario, or Digital Twin of the Fischertechnik 4.0 Training Factory is the scenario that represents the current state. It is the automated version of the Initial scenario. Essentially and in comparison with the Initial scenario, this scenario substitutes the workers by an automated three-axis articulated robot for the workpiece movement, automates the stations as there is no need for workers to process pieces in stations, eliminates the final storage by using a Pull strategy for processing workpieces and combines the two quality stations into one.

The *Overproduction* KPI is not needed as overproduction does not exist with the Pull strategy and in the Fischertechnik 4.0 Training Factory. Instead, the VGR percentages are going to be shown as it is an essential component within the production line. The Digital Twin offers the following results after simulating 7'5h with the standard parameters in Siemens Tecnomatix:

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[70] Table 5.6: Recollects the first KPIs of the Initial scenario simulation after 7'5h. Own source.
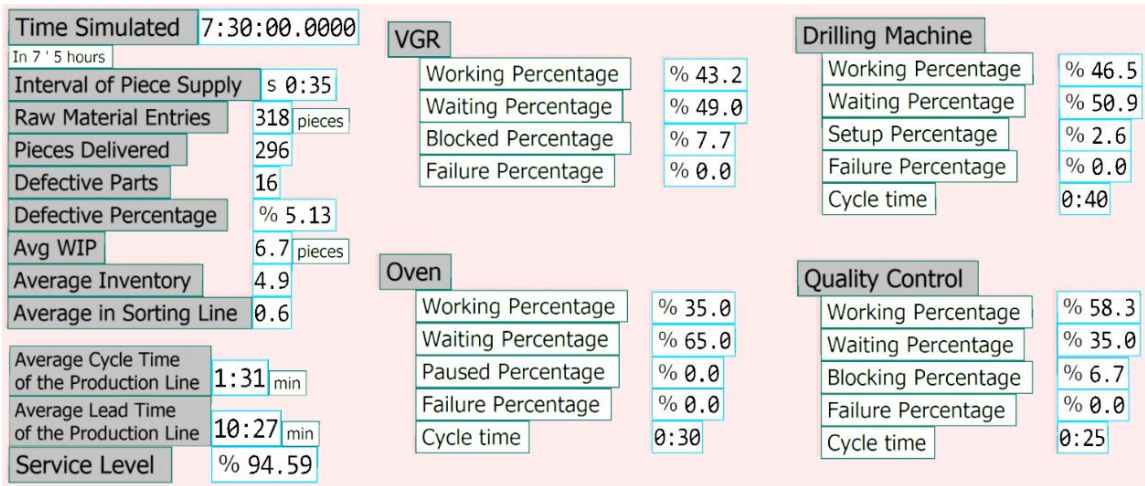
Figure 5.2: Digital Twin results[71]

KPI	Result
Time Simulated	7h 30min
Raw workpiece entries Workpieces delivered Defective workpieces	318 pieces 296 pieces 16 pieces
Defective percentage Service Level	5'13 % 94'59 %
Average Initial inventory Average Pieces in Sorting Line	4'9 pieces 0'6 pieces
Average Cycle Time Average Lead Time Average Work-in-Progress	1min 31s 10min 27s 6'7 pieces
Oven Station	35 % Working 65 % Waiting
Drilling Machine Station	46'5% Working 50'9 % Waiting 2'6 % Setting Up
Quality Control Station	58'3% Working 35 % Waiting 6'7 % Blocking
VGR Robot	43'2 % Working 49 % Waiting 7'7 % Blocked
Space Occupied	24x20 units 480 unit^2

Table 5.7: Digital Twin results[72]

Results are discussed in the KPI comparison subchapter further on.

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[71] Figure 5.2: Shows the results recorded inside the Digital Twin. Own source.
[72]Table 5.7: Recollects the KPIs of the As-Is scenario simulation after 7'5h. Own source.

5.5. To-Be production plant scenario

The To-Be scenario, or the improved Digital Twin, is the last scenario created in Siemens Tecnomatix. Essentially, this future scenario represents the Digital Twin including some changes in order to improve the current state. These implementations were the consequences of one single implementation: a complete Pull strategy. While the current state uses Pull strategy for processing workpieces, this scenario not only uses Pull strategy for processing workpieces, but also for the workpiece supply, supplying the correct workpiece according the client order.

The KPIs used for this simulation are the same as the current state or Digital Twin and does not need the *Overproduction* KPI. Instead, a new KPI is introduced, called *Avg Time Urgent Parts*, which is the time the system reacts to a defective part and is going to be explained with the KPI comparison. After a 7'5h simulation in Siemens Tecnomatix, the To-Be offers the following results:
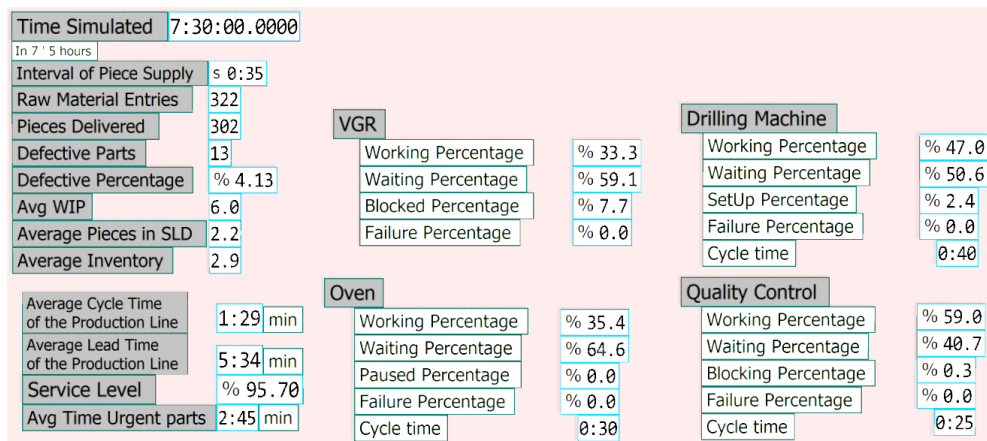
Figure 5.3: To-Be scenario results[73]

KPI	Result
Time Simulated	7h 30min
Raw workpiece entries Workpieces delivered Defective workpieces	322 pieces 302 pieces 13 pieces
Defective percentage Service Level	4'13 % 95'7 %
Average Initial inventory Average in Sorting Line	2'9 pieces 2'2 pieces
Average Cycle Time Average Lead Time Average Time Urgent parts Average Work-in-Progress	1min 29s 5min 34s 2min 45s 6 pieces

Table 5.8: First To-Be scenario results[74]

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[73] Figure 5.3: Displays the results of the To-Be simulation after 7'5h. Own source.
[74] Table 5.8: Displays the results of the simulation of the To-Be scenario. Own source.

KPI	Result
Oven Station	35'4 % Working 64'6 % Waiting
Drilling Machine Station	47 % Working 50'6 % Waiting 2'4 % Setting Up
Quality Control Station	59% Working 40'7 % Waiting 0'3 % Blocking
VGR Robot	33'3 % Working 59'1 % Waiting 7'7 % Blocked
Space Occupied	24x20 units 480 unit^2

Table 5.9: Second To-Be scenario results[75]

The next subchapter focuses on the comparison of the three different scenarios and provides comments on these results.

5.6. Comparison of KPIs

After presenting the results of each simulation, this subchapter focuses on comparing the result given through each KPI, providing a comment, possible reason, or observation that may explain the change in the results.

As already commented, the comparison is possible because the parameters used in each production line inside the components are identical, including the simulation time. This means that changes in the provided results are based on the implementations made and have not been adulterated by making a process time faster, by changing material supply intervals or any other parameter.

Table 5.10, Table 5.11 and Table 5.12 show the resulting KPIs of each scenario, the KPIs are separate in 3 groups and discussed according the group. Additionally, changes between the scenario analysed and the previous one are visualized with percentages. This means that the Initial scenario has no percentages, the As-Is scenario is compared with the Initial scenario, and the To-Be scenario is compared with both Initial and As-Is scenario. These percentages make changes within the KPIs more visible and interpretable and are going to be used to discuss the change.

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[75] Table 5.9: Displays the results of the simulation of the To-Be scenario. Own source.

KPI	Initial Scenario	As-Is Scenario		To-Be Scenario		
Raw Material Entries	403 pieces	318 pieces	(-21'1%)	322 pieces	(-20'1%)	(+1'3%)
Pieces Delivered	278 pieces	298 pieces	(+7'2%)	302 pieces	(+8'6%)	(+1'3%)
Defective Parts	16 pieces	16 pieces	0%	13 pieces	(-18'8%)	(-18'8%)
Defective percentage	5'8%	5'1%	(-0'7%)	4'1%	(-1%)	(-1%)
Space Occupied	41x14 units 574 unit^2	24x20 units 480 unit^2	(-16'4%)	480 unit^2	(-16'4%)	0%

Table 5.10: First table of results[76]

Table 5.10 shows the first and most basic results of the simulation. These KPIs are straightforward and not decisive or crucial in an analysis. However, it briefly illustrates the effect of changing from Push to Pull strategy.

The *Material Entries* have been reduced considerably (-21'1% and -20'1%) in the As-Is and To-Be scenario respecting the Initial scenario. This is due the mentality related to the strategy used. With Push strategy, a production line is focused on producing as many parts as possible, going the material supply according with it, and indirectly, as many parts as possible are supplied. Additionally and in combination with what just has been said, in the Initial scenario one worker is specially focused in the material supply (worker 1), while in the next scenarios, the crane is the responsible for the material supply, among other tasks. This makes the initial scenario capable for more supply, while in the other scenarios, it is limited because the crane needs to multi-task.

Despite of the significant reduction of workpiece supply within the 7'5h in the As-Is and To-Be scenario, the output, or *Delivery to Client*, has increased significantly in both scenarios (+7'2% and 8'6%). This could be due to two factors: the general automation in processing and quality station, and to the reduction of piece transport within the production line. This last aspect is mainly provoked by the shape of the production line. The Initial scenario is linear, which takes more *Space*, while in the Digital Twin, because of the U-shape, stations are more concentrated around the VGR crane, reducing considerably the space. This can be visualized with the 16'7% space reduction. Despite the impossibility to track the distance made by a workpiece within the production line, generally and within the same speed conditions, less space in a production line means less need for transport, which leads to time reduction.

Finally, a change in *Defective Parts* can be visualized. This change is not representative, as the parts are considered randomly but within a percentage, defective. This depends on the Randomseed[77] used. In addition to the unpredictable defective sort, notice that a defective part is considered defective after it has been processed in the Drilling Machine Station. This means that the real defective rate is not depending on the pieces delivered, but on the pieces processed in this station. This is especially relevant in the Initial scenario, as the Drilling Machine processes 389 workpieces in 7'5h (workpieces are stored in finished-workpiece warehouses), meaning that the 16 defective workpieces truly represent a 4'1% of the pieces processed (16 / 389).

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[76] Table 5.10: Shows the basic KPIs resulted from the 7'5h simulation in each scenario, including percentages. Percentages are calculated by dividing the difference between KPIs, and the previous result. Own source.

[77] See the Siemens Tecnomatix Booklet for more information.

KPI	Initial Scenario	As-Is Scenario		To-Be Scenario		
Average WIP	55'2 pieces	6'7 pieces	(-87'9%)	6 pieces	(-89'1%)	(-10'4%)
Average Inventory	$11'1 + 8'4 + 15'5 + 17'3$ 52'3 pieces	$4'9 + 0'6$ 5'5 pieces	(-89'5%)	$2'9 + 2'2$ 5'1 pieces	(-90'2%)	(-7'3%)
Average Cycle Time	1 min 37s	1 min 31s	(-6'2%)	1 min 29s	(-8'2%)	(-2'2%)
Average Lead Time	26 min 41s	10min 27s	(-60'8%)	5min 34s	(-79'1%)	(-46'7%)
Service Level	100%	94'6%	(-5'4%)	95'7%	(-4'3%)	(+1'1%)

Table 5.11: Second table of results[78]

The second table provided for the comparison of results displays some of the most important KPIs within factories and production lines. This table shows the most significant changes of the three scenarios.

Starting from the *Average Inventory*, calculated with workpieces as a unit, important changes are visualized in the two last scenarios in comparison with the first one (89'5% and 90'2% reduction). This is clearly due to the Pull strategy, as by introducing Pull strategy for processing workpieces, the three finished-goods warehouse can be removed. The finished-goods warehouses were representing most of the average inventory in the Initial scenario (41'2 pieces of the 52'3 total).

Additionally, the To-Be scenario reduces the *Average Inventory* by a 7'3% respecting the Digital Twin. This is due the complete Pull Strategy used in this future scenario. The HBW inventory in the future scenario is used as security stock, so the inventory in HBW in this scenario will always be nearly to 3 pieces (1 piece of each colour), being reduced by 2 workpieces if it is compared with the As-Is scenario. The 2 workpiece reduction in average inventory is slightly compensated with more accumulation of workpieces in the Sorting Line in the To-Be scenario (from 0'6 to 2'2 pieces), that is due to the lack of capacity of the VGR crane to multi-task and the crane is slightly overfloated with the workpiece transport in the SLD section. Perhaps this deterioration, the complete average inventory is still reduced in the future scenario (from 5'5 to 5'1 pieces).

A consequence of the inventory reduction, is a consequently reduction in *Average Lead Time*. The inventory reduction with the same or more deliveries to client means that the Inventory Turnover ratio increases, ratio that indicates how many times an inventory has been replaced in a certain time, so the time spend by a workpieces within the production line decreases. The KPI has always been improved with significant reductions with every implementation introduced.

Due to the combination of both KPIs explained above, the *Average WIP*, or Work-In-Progress, measured with workpieces as a unit, is reduced in both As-Is and To-Be scenario, again, significantly. The average WIP measures the average of pieces that are within a specific section in a factory, and in this case, the production line; and as the average inventory is considerably reduced, including also the lead time in the production line, or the time spent by a workpiece inside the production line, this means that less pieces are being processed or waiting to be processed, leading to decreases in the WIP. A considerably great result is achieved in the Digital Twin and improved further in the future scenario.

The *Average Cycle Time* is improved thanks to the increase in Client Delivery, as this is measured by dividing simulation time (constant, 7'5h) with the Client Deliveries.

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[78] Table 5.11: Own source.

Finally, a considerable deterioration of *Service Level* is observed in the last two scenarios, meaning that the client order sequence is not always accomplished. This is a consequence of eliminating the finished-goods warehouse, because when a workpiece is considered as defective, the piece cannot be directly replaced and the sequence is disrupted, decreasing the Service Level KPI.

The decrease in *Service Level* could suppose a major issue in production line and is intended to be fixed in the future scenario by the security stock in HBW. While in the Digital Twin, a defective part is never delivered, and it is a piece lost in the Client Order, in the future scenario, the defective piece is replaced with the same colour piece of the security stock, providing the client the correct amount of pieces, even if the sequence is slightly disrupted. This still reduces the Service Level but provides the client the correct number of pieces. The time to react to a defective part is showed by the *Average Time of Urgent Parts* in this future scenario.

KPI	Initial Scenario		As-Is Scenario			To-Be Scenario			
Working Percentages	Oven Drilling M. 1° Quality 2° Quality	51% 67'8% 43'9% 25'7%	Oven Drilling M. Quality VGR	35% 46'5% 58'3% 43'2%	(-16%) (-21'3%) (+14'4%) -	Oven Drilling M. Quality VGR	35'4% 47% 59% 33'3%	(-15'6%) (-20'8%) (+15'1%) -	(+0'4%) (+0'5%) (+0'7%) (-9'9%)
Waiting Percentages	Oven Drilling M. 1° Quality 2° Quality	49% 27'1% 56'1% 74'3%	Oven Drilling M. Quality VGR	65% 50'9% 35% 49%	(+16%) (+23'8%) (-21'1%) -	Oven Drilling M. Quality VGR	64'6% 50'6% 40'7% 59'1%	(+15'6%) (+23.5%) (-15'4%) -	(-0'4%) (-0'3%) (+5'7%) (+9'9%)
Other Percentages	Drilling M. (Set Up)	5'1%	Drilling M. (Set Up) Quality (Blocking) VGR (Blocked)	2'6% 6'7% 7'7%	(-2'5%) - -	Drilling M. (Set Up) Quality (Blocking) VGR (Blocked)	2'4% 0'3% 7'7%	(-2'7%) - -	(-0'2%) (-6'4%) 0%

Table 5.12: Third table of results[79]

The percentages presented in the third table of results are indicators which confirm the changes visualized with the previous tables and represent a different approach on how to visualize indicators. These indicators are provided by Siemens Tecnomatix by default and do not need any calculation to been obtained.

Through the percentages of the Initial scenario the bottleneck can be observed. The bottleneck is the Drilling Machine as the station requires more work and processing than the other stations (67'8%). The percentage might not be higher due the fact that it requires pieces to be transported manually into the station, which requires a certain percentage of total time. On the other hand, we can observe that the Final Quality station is waiting, and unused, most of its time (74'3%). This can be because of the waiting for the correct pieces to arrive at the final-good warehouse, as they do not arrive in the correct client order, because it is located after the bottleneck, which limits and slows down the production, and because of the fact that pieces need to be picked up and transported manually from the warehouse to that quality station.

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[79] Table 5.12: Own source.

Some of the implementations done in the Digital Twin was merging the two quality stations into one due to the low working percentages of both quality stations in the Initial scenario, and processing only the correct number of workpieces (pull strategy).

Both changes are visualized through the working percentages of the As-Is scenario: the Quality Station usage has increased significantly being the most used station (it needs to assume the initial and final quality check at the same time), while the less processing of workpieces due the Pull strategy has reduced significantly the usage of the Drilling Machine (the Drilling Machine processes only the workpieces needed). The combination of both factors changes the bottleneck of the production line, going from the Drilling Machine in the Initial Scenario to the Quality Station in the Digital Twin.

The previous fact can be verified by observing the increased *Blocking percentage* of the Quality Station in the Digital Twin scenario, meaning that this station is blocking the workpiece flow a 6'7% of the time.

Finally, the implementations introduced in the To-Be scenario are not making significant changes respecting working percentages of the Digital Twin, The only significant difference respects to the VGR working percentage, as this might due to skipping the HBW in the main flow of workpieces: the VGR does not need to unload a piece to the HBW and load a different one to bring it to the Oven; instead, it brings the piece directly to the Oven skipping an unneeded movement, which might reduce its working percentage in 9'9%.

5.6.1. Final consideration

The results and the comparisons have been presented. In summary, by implementing a progressive Pull Strategy from the Initial scenario to the To-Be scenario, inventory, lead time, WIP average and working percentages have been reduced upon to 90'2% respecting the initial scenario.

Lower lead time makes a production line more flexible and adaptable to the client demand, lower inventory reduces logistic costs and visualizes the problem in the production line easier in order to fix them, lower working percentages on machinery might reduce machine failure and gives time for a good machine maintenance, and is even better when the overall output of the production line has even increased with this lower working percentage.

However, these changes in the results have sacrificed one KPI, which is essential in most of the industries: Service Level. The low Service Level of the Digital Twin is due to the haphazard material supply and client demand, which are not correlated, the defective pieces, which affect directly on the sequence of material supply as the Digital Twin production line has no capacity to react to these defective parts, and the small capacity of the store, which does not store enough pieces, which can lead to a production line collapse if the client order demand changes suddenly to a higher demand of a specific piece colour.

The intend made on the To-Be scenario has been to solve or improve this problem, which could not be solved completely. Perhaps of having still a low Service Level, defective parts are compensated with safety stock quickly (*Average Time for Urgent Pieces*: 2 min 45s) providing the client the correct number of pieces, even if it has not been delivered in the correct sequence. This improvement still penalizes the service level but improves the production line general reaction to these defective parts.

In general, through these three examples, several aspects can be observed:

- The 4.0 Training Factory can be improved, this is shown through the improvements made in its Digital Twin.
- The use of a Digital Twin is visualized, as in this case, the Digital Twin is used to implement virtual improvements that could be implemented in the real and physical production line of the 4.0 Training Factory. This could be done in the next stage of the project.
- Any change realized within a production line provokes a cascade of different changes, so this needs to be considered before any implementation. One change (Pull strategy) has caused different results within the factory.
- Implementations are easier to implement in virtual scenarios than in real-world scenarios. While the changes can be made in the Digital Twin with certain easiness, the implementations in the physical 4.0 Training Factory are not possible.

SYNOPSIS

- The Fischertechnik 4.0 Training result analysis is extremely poor because data extraction is poor. This is due to the fact that in the standard scenario pieces have to be moved or ordered manually, due to the lack of knowledge of Node-RED, and due to the incapacity to simulate several hours in several hours.

- The Siemens Tecnomatix software by contrast, allows to gather more data which can be processed and analysed through KPIs.

- A gradual improvement in KPIs of the scenarios is observed, having a significant improvement from the initial state to the current Digital Twin, and a small improvement with the future Digital Twin scenario.

- Through the Siemens software, the Digital Twin is analysed, and improvements are tested and implemented. These improvements need to be implemented in the physical production line in the last step of the Digital Twin cycle.

6. Academic Booklets

After having presented the tools used through the previous chapters with inside explanations, a Digital Twin and scenario examples, this chapter is going to focus on giving further details related to the booklets that complement this document. The aim of this chapter is to provide details of these booklets for a better comprehension and to present the contents within these booklets.

The first part of this chapter is focused on the Fischertechnik 4.0 Training Factory booklet, while the second part is focused on the Siemens Tecnomatix Plant Simulation booklet

6.1. Fischertechnik 4.0 Training Factory

The Fischertechnik 4.0 Training Factory Booklet has two main objectives: show how to configure the Fischertechnik model from the beginning and provide a solid basis of knowledge related to this factory to use this basis for implement future changes and improvements within the factory.
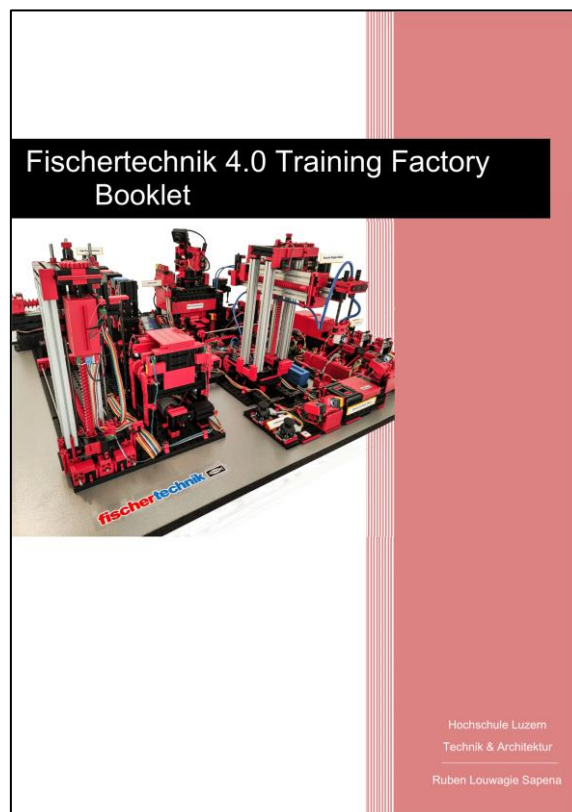

Figure 6.1: Fischertechnik Booklet front page[80]

The Fischertechnik 4.0 Training Factory Booklet is intended to be for academic purposes and to help future students to comprehend the physical simulation model in order to save time and obtain results faster.

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[80] Figure 6.1: Shows the cover of the Fischertechnik Booklet provided. Own source.

The booklet starts with a quick introduction to the Fischertechnik 4.0 Training Factory, continuing with chapters that explain the individual components, how to configure the Fischertechnik model from the very starting point in order to make the model run on the standard and basic scenario, code-programming comments and an introduction to the Node-Red tool.

Chapter	Explanation
Introduction	Introductory chapter that is focused on providing a basic and generic overview of what Siemens Tecnomatix software is used for
Individual Factory Components	Chapter that explains with more detail each module of the Fischertechnik 4.0 Training Factory
Getting Started	Chapter that aims to extensively show the initial configuration needed of the Fischertechnik 4.0 Training Factory before running its standard scenario
Block Diagram of the Factory	Section where more insights to the TXT controller diagram are given, explain more detailed how the TXT controller works
Factory Basic Running	Chapter provides information on how to start the basic scenario running and explains with details this standard scenario
Programming	Gives insights of the internal code-programming of the Fischertechnik as commented in section 3.2, page 19 of this document
Node-RED	Chapter where the Node-Red tool is presented for a possible future use

Table 6.1: Fischertechnik Booklet chapter list[81]

The booklet does not substitute the Fischertechnik manual specially provided for this model, which is more extend and provides further basic details. The booklet aims to resume the Fischertechnik manual, plus give an additional perspective after having used the tool, configurate it and comprehend it.

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[81] Table 6.1: Provides the list of chapters of the Fischertechnik booklet with a explanation of each chapter. Own source.

6.2. Siemens Tecnomatix Plant Simulation

The second booklet provided is the Siemens Tecnomatix Plant Simulation booklet.

This booklet aims to provide a student with an explanation and an introduction to this specific software, and provide the necessary tools needed for constructing a basic-intermediate simulation model in this software. This is done by using an example model, which is created step by step throughout the model, enabling the user introduce several aspects easily with this example.
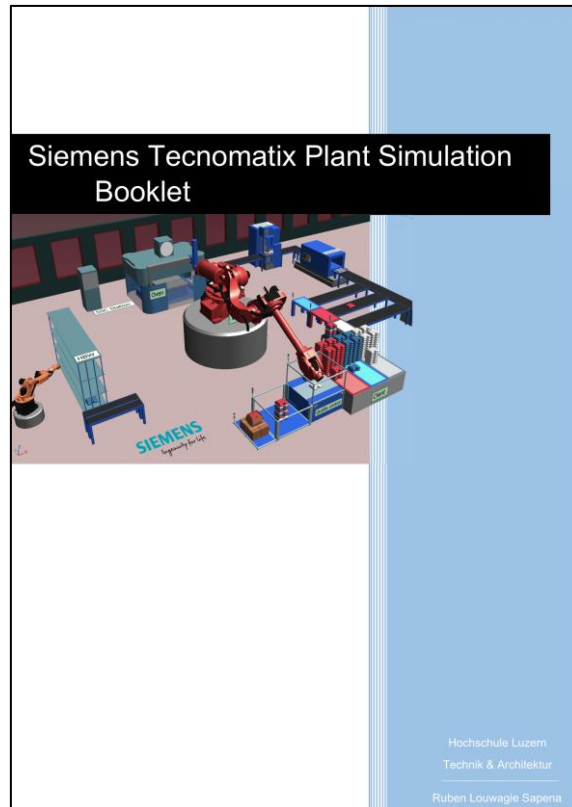
Figure 6.2: Siemens Tecnomatix Booklet front page[82]

The Siemens Tecnomatix Plant Simulation Booklet is intended to be for academic purposes and to help future students to comprehend Siemens software in order to create scenarios on a basic and intermediate level.

6.2.1. Introduction to the booklet

The booklet is provided to learn easily how to model in Siemens Tecnomatix. This is done through several examples given throughout 17 pages, divided in 6 chapters which are explained in the following table.

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[82] Figure 6.2: Shows the cover of the Siemens Tecnomatix Booklet provided. Own picture.

Chapter	Explanation
Introduction	Introductory chapter that is focused on providing a basic and generic overview of what the Fischertechnik consists of and its functionality
Tecnomatix Interface	Chapter that explains the different interfaces and folders within the software.
Scenario Basics	Chapter that aims to show the basic components and objects within the software.
Getting Started with Examples	Chapter that provides easy steps to build a basic simulation model and learn the basics of modelling in the software
Basics of SimTalk 2.0	Chapter which provides general information of SimTalk with an easy example on how to use it
Final considerations	Chapter with final considerations or recommendations on how to proceed with the software

Table 6.2: Siemens Tecnomatix Booklet chapter list

The Siemens Tecnomatix Plant Simulation booklet does not substitute the Siemens Tecnomatix Help Guide. This booklet provides initial and useful information about the software which needs to be complemented with the guide provided by Siemens.

SYNOPSIS

- The Fischertechnik 4.0 Training booklet aims to explain the basics of the tool for a better comprehension that will allow to improve the Fischertechnik model in the future.

- The Siemens Tecnomatix Plant Simulation software aims to explain the basics of the software to allow future users to create a personalized intermediary-complex scenario.

7. Discussion

Chapter 7 is the final chapter of the document. This chapter intends to summarize the results of the project realized, including comments, recommendations and personal beliefs related to the project and the tools used in it.

The project concludes with a discussion of both Fischertechnik 4.0 Training Factory and Siemens Tecnomatix Plant Simulation software as a tool for learning, training and simulation purposes, following with a briefing of the results achieved compared to the initial objectives, and finally with a recompilation of different recommendations, comments and a summary of the personal experiences I have personally passed through with the realization of this project.

7.1. Fischertechnik use as a learning tool

Fischertechnik 4.0 Training Factory is a powerful learning tool, it can show different aspects related to the 4.0 Industry not only through an academic perspective, but also through a professional one. It shows briefly very important features related to the 4.0 Industry used at a larger scale in real-world factories. Even if the components used are basic in comparison to what a real production line could contain, as already said previously in this document, these are only representative.

The 4.0 Training Factory is dense in terms of C++ code-programming. This code programming complicates the usage of this tool for a beginner user and makes the learning curve steeper to achieve results. Furthermore, the Node-RED can be interesting and useful to use with the Fischertechnik model, yet due the lack of time, no deeper insights could be given related to this tool.

In addition, this Fischertechnik model is a relatively recent model introduced in the market, this means that information related to this model, as well as the know-how in the Fischertechnik community is not as available as in other models. Plus, the Fischertechnik company provides help, information, and tips related on how to use the standard scenario properly, but do not go beyond the standard scenario, relying this to the Fischertechnik community and forum[83] and giving the users freedom to explore..

Focusing on the Operations Management module or derivates, the tool cannot be used straightforwardly, as implementations and changes are not easy to introduce without a previous knowledge of C++ and a deeper comprehension on how the tool operates. For being used in this module, different scenarios or implementations need to be done previously, and because this is more digitally focused, implementations will need to be done in another module or by an advanced user of C++. Despite having potential, the 4.0 Training Factory needs to be worked through previously in order to be used in Operations Management.

In essence and to summarize, the Fischertechnik model has got the potential for a proper use, related to Operations Management, however it needs previous work, and the most immediate and clear use that could be given to the Fischertechnik model is more related to more technical subjects, as mechatronics, or generic Digital Engineering subjects. An additional use could be Raspberry Pi related, as the 4.0 Training Factory can be used for practical implementations with this device and, additionally, learn the M2M protocol.

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[83] https://forum.ftcommunity.de/

7.2. Siemens Tecnomatix use as a learning tool

Like the 4.0 Training Factory, Siemens Tecnomatix Plant Simulation is again a powerful learning tool. It is as said through the chapters, versatile and commonly used in companies, which means that the tool is robust, reliable, and at least, useful. Perhaps of being widely used within companies, its use is universities is not as clear.

Despite this last fact, through the realization of this project, it has been seen that Tecnomatix could present different product and manufacturing related topics with certain easiness for different modules. On the other hand, 4.0 Industry topics are not as easy to be presented through the Siemens software, besides of showing Siemens Tecnomatix as a 4.0 Industry tool itself. The components within the software are not 4.0 Industry related and rather basic. To visualize 4.0 Industry features, the 4.0 Training Factory is clearly more suitable.

The learning curve in Siemens Tecnomatix is not as steep as it could be with the Fischertechnik model. This is due several facts, but mainly because the tool reduces complexity within the parameters and code-programming, because the tool has been used for years in the market (since 2009) which means that know-how and information around this tool is easier to find, in the broad internet and specifically in Siemens Tecnomatix forum[84], and finally, the learning curve is not as steep because of the complete help-guide provided by Siemens inside the software where every detail is explained. Additionally, the book *Tecnomatix Plant Simulation* by Steffen Bangsow could not be reached. This book contains deep insights of modelling and programming in Tecnomatix, with examples, which could be extremely useful. However, the expert who created the book has been contacted and has helped by solving specific doubts software related.

The Siemens Tecnomatix software as commented has got limitations if used as a Digital Twin, due to the feedback needed of the physical system within the software. However, its usage as a simulation software is still important. Plus, despite it has not been possible to implement the Fischertechnik 3D CAD files available for this project into the Siemens Tecnomatix software, it is still believed this can be achieved, allowing to create accurate and realistic scenarios in terms of graphics.

Related to the Operations Management module and derivates, Siemens Tecnomatix is strongly recommended for its usage due to the relatively easiness to represent Operations Management concepts with this software. No specific technical skills are needed. The recommendation comes as a consequence of the topics given through this subject, related to manufacturing management and resource planning, quality management, production management, logistics, etc. which are to some extend incorporated in the software.

In essence, Siemens Tecnomatix can be seen as a learning tool through two different perspectives: as a basic Digital Twin software, more related to the 4.0 Industry topic, and as a simulation software, more related to the logistics and manufacturing management topic.

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[84] https://community.sw.siemens.com/s/topic/0TO4O000000MiinWAC/plant-simulation-forum

7.3. Summary of the results

Targets were set in the starting point of the project. These targets were modified after the midterm checkpoint of the project due to the complexity and setbacks related to the Fischertechnik tool, and the focus of the project was slightly changed in order to deep more into the Siemens Tecnomatix software. However, these modified targets were the targets stated in the beginning of this document.

This subchapter aims to expose these objectives and observe at what extent the results have met the initial targets. The initial aim of the Bachelor Thesis was to:

Target 1: Provide a manual of the Fischertechnik 4.0 Training Factory for academic purposes in order to explain how to configure the model, how to simulate its basic scenario and how to extract data from this model.

Target 2: Fulfil an analysis of the Fischertechnik 4.0 Training Factory for an academic purpose.

Target 3: Introduce Node-RED as a complementary tool for Fischertechnik 4.0 Training Factory.

Target 4: Provide a manual in order to use Siemens Tecnomatix Plant Simulation for academic purposes. How to modify different scenarios and extract relevant data from these scenarios to facilitate further analysis.

Target 5: Provide a basic Digital Twin of Fischertechnik 4.0 Training Factory, as well as an antecedent and a future scenario related to the Digital Twin with their applicable analysis.

The next figure shows at what extend these targets have been accomplished throughout the project. Comments are following to validate the percentages indicated.
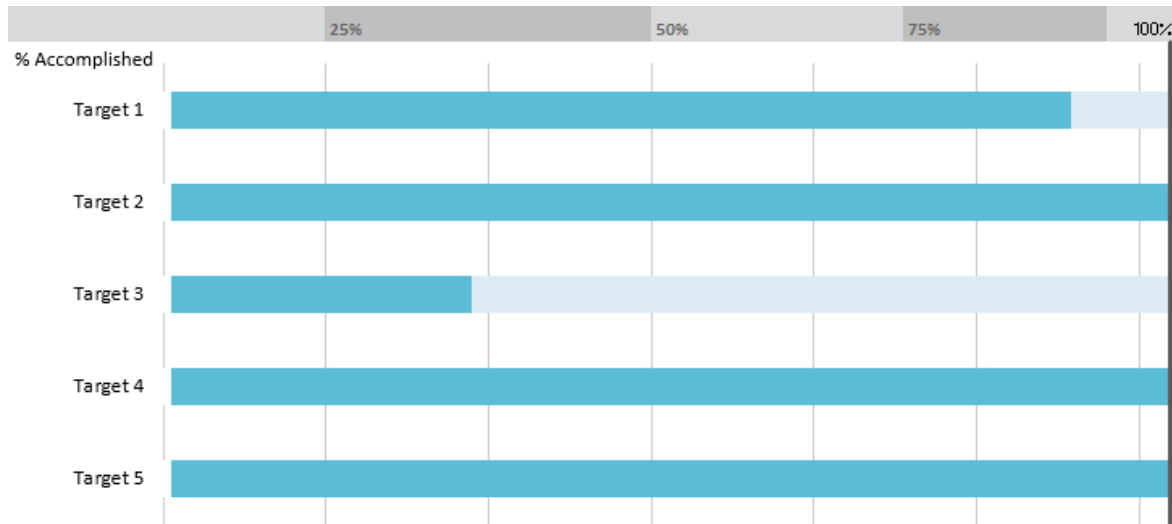

Figure 7.1: Objectives-Results comparative chart[85]

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[85] Figure 7.1: Own source.

The 1st target is accomplished at 90% respecting the initial aim. The manual explains how to configurate the Fischertechnik 4.0 Training Factory and how to run the standard scenario. However, the data extraction is not specifically explained because this requires more insides of the Node-RED tool which has not been analysed due lack of time.

The 2nd target has been accomplished. The Fischertechnik 4.0 Training Factory has been analysed with an academic perspective and comments on that analysis are given throughout the document.

The 3rd target, which is related to the first, is generally not accomplished. The Node-RED has not been investigated and combined with the Fischertechnik model, this tool has been introduced and only been used in its basic version as showed by the Fischertechnik company.

The 4th target has been accomplished. A Siemens Tecnomatix Booklet has been provided with the document to provide future users useful information related to the software.

The 5th target has been accomplished. A complete Fischertechnik 4.0 Training Factory Booklet is provided which resumes and completes the Fischertechnik manual and helps a future user to make a proper use of the Fischertechnik model.

In essence, the targets defined in the midterm checkpoint of the project have been reached and have met the expectations, despite the Node-RED tool. This tool could have been analysed if more time were available, however the need to change the targets at the midterm checkpoint has limited the time considerably.

7.4. Recommendations and personal experience

This final subchapter aims to provide specific recommendations related to the usage of both tools and gives an overview of the personal experience throughout the project fulfilment.

Firstly, as seen throughout the document, the Fischertechnik model is a complex tool, which is also delicate and fragile, so modifications on the tool need to be done with an advanced user or expert.

Both tools need a previous learning and training. The booklets aim to facilitate this by offering a solid basis for further learning and training, and by comprehending the tool before using it. Both booklets need to be complemented with the corresponding official manual or helping guide by the companies.

Additionally, an easier and recommendable approach that should be given when learning, is by visualizing examples. Examples are easier to comprehend, replicate, and solve specific doubts. Therefore, Steffen Bangsow website and Siemens Tecnomatix examples are strongly recommended to be used when modelling in Siemens Tecnomatix, this is said in the Siemens Tecnomatix booklet. Further on, this is one of the several reasons of the not accomplished Fischertechnik targets. The model used is the newest in the market, which means that less information, and examples, is available, while Siemens Tecnomatix is being used since 2009. In addition, Fischertechnik does not provide examples or further information for the model, and relies this exclusively on the Fischertechnik community, while Siemens encourages and enhance it for a better user-experience.

This lack of user-experience provided by Fischertechnik has provoked moments of frustration, specially during the first part of the project. This is also due to the fact that more advance knowledge of digitalization and C++ is needed to use properly this tool, as the experts that where contacted where software or digital engineers.

Furthermore, because of the academic perspective given, and the lack of initial knowledge on how to use Fischertechnik 4.0 Training Factory and Siemens Tecnomatix, meaning that everything had to be learnt from 0, this document contains less technical information, changing the focus to comments, steps or explanations. This also leads to more writing, and less charts, or number-related information. Perhaps of being frustrating in certain moments, this has led to several positive aspects.
Due to this project, Siemens Tecnomatix has been comprehended extensively, improving considerably the knowledge around simulation modelling, specifically in this software. The need to explain through the booklets and throughout the document how both tools operate, helps and forces the person that explains, to comprehend more deeply. In addition, perhaps of not being able to use Fischertechnik 4.0 Training Factory profoundly, topics and insights related to the 4.0 Industry have been learnt and comprehend, and also the general understandings on how an automated production line functions have been achieved.

Despite the Covid-19 pandemic occurred during the realization of the project, leading to changes in the procedure, these changes have not affected as much as it has affected to other projects. The pandemic has affected in terms of information available, depending most of it to content the content available on the internet, as for example, e-books. Also, the support of persons like advanced C++ users for Fischertechnik, or just the supervision of the supervisor has been limited. Fortunately, the project could have been realized and delivered.

In general, after completing the project, first important project, satisfaction is achieved with the final output. Through this project, abilities like profound analysis capacity, correct prioritizing, working under pressure, fast learning, and formal writing, among others, have been put to test. Even there is always a room for improvement, and several aspects could not have been explained with the detail as wished, the need to prioritize and sacrifice this for a better overall and project delivery has been learnt, and applied. Additionally, by challenging myself and write the document in my second language, English, improvements have been achieved with it, and a general feeling of realization is felt.

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Appendix

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Gantt Diagram of the project

| Activity	Status	% ...		January 2020 · 16 · 17 · 23 · 24 · 01 · 02	March 2020 · 08 · 09 · 15 · 16 · 22 · 23 · 29 · 30	April 2020 · 05 · 06 · 12 · 13 · 19 · 20 · 26 · 27	May 2020 · 03 · 04 · 10 · 11 · 17 · 18 · 24 · 25 · 31 · 01 · 07 · 08
Research and Analysis							
Read about 4.0 Industry	Ended	100%					
Plan resources	Ended	100%					
Supervisor Meeting	Ended	100%					
Writing	Ended	100%					
Midterm Checkpoint	Ended	100%					
Fischertechnik tool							
Research about Fischertechnik	Ended	100%					
Fischertechnik Programming	Not accomplished	30%					
Node-RED	Not accomplished	50%					
Siemens Tecnomatix							
Research about Siemens Tecn...	Ended	100%					
Siemens Tecnomatix Porgram...	Ended	100%					
Results comparison	Ended	100%					

Appendix Figure 1: Project Gantt Diagram. Starting from 15/02/2020 to 07/06/2020.

Risk Chart of the project

Bachelor Thesis Risk Chart					
	RISKS	Probability	Consequence magnitude	Posible causes	Posible prevention - solution
	Fischertechnik risks				
R1	Being ignored by the company	3	3	No interest once the product has been sold	Highlight their benefit from the project
R2	Broken piece at the simulation model	2	4	Accident while simulating, non-users using it	Protect the simulation model
R3	Electronical failure at the simulation model	1	4	Liquid pooring, cable rupture	Not permitted to eat or drink close to the model
R4	Program data and parametres deleted	2	1	Accident while programming	Save data in the cloud
R5	Internet not working at presentation day	2	3	Different Wi-Fi hotspot and configuration	Preparation and testing before showing
	Digital Twin and Simulation Software risks				
R6	No useful Digital Twin or software found	2	4	Not affordable, not proper for academic use, not connectable with Fischertechnik	Making use of Tecnomatix
R7	Being ignored by companies	3	2	No interest because there is no economic benefit	Contact several persons or companies
R8	Information and recollected data lost	4	2	Accidental deleting or simply not saving	Save data in the cloud
R9	Not possible to simulate the "Lernfabrik"	2	3	Not compatible, high complexity	Make a more basic simulation model
R10	Not possible to interact DT or SS with the "Lernfabrik"	3	2	Fischertechnik's poor interconectivity with other tools	Work with it separatetly
	Other risks				
R11	Laptop problem	1	4	Information deleted, laptop failure or broken	Save everything on the cloud
R12	Coronavirus	2	3	Disease expansion	Take necessary preventions, work at home

Appendix Table 1: Risk Chart.

Displays the Risk Table of the project, presenting the risks visualized. Probability of occurrence and consequences are shown, as well as causes and solutions against these risks.
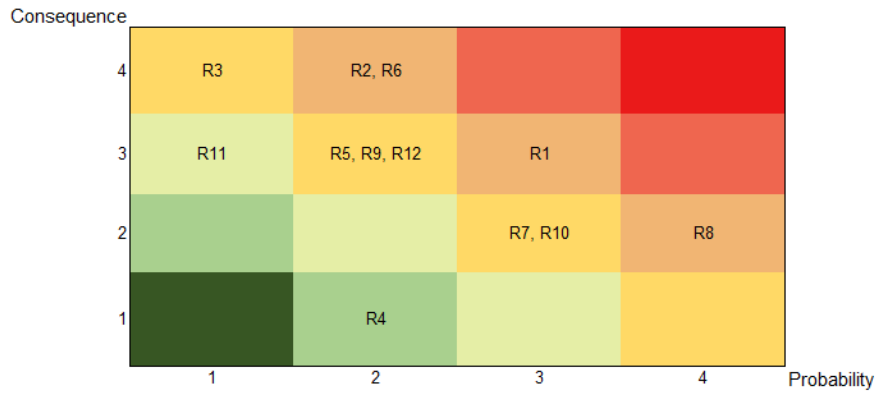
Different consequences			Different probabilities	
Critical	4		High unlikely 0-24%	1
Major	3		Possible 25-49%	2
Minor	2		Probable 50-74%	3
Insignificant	1		High likely 76-100%	4

Appendix Table 2: Risk Chart.

The risks are displayed in a matrix to visualize the importance of each risk.

Booklets Provided
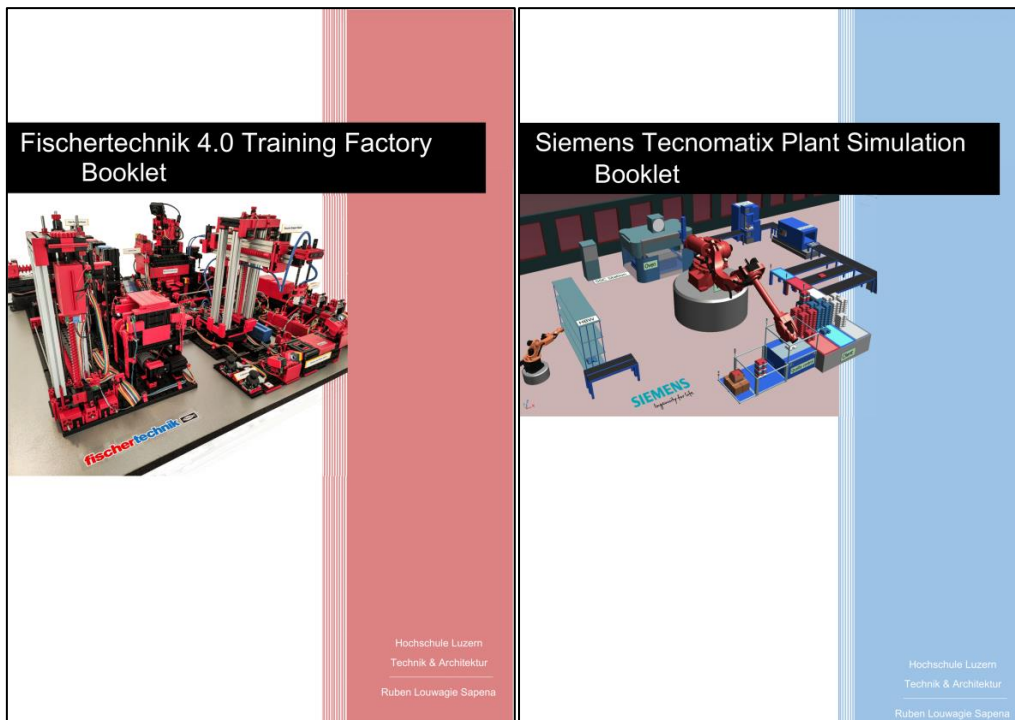
Appendix Figure 2: Front pages of the two booklets provided.

Additional Manuals and references

Appendix Figure 3: Front page of the Fischertechnik manual for the 4.0 Training factory.

Appendix Figure 4: Front image of the Siemens Tecnomatix helping guide

Fischertechnik time samples

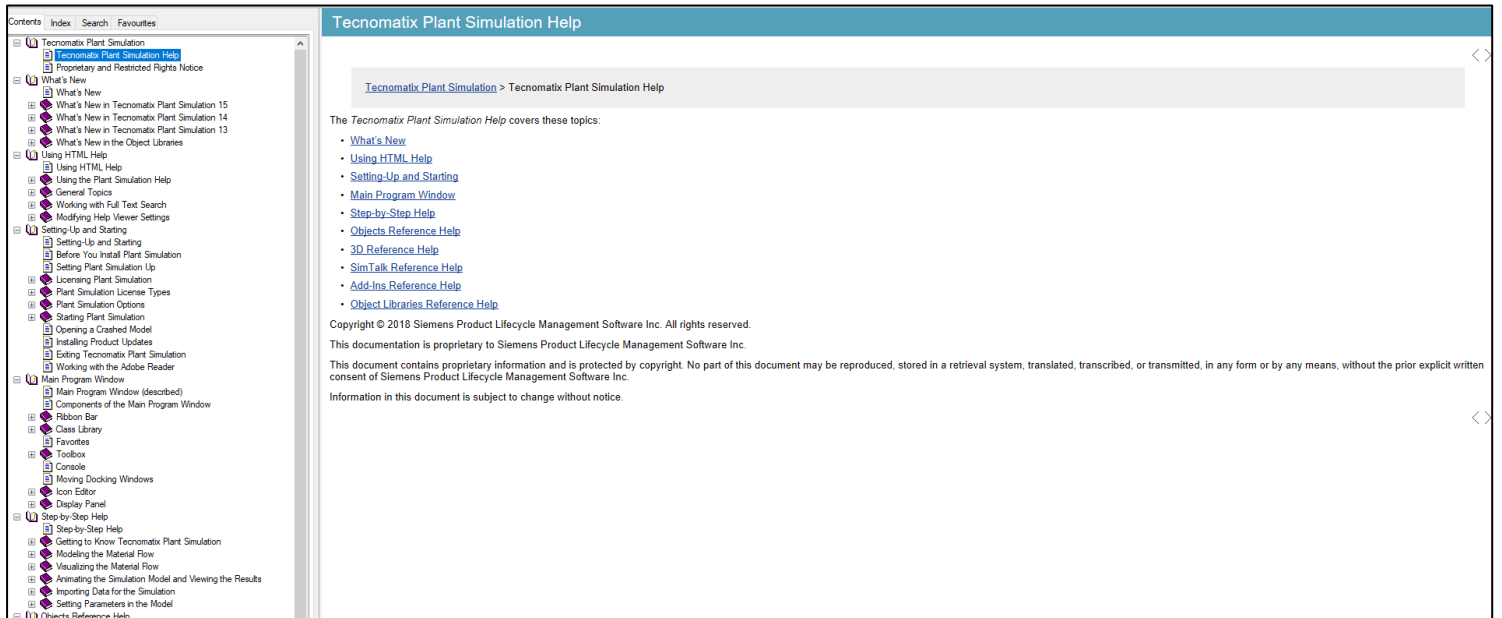| Fischertechnik time samples (s)	1	2	3	4	5	6	7	8	9	10	Mean
Quality control	25.2	25.24	25.51	24.96	25.14	25.87	25.8	25.64	25.39	25.53	25.428
Workpiece supply	60.91	61.39	62.03	62.14	61.45	61.89	61.93	61.88	61.97	61.94	61.753
Workpiece process	73.11	72.45	72.29	72.33	72.03	72.14	71.95	72.06	72.09	72.35	72.28
Production line Lead Time	115.4	114.31	114.4	116.03	116.14	115.28	115.71	114.74	115.12	115.01	115.214

Appendix Figure 5: Fischertechnik time samples

Usage of time

Use of Time	Hours*	Percentage
Fischertechnik 4.0 Training Factory	80	22'2%
Siemens Tecnomatix software	110	30'6%
Research	50	13'9%
Writing	120	33'3%
Bachelor Thesis project	360	100%

*Estimations

Appendix Table 3: Estimated usage of time table

Siemens Tecnomatix insights

Enter the **M**ean **T**ime **T**o **R**epair (MTTR) of the machine. Optionally you can also enter the lower bound and upper bound for the **Erlang**-distribution. *Plant Simulation* then computes the **Erlang**-distribution and the **negative exponential distribution** from these values. When you enter the lower bound and the upper bound for the **Erlang**-distribution, *Plant Simulation* computes the MTTR.

☑ Availability ▣   MTTR[, Lower Bound, Upper Bound]
Availability: 95 % MTTR: 1:00   ▣

The mean time to repair is a measure of maintainability. It is the average time required to repair this machine.

For simulating repair times during the duration of a failure *Plant Simulation* uses the Erlang-distribution. This **Erlang**-distribution is the sum of two independent exponentially distributed random numbers with the same parameter β. The used **Erlang**-distribution also has the property $\sigma = \mu/\sqrt{2} \approx 0.707\,\mu$.

The picture of the probability density function of this random number shows that very short and very long repair times occur very rarely. Repair times that are located around the value μ/2 are most common.

Erlang (10, 7.07)
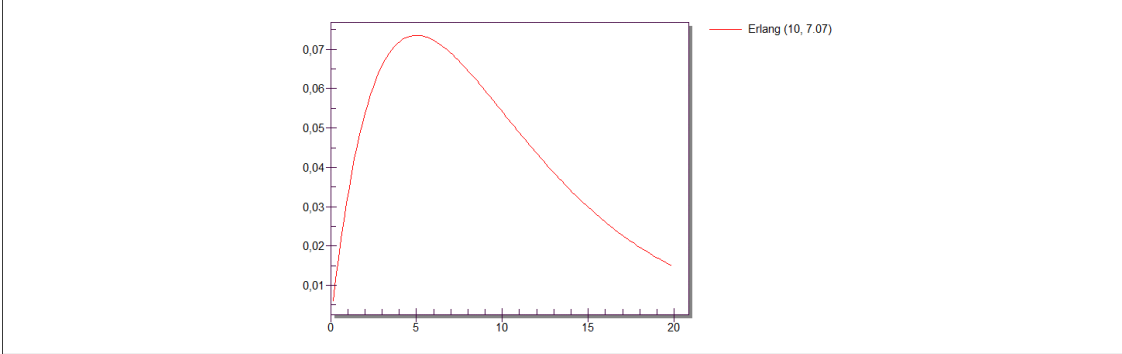
Figure 7-1. Density function of the distribution for repair times with a mean value of μ= 10

The object only inherits the values for the Availability and the **MTTR**, when it also inherits the Availability as such from the parent dialog, i.e., when the inheritance button next to the check box looks like this ▣

When you set these two values via information flow with these attributes, the following assignments

```
MyStation.Failures.MyFailureProfile1.MTTR := 60
MyStation.Failures.MyFailureProfile1.Availability := 100
```

result in an MTTR of 0, i.e., the *Station* will not fail during the simulation.

Appendix Figure 6: MTTR for machine failure explanation in Tecnomatix help guide

Appendix Figure 7: Recompilation of the Methods used in the Digital Twin

```
//Calculation of the Defective Percentage

def:=(DPS_ClientB.NumMU + DPS_ClientR.NumMU + DPS_ClientW.NumMU)
DPS_ClientB.Pieces_Delivered:=def

    x:=((BadQuality.NumMU*100) / ((DPS_ClientB.NumMU + DPS_ClientR.NumMU + DPS_ClientW.NumMU) + BadQuality.NumMU))

    DPS_ClientB.Defective_percentage := x


//Calculation of the average Lead Time

@.LeadTime:= (EventController.SimTime - @.LeadTime)
DPS_ClientB.TotalLeadTime += @.LeadTime

DPS_clientB.Avg_LeadTime:= (DPS_ClientB.TotalLeadTime / (DPS_ClientB.NumMU + DPS_ClientR.NumMU + DPS_ClientW.NumMU))


//Calculation of the Service Lvl

DPS_ClientB.Service_Level := ((DPS_ClientB.Pieces_Delivered-BadQuality.NumMU)*100 / DPS_ClientB.Pieces_Delivered)


//Calculation of the average Cycle Time

    DPS_ClientB.Avg_Cycle:=(EventController.SimTime / (DPS_ClientB.StatNumIn + DPS_ClientR.StatNumIn + DPS_ClientW.StatNumIn))

//Calculation of the Work In Process (WIP)

    DPS_ClientB.WIP:= (DPS_entry.StatNumOut - DPS_ClientB.Pieces_Delivered - BadQuality.StatNumIn)
    DPS_ClientB.TotalWIP+=DPS_ClientB.WIP

    DPS_ClientB.Avg_WIP:= DPS_ClientB.TotalWIP / DPS_ClientB.Pieces_Delivered


//Calculation of the average nº of workpieces in the Sorting Line

    SLD_Red.TotalPieces += (SLD_Red.NumMU + SLD_Blue.NumMU + SLD_White.NumMU)

    SLD_Red.Avg_SLD := SLD_Red.TotalPieces / SLD_Red.Counter

    SLD_Red.Counter += 1
```
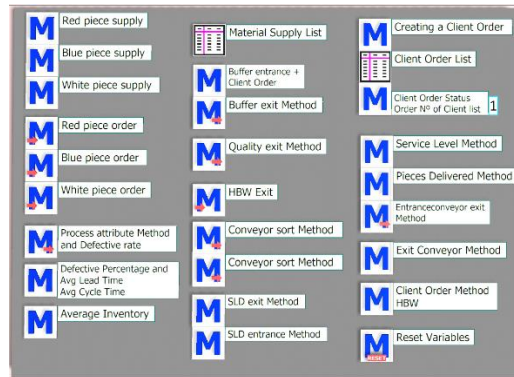
Appendix Figure 8: KPI calculation in the Digital Twin in SimTalk 2.0

```
    //Calculation of the average Lead Time

    @.LeadTime:= (EventController.SimTime - @.LeadTime)
    DPS_ClientB.TotalLeadTime += @.LeadTime
    DPS_clientB.Avg_LeadTime:= (DPS_ClientB.TotalLeadTime / (DPS_ClientB.NumMU + DPS_ClientR.NumMU + DPS_ClientW.NumMU))

    //Calculation of Urgent Pieces Lead Time

if @.Urgent = true

    @.UrgentLeadTime:= (EventController.SimTime - @.UrgentLeadTime)

    DPS_ClientB.TotalUrgentLead += @.UrgentLeadTime

    DPS_ClientB.Avg_UrgentLead:= (DPS_ClientB.TotalUrgentLead / DPS_ClientB.UrgentCount)
end

    //Calculation of the average Cycle Time

if DPS_ClientB.Pieces_Delivered > 0

    DPS_ClientB.Avg_CycleTime:= (EventController.SimTime / (DPS_ClientR.NumMU + DPS_ClientB.NumMU + DPS_ClientW.NumMU))

end

    //Calculation of the Service Lvl

    DPS_ClientB.Service_Level := ((DPS_ClientB.Pieces_Delivered-BadQuality.NumMU)*100) / DPS_ClientB.Pieces_Delivered

    //Calculation of the average WIP

    DPS_ClientB.WIP:= (DPS_entry.StatNumOut - DPS_ClientB.Pieces_Delivered - BadQuality.StatNumIn)
    DPS_ClientB.TotalWIP+=DPS_ClientB.WIP

    DPS_ClientB.Avg_WIP:= DPS_ClientB.TotalWIP / DPS_ClientB.Pieces_Delivered

    //Calculation of the average nº of workpieces in the Sorting Line

    SLD_Red.TotalPieces += (SLD_Red.NumMU + SLD_Blue.NumMU + SLD_White.NumMU)

    SLD_Red.Avg_SLD := SLD_Red.TotalPieces / SLD_Red.Counter

    SLD_Red.Counter += 1
```

Appendix Figure 9: KPI calculation in the Digital Twin in SimTalk 2.0.
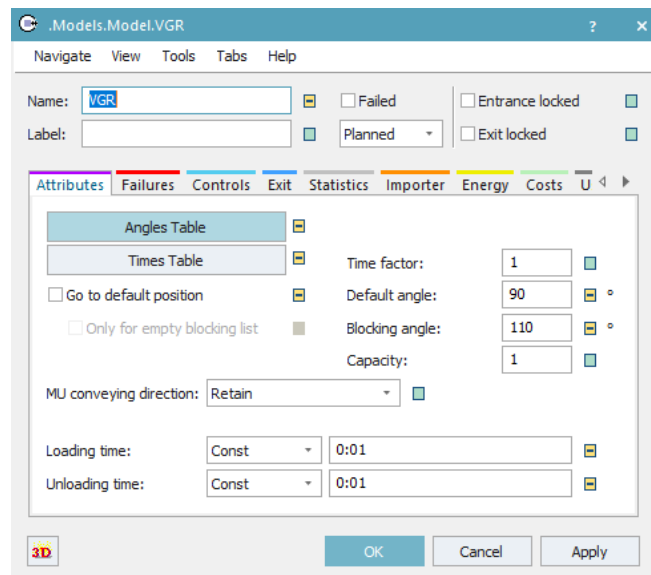
Appendix Figure 10: VGR parameters

.Models.Model.VGR.Times Table

Full\Empty	Drain	DPS_source	HBW	MPO_1	DPS_client	SLD_Blue	SLD_Red	SLD_White	quality_control	DPS_entry	VGR	DPS_ClientB	DPS_ClientW	DPS_ClientR	Drain5
Default Angle		3.4828	5.5321	3.1417	2.0431	0.5883	0.0000	0.5883	2.6846	3.9032	0.0000	1.2784	1.4277	1.1202	1.2514
Store3															
Store31															
Store32															
Drain	0.0000											7.0852	6.9359	7.2434	4.8545
DPS_source		0.0000	2.9851	5.3755	1.4397	4.0712	3.4828	2.8945	0.7982	0.4204	3.4828	10.2721	10.1228	10.4303	1.6676
HBW		2.9851	0.0000	2.3904	4.4247	4.9438	5.5321	5.8795	8.0000	2.5647	5.5321	7.2204	7.0711	7.3786	4.7193
MPO_1		5.3755	2.3904	0.0000	5.1848	2.5534	3.1417	3.7300	5.8263	4.9551	3.1417	4.8300	4.6807	4.9882	4.8903
DPS_client		1.4397	4.4247	5.1848	0.0000	2.6315	2.0431	1.4548	0.6415	1.8601	2.0431				
SLD_Blue		4.0712	4.9438	2.5534	2.6315	0.0000	0.5883	1.1767	3.2729	4.4915	0.5883	2.2766	2.1273	2.4348	2.3369
SLD_Red		3.4828	5.5321	3.1417	2.0431	0.5883	0.0000	0.5883	2.6846	3.9032	0.0000	1.6883	1.5390	1.8465	1.7486
SLD_White		2.8945	5.8795	3.7300	1.4548	1.1767	0.5883	0.0000	2.0963	3.3148	0.5883	1.0999	0.9506	1.2581	1.1602
quality_control		0.7982	8.0000	5.8263	0.6415	3.2729	2.6846	2.0963	0.0000	4.0000	2.6846	0.9963	1.1456	0.8381	0.9360
DPS_entry		0.4204	2.5647	4.9551	1.8601	4.4915	3.9032	3.3148	2.5000	0.0000	3.9032	9.7133	9.5640	9.8715	2.2264
VGR		3.4828	5.5321	3.1417	2.0431	0.5883	0.0000	0.5883	2.6846	3.9032	0.0000	1.6883	1.5390	1.8465	1.7486
DPS_ClientB	7.0852	10.2721	7.2204	4.8300		2.2766	1.6883	1.0999	0.9963	9.7133	1.6883	0.0000	0.1493	0.1582	0.0603
DPS_ClientW	6.9359	10.1228	7.0711	4.6807		2.1273	1.5390	0.9506	1.1456	9.5640	1.5390	0.1493	0.0000	0.3075	0.2096
DPS_ClientR	7.2434	10.4303	7.3786	4.9882		2.4348	1.8465	1.2581	0.8381	9.8715	1.8465	0.1582	0.3075	0.0000	0.0979
Drain5	4.8545	1.6676	4.7193	4.8903		2.3369	1.7486	1.1602	0.9360	2.2264	1.7486	0.0603	0.2096	0.0979	0.0000
Conveyor5	1.0529	2.1340	0.9177	3.3082		5.8615	5.5501	4.9618	2.8656	1.5752	5.5501	3.8619	4.0112	3.7037	
EntranceConveyor	2.1030	1.0838	1.9679	4.3583		5.0883	4.5000	3.9117	1.8154	0.5250	4.5000	2.8117	2.9610	2.6535	
ExitConveyor	1.8794	1.3075	1.7442	4.1347		5.3120	4.7237	4.1353	2.0391	0.7487	4.7237	3.0354	3.1847	2.8772	
Store			5.1332	4.4764		1.9231	1.3347	0.7464	1.3499	2.6402	1.3347	0.3536	0.2043	0.5118	
BadQuality			5.2177	4.3918		1.8385	1.2501	0.6618	1.4345	2.7248	1.2501	0.4381	0.2888	0.5963	

OK   Cancel   Apply

Appendix Figure 11: VGR timetable according to the different components

Interview Transcription

Interviewer: Ruben Louwagie
Interview partner: Alex Steiger
Company: Fischertechnik GmbH
Position in the company: Development Department
Medium of questioning: e-mail

1. I have problems with connecting the TXT controller to the internet through to cloud. I have done exactly what is recommended in the Fischertechnik manual, what can I do?

   Please check the network setting of the TXT controllers
   https://github.com/fischertechnik/txt_training_factory/blob/master/doc/Network_Config.md.

2. Is there any further information related to the Fischertechnik model in order to play, experiment and test with the 4.0 Training Factory? Like for example increasing speed or make it possible to process several pieces at the time?

   The Training Factory Industry 4.0 model is delivered with a standard demo program.

   If you want to implement your own scenarios, you must implement your own C programs.

   You can find the source code of the standard demo programs on GitHub:

   https://github.com/fischertechnik/txt_training_factory

   The fischertechnik cloud can only be connected with fischertechnik TXT controllers.

3. But I have seen that different tools can be used to complement the Fischertechnik, for example with a PLC software. Can you provide any recommendation or help for this?

   Please note that we do not supply any software for a PLC and unfortunately we cannot provide any support regarding the PLC software.

4. How does Node-RED complement the 4.0 Training Factory? Can I ask as a client workpieces through the Node-RED dashboard which are not previously supplied?

   Node-RED is a tool that serves an example on how to integrate an own scenario to the Fischertechnik 4.0 Training Factory. Please note that the Node-RED example in Github is not complete. You can only order workpieces which exist in the storage, for example. The state of the High-Bay-Warehouse is not implemented in Node-RED example. If you use the fischertechnik Cloud, you can order only allowed workpieces in the warehouse.

5. The files that I try to upload into the TXT controller does not appear in it. Which kind of files can be uploaded, and how, to these TXT controllers?

   You can not download source files directly to the TXT controller.

   You have to use a cross compiler to compile the sources and then you can download the binary to the TXT controller.

   Please read this doc, you need e.g. eclipse CDT:

   https://github.com/fischertechnik/txt_training_factory/blob/master/doc/IDE_Setup.md

6. My TXT controller turns on, but stays on a white screen, what can I do to fix it?

   If the white screen on the TXT controller is permanent white, so the TXT controller is defective and should be repaired or replaced. Try to restart the TXT control first, and it doesn't work, we will replace it.

7. I need to recalibrate the HBW module, and I tried to calibrate it without result. As the calibration positions are not said in the manual, can you tell me how to exactly calibrate it?

   The calibration of HBW is stored in a JSON file on the HBW TXT controller, see

   https://github.com/fischertechnik/txt_training_factory/blob/master/TxtSmartFactoryLib/src/TxtHighBayWarehouseCalibData.cpp

   check file

   Data/Calib.HBW.json

   There are 4 x 2 values, in that order:

   - A1, B2, C3
   - Conveyor pos

Interviewer: Ruben Louwagie
Interview partner: Guido Schubert
Company: Fischertechnik GmbH
Position in the company: Sales Director
Medium of questioning: e-mail

1. Could I please ask you some questions related to Fischertechnik's cloud and also about its functionalities beyond the general and most obvious ones?
   Or even if you could provide someone's contact that could answer me simple questions that I will need to know to proceed with my Thesis would be also very helpful.
   Do you know if there is any simulation software that could connect with Fischertechnik's cloud? Like for example a Digital Twin.
   Maybe a software that general clients use in order to connect with Fischertechnik Lernfabrik's cloud.
   Or are you aware about any digital simulation software, that somehow, could complement Fischertechnik's Lernfabrik 4.0?

   We have good news in the way that Hochschule Luzern got already the CAD data of the fischertechnik Lernfabrik and has signed
   a NDA with us, so everybody in Hochschule Luzern can use the data or your internal projects.
   I can help you with contact of 2 people, pls get in touch with them and see if the CAD data does help for your needs.
   Mr Pierr Kirchhofer
   pierre.kirchhofer@hslu.ch
   Mr Matthias Kilchenmann
   matthias.kilchenmann@hotmail.com
   What we also can help with is a contact to Siemens plant simulation department if helpful, they're located in Munich.
   They're using the previous fischertechnik model (fischertechnik factory simulation) for their plant simulation tool.
   Not sure if helpful for you but if you like, I bring you in contact with them.

Mr Louwagie, I also would like you for a favour if possible.

We are on the way to add such projects like you're planning onto our website to show as reference and ideas to other universities and interests.

Are you able/allowed/interested to share your results with us so we present it to a wider audience thru our webside?

Would be great if you're intersted in, just let me know and we get in closer touch when your project is ready to share

2. I think it could be very helpful if you put me in contact with the Siemens plant simulation department as they might combine Fischertechnik with one of their tools. Of course I would not mind to share my results with you, I will keep in touch with you for that.

   I have recently seen that SAP software also has managed to connect to Fischertechnik Learning Factory in order to simulate different scenarios.

   https://www.sap.com/assetdetail/2018/08/dc65b47b-157d-0010-87a3-c30de2ffd8ff.html

   Do you have any information about it, or could you provide me a contact to ask them about it? And please if you also could provide me Siemens Plant Simulation contact from Munich, where they use Fischertechnik as I told you before.

   Thank you for your kind message.

   I have also seen your comment posted on SAP's blog site.

   Let me first mention that you and SAP are <u>NOT</u> using the same fischertechnik factory.

   Hochschule Luzern is running the latest version while SAP is using a previous model and the SAP ft connector is based on that.

   The fischertechnik TXT controller running both factories is the same, true. But the software used is different.

   In your model, <u>Training Factory Industry 4.0</u>, the software used is written in C/C++.

   In the SAP model, <u>Factorysimulation</u>, the software used is RoboPro, a fischertechnik own software.

   This may not mean a big difference for your needs but Jochen Rundholz from SAP is the right contact for your questions.

   If he is not reacting to your question via the SAP blog you may contact him directly thru <u>jochen.rundholz@sap.com</u>

   Contact to Siemens follows soon.

Interviewer: Ruben Louwagie
Interview partner: Jochen Rundholz
Company: SAP SE
Position in the company: n.d.
Medium of questioning: e-mail and forum

1. Good evening, My name is Ruben Louwagie, I'm a student of the Hochschule Luzern, Switzerland. I'm currently working on my Bachelor Thesis using Fischertechnik's simulation model "Training Factory Industry 4.0". Analysing its potential, both in academic environments as in professional environments. As I have seen you have worked with it, I would be very pleased if you could provide me some public information that you could have related to Fischertechnik. I have also seen you collaborate with Fischertechnik and can connect with their cloud through SAP (following link). https://www.sap.com/assetdetail/2018/08/dc65b47b-157d-0010-87a3-c30de2ffd8ff.html I would like to know about it, as its availability, if there is a Demo, different options, and so one. It would be very useful.

   Hello Ruben, we are connecting the FT setup to our own cloud. I have written a FT connector to connect to the TXT controllers and control FT models. Take a look here

   https://blogs.sap.com/2018/04/05/demo-connector-for-fischertechnik-part-1/
   https://blogs.sap.com/2018/04/06/demo-connector-for-fischertechnik-part-2/
   https://blogs.sap.com/2018/04/06/demo-connector-for-fischertechnik-part-3/
   https://blogs.sap.com/2018/04/06/demo-connector-for-fischertechnik-part-4/

   This might answer some of your questions. If you like we can have also a short call to see what exactly you are looking for.

2. Thank you very much for your reply. I have been told that my version of the Fischertechnik Learning Factory is a new version, which works with C++ and not with RoboPro as yours do. I am looking the blog again if I can still apply something that you did to my model. As a quick question, what kind of files did you upload to the TXT controllers?

   I believe you are wrong (sorry to be so frank – Germans...;-)). When you refer to "new version" I believe you talk about the factory having the RFID reader, the environment sensor and the camera, correct? This version uses still the TXT controllers, you can connect to the TXT controllers using RoboPro, using the C++ API or what I did is I looked into the protocol how the C++ API communicates and built that in Java for my connector. I am pretty sure that your model can be accessed the same way!

   I did not upload any file to the TXT controller, you only have to do that (from RoboPro which I am not using) if you want to run it in the so called offline mode. I am using the online mode, so I am constantly connected via network (network via USB) to all the 5 controllers and communicate constantly from my ftconnector tool.

3. Yes, I'm talking about that factory model.
   They told me that the software of the previous version is written in RoboPro, while this new one is written in C++.
   Does this affects your ft connector? Another question would be, which SAP tools should I use in order to implement your feature?

   -No answer-

Interviewer: Ruben Louwagie
Interview partner: Steffen Bangsow
Company: Steffen Bangsow Advanced Simulation Services
Position in the company: Founder
Medium of questioning: e-mail and forum

1. With *services* activated, what is the difference between @.move and @.move(station)?

   @.move uses the exit strategy of the station to find the success @.move uses the exit strategy of the station to find the successor (e.g. calling the transport exporter or select the next free successor), starting from v. 14.2 you may combine the exit strategy (+connectors) with the transport importer
   with move(destination) you bypass the exit strategy of the station and this does not make sense in the case of transport importer/exporter

2. How can I remove Mus from a Store by pressing a button? (Picture attached)

   By introducing inside the button's control method the following expression:
   store.cont.move(station)

3. My worker blocks himself while carrying parts, can you give me some advice to avoid it? And I want to create batches in the production line, can you provide me some help for it? (Example scenario is attached)

   you could insert an exit control into the source and wait there until the station and the worker is empty
   add a transport importer to the store (destination assembly) and connect the store with the assembly; the assembly will pull the parts depend on the assembly list; the worker will transport the parts
   activate and set up the transport importer of the store

   look here for an example
   http://www.bangsow.eu/detail.php?id=798
   I also inserted a small control into the broker, to avoid the call of the source, if the station is occupied. (example file is attached)

4. How can I create entities by pressing a button?

   Assuming that you don't run out of events before pressing the button (then the model will stop), you could open/close the Exit of your Source with a Control method of the button like this:
   // Wait until previous click-events were handled
   waituntil Source.ExitLocked prio 1
   // Let 1 part out of Source
   Source.ExitLocked := false
   waituntil Source.Occupied prio 1 --> wait until part is actually created
   waituntil Source.Empty prio 1 --> wait until part has left the Source
   Source.ExitLocked := true --> wait for next button click

5. How can I move specific entities from the store, depending on the name?

   findPart("PartName") would be the right choice, for example:
   var o: object := MyStore.findPart("Container") -- assigns for example .MUs.Container:1

6. How can I create random numbers in Simtalk?

   the methods start with z_
   just look for in the help guide

7. The PickandPlace stops at the end of the cycle, how can I prevent it?

   you don't need a target control in the PP, activate instead in the MU class (class library) the
   automatic routing, then the PP will follow the destination attribute of the MU
   to re-start the cycle you need to wait in the exit control of the source, until the PP und Station is
   empty (same in the store):

   1. waituntil station.occupied=false and PP.occupied=false
   2. @.destination:=Station
   3. @.move

   (example file is attached)

8. How can I make the PickandPlace robot to wait until a entity is processed before moving?

   three things:
   deactivate move to standard position in the PickAndPlace
   wait in the exit control of station until station1/2 and PickAndPlace is empty
   use the automatic routing of the part to send the part to the right destinations (see exit control of
   station1)
   (example file is attached)

9. How can I record times, for example how much a MU spent in a certain station?

   I think there are many ways to do this:
   Writing in the data table

   Writing in Userattribute in the MU

   For example: you create an attribute named TimeInStationA: time

   When the Mu enters in the station A: with a method in the entrance of the stationA before
   Actions: @.TimeInStationA := EventController.SimTime

   and with an other Method in the RearExit of the same Station: @.TimeInStationA :=
   EventController.SimTime - @.TimeInStationA

   It depends in what is your goal at the end
   (picture is attached)

10. How can I find a MU in storage with a specific attribute?

have a look at the method findAttr, in connection with contentsList

```
var PresentParts :table
@.ContentsList(PresentParts)
//set cursor to the first cell
PresentParts.setCursor(1,1)
//search
var part:object
if PresentParts.findAttr("AttributName",AttributeValue) then
part:=PresentPart(presentPart.cursorX,presentPart.cursory)
part.move(destination)
end
```

11. Is there a way to make high-quality screenshots of the simulation model?

try: 3D - Export Scene - Export Bitmap

Interviewer: Ruben Louwagie
Interview partner: Ueli Wunderli
Company: Siemens AG
Position in the company: n.d.
Medium of questioning: e-mail

1. I would like to know if Siemens has got a Digital Twin service. The Hochschule Luzern could be interested. Is there any demo or student license available?

May I ask you to describe digital twin services a little bit more in detail? Certainly we have the software portfolio to realize the digital twin concept. Which services you expect or are you looking for?

As HSLU is using our NX software for education you need to contact Pierre Kirchhofer to apply for a home use NX license. However, I am not familiar with the concept of academic home use NX licensing at HSLU and if they support this concept.

2. I'm looking for a basic Digital Twin or a demo in the market, in order to represent the Fischertechnik's 4.0 Lernfabrik, and interact with its cloud. https://www.fischertechnik.de/de-de/produkte/lehren/trainingsmodelle/551584-edu-lernfabrik-4-0-9v-simulation
If it wouldn't be possible, I have currently Siemens Tecnomatix as plan B.
Are you aware of any simulation model in Tecnomatix of a Fischertechnik's tool, or something related that might be useful?

(Reply in German)

Besten Dank für Ihre Mail. Wir freuen uns, wenn Sie Plan Simulation aus dem Tecnomatix Portfolio an der HSLU einsetzten.

Folgende Informationen und URL's haben wir Ihnen zusammengestellt.

- Die JKU Linz hat mit Start 2014 Projekte mit solch einer Fischertechnik Fabrik umgesetzt, MCD, Process Simulate und Plant Simulation. Einige Bachelor Arbeiten wurden damit gemacht.
- http://www.math4fun.de/ à Links auf „Artikel" und dann auf „Kurs Plant Simulation Hochschule Esslingen" = fertige Vorlesungsunterlagen (Basics) mit Übungsbeispielen, frei zur Wiederverwendung
- Lektüre/Buch mit einfachen und anspruchsvolleren Beispielen https://www.amazon.de/Tecnomatix-Plant-Simulation-Modeling-Programming/dp/3319364499/ref=sr_1_2?__mk_de_DE=%C3%85M%C3%85%C5%BD%C3%95%C3%91&keywords=plant+simulation&qid=1583850775&sr=8-2

- 20 Kurzvideos zu Getting Started (Basisfunktionalitäten) https://www.youtube.com/watch?v=eLUkr0gZtAg&list=PL1m1vu8_quoAaezQsacD6jO_AK8Wvnjg-
- Self-Trainings in der Basis installation von Plant Simulation
- Plant Simulation Kurse im Learning Advantage, Herr Lustenberger oder Herr Kirchhofer verwaltet diese Accounts zu diesem e-Learning Portal.
- Für Fragen empfehlen wir Ihnen über die Community zu gehen: https://community.sw.siemens.com/s/topic/0TO4O000000MihdWAC/tecnomatix

Wir selber haben leider keine Modelle von der Fischertechnik Lernfabrik 4.0. Wir erachten jedoch die FT Lernfabrik 4.0 als ideale Basis um eine Industrie 4.0 Umgebung zu simulieren und die Prozesse und Zusammenhänge mit den Studierenden aufzubauen und zu verstehen.

Unser Tecnomatix Spezialist aus Österreich hat angeboten, dass wir für eine Übersicht der Tecnomatix-Produkte oder einem Austausch zu Ihrem Thema eine Telefon Konferenz organisieren könnten.

So, nun hoffen wir das Sie bereits mit den aufgeführten Links und Informationen etwas passendes finden.

Lassen Sie mich wissen, wenn Sie weitere Plant Simulation User auf der HSLU Lizenz benötigen.