**INSTITURO SUPERIOR DE ENGENHARIA DE LISBOA**

**Área Departamental de Engenharia Mecânica**

**ISEL**

# Virtual Reality Project of a Process Controlled by Logic Controllers

ANA CATARINA DUARTE DA SILVA

Degree in Mechanical Engineering

Thesis to obtain the Master of Science Degree in Mechanical Engineering

Supervisor(s):

Prof. Francisco Mateus Marnoto de Oliveira Campos

Prof. Mário José Gonçalves Cavaco Mendes

Examination Committee:

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**Dezembro de 2019**

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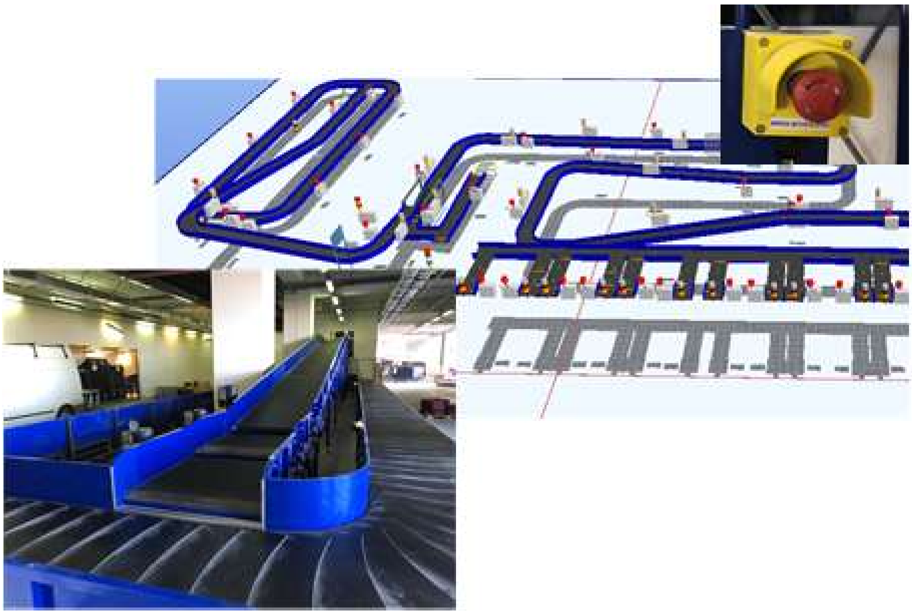

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”Wings are freedom only when they are wide open in flight.
On one’s back they are a heavy weight.”
-Marina Tsvetaeva

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## Resumo

A Indústria 4.0, com base nas tecnologias digitais e na automação, permitiu que os processos pudessem ser explorados digitalmente antes, durante e após a construção do processo efetivo. Uma dessas tecnologias é a realidade virtual, cuja exploração oferece inúmeras possibilidades à indústria. Foi com esse factor em conta que optei por este tema, motivada pelo impacto que esta inovação tecnológica já tem e ainda pode vir a ter nos processos, nomeadamente a possibilidade de melhorá-los com a utilização do comissionamento virtual.

Com o objectivo do comissionamento virtual em mente, foi utilizado como estudo de caso um sistema de tratamento de bagagens do aeroporto de Santorini, sistema esse comandado por um controlador lógico e o ambiente virtual, criado a partir do software Emulate3D.

O processo escolhido para este trabalho foi a área das partidas, que envolve a rota entre o check-in e a expedição para o avião, retirado do caso de estudo referido. A partir da utilização do software de realidade virtual e da análise do processo controlado por autómatos programáveis, é possível o objetivo de comissionar virtualmente a cópia digital. Também foi desenvolvido uma interface homem-máquina para aproximar o modelo do real e facilitar no comissionamento.

A criação de uma cópia digital do sistema, com base nos desenhos técnicos, permitiu um modelo virtual muito próximo do sistema real. É possível, com isso, fazer o comissionamento virtual, que leva à descoberta de problemas no código da automação e facilita o comissionamento real no fim do processo, pois elimina uma grande parte dos atrasos e custos dessa fase, considerados dois fatores chave na indústria.

**Palavras-chave:** Realidade Virtual, Indústria 4.0, Simulação, Programação de PLC, Sistema de Tratamento de Bagagens, Commissionamento Virtual

## Abstract

Industry 4.0, based on digital technologies and automation, allowed processes to be digitally exploited before, during and after the actual process was built. One such technology is virtual reality, the exploration of which offers the industry numerous possibilities. It was with this factor in mind that I opted for this theme, motivated by the impact that this technological innovation already has and may still have in the processes, namely the possibility of improving them with the use of virtual commissioning.

With virtual commissioning in mind, a baggage handling system from Santorini airport was used as a case study. This system is controlled by a logic controller and the virtual environment was created from Emulate3D software.

The process chosen for this work was the departures area, which involves the route between check-in and dispatch to the plane, taken from the case study mentioned. From the use of virtual reality software and the analysis of the process controlled by logic controllers, it is possible to virtually commission the digital twin. A human-machine interface was also developed to bring the model closer to the real one and to facilitate the commissioning.

Creating a digital twin of the system, based on the technical drawings, allowed a virtual model very close to the real system. This enables virtual commissioning, which leads to the discovery of automation code problems and facilitates actual commissioning at the end of the process, as it eliminates much of the delays and costs of this phase, which are considered two key factors in the industry.

**Keywords:** Virtual Reality, Industry 4.0, Simulation, PLC Programming, Bag Handling System, Virtual Commissioning

## Resumo Extendido

O presente trabalho visa a utilização de um software de realidade virtual num processo controlado por autómatos programáveis, com o objetivo deste ser comissionado virtualmente. Paralelamente, foi desenvolvida uma interface homem-máquina para a ligação entre os utilizadores e o sistema modelado. Os testes de comissionamento virtual permitem mais facilmente aplicar correções, antes de a necessidade destas ser detetada num processo de comissionamento normal, o que permite uma redução de custos e tempo. O processo escolhido para este trabalho foi o sistema de tratamento de bagagens do aeroporto de Santorini, na Grécia, mais especificamente a área das partidas, dado que estas envolvem o percurso de uma bagagem desde o momento em que o cliente realiza o seu check-in até chegar ao local do despacho para o avião respetivo.

Os controladores lógicos programáveis têm sido uma constante na indústria desde que surgiu a necessidade de automatizar os seus processos. Um controlador lógico é definido sucintamente pela sua quantidade de memória e número de entradas e saídas, podendo estas ser digitais ou analógicas. Com uso de sensores (entradas) e atuadores (saídas) ligados a um controlador lógico que na sua memória tem um conjunto de instruções, ou seja, um programa lógico de controlo que responde às mudanças de estado das entradas - alterando as saídas consoante as indicaçõs desse programa -, é possível automatizar um processo. Um controlador lógico programável pode ser aplicado a um sistema de tratamento de bagagens, tanto das partidas como das chegadas de um aeroporto. Este trabalho usou o programa para um controlador lógico programável da *SIEMENS*, da linha *SIMATIC S7-1500* com o *CPU 1516F*.

A ligação, entre o utilizador e as máquinas, é feita através de uma Interface Homem-Máquina. Esta interface é a ferramenta principal por onde o utilizador envia ou recebe informações do e para o sistema. A programação da Interface Homem-Máquina neste trabalho foi feita para um ecrã táctil *SIMATIC HMI TP1200 Comfort*. O sistema de tratamento de bagagens foi dividido ao longo de cinco páginas, cada transportador é representado e o seu estado é mostrado através da mudança de cor que este sofre. Também é possível encontrar uma lista de alarmes com o seu estado (resolvido ou por resolver) no ecrã *Alarms*. A Interface Homem-Máquina está instalada no painel de controle central que se encontra num local acessível aos utilizadores. Uma boa Interface Homem-Máquina tem em consideração três coisas principais: O local onde é colocado, este deve ser acessível e perto do sistema que tem de controlar; A informação que dá, esta tem de ser personalizada tanto ao nível de permissões do utilizador como à necessidade do mesmo; E à informação que recebe, o sistema pode estar dependente de ordens ou *inputs* vindos da interface, se estas ordens não forem possíveis de dar ao sistema este pode não conseguir funcionar como é esperado.

Um aeroporto tem duas zonas principais de sistemas de tratamento de bagagens. A zona das partidas, que lida com as bagagens que chegam com o cliente e saem num avião, e a zonda das chegadas, que lida com as bagagens que chegam num avião e saem com o cliente. O início do sistema de tratamento de bagagens nas partidas são os check-ins, que enviam a bagagem para um transportador coletor que as leva para o resto do sistema. De seguida, as bagagens passam no raio-X que faz uma inspeção automática de segurança, aceitando, rejeitando, ou, em caso de dúvida, enviando a bagagem para um segundo nível de segurança. As bagagens são separadas por um transportador separador de bagagem que permite a separação entre a bagagem segura e a considerada ameaça. A bagagem segura segue para o carrossel de onde é feito o despacho para o avião. A bagagem considerada ameaça é rejeitada, ficando à responsabilidade das equipas de segurança.

A Realidade Virtual permite que os seus utilizadores tenham uma versão do sistema real num ambiente virtual a três dimensões com respostas visuais e auditórias. Esta tecnologia pode ser usada como uma ferramenta da engenharia, para educação de futuros engenheiros ou médicos, para formação de operários em várias áreas como por exemplo manutenção, para simulação de sistemas, e até para suporte de serviços. Reunir informação proveniente do sistema real a tempo real permite a analise do estado do sistema a qualquer momento ajudando a prever falhas ou mudanças na produção, o que por sua vez facilita a perceção da necessidade de manutenção ou reparação. Por último, a realidade virtual permite o comissionamento dos sistemas antes do fim do projeto, diminuindo o tempo, o custo, os erros e as falhas no sistema final caso esta tecnologia não fosse utilizada. Os *software* de realidade virtual para comissionamento virtual devem ter bons gráficos, simulação baseada na vida real, deteção de colisões confiável, também deve suportar a marca e modelo do controlador lógico programável e da interface homem-máquina usada no sistema real. O *software* usado no decorrer deste trabalho foi o *Emulate3D* da *Rockwell Automation* que digitalmente simula, imitando o comportamento de um sistem sem ser necessário reproduzir os seus componentes, ou emula, reconstrui um sistema com base no entendimento do funcionamento do mesmo com um resultado próximo ao original, sistemas automatizados antes de serem feitos custos de automação e produção, cumprindo os requistos para o objetivo final do comissionamento virtual.

Comissionamento virtual é o conjundo de testes a uma cópia digital de um sistema real, com uso de *software* de realidade virtual e outros *software* de desenho assistido por computador 3D. O objetivo do comissionamento virtual é a possibilidade de testar mudanças e atualizações do sistema antes destas serem implementadas no sistema real, ou, até mesmo, antes do sistema real estar pronto para testes de *software*. O ambiente virtual permite ao engenheiro confirmar que o código do controlador lógico programável e da interface homem-máquina estão a funcionar corretamente. Os benefícios desta tecnologia são bastantes e com grande peso na indústria. Estes incluem uma redução do tempo de entrega do projeto para o cliente devido à confirmação virtual anterior que a parte automatizada funciona como é esperado. Também é reduzido o desperdício uma vez que são necessários menos protótipos. Além disso a correção de erros é mais barata, uma vez que estes são encontrados mais cedo no processo. Ao mesmo tempo, leva a uma qualidade superior do *software*.

O *software* utilizado para o comissionamento virtual neste trabalho é o mesmo usado na realidade virtual, *Emulate3D* da *Rockwell Automation*. Este permite fazer o comissionamento, através da conecção do modelo criado ao autómato programável que controla o sistema, para além de modelar uma cópia virtual do sistema real. A cópia digital envia informações sobre o comportamento real do sistema sendo possível comissionar os sistemas de visualização, como, por exemplo, as interface homem-máquina, apenas ligando essa interface ao autómato programável da mesma forma que é ligado no sistema real.

A ligação entre os vários temas abordados neste trabalho é a Indústria 4.0, e a forma como a revolução industrial baseada na presente era digital permitiu tudo o que foi descrito. Sensores e atuadores habilitaram as máquinas a se conectarem a um autómato programável, entre si e até mesmo à internet, para diminuir a intervenção humana necessária em processos industriais. A diminuição da mão de obra humana diminuiu também aos riscos de segurança, os erros, o custo e o tempo do processo. Para diminuir ainda mais esses parâmetros chaves devem ser usados a realidade virtual e o comissionamento virtual, que criam e testam um modelo virtual de um processo controlado por autómatos programáveis. Durante o trabalho o Emulate3D comunica com o autómato para que na realidade virtual sejam executados os seus comando e por sua vez envia dados do processo de volta ao autómato. A interface Homem-Máquina é executada simultaneamente, assim os utilizadores podem verificar os comandos feitos na realidade virtual.

**Palavras-chave:** Realidade Virtual, Indústria 4.0, Simulação, Programação de PLC, Sistema de Tratamento de Bagagens, Commissionamento Virtual

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# Acronyms

| | |
|---|---|
| BHS | Bag Handling System |
| CAD | Computer-Aided Design |
| CCP | Central Control Panel |
| CIB | Check-In Interface Box |
| CPS | Cyber-physical Systems |
| CPU | Central Processing Unit |
| DB | Distribution Box |
| FDB | Field Distribution Board |
| FB | Function Blocks |
| FC | Functions |
| GUI | Graphical User Interface |
| HMI | Human-Machine Interface |
| IATA | International Air Transport Association |
| ICT | Information and Communication Technologies |
| IIoT | Industrial Internet of Things |
| IoT | Internet of Things |
| JTR | Santorini International Airport |
| JTR - BHS | Santorini International Airport Bag Handling System |
| OB | Organization Block |
| OOG | Out of Gauge |
| PDP | Power Distribution Panel |
| PLC | Programmable Logic Controller |
| SCADA | Supervisory Control and Data Acquisition |
| SPPAL | Siemens Postal, Parcel & Airport Logistics |
| TIA Portal | Totally Integrated Automation Portal |
| UPS | Uninterruptible Power Supply |
| VSU | Vertical Sorting Unit |
| VSU IB | Vertical Sorting Unit Interface Box |
| VC | Virtual Commissioning |
| VR | Virtual Reality |

# Chapter 1

# Introduction

Industry 4.0 has been around for less than a decade making it the most recent industrial revolution, being led by the Internet of Things (IoT), Cyber-Physical Systems (CPS), Big Data, and Automation. Each revolution was propelled by new technologies and innovation [1]. Starting in the 18th century the use of steam power changed the way goods were crafted by hand to being produced in mass quantities in factories [2]. The second revolution happens with the advances in steel and iron productions and with the invention of electricity [3]. Information and automation technology in the fast-paced digital era have propelled the global economic development and the manufacturing defining the third industrial revolution [4]. Finally, the industry is living its fourth revolution, also known as, Industry 4.0 which focuses on interconnectivity, automation, machine learning, and real-time data. Its main objective is to respond to the needs of every company to connection and access to real-time information across processes, products, and people [5]. Figure 1.1 shows a simplified timeline of the four industrial revolutions.

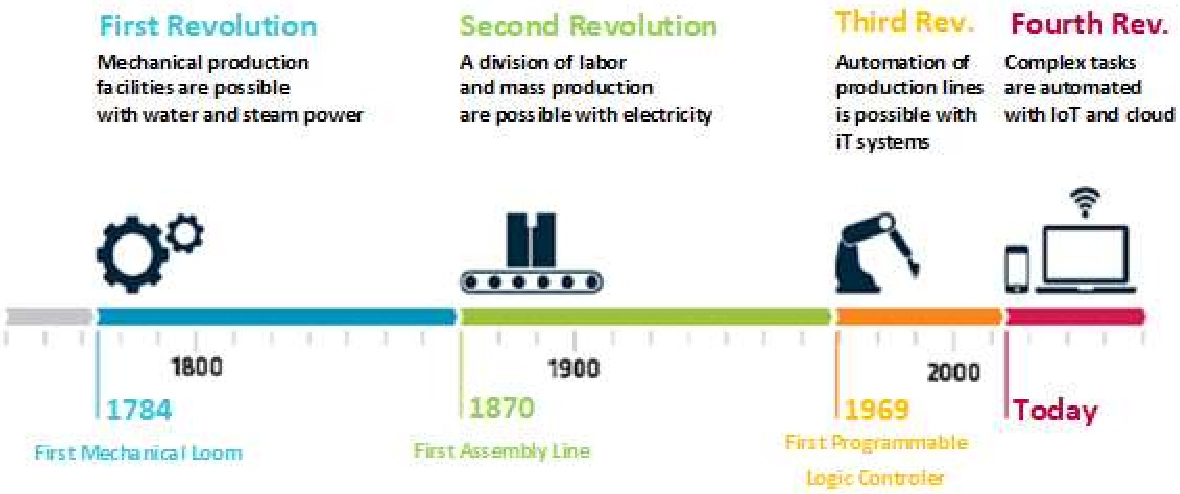



Figure 1.1: Industry revolutions timeline (Adapt. from [1]).

Virtual Reality (VR) is seen in the game industry as the new generation, and a lot of improvement has been made in that technology making it more user-friendly. The industry has also been using virtual reality, it uses it as a complement to the real processes, training and/or virtual commissioning. Productivity and revenues are expected to rise with the new technologies from Industry 4.0, this includes virtual reality, internet of things, automation and artificial intelligence [6].

This chapter aims to introduce the topic of the master thesis, explaining the motivations that led to the choice of the theme, the objectives to be achieved, how the software for both the Virtual Reality and the programmable logic controller (PLC) programming was chosen, and the structure adopted for a better understanding of the developed theme.

## 1.1 Motivation

The choice of this theme for a Dissertation was motivated, in a more immediate approach, by the possibility to explore the impact the use of a virtual reality model has in an automated process and how it can be further improved by the use of virtual commissioning allied to a digital twin of the system.

The last couple of decades have introduced and improved several features that prompted the industry to change. Information and Communication Technologies (ICT) have improved substantially, which makes them cheaper and easier to find. These technologies allowed the digitalization of many processes. It has never been easier to communicate with machines and let machines communicate with each other.

In spite of being relatively simple to automate an industrial process using a programmable logic controller, it brings a problem as sometimes it is hard to predict how machines respond to it and the connection between each other. This problem may be attenuated using simulation before implementation which can be performed with virtual reality. As an example: bad electric installations on-site can generate doubt in where the errors come from, emulation and virtual reality allow to eliminate ambiguities since the automation code and the interfaces are commissioned before hand. This allows other problems to be diagnosed and corrected on-site. Virtual Reality uses the real process with all their parts and the automation program to emulate how everything works together allowing for corrections either on the hardware or on the software.

It was also motivated by the possibility to work in a corporal context, Siemens Postal, Parcel & Airport Logistics (SPPAL) generously offered their facilities, software, hardware and knowledge needed to develop this work. This was extremely helpful but also imposed some constraints. For example, even though this work was limited to a time frame SPPAL was not, making it difficult to sometimes get everything needed for the work being developed as the project hadn't reached that point of the process yet. On the other hand, there were a lot of qualified people with a considerable amount of knowledge in the field, that helped to deepen the knowledge in the areas of PLC programming and a Human-Machine Interface (HMI) design, and also to acquire new knowledge in virtual reality, virtual commissioning and bag handling systems. Developing this work with SPPAL allowed the use of better software for the virtual reality and for the PLC programming, as well as, access to cutting edge hardware in the automation department, especially considering that SPPAL is one of the market leaders in automation. With several bag handling systems around the world, SPPAL was able to develop a unique approach to these challenges, bettering themselves with each new project, optimizing the PLC code for a faster one and with fewer errors and upgrading the software to meet the needs for each project. Finally, the possibility to cooperate with different teams was also motivational, being able to interlock different skills in a real-life project showed how different areas of engineering complement and depend on each other.

## 1.2 Objectives

This dissertation intends to create a Virtual Commissioning (VC) system in a virtual reality environment to help solve some of the problems of only using normal commissioning in the real system after all other steps of the project have happened.

The commissioning of a system usually happens at the end of the process which presents a few disadvantages. It is hard to accurately predict a time frame for on-site commissioning and that can delay the deadline. This is critical in fully automated systems as the interaction between different parts of the system is crucial and it is necessary to maintain a constant flow throughout. Designing the system in a virtual reality software allows the commissioning to be made earlier on the process, even before the construction or assembly of the physical model.

The main purpose of this master thesis is to design a PLC controlled process in virtual reality software, other industry 4.0 concepts will be addressed, for example, simulation, communication, and supervision. The process chosen will be based on a bag handling system (BHS) for the Santorini International Airport (JTR). The International Air Transport Association (IATA) airport code for the airport is JTR and was chosen by IATA itself, this code is composed of three letters and designates the airport.

To achieve this Rockwell's Software Emulate3D will be used to design the bag handling system (BHS). This software offers the necessary environment and the possibility to connect the final model to a PLC program. Acting as the real system the digital twin created in Emulate3D sends information to the PLC, which in turn responds to the system with the information needed to keep it working, after receiving the information the PLC also communicates with an HMI. The HMI is one of the tools used in the process of virtual commissioning making one of the objectives the construction of the HMI that accompanies the bag handling system.

## 1.3 Software

Two different software were used along the course of this project. The first was the one used to create the digital twin of the bag handling system for the virtual reality and the virtual commissioning, the other was the one used for PLC programming and HMI building.

### 1.3.1 Virtual Reality Software

With all the Virtual Reality Software existing in the market, it is important to make an informed choice. In order to meet the objectives of this thesis, the software to be used must fulfill several requirements, namely:

- 3D Virtual Reality
- Connection to a PLC
- Third-Party Computer-Aided Design (CAD) software compatibility
- Total Immersion (Optional)
- Completed Version (Optional)

One of the possible solutions for virtual reality factory floor planning is Tecnomatix Plant Simulation. However, the student version doesn't comply with the requirements as it doesn't allow for a connection with a PLC, one of the most important aspects required. It also doesn't have third-party CAD software compatibility or total immersion [7].

Real Games offers Factory IO another virtual reality software. This software allows a PLC to control the model created. However, there is no information regarding importing 3D objects from third-party CAD software and it also doesn't offer total immersion [8].

Emulate3D from Rockwell Automation was the software used in this master's degree thesis. It is the software used by the emulation team at SPPAL. It offers compatibility with several different PLCs, the possibility to import 3D objects from third-party CAD software and total immersion if necessary [9].

### 1.3.2 PLC and HMI Software

The choice of the PLC and the programming software must guarantee that the PLC system is compatible with the Virtual Reality software. A list of the software/hardware compatible with Emulate3D is available in its website [10].

Considering that the PLC was already selected by the Siemens Postal, Parcel & Airport Logistics automation team, a SIEMENS Simatic S7-1500, and that this PLC is compatible with Emulate3D then the software used for the programming was the SIEMENS Totally Integrated Automation Portal (TIA Portal). This software was also used to build the HMI.

## 1.4 Master Thesis Outline

This Master Thesis is organized in five chapters, the first chapter introduces the reader regarding the set of subjects that will be studied throughout the document. Followed by the second chapter, a bibliographical revision is made regarding Industry 4.0 and Virtual Reality.

The third chapter, presents the Santorini International Airport Bag Handling System (JTR-BHS). With indispensable information to the development of the present work it explores the virtual reality software used to model the bag handling systems, how to connect to the logic controller, how it was scripted, and describes the virtual commissioning.

The fourth chapter describes the Human-Machine Interface designed for the system and also describes the bag handling system control, detailing the functions programmed in the PLC.

Finally, concluding remarks are provided in the fifth chapter, as well as, possible future work related to this theme.

# Chapter 2

# State of the Art

In this chapter the state of the art is developed to introduce and summarize some of the themes that are covered in this dissertation, displaying their scientific rigor and how they are being explored currently.

## 2.1 Introduction

Throughout the time, the industry has gone through several revolutions, from the steam to the automated production. In the fourth revolution, automation helped turn complex machines and production lines simpler and more efficient, with user-friendly machines. Industry 4.0 is the name given to such revolution and relays on the internet and automation.

M. Dahl [11] defines Virtual Reality as ”a technology used to provide the user with an experience of the real world in a virtual environment by using visual, audible, and haptic feedback”. VR software can no longer be ignored by the industry. Even though it is used mainly for entertainment purposes, like games and short films. Virtual Reality has a plethora of other applications, from supporting the production to showcase a product to a possible client. Virtual reality can be of great help and use.

Virtual Commissioning consists of the validation of a system in a virtual environment [11]. Most of the time the engineering results from different areas, mechanical, electric or software meet for the first time in the commissioning resulting in delays for the necessary adjustments [12]. Using virtual commissioning allows for a verification of the system earlier even before the physical commissioning is discussed [13].

The bag handling system impacts the passengers as well as the airlines making this a key process in an airport. Being extremely important since any error may result in the damage, delay or loss of a bag [14]. Additionally, it can cause serious additional expenses for the airport since inefficient baggage handling may cause delays [15].

## 2.2 Industry 4.0

The Industry has gone through several revolutions, being the fourth one known as the digital revolution. This revolution is the consequence of the exponential growth that the Information and Communication Technologies had in the last years and the widespread application of the internet [16]. Smaller, more powerful and cheaper sensors, artificial intelligence and even machine learning have played a major role in this revolution [17]. Industry 4.0 (Figure 2.1) is characterized by the extensive use of the Internet as well as other smart technologies.


Figure 2.1: Industry 4.0 parts (Adapt. [18]).

Industry 4.0 manufacturing doesn't rely on scale and volume, but on a closer, more flexible and better-localized production [16]. Its main objective is to fulfill individual customer needs and promotes a link between physical sensors, devices, and the internet [19]. Industry 4.0 favors what is called mass customization, allowing the customer to personalize the product offered by the company to meet its needs.

Some of the characteristics of today's industrial environment are strong competition, a short product life cycle with the increased complexity of the products and the processes. This leads to the need to provide innovative and individual products of good quality, produced faster and cheaper. An automated process offers a solution with an integrated approach to better products and processes [20].

### 2.2.1 Internet of Things

The Internet of Things and the Industrial Internet of Things (IIoT) are a worldwide network of objects that communicate with each other through protocols [19]. Smart and connected objects represent opportunities for new functionalities, better reliability, and capabilities that go beyond traditional boundaries [21]. This requires that all members, objects, and users, have access to the internet that has smart technologies without spatial or temporal boundaries.

The Internet of Things is supported by three main features: context, omnipresence, and optimization. Context refers to the likelihood of advanced objects interaction with an existing atmosphere and immediate response if something changes; Omnipresence offers data of objects as location, physical and even atmospheric conditions; Finally, optimization shows that objects nowadays are more than the connection between human operators and human-machine interfaces [19]. In conclusion, the Internet of Things can be defined as the possibility of turning physical things into smart things with the use of small internet-connected computers [21].

Since the IoT depends on fast internet in the future the new 5G might be of help. Faster speeds, lowered latency, network support, and expansion of cell sites [22] will probably replace the "different Profibus standards and the current fragmentation in the factory environment" [23]. Security will be an important factor to consider and the companies need to keep an eye on the parts of the process that might be vulnerable.

### 2.2.2 Cyber-physical Systems and Smart Factories

Cyber-physical systems are systems that connect the physical and the virtual world [21]. More specifically it can be defined as the systems in which the physical space, with natural and human-created systems, are integrated with cyberspace, with computation, communication and management systems [19]. Sensors in machines communicate with each other and with the user through the internet to give information about machine statuses and needs.

Smart factories include CPS, IoT, and cloud computing [17]. The connection between the CPS and the IoT is what enables the smart factory, as the CPS communicates through the IoT to create a decentralized production system [21].

## 2.3 Virtual Reality

While Industry 4.0 deals with the link through the internet and data chains of all parts of a machine, virtual reality allows visualization of the monitoring or reporting data [24]. Josef Wolfartsberger et al [25] define virtual reality as ”the term used to describe a computer-generated, three-dimensional environment, which can be explored and interacted with by one or more persons”.

It is not new that production lines or facilities use dedicated software Computer-Aided Design, Computer-Aided Architectural Design, or Building Information Modeling to plane and design. However, they are less ideal to evaluate human factors, for example, sizes, distances, and constraints at the workplace [26, 27]. Virtual Reality can help close this gap as the immersion of the user will give physical feedback.

Total immersion or immersion is the term used to describe a virtual reality that shuts the users from reality while feeding them virtual information. This experience is made through a head-mounted display, controllers with position tracking, and stereo headphones [28].

Researches recognize the potential in virtual reality as a tool for assembly analysis, training and process, and path planning [29]. Virtual reality has a huge potential which prompted the interest of researchers in this matter. Hence, it is expected for this technology to expand in the next few years.

### 2.3.1 Virtual and Augmented Reality

Virtual and Augmented Realities can be used for training, resulting in better interaction between humans and machines. This allows for:

- Expedite reconfiguration;
- Support operators;
- Implement virtual training;
- Better efficiency when managing warehouses;
- Support advanced diagnostics;
- Minimizing risk by interacting with the working environment. [16]

Virtual reality can be used as an engineering tool, in medical and engineering education or advanced training and simulation systems [30]. The broad range of use shows how powerful the virtual reality technology is and how it can be used for several different purposes.

Virtual Reality shows great potential for industrial applications, such as simulations of complex maintenance tasks, prototyping or design review [25]. The manufacturer can create a series of Virtual or Augmented Reality scenes to support his services using CAD information [31]. This can be a differentiation factor over the competition.

The possibility to test the model without the time and cost of building the real-life model and reducing the errors in the final product [25, 27] is without a doubt one of the most important advantages presented by this technology. Prototypes could solve this, but this method is costly and can only be accomplished in the end phase of the design process [32].

The possibility to collect and analyze data in real-time allows a permanent track and analyze the status of the plant to react immediately to failures or production changes [33]. This expedites any measure needed for maintenance or repair, for example.

### 2.3.2 Digital Twin

A digital twin is a ”virtual representation of a product, production process, or performance” [34]. The virtual model copying a physical model, even before it is constructed, is called a digital twin and is used for virtual reality and for virtual commissioning.

The industry is full of examples of companies using digital twins, from NASA using it to rescue the Apollo 13 mission, and now to explore next-generation vehicles and aircraft [35], to the McLaren Group, in Formula 1, using it to boost car performance, it shows how several elements of the car perform and how to improve them [36].

Competition pressure has led industries to use digital twins in more than the early design phases and decision-making process. There is an increasing demand in other phases, for example commissioning, operation and retrofitting. Figure 2.2 represents the parts of the system where the use of a digital twin can have a positive impact. Virtual commissioning technologies are leading the way in control software testing before commissioning, a more realistic operator training, safer modifications and optimizations even during operation, along with, retrofitting and refurbishment [37].

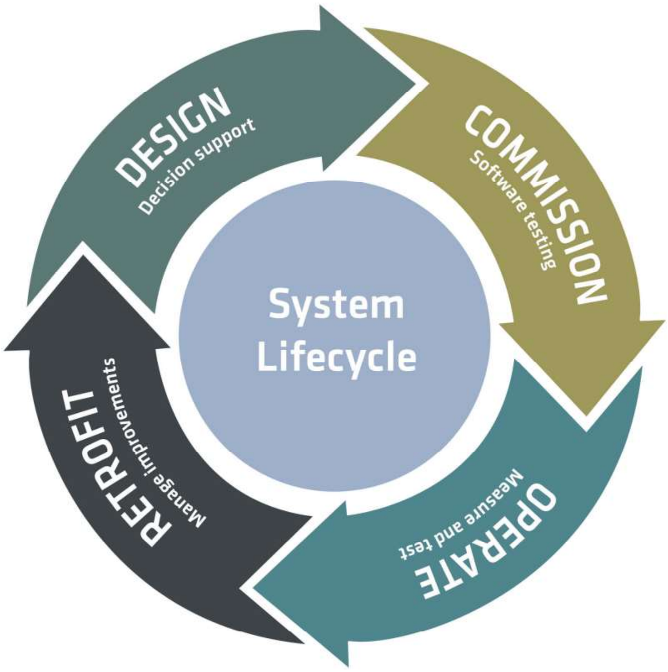



Figure 2.2: System Lifecycle phases where it is possible to use digital twins [37]

### 2.3.3 Virtual Reality for Factory Planning

Even though factory floor planning is already done virtually there is still a lack of immersion. Immersion is when the user is fully integrated with the virtual world. With immersive VR other users from different areas may explore and evaluate the model even if they are not CAD experts [26]. In factory planning, there is more than one area involved, for example, the logistics team has a different viewpoint from an automation expert.

Virtual Reality also allows the experts to note interesting areas or mark errors, while "walking" through the virtual model (Figure 2.3), this can be accomplished with taking screen-shots of the user's field of view [26]. Even though it is difficult to envision how the layout of a factory will be grasped by users after being built, virtual reality reduces the difference between a virtual model and its physical environment.

Figure 2.3: User ”walking” through a factory planned in virtual reality [38].

### 2.3.4 Virtual Reality in the Education

Lastly, companies to be able to manage the increasing complexity of the systems, need well-trained employees. However, for that new learning concepts are needed [39]. Games and virtual reality mechanisms are motivational and aid in learning complex skills. Simulations in a virtual reality context provide a more realistic environment in which students can explore and experiment. Also, the level of interactivity in these simulations allows the student to see the models created by them present immediate or faster results [40]. In this way, virtual reality in education can successfully drive the students into better comprehension of practical applications of what is presented in classes.

The connection between virtual reality and viewing mechanisms can be used for educational purposes, as it can show complex systems in 3D and allows student's direct interaction. To get a better understanding of the system, the student can rotate, move, zoom in or out [24]. This can be very helpful as it can be hard to get some pieces of hardware to show and explain to the class. This way every student can not only observe the object or system in question but also take it apart for a better understanding of the components.

## 2.4 Virtual Commissioning

Virtual Commissioning is defined by Tobias Lechler, et al [12] as ”the early development and validation of PLC code using a simulation model”. Sara Alszer, et al [41] adds that it happens ”even before the real commissioning”.

Virtual Commissioning aims automated systems and industrial equipment. With a virtual model of mechanical, electrical, and control systems validates the operation of a production system before the actual physical implementation [20], it also enables a safe way of testing the integration of new technology or software, since there is no risk of physical destruction in the virtual model and there exists an unlimited number of prototype parts in it [11]. Using VC reduces the testing and integration time during the developmental phase [11]. It allows for a 75% reduction of real commission time vs direct real commissioning at the plant [41].

Two errors can happen when the real system is tested. The first is that the physical wiring of the equipment is faulty. The second is that the logic in the PLC is not working as expected. The intention is by using a simulation model of the system, unwanted behavior can be detected before the physical installation. If the real commissioning does not behave equally with the virtual testing of the model, then the error is more probably in the physical wiring [11]. This is useful for the engineers or operators later in the process.

Figure 2.4 shows how the normal plant life cycle can be accompanied by a parallel line of simulation and virtual commissioning [42]. Comparing the two lines is possible to see that virtual commissioning comes a lot earlier in the process than the real commissioning.

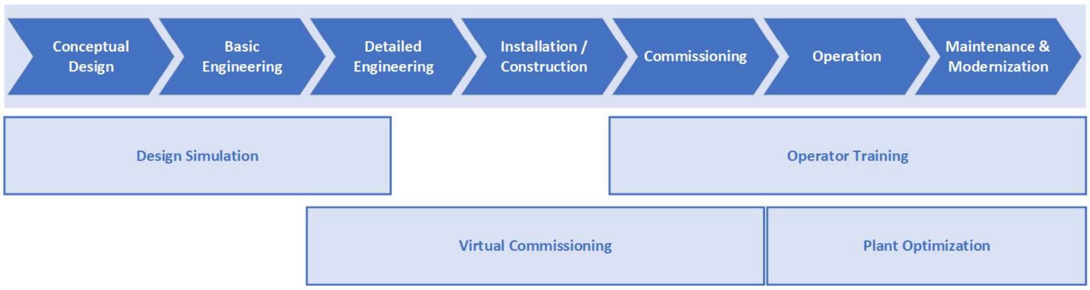



Figure 2.4: Simulation over the life cycle of a process plant (Adapt. [42])

## 2.5 Baggage Handling System

Baggage Handling is the name given to the process that goes from the moment baggage is dropped at the check-in until it is collected in the baggage claim area [15]. Automated BHS are present in most of the major airports today. While the movement in the terminal is automated, there are still manual operations, like distribution and aircraft loading [14]. Figure 2.5 shows the whole process baggage goes through for departures. Starting in the check-in going through the BHS and finishing in the corresponding departing flight.

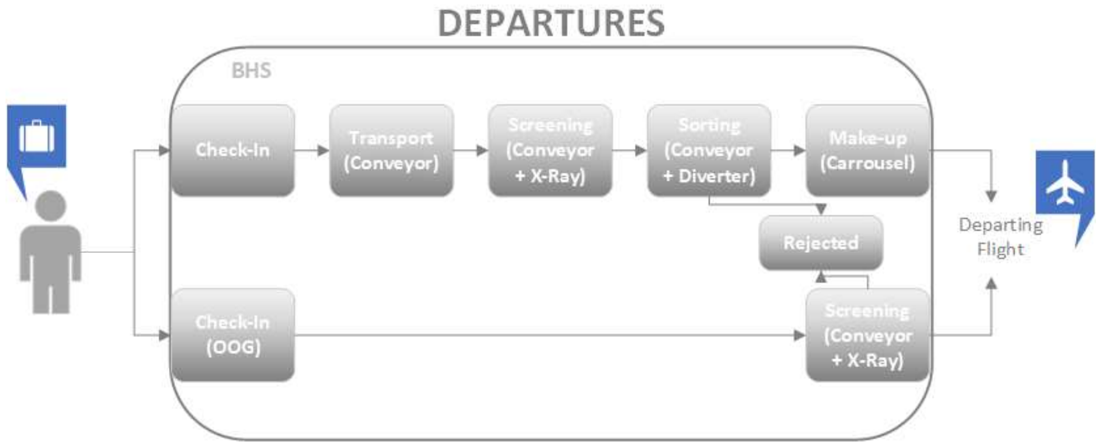



Figure 2.5: Baggage handling process for departures.

Out of gauge (OOG) baggage requires more attention while handling. It is any bag that falls out of conventional formats, such as surfing boards or wheelchairs [43]. The OOG line is a parallel line that has a dedicated X-Ray machine.

A bag handling system consists of a series of conveyors, X-Rays, diverters, and carrousels with the purpose of moving the bags from the check-ins to the aircraft [14]. On the check-in a bag is assigned an identifying bar code with information about the flight and another relevant information, then the bag is conveyed accordingly to the bar code. An X-Ray in the screening area makes sure that any prohibited item is not loaded onto the airplane. If the X-Ray identifies a threat the luggage goes to a second security screening level, if not it is sent to the output pier to be loaded onto the airplane [15].

## 2.6 Conclusions

This state of the art focused on the fourth industrial revolution and the role of the virtual reality in this revolution. Even though Industry 4.0 has been around for at least the past decade there is still a long way to go. New technologies are always being developed and so it is important to be aware of any new change or solution for a problem. Virtual Reality is a powerful, yet underrated tool. It can drastically reduce both the cost and the time of the process, especially in the design phase.

Virtual Reality has an important role not only in industry but in many other areas such as education, medicine, and others making it a very powerful tool. When combined with virtual commissioning it can translate in a decrease in time and cost of a project.

The baggage handling system are complex process of several conveyors and other special equipment. A virtual reality software allied to virtual commissioning will help the airport, or third party contractor to test the PLC code without having to stop the system, if it is already at work, or delay the turnaround as a result of unpredictable issues.

# Chapter 3

# Virtual Reality - Case Study

The first section of this chapter aims to explain the information needed beforehand for a better understanding of this Master Thesis. This section divides the Santorini International Airport Bag Handling System into several parts to better explain each one, describes special equipment present in the system and shows how the system information comes from the mechanical project department.

The second section of this chapter shows how the virtual reality was used in the course of this thesis. Not only to make the model, but also to virtually commission.

## 3.1 Bag Handling System Description

The complete mechanical project of the Bag Handling System is necessary as the most important information needed to make a digital twin is represented there. The appendix A shows one of the pages that are needed. The system is divided into eight different parts.

- Check-In
- Take Way Conveyor
- Transport
- Screening
- Sorting
- Rejecting
- Make-up Carousel
- Out of Gauge

The system (Figure 3.1) starts in the check-in that loads the bags into the take-away conveyor leading to the transport, then to screening, that divides in sorting and rejecting, sorting goes to the make-up carousel and reject take the bags out of the system. The out of gauge part is independent. There is only one of each part, every equipment is called depending on where it is and what is its number, table 3.1 shows how.

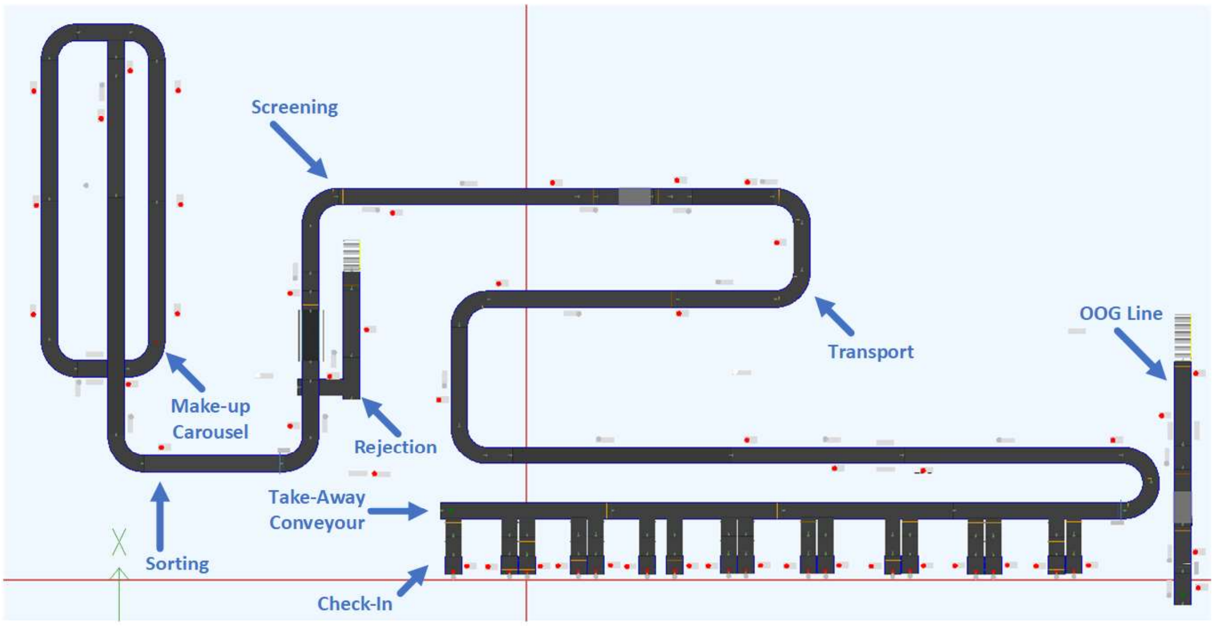



Figure 3.1: Designation of the parts of the bag handling system.

Table 3.1: Denomination of every equipment (Columns) in each part (Rows) in the system, where # is an identifier number.

| | Conveyor | X-Ray Machine | Vertical Sorter Unit | Roller Table |
|---|---|---|---|---|
| Check-In | CKN#.BCV# | N/A | N/A | N/A |
| Take-Away Conveyor | CIL#.BCV# | N/A | N/A | N/A |
| Transport | TRP#.BCV# | N/A | N/A | N/A |
| Screening | SCR#.BCV# | SCR#.XRA# | SCR#.VSU# | N/A |
| Sorting | SOR#.BCV# | N/A | N/A | N/A |
| Rejecting | REJ#.BCV# | N/A | N/A | REJ#.ROL# |
| Make-up Carousel | MUC#.BCV# | N/A | N/A | N/A |
| Out of Gauge | OOG#.BCV# | OOG#.XRA# | N/A | OOG#.ROL# |

### 3.1.1 Check-Ins

The first step baggage makes through the process is in the check-in (Figure 3.2). In JTR-BHS seventeen check-ins work in parallel, each one being composed of three different conveyors. The first one measures the bag height, weight, and length, the second conveyor is where the worker labels the bag. Lastly, the third conveyor dispatches the bag to the takeaway conveyor. The airport worker responsible for the check-in can control it with a Check-In Interface Box and a pedal, this interface box is better described in Appendix C.1.6.

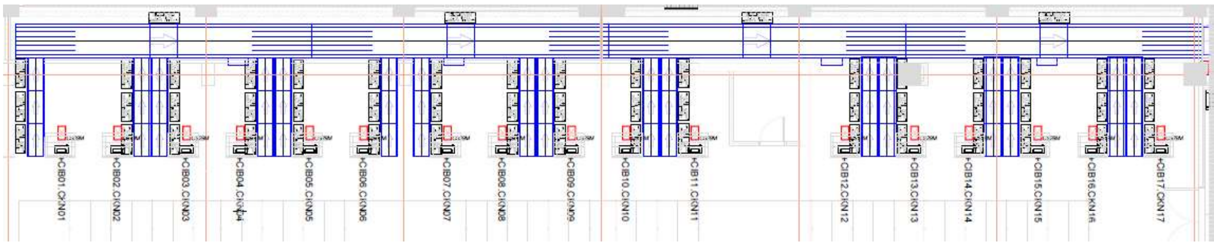


Figure 3.2: Check-in representation in the Mechanical Project.

### 3.1.2 TakeAway Conveyors

The takeaway conveyor (Figure 3.3) incorporates four straight conveyors (Appendix C.2.1) that receive the bags from the check-in and take them to the transport part of the system. Its only objective is to unload bags from the check-in. It does so using a function evaluating if a bag has space to be loaded on to the conveyor without hitting other bags already in it (Section 4.3.4).

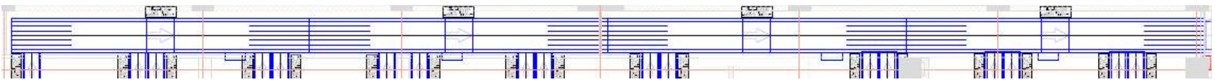


Figure 3.3: Take Away Conveyor representation in the Mechanical Project.

### 3.1.3 Transport

The transport section (Figure 3.4) has six curved conveyors and eleven straight conveyors, making a total of seventeen conveyors. The curved conveyors have 90 degrees curves and the straight conveyors vary in size and inclination. This is the first appearance of metering conveyors (Appendix C.2.2).

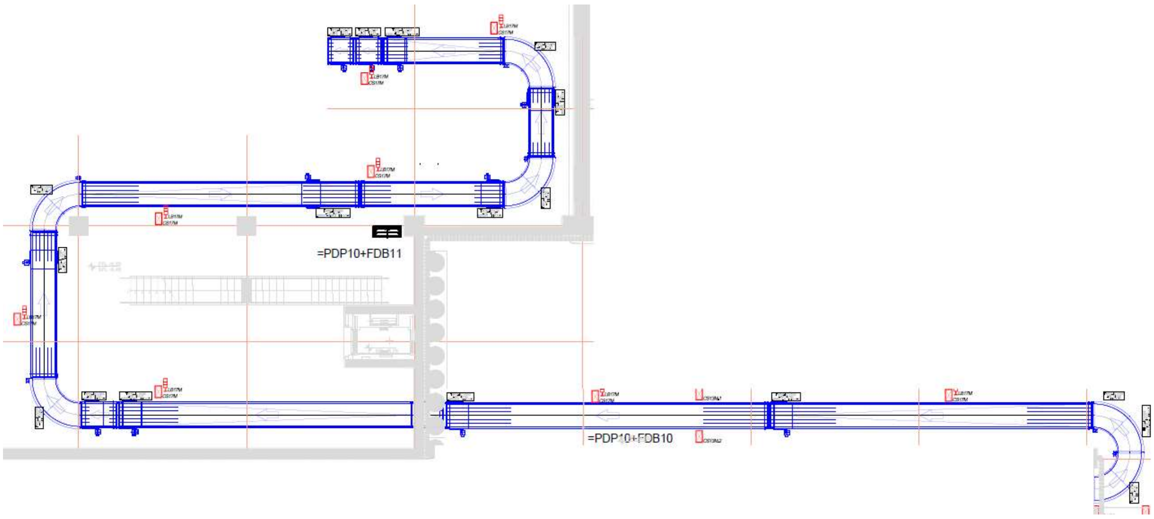



Figure 3.4: Transport Conveyors representation in the Mechanical Project.

### 3.1.4 Screening

The screening (Figure 3.5) refers to the part between the X-Ray machine and the Vertical Sorter Unit (VSU). In the middle there are six conveyors, only one is curved. The X-Ray machine is in the beginning and has a description in Appendix C.3.2. The Vertical Sorter Unit is in the end and has its description in C.3.1.

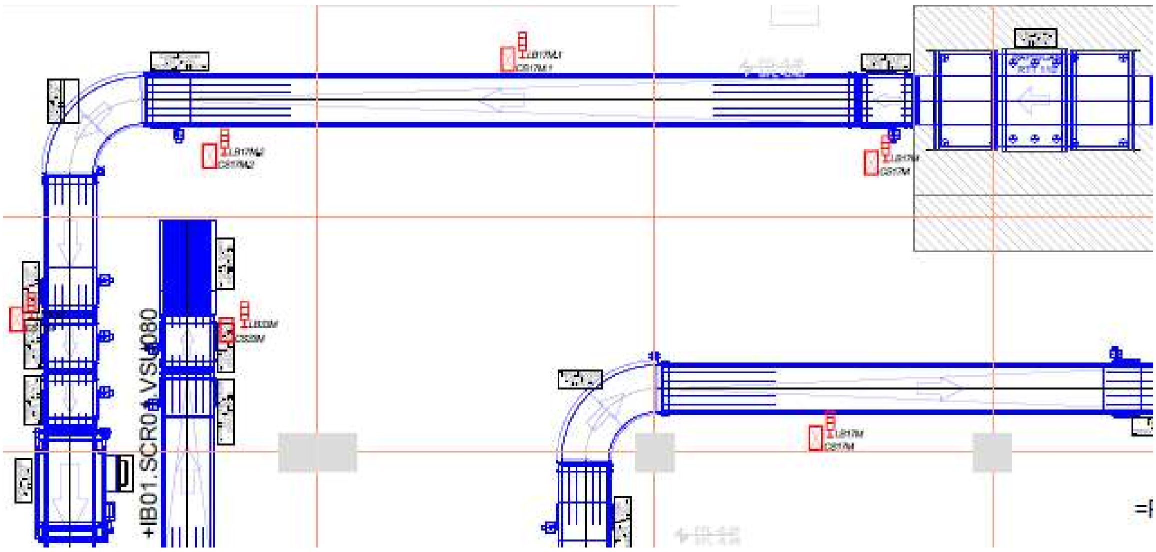


Figure 3.5: Screening Conveyors representation in the Mechanical Project.

### 3.1.5 Sorting

The sorting part (Figure 3.6) refers to the part after the Vertical Sorter Unit up to the carousel, with seven straight conveyors and two curved conveyors. It is used after the bags have been approved.

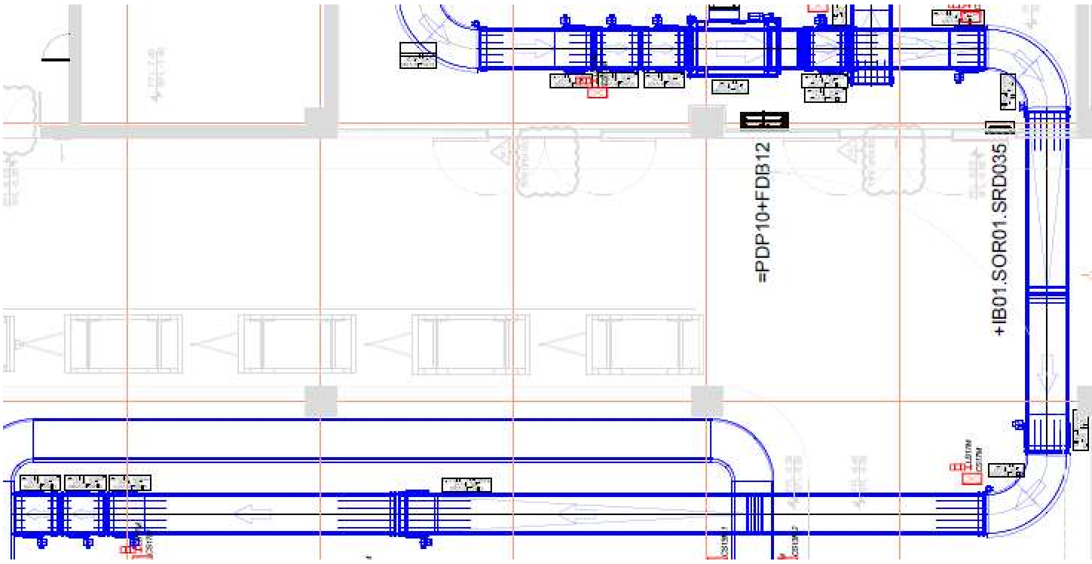



Figure 3.6: Sorting Conveyors representation in the Mechanical Project.

### 3.1.6 Rejecting

The rejection part (Figure 3.7) is where the bags that weren't approved go for disposal. It refers to the part after the Vertical Sorter Unit and is made up of five conveyors and one roller table (Appendix C.2.5).

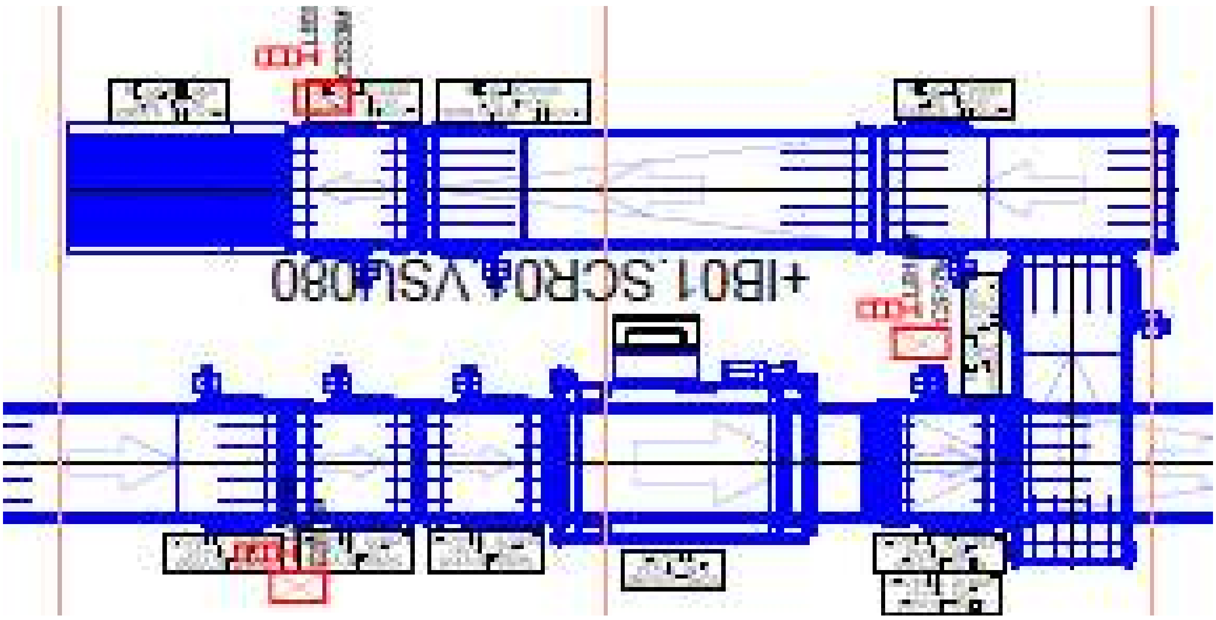



Figure 3.7: Rejection Conveyors representation in the Mechanical Project.

### 3.1.7 Make-up Carousel

The Make-up Carousel (Figure 3.8) refers to the carousel at the end of the system where the workers can take the bags to the aircraft. It is composed of four curved conveyors and four straight conveyors. Appendix C.2.4 gives a description of the make up carousel. The way the sorting line ends in the carousel is called induction and is described in appendix C.2.3.

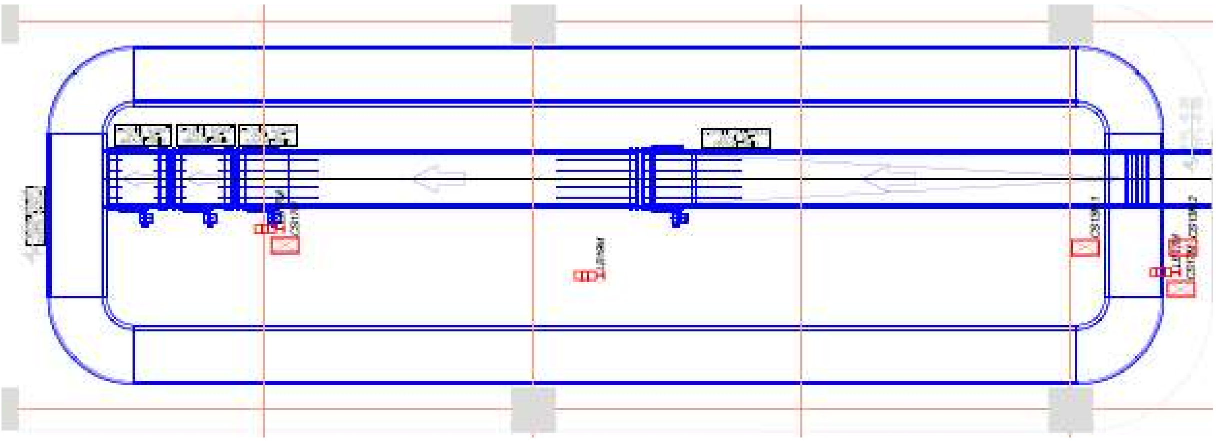


Figure 3.8: Make-up carousel representation in the Mechanical Project.

### 3.1.8 Out of Gauge

The Out of Gauge part (Figure 3.9) is an independent part of the system that handles any bag that has an odd shape or is too big for the normal check-ins. It is composed of four conveyors, one X-Ray machine and one roller table.

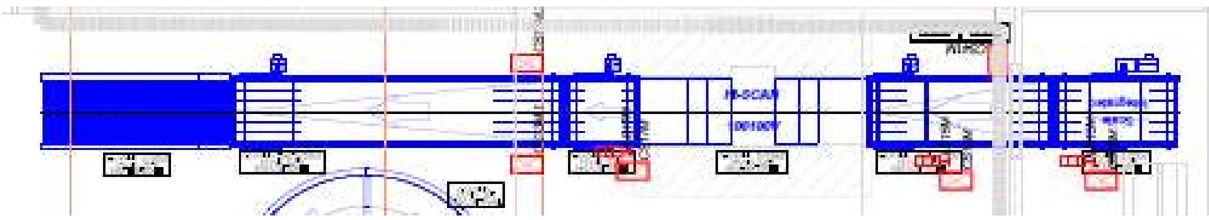


Figure 3.9: Out of Gauge Conveyors representation in the Mechanical Project.

## 3.2 Virtual Reality - Emulate3D

The Emulate3D software connects directly to the PLC, writing to PLC inputs and reading from PLC outputs while changing the virtual equipment states. After modeling the interactive parts of the bag handling system, it is possible to virtual commission. Emulate3D allows testing earlier in the project timeline at a lower cost. This type of system can only be fully tested when complete, placing the tests at the end of the project. This presents a problem as the duration of such tests is difficult to foresee.

### 3.2.1 Graphic Representation

The Emulate3D offers an extensive library with objects for the different industries. It also accepts 3D models from third-party CAD software. This allows a more personalized experience, closer to reality.

To create a bag handling system it is necessary to use representations of the real system. From a schematic or technical drawing of the project, it is possible to build a virtual version.

Every object can be changed to match its real-life image. For that, it is necessary to know a few details (Table 3.2 and 3.3). For example, lengths, inclination angles, speeds, and even distances.

Table 3.2: Objects' details for parameterization.

| Object | Velocity (m/s) | Length (mm) | Angle (°) |
|---|---|---|---|
| CKN01.BCV010-CKN17.BCV030 | 0.5 | 1200 | 0 |
| CIL01.BCV010-CIL01.BCV040 | 0.7 | 10800 | 0 |
| TRP01.BCV010-TRP01.BCV020 | 1 | | 0 |
| TRP01.BCV030 | 1 | 13900 | 1.2 |
| TRP01.BCV040 | 1 | 13900 | 0 |
| TRP01.BCV050 | 1 | 14200 | 10.56 |
| TRP01.BCV060 | 1 | 1600 | 0 |
| TRP01.BCV070 | 1 | | 0 |
| TRP01.BCV080 | 1 | 6350 | 0 |
| TRP01.BCV090 | 1 | 13900 | 0 |
| TRP01.BCV100 | 1 | 12000 | -3.823 |
| TRP01.BCV110 | 1 | 6200 | 0 |
| TRP01.BCV120 | 1 | | 0 |
| TRP01.BCV130 | 1 | 3000 | 0 |
| TRP01.BCV140 | 1 | | 0 |
| TRP01.BCV150 | 1 | 5350 | -11.756 |
| TRP01.BCV160 | 0.7 | 1200 | 0 |
| TRP01.BCV170 | 0.5 | 1200 | 0 |

Table 3.3: Objects' details for parameterization (Cont.).

| Object | Velocity (m/s) | Length (mm) | Angle (°) |
|---|---|---|---|
| SCR01.XRA010 | 0.5 | | 0 |
| SCR01.BCV020 | 0.5 | 1200 | 0 |
| SCR01.BCV030 | 0.5 | 15250 | 1.3 |
| SCR01.BCV040 | 0.5 | | 0 |
| SCR01.BCV050 | 0.7 | 300 | 0 |
| SCR01.BCV060 | 1 | 1200 | 0 |
| SCR01.BCV070 | 1.25 | 1200 | 0 |
| SCR01.VSU080 | 1.4 | | 0 |
| REJ01.BCV010 | 1.4 | 1200 | 2.2 |
| REJ01.BCV020 | 1.2 | 2950 | 0 |
| REJ01.BCV030 | 1 | 2700 | 0 |
| REJ01.BCV040 | 0.7 | 4250 | 4.832 |
| REJ01.BCV050 | 0.5 | 1200 | 0 |
| REJ01.ROL060 | 0 | 2000 | 0 |
| SOR01.BCV010 | 1 | 1200 | 0 |
| SOR01.BCV020 | 1 | 3600 | 6.374 |
| SOR01.BCV030 | 1 | | 0 |
| SOR01.BCV040 | 1 | 4100 | 0 |
| SOR01.BCV050 | 1 | | 0 |
| SOR01.BCV060 | 1 | 9450 | 12.3 |
| SOR01.BCV070 | 1 | 7550 | 0 |
| SOR01.BCV080 | 1 | 1200 | 0 |
| SOR01.BCV090 | 1 | 1200 | 0 |
| MUC01.BCV010 | 0.5 | 3290 | 0 |
| MOOG1.BCV010 | 0.25 | 2000 | 0 |
| MOOG1.BCV020 | 0.25 | 3000 | 7.759 |
| MOOG1.XRA030 | 0.25 | 3585 | 0 |
| MOOG1.BCV040 | 0.25 | 1200 | 0 |
| MOOG1.BCV050 | 0.25 | 5300 | 0 |
| MOOG1.ROL060 | 0 | 3000 | 0 |

All of those characteristics should be chosen on the project. After that, they are communicated to the emulation team that can create the virtual reality environment from them.

Every object has three main ways to be personalized:

- Properties Window;
- Control Button Interface; and
- Scripts.

Figure 3.10 shows the important information taken from the project drawing. For any conveyor, straight, curved, metering, carousel, X-Rays and VSU, it is necessary the name, length, angle of inclination/declination, if relevant, and speed.

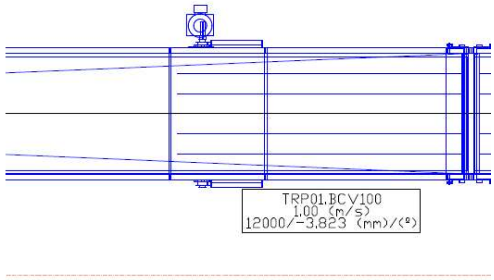



Figure 3.10: Information taken from the project.

The name chosen for the conveyor won't have an impact on the system. However, for coherence and to facilitate the connection between the virtual reality and the PLC, it is recommended to use the same name as in the project.

The properties window (Figure 3.11) can be accessed on the left side of the screen. The simple version allows for the changing of the main necessary things. In the dimensions tab, it is possible to change the length. In the General tab, the name can be changed. The speed is changed in the Motor tab. The longer version can be accessed by the cube in the top and allows for a more detailed manipulation, for example, to change the incline angle or the angle for a curve. Every object has a specific look described in table 3.4.

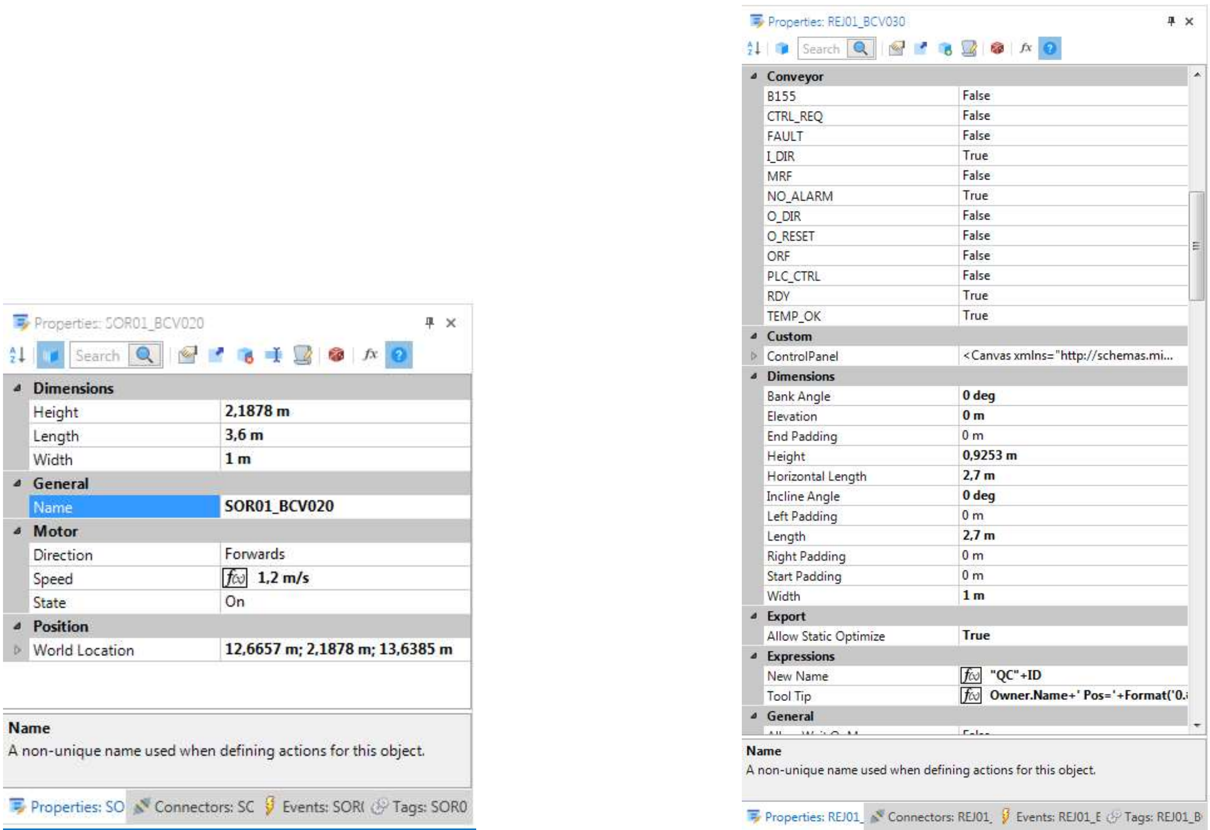
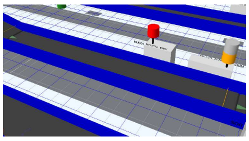
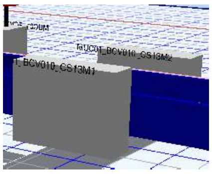
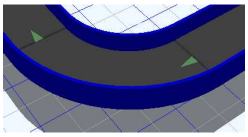
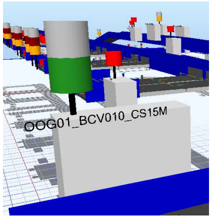
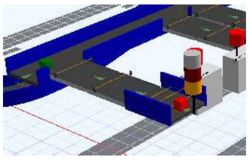
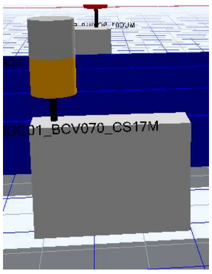
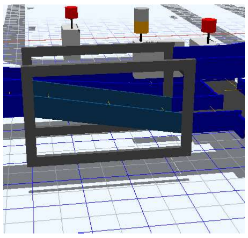
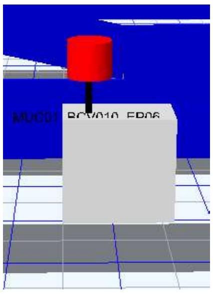
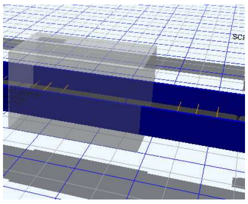
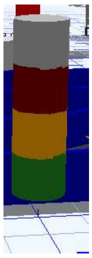
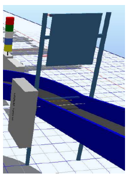
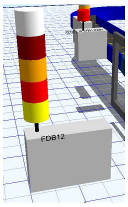
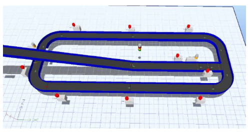
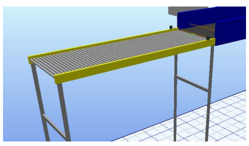



Figure 3.11: Properties window, simple version and general tab.

Table 3.4: Graphic representation of the objects in the software.

| Graphic Representation | Description | Graphic Representation | Description |
|---|---|---|---|
|  | Straight Conveyor |  | Passage Way |
|  | Curved Conveyor |  | Beacon 15M |
|  | Check-In |  | Beacon 17M |
|  | VSU |  | Emergency Stop |
|  | X-Ray |  | Beacon19M |
|  | Fire door |  | FDB |
|  | Carousel |  | Roller Table |

### 3.2.2 Assembling

On the left side of the screen, there is the catalog, the software offers several pre-made catalogs and the possibility of creating new ones, where all the objects are stored. They can be dragged into the field to place them in the system.

While moving objects it is possible to align them with another object just by simply dragging the said object to where the connection to the second object is supposed to be. This snaps them together making a connection between them.

Grouping objects allows for a simpler system. Examples of grouped objects are the carousel and the check-in. The carousel is composed of ten children, four curved conveyors, and six straight conveyors. The check-in is composed of three conveyors, five photocells and a light beacon. After grouping, the objects need a new script that will rule the group and their children.

### 3.2.3 PLC Connection

The purpose of Emulate3D Controls Testing is that instead of wiring the PLC IO points to the real world they can be wired to the virtual model. Applications for this are:

- Emulation/Controls Testing - Testing a real PLC to the virtual system built
- Supervisory Control and Data Acquisition (SCADA) - With the state changes in the PLC highlight in different colors areas of the 3D conveyor model
- Human-Machine Interface - As a normal HMI along with presenting visual feedback executes script code to change motors state for example.

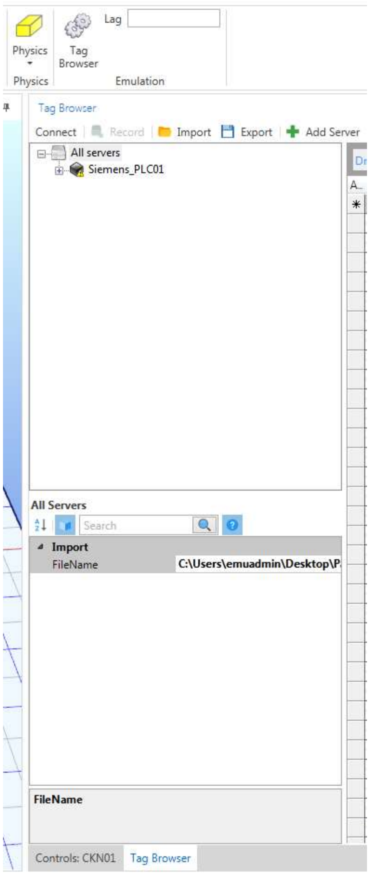



Figure 3.12: Tag browser.

The Tag Browser (Figure 3.12) is used to connect the virtual model to the external PLCs. Tag Binding designates how a PLC tag is wired to the model. There are two types of binding:

Visual Property Binding. When the PLC IO is changed it updates the corresponding property on the model is updated or calls a function. If the property is changed on the model it shows directly on the PLC IO point.

Constant Binding. Usually, it is used in IO points not being tested with a predefined value. It can still be tested by overriding the value.

If the tag is set to ReadFromPLC then the changes in the PLC are reflected in the virtual model. If the tag is set to WriteToPLC then the changes in the virtual model are sent to the PLC.

Each PLC has a different Tag Server in Emulate3D. To configure a new Tag Server Connection manually in the Tag Browser Add Server should be pressed, a dialog showing the three types of server appears:

- Server / PLC
- Bus / Protocol
- Hardware Adapter

Making a Siemens Tag server starts by choosing the correct protocol that is going to be used to connect to the PLC. If there is a physical PLC S7 Functions is the protocol needed, it requires a TCP/IP connection to an Industrial Ethernet card but does not require any changes in the S7 project. On the other hand, if the connection to the Siemens PLC simulator is necessary PLCSIM is the protocol that should be chosen.

### 3.2.4 Scripts

Emulate3D offers further customization of the behavior of the components through scripting. Scripting is used to:

- Define what actions take place when the system has a reset
- Acknowledge and behave accordingly to sensor or contact events
- Control specific behavior (eg lowering a fire door)
- Drive the system Graphical User Interface (GUI)

Four different programming languages/environments are offered C#, Java Script, QuickLogic and Ladder Logic. This work focus on C#.

The beginning of every script provides the compiler a context for the rest of the program. The next part starts the class and initiates the variables from the PLC. Initiating a variable follows the template in the code 3.1.

```
[DefaultValueAttribute(false),Description("Description of the
    variable"),Category("Conveyor")]
[Auto]CustomPropertyValue<Boolean> Variable;
```

Code 3.1: Initialization of the variables.

If a tag should have a certain value when the system is reset the code 3.2 is used to predefined that value. It can also be used with if statements or for calling functions.

```
[Auto] void OnReset(StraightBeltConveyor sender) {
   O_DIR.Value=false;
   I_DIR.Value=true;
   RDY.Value=true;
   NO_ALARM.Value=true;
   FAULT.Value=false;
   TEMP_OK.Value=true;
   if(B155) B155.Value=false;
   else B155.Value=true;
   PHOTOCELL_Location (sender);
}
```

Code 3.2: On Reset function.

The code in 3.3 is used for when a ReadFromPLC tag is bounded to a custom property. When that property is updated in the PLC the custom property is updated and the code inside is called. In this specific case the objective is to change the direction of the conveyor, by changing the custom property IsMotorOnForwards or IsMotorOnReverse to the new value or old value on O_DIR. If O_DIR value is updated from 0 to 1 than IsMotorOnForwards is updated to 1 and IsMotorOnReverse to 0, and vice versa.

```
[Auto] void OnO_DIRUpdated (StraightBeltConveyor sender, Boolean value, Boolean oldvalue){
   sender.IsMotorOnForwards = value;
   sender.IsMotorOnReverse = oldvalue;
}
```

Code 3.3: Part of code to change the direction the conveyor is running.

An example of a function is the location of the photocells in the conveyor (Code 3.4.). As the conveyor has several photocells with a fixed position it is important that the reset of the system doesn't move those photocells for other places.

```
void PHOTOCELL_Location (StraightBeltConveyor sender){
    double BeltLength = sender.Length;
    PhotoEye B111 =sender.FindChild("B111") as PhotoCell;
    if (sender.ContainsChild(B111)){
        B111.Position = BeltLength - 0.30;
    }
    PhotoCell B118 =sender.FindChild("B118") as PhotoCell;
    if (sender.ContainsChild(B118)){
        B118.Position = 0.30;
    }
    PhotoCell B113 = sender.FindChild("B113") as PhotoCell;
    if (sender.ContainsChild(B113)){
        B113.Position = BeltLength / 2;
    }
}
```

Code 3.4: Example of a function, position of the photocells in the conveyor.

An object can send information to their children. The script for the check-in sends information for the light beacon in certain situations (Code 3.5.).

```
[Auto] void OnSIN_ESTOPUpdated (GroupObject sender, Boolean value, Boolean oldvalue){
    Visual estop = sender.FindChild("LB29M") as Visual;
    estop.SetCustomPropertyValue("SIN_RED", value);
}
[Auto] void OnSIN_FAULTUpdated (GroupObject sender, Boolean value, Boolean oldvalue){
    Visual estop = sender.FindChild("LB29M") as Visual;
    estop.SetCustomPropertyValue("SIN_ORG", value);
}
```

Code 3.5: Parent sending information to children.

When using the model to validate the system it can be important to generate bags automatically. That can be made with the following piece of code (Code 3.6.):

```
[Auto] void OnAutoBagUpdated (GroupObject sender, Boolean value, Boolean oldvalue){
    if (value){
        if (NowCreate) NowCreate.Value=false;
        else NowCreate.Value=true;
       // yield return Wait.ForSeconds(TimeBag);
       // loadbag.CreateLoadNow();
    }
}
[Auto] IEnumerable OnNowCreateUpdated (GroupObject sender, Boolean value, Boolean oldvalue){
    StraightBeltConveyor bcv010 = sender.FindChild("BCV010") as StraightBeltConveyor;
    LoadCreatorVisual loadbag = bcv010.FindChild("LoadCreator") as LoadCreatorVisual;
    if (AutoBag){
        yield return Wait.ForSeconds(TimeBag);
        loadbag.CreateLoadNow();
        NowCreate.Value=oldvalue;
    }
}
```

Code 3.6: Generating bags automatically.

### 3.2.5 Virtual Commissioning

Emulate3D can be used to virtual commission the PLC and SCADA. In the PLC it is possible to test the functions and the logic, for that the virtual model imitates the real model by creating bags and making it go through the system. In SCADA, the objective is to test the animations and redundancy functionality, that happens by forcing the signals to get a response from SCADA.

The tags from the PLC code are imported into Emulate3D by a Excel spreadsheet with the columns in the table 3.5. One row is needed for each tag. On Emulate3D the the spreadsheet is imported from the Tag Browser.

Table 3.5: Tags configuration from PLC to Emulate3D.

| Tag | Server | Address | Access | Visual | Property |
|---|---|---|---|---|---|
| Tag name from PLC | 'SIEMENS' | PLC address | 'WriteToPLC' or 'ReadFromPLC' | 'Visual Binding' | Property on visual |

Some examples of how the table with the tags to be imported to Emulate3D should look like is represented in table 3.6. The first column is the tag name in the PLC, the third column is the tag address in the PLC and the last column is the property name in Emulate3D with this three information is possible to cross-reference the information from the PLC to the Virtual Reality.

Table 3.6: Tags configuration from PLC to Emulate3D, example.

| Tag | Server | Address | Access | Visual | Property |
|---|---|---|---|---|---|
| PB_FOOT_CKN01 | Siemens | I2002.5 | WriteToPLC | VisualBinding | CKN01.PB_FOOT |
| PB_FOOT_CKN02 | Siemens | I2032.5 | WriteToPLC | VisualBinding | CKN02.PB_FOOT |
| PB_FOOT_CKN03 | Siemens | I2062.5 | WriteToPLC | VisualBinding | CKN03.PB_FOOT |
| PB_FOOT_CKN04 | Siemens | I2092.5 | WriteToPLC | VisualBinding | CKN04.PB_FOOT |
| PB_FOOT_CKN05 | Siemens | I2122.5 | WriteToPLC | VisualBinding | CKN05.PB_FOOT |

The Tag Grid (Figure 3.13) shows all the tags loaded, their name and address and their binding. Shows the tag value set by the PLC or the model. It can be used to add new tags or bind tags to visual properties. And can be used to force or unforce values, overriding the value of that tag from the model or PLC.

The user forcing tag values overrides the value coming from the PLC or the model. It is possible to force a value by clicking the checkbox in the Value column, or right-clicking on the respective tag and selecting Force. When forced the Tag cell in the Value column turns orange and won't change even if it changes in the PLC. To unforce, a tag right-click on the tag and select Unforce, the color of the cell turns back to green or white.

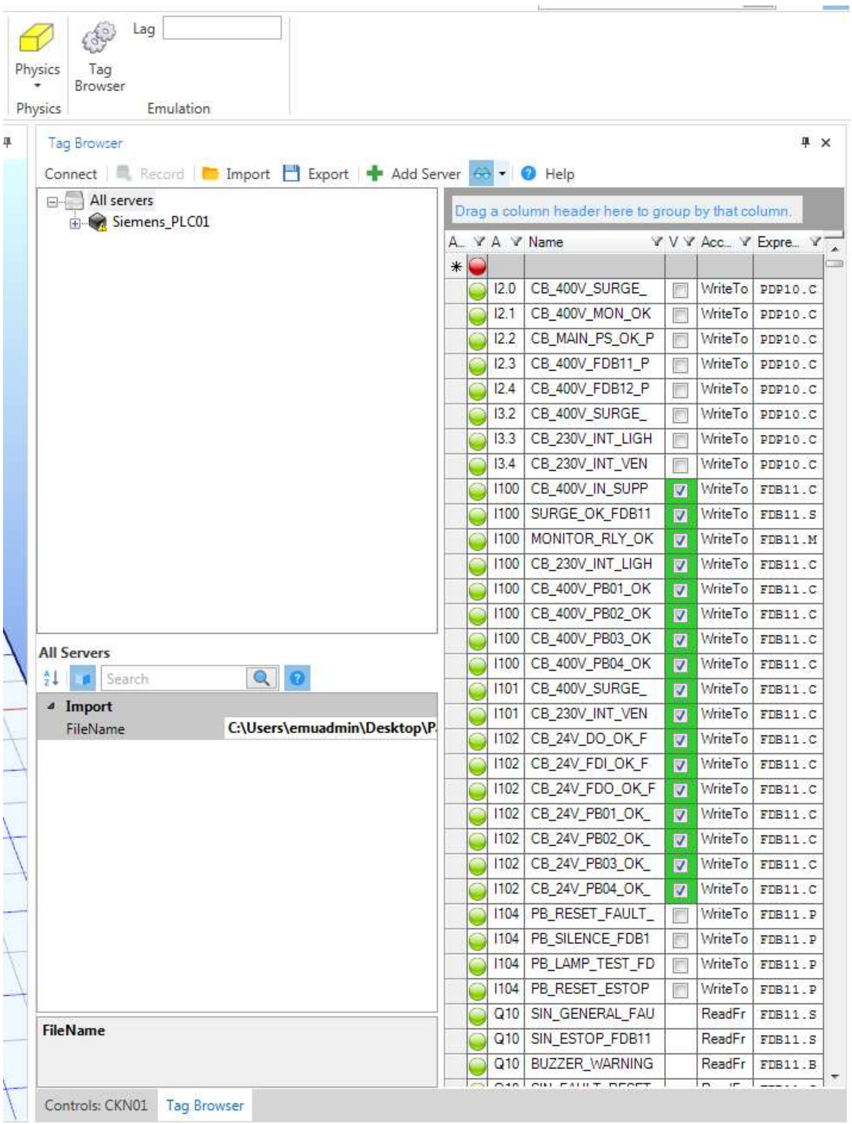



Figure 3.13: Tag Grid.

The virtual commission tests are divided in two parts. Single components and conveying lines. Single components tests include emergency stops, power line circuit breakers, jams on conveyor belts, and over height and length detection. Conveying lines test the start pier conveyor, dieback stop and restart, and merge strategy. The order of the virtual commissioning is irrelevant, but a procedure has to be followed by each test. When no constraint is made in the system, but it is running then bags should move freely (Figure 3.14.).

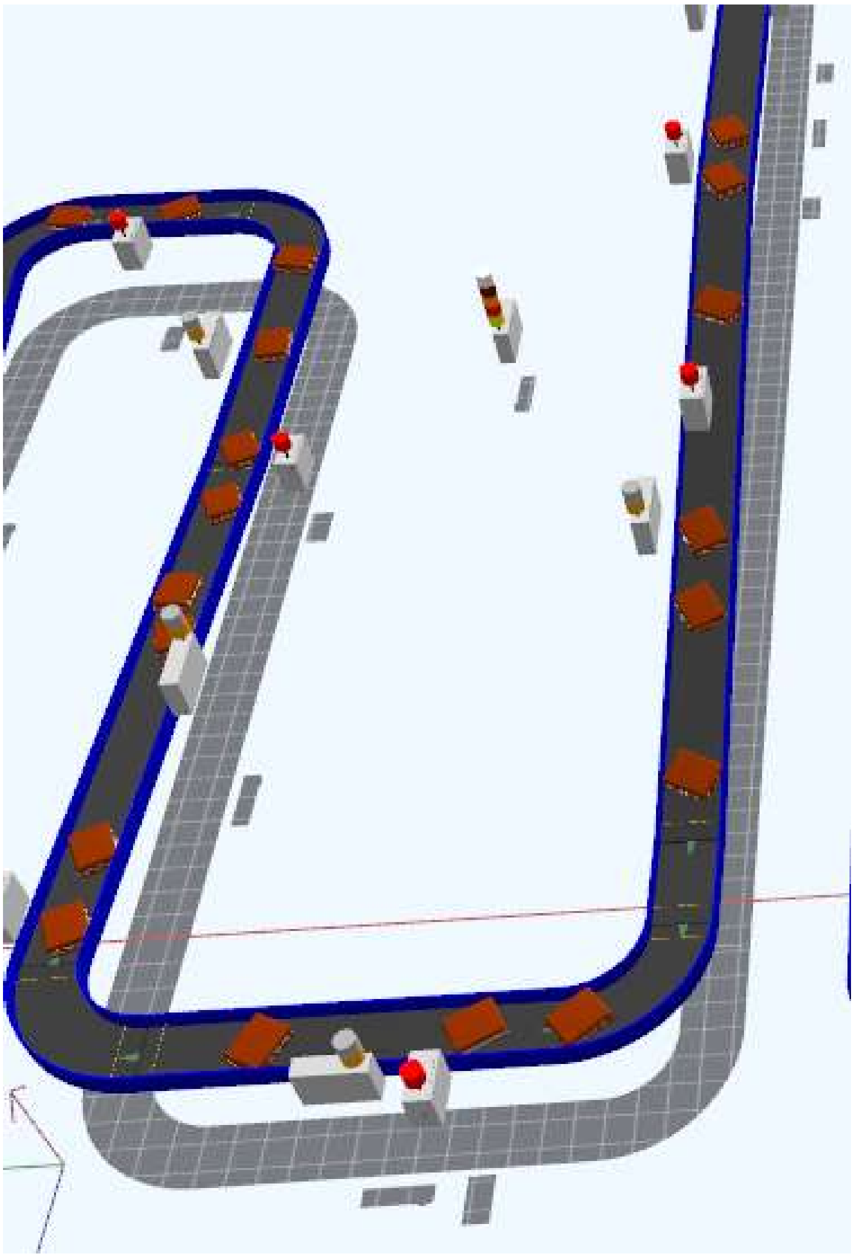


Figure 3.14: Bags moving freely on the Bag Handling System.

The emergency stop buttons (Appendix C.3.5.) are tested by zone, following the procedure detailed below:

1. Start the conveyor line
2. Pressing one of the emergency push buttons associated with the specific zone to be tested

It is expected that the conveyors in that stop zone shut down along with the neighboring interlocked zones, an alarm message is displayed and the emergency stops must be visible and flashing. In the visualizations systems, the corresponding conveyors and fault messages must be displayed. To test the reset of the emergency stops:

1. Release the emergency push button
2. Press the reset push button in the corresponding Field Distribution Board (FDB) panel

After the reset all conveyors are expected to restart. Then the procedure is repeated for all emergency stop groups.

Power Line Circuit Breakers are tested one by one with the following procedure:

1. Start the conveyor line
2. Switch the power line circuit breaker off

Checking the status in the visualization systems must show the respective conveyor statuses and in the Emulate3D it must immediately stop. The next step is to switch it back on:

1. Switch the power line circuit breaker on
2. Reset the alarm

After the activation of the circuit breaker the respective FDB cabinet's fault reset button starts blinking. When the alarm is reset, the conveyor must start automatically in the Emulate3D.

To simulate a jam on a conveyor belt:

1. Start the conveyor line
2. Cover the photocell at the end of the conveyor
3. Measure the time until the conveyor stops

The belt must stop after 5 seconds and it has to show an alarm and status change, the rest of the line after the belt experiencing a jam continues to run. An attempt to reset the fault in the Emulate3D and via HMI or SCADA while the photocell is still covered should not be possible, and should only happen after the photocell is no longer covered.

Overheight and overlength detection testes happen in the check-ins. Every check-in must be tested individually. For overheight detection:

1. Open the check-in
2. Place a bag covering the height photocell

This will stop the belt immediately and a visual alarm is activated. It will only be possible to reset the alarm in Emulate3D after the photocell is no longer covered.

Overlength detection tests are when a bag obstruct the initial and end photocell in the first conveyor. When this happens the receiving conveyor has to stop immediately and a visual alarm is activated in the check-in. In the HMI or SCADA, there are an alarm and status change. As expected it should only be allowed to reset the alarm in Emulate3D after the bag has been removed.

The virtual commissioning of conveying lines is divided into start pier conveyor, dieback stops and restart and merge strategy. Start Pier Conveyor is as simple as pressing the start push button of each conveyor and checking that the conveyor starts after the warning time.

Dieback stops and restarts test the storage of bags in a conveyor when the next conveyor is not running (Figure 3.15). The following procedure is used:

1. Insert a bag onto a conveyor (A)
2. Cover a photocell to start the conveyor
3. Insert more bags onto conveyor A
4. Switch off the next conveyor (B)

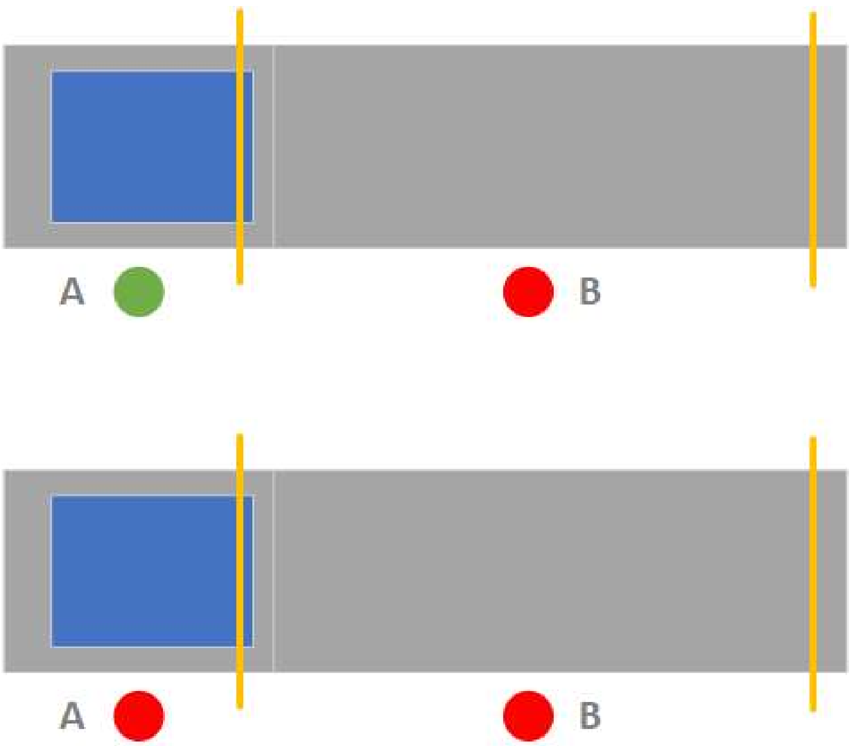



Figure 3.15: Dieback mode.

The expected result is that the bags are transported to the end of conveyor A and correctly stored. When the conveyor B is switched on and the alarm is reset the conveyors restart sequentially and all bags are transported through conveyor B. This will affect every conveyor before the conveyor that has a fault and the stop and the restart are sequentially starting on the conveyor next to the one with the problem and going back to the beginning.

Finally, the merge strategy tests the induction of bags on to a different line. The procedure is only applicable to areas where there is an induction:

1. Insert 10 bags on the conveyor just before the receiving line
2. Ensure at least a 2-meter gap between bags
3. Inset 10 bags on the conveyor of the induction line
4. Start both lines

The bags on the induction line are inducted between bags of the receiving line. However, the receiving line should have priority, the induction line only uses available gaps.

Every single test conducted in the virtual reality software as virtual commissioning will help debug the PLC code and the visualization systems, HMI and SCADA. Any correction to this can be made easily in the office before there is the need to commission the real system. When that part of the project is reached the engineer responsible for the commissioning has more confidence testing on-site, knowing that any fault that may occur should only be between the connection of the PLC and the system, or in the electric installation.

# Chapter 4

# Bag Handling System Control

An HMI was designed specifically for JTR-BHS, with several screens. Not only it provides the operators with useful information on the state of the system, but it also allows such operators to give inputs to the PLC program, according to their security clearance. The first part of this chapter describes the HMI and its screens.

The bag handling system, previously mentioned, is controlled by a SIEMENS SIMATIC S7-1516F. The second part of this chapter aims to explore the several functions used to control such system. These functions were not developed for the purpose of this master thesis. The program was developed by a team of programmers working for Siemens Postal, Parcel and Airport Logistics. However, for a better understanding of the model, a shallow description of these functions is included.

## 4.1 Human-Machine Interface

The Human-Machine Interface is the part that communicates with the user. ISO 9241-110:2006 [44] defines a user interface or HMI as ”all components of an interactive system (software or hardware) that provide information and controls for the user to accomplish specific tasks with the interactive system.” An interactive system is defined as the ”combination of hardware and software components that receive input from, and communicate output to, a human user in order to support his or her performance of a task.” The HMI is where the user is in contact with the machine and can be represented schematically as in figure 4.1

A simple example of an HMI is a light switch where the machine is the light and the human is the user turning it on or off. However, for it to be useful it has to be tailored to the user needs and abilities. A light switch in the basement wouldn’t be appropriate for a light on the second floor.


Figure 4.1: Schematical representation of the use of an HMI.

The HMI System is developed using TIA PORTAL Software and local mimic panel TP1200 Comfort, with the datasheet represented in the appendix B.2. The HMI provides equipment status and statistical information from the baggage handling system.

The PLC and HMI are connected, the PLC ensures the automatic processing of baggage near the field sensor devices, the HMI shows the system information and allows manipulation.

### 4.1.1 Template

The TIA Portal V13 allows the developer to make numerous templates granting better management of the several screens needed. Templates standardize the visuals between screens. They should always be used.

Inside the project tree and under the display is the folder Screen Management that contains the Template folder where they should be created. The template can be selected in each screen's properties (Figure 4.2).

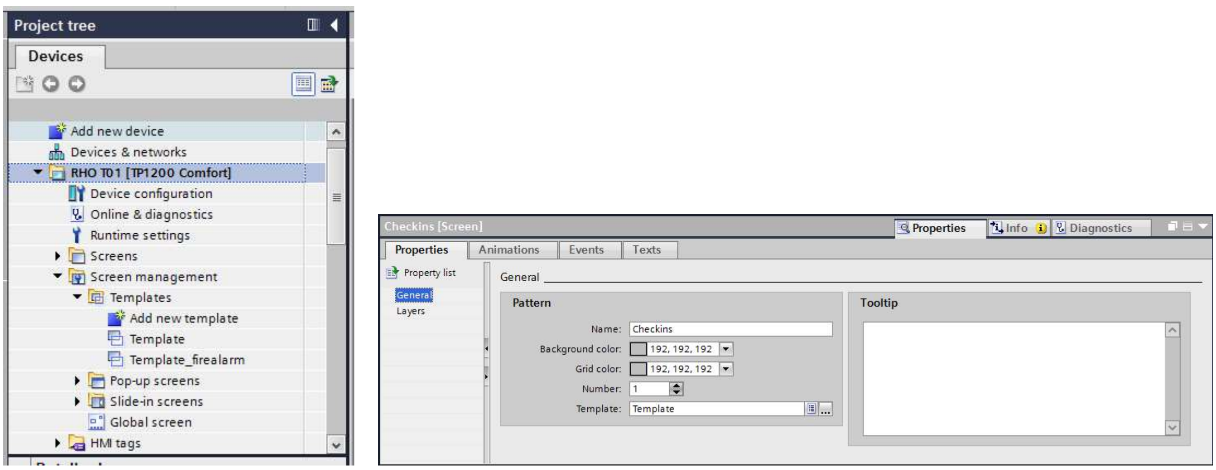



Figure 4.2: In the left Project Tree, in the right Screen Properties.

In this case study, only two templates are needed. One for the fire alarm and the main template for all the other screens. The layout for the main template is divided into five sections (Figure 4.3). Section A, the header, gives information on the HMI System time and status of the connection to the PLC. Section B, the navigation menu, is used to switch between screens, toggle on and off labels and make a general reset. Section C, the main area, displays the screen selected in the navigation menu (Section B). Section D, status window, shows the detailed status of the selected equipment and allows the operator to run commands. Lastly, section E, alarm banner, display the currently active alarms, it can show up to 6 alarms.

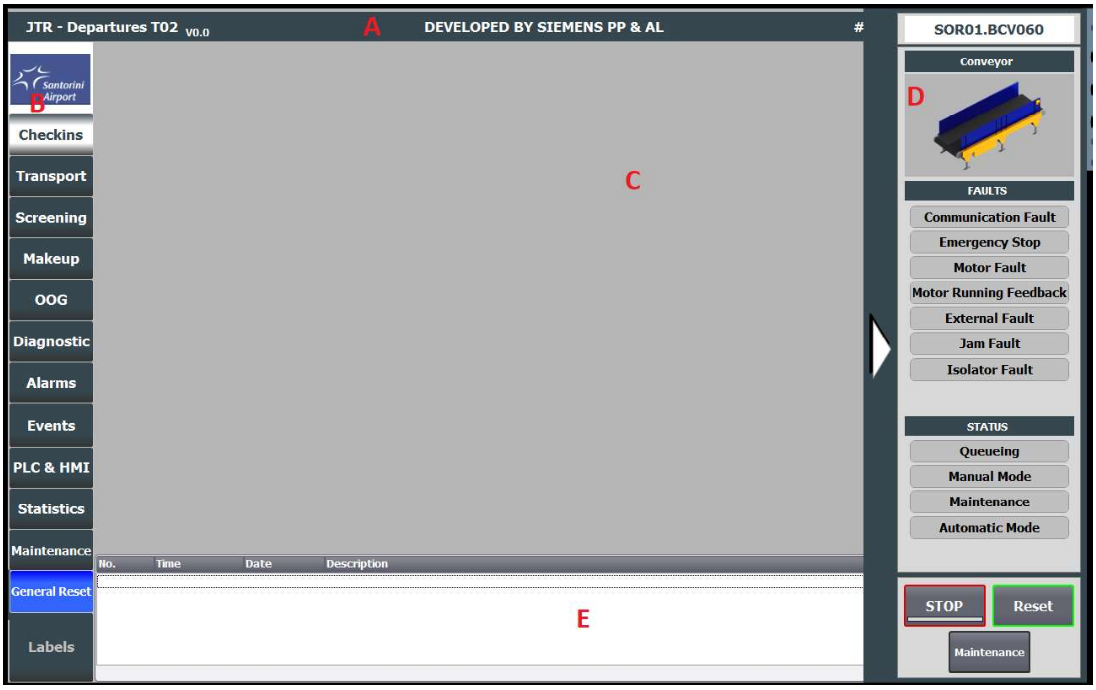



Figure 4.3: Main template layout.

The buttons on the right side allow the operator to change between screens. When a button is selected it will show the required screen, turn white and shift the one selected before back to gray. Animations and events are used for this purpose. It takes two click events to achieve this, these are created in the events tab. The first event changes the active screen to the desired one, the second modifies the value of a UInt internal tag, each button has a specific value. This tag calls an animation that changes the appearance of the button to white or gray.

The alarm banner at the bottom is a control in the Toolbox called ”alarm view”. It displays alarms, in list form, that happen in the Runtime.

In the top right corner of the header, the time and status of the connection to the PLC are visible. The time is imported from the PLC by a tag with the data type Date and Time. The connection to the PLC changes appearance between red, not connected, and green, connected, from a binary tag, with a mask it is possible to change the screen to one with the PLC information on clicking the connection square.

### 4.1.2 Screens

For a bag handling system HMI, it is important to have some standard types of screens. They are:

- Process;
- History;
- Information;
- Statistics;
- Administration;
- Message.

Check-Ins, Transport, Screening, Makeup, and OOG are process screens. Alarms and Events are history screens. Diagnostics, PLC & HMI and Maintenance are information screens. Statistics is the statistics screen. Users is the administration screen. Finally, Fire Alarm is the message screen.

**Process Screens**

The process screens allow real-time detailed visualization and show information on the conveyors that make part of the system, they show the layout and status of each conveyor, emergency stop and other components. The objects and their respective color codes are represented as shown in Annex D. When the status of any object changes that information is shown in the HMI by triggering the fault or status in the status window and by changing the color of the faceplate.

The Labels button on the left bottom corner shows or hides the identification of the equipment in the layout, the identification is also shown at the top of the status window. To open a status window it is necessary to click on the respective equipment faceplate. There are thirteen different status windows, Straight and Curve Conveyor, carousel, Check-In, VSU, X-Ray, FDB, Uninterruptible Power Supply (UPS), Distribution Box (DB), Power Distribution Panel (PDP), and Central Control Pane (CCP) Cabinets, Fire Door and Roller Table. They are divided in three sections (Figure 4.4).

Section A shows any fault, section B shows the status of the equipment and lastly, section C allows the user to send commands. The status windows for the Carousel, Straight and Curve Conveyor are identical changing the type and image on the top.

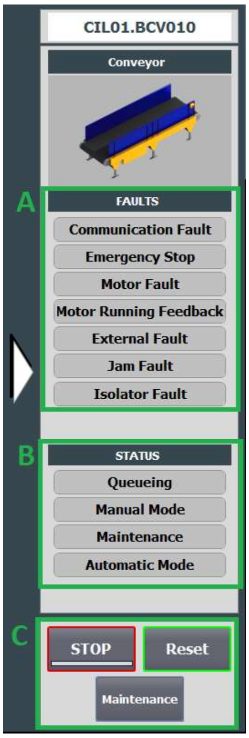



Figure 4.4: HMI Status Window Example.

### History Screens

The HMI archives alarm messages of the equipment controlled by the PLC. History screens show information on active alarms and events. While the banner, that is always visible in the lower part of the window, has a limit of seven simultaneous alarms, the complete list of alarms can be visualized in the Alarms screen and the events list on the Events screen.

Active alarms are represented by an I (in), solved alarms are represented by an O (out). This way it is possible to distinguish between the two. The nomenclature can be changed by the programmer, for example, an X for the active alarms and a check for the solved ones.

### Information Screens

Information about the network diagnostics, maintenance logs, and the PLC & HMI can be found in one of the three information screens.

The Network Diagnostic provides a visual representation of the current network status. In case of a malfunction in one of the Automation Network Devices, an alarm is triggered and the respective faulty equipment is represented in red.

The Maintenance Mode Logging View shows and logs repair times. The records have a description of the equipment that was placed in maintenance mode, a timestamp for the beginning and another when the operator disables the maintenance mode indicating that the equipment is ready for operation. As for the Alarms screen, in the maintenance logs screen, any active maintenance is represented by an I (in), any finished maintenance is represented by an O (out). This mode is activated in the status window by clicking on the maintenance mode button. When activated the HMI system archives these records with the timestamps and a message.

The PLC & HMI window (Figure 4.5) has three sections. Section A, PLC, displays the faults of the PLC controller. Section B, HMI, allows access to functions as Calibrate or Clean Screen, as well as access to the User Administration screen. Section C, Installation, allows the operator to start or stop the installation and shows the self-test running state. This self-test starts when the start button is clicked and stops when all the conveyors are tested. The start button flashes green during this test.

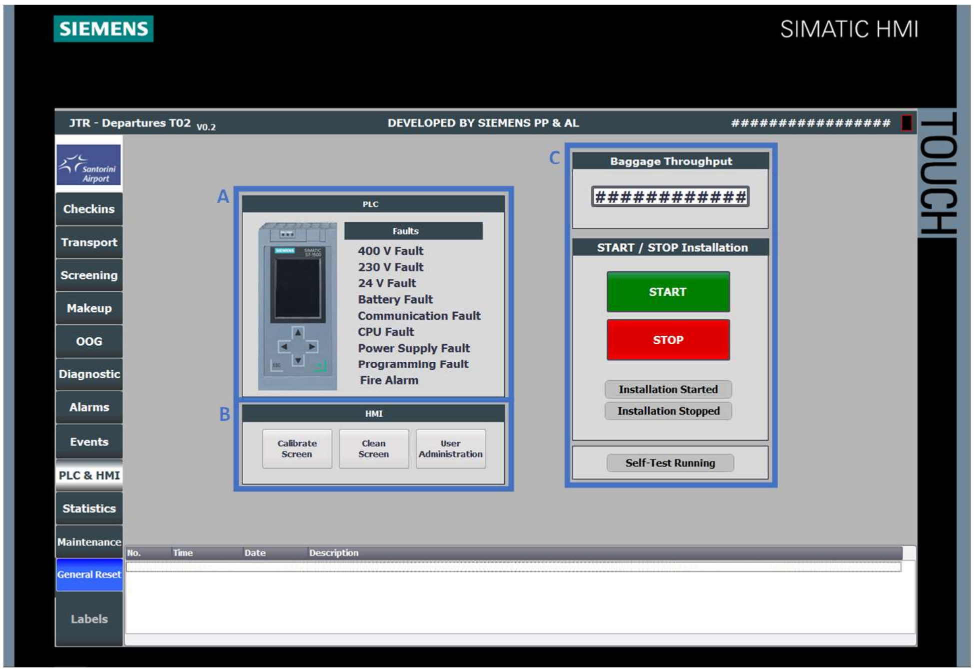



Figure 4.5: PLC & HMI window.

### Statistics Screen

The statistical points are strategically chosen along with the system. These points are represented by a capital letter, as exemplified in figure 4.6, clicking in it shows the statistical data. The decision to make a conveyor a statistical point is based on if there are bags entering the system, for accepted or rejected bags and after screening (Schematically represented by figure 4.7.).

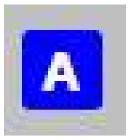



Figure 4.6: Statistical Point faceplate.

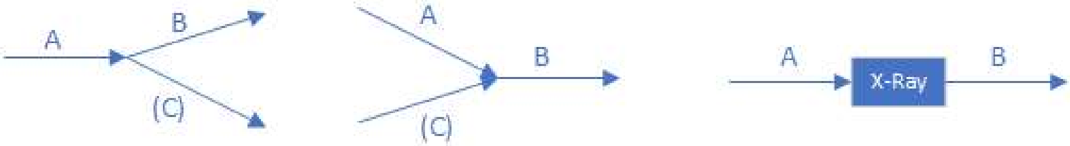



Figure 4.7: Representation of the important points for statistics purposes.

Converging or diverging spots before and after an X-Ray don't need for statistical points. The statistical points represented by (C) are optional, as A-B=C or B-A=C and so it can be mathematically calculated and there is no need to use it. In JTR departures there is no case of convergent spots, one divergent spot after the VSU and an X-Ray machine. The points chosen were:

- A - TRP01.BCV150, before the X-Ray machine
- B - SCR01.BCV060, after the X-Ray machine and before the VSU
- C - REJ01.BCV020, after the VSU for the rejected bags
- D - SOR01.BCV040, after the VSU for the accepted bags

The Tracking & Evaluation assists the operator in showing the current tracking performance. The ratio shown in the tracking performance percentage is color-coded, conveyors with tracking below 99% are presented in yellow, below 98% the color changes to red.

### Message Screen

In the event of a fire the command received by the fire alarm screen has priority over everything else. An indication pops up with the FIRE ALARM signal in the HMI (Figure 4.8) and stays visible as long as the signal remains active.


Figure 4.8: Fire Alarm screen.

## 4.2 Control Software Functions

### 4.2.1 PLC Program and Structure

The PLC is programmed in SIEMENS TIA Portal v14 software. It is structured in multiple files or blocks. The main program consists of a Main file to manage and organize additional files in the program structure, and a set of auxiliary files, they are common to all PLCs, providing information about communication tasks, switch on the procedure or failure handling.

Structured programming consists of within a PLC program an object of the same type exists only once. For example, for the different types of conveyors, there are special blocks that are programmed only once in the PLC. Each conveyor then calls the specific program. This method allows for, if any change is needed, to only be made once. This makes the changes much easier and reduces the level of risk.

There are different types of PLC program blocks and each has its specific logical function. The Organization Block (OB) is the interface of the PLC operating system, it is used for a structured call for user program logic functions. Functions (FC) are blocks without static data, there is the possibility of handing over parameters within the program. Function Blocks (FB) contain segments of the user program and can be provided with an accompanied memory area, there is also the possibility for handing over parameters within the program, suitable for programming often recurrent logic functions. Finally, Data Blocks are structured data files for a function block or structured global data files, valid in all the program.

Separate function blocks are used for self-contained control functions. The same functions can be repeated several times, using different parameters or variable values.

### 4.2.2 Control Functions

The PLC executes control tasks to each individual conveyor in a way that the baggage transport functions are according to the project specifications. Some of those functions are the automatic start and stop of conveyors, the power-saving function, e-stop handling, baggage tracking, failure management and malfunctions, and message management.

The automatic start functions start a line of conveyors, starting at the first one. The power-saving function allows a conveyor to be stopped if, during a certain amount of time no baggage is detected coming in or going out, it can be activated to each line. The emergency stops are triggered by buttons distributed along with the areas, the activation of any of these buttons immediately stops all conveyors on that area. The baggage tracking function identifies the position of the baggage in the tracking lines. Failure management service is enforced to protect baggage or conveyors against damage. The message management service gives information on the material flow to higher control levels.

### 4.2.3 Failure Handling

The PLC-Hardware failure monitoring is handled via OB. The OBs are the interface between the program and the PLC operating system and are responsible for the program initialization and time controlled operations. These OBs (Table 4.1) assure that events can be evaluated and necessary actions can be taken.

Table 4.1: Standard OBs.

| Standard OBs | Failures |
|---|---|
| OB20 - OB23 | Time-delay interrupts |
| OB30 - OB38 | Cyclic interrupts |
| OB40 - OB47 | Hardware interrupts |
| OB100 - OB102 | PLC Start up handling |
| OB121 - OB122 | Synchronous errors |

To prevent unnecessary cascading of fault messages, measures are taken to ensure that related fault messages are masked, in a way that only faults that have occurred are reported. The PLC cycle time does not exceed 50 milliseconds and allows an expansion of at least 25% [45].

## 4.3 PLC Functions

### 4.3.1 Check-In

The 17 Check-In counters have three segments (Figure 4.9). The first segment is a weighing conveyor and is also used to detect over length bags if both the initial and end photocell are obstructed at the same time. The second is the labeling conveyor. Lastly the third is the dispatch conveyor. This configuration allows the dispatch of baggage to the takeaway conveyor using the third conveyor while placing simultaneously another baggage on the weighing conveyor.

For the check-in to work the key switch needs to be in the open position. Switching off a check-in counter stops immediately all three check-in conveyors and cancels any dispatch request made. Switching the desk on again initiates the conveyors in a standstill and to run require the operator for input.

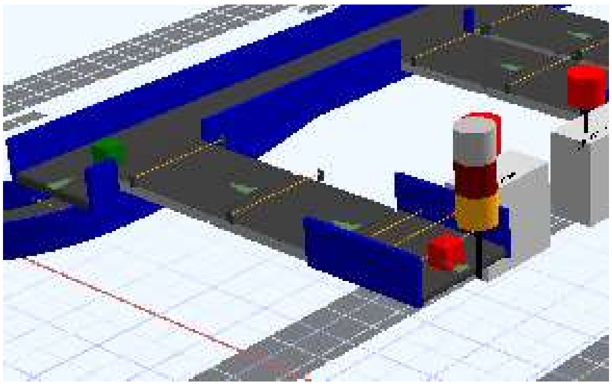


Figure 4.9: Check-In counter.

### 4.3.2 Takeaway Conveyors

After the check-in is successful, the PLC uses the Window Reservation Function to introduce baggage onto the takeaway conveyor. This function ensures that every check-in counter has an equal opportunity to induct baggage.

The next available space before the check-in counter that requested a window is reserved. When the reserved gap reaches the respective dispatch conveyor the bag is inducted into the assigned window onto the takeaway conveyor. If the window is missed the check-in automatically requests a new one. If three successive windows are lost by the same check-in an alarm is raised in the HMI.

The figure 4.10 shows the window reservation model. The windows are marked in blue and green. The forth check-in as requested a window for dispatching a bag. The next available window is reserved and, once the window reaches the check-in the bag is dispatched. The eighth check-in had previously requested a window. The window has arrived and the bag has been transferred to the takeaway conveyor.

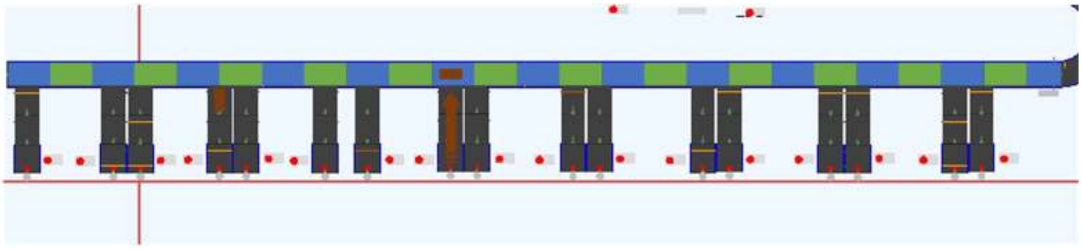


Figure 4.10: Takeaway Conveyor Reservation Model

### 4.3.3 Screening

Hold baggage screening contains 3 levels of security (Table 4.2).

Table 4.2: Hold baggage screening levels.

| Level | Type |
|---|---|
| 1 | Automatic X-Ray decision |
| 2 | Operator review of X-Ray image |
| 3 | Manual inspection |

Level 1 consists of an X-Ray machine (Figure 4.11) with explosive detection capability. This machine can make an automatic decision if the bag is rejected or cleared.

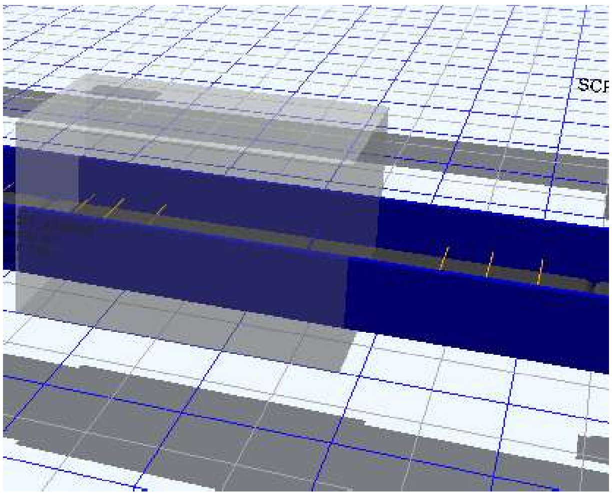


Figure 4.11: Level 1 - X-Ray machine.

Any baggage that is not cleared by the level 1 continues to level 2. Where a security officer views the image taken by the X-Ray machine (Figure 4.12). Based on these images the security officer decides if the bag is cleared.

Figure 4.12: Exemplification of an X-Ray machine image [46].

The decision point is the VSU and the travel time of the bag from the X-Ray machine to that point is at least 40 seconds allowing the operator to make a decision. When the bag reaches the decision point the last decision received is taken into consideration when rejecting or accepting the bag. The PLC makes a decision according to the table 4.3.

Table 4.3: PLC decision.

| Decision received | Decision |
|---|---|
| Clear | Accept |
| Unclear | Reject |
| Unknown | Reject |
| Time Out | Reject |
| Tracking lost | Reject |

If the bag is considered not clear it is diverted to the level 3 or Manual Inspection. The bag is still tracked until it reaches the operator. When the bag reaches that position a beacon turns on indicating the presence of a bag. A tag containing the bag-id is printed, the operator must place it in the bag and press the start button to transfer it to the roller table.

### 4.3.4 OOG Line

The OOG line starts with a control station (CS15M) and a light beacon (LB15M) these allow the operator to start or stop the pier conveyor. At the end of the line, mechanical protection is installed at the end of the roller table to prevent baggage from falling.

Both upstream and downstream conveyors run in the same direction as the X-Ray machine. The upstream conveyor only runs backward until the bag obstructs the initial photocell of the conveyor making the conveyor stop to prevent the bag from being transferred to the pier conveyor running forward.

### 4.3.5 Self-Test

The self-test is done automatically when the HMI's Start Installation button is pressed. It consists of starting all conveyors from the start-up to the carousel sequentially. When the start button is pressed a warning start-up alarm sounds and the first conveyor starts. After checking that the conveyor is running the PLC starts the next conveyor and onward, until the last one. When the last conveyor starts the system is ready to receive bags.

If for any reason one conveyor doesn't start the system stops the self-test and doesn't accept any baggage. After the maintenance personnel solves the problem a new self-test must be done.

This test is only needed if the stop button in the HMI is pressed if not the system is always ready to receive baggage.

### 4.3.6 Tracking

Baggage tracking synchronizes the physical transportation of a bag with its respective tracking data. To track, the PLC uses the initial and end photocells, as well as the encoder, which provides a clear indication of the belt movement. The tracking area is marked with green lines in figure 4.13.

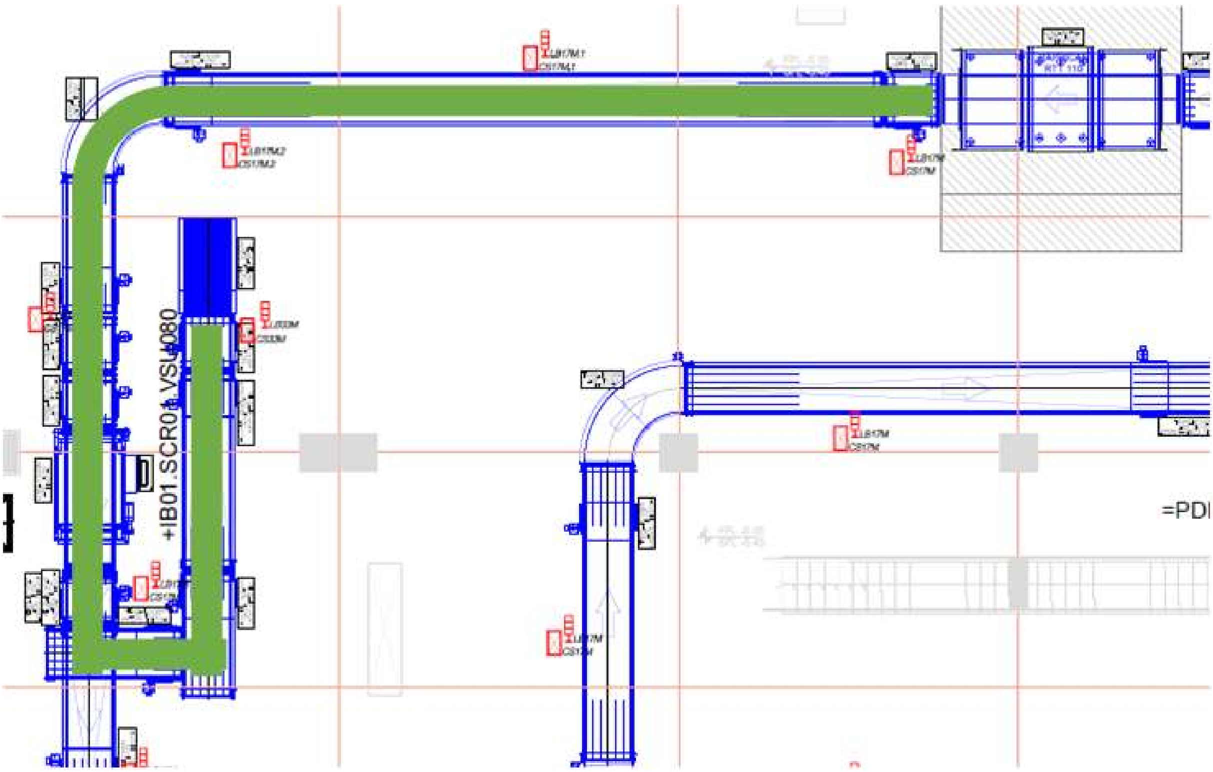



Figure 4.13: Tracking location.

The initial and end photocells inform the PLC when a bag enters and exits a specific section. The incremental encoder helps to ensure a high level of accuracy tracking with the monitoring of conveyor movement. An incremental encoder consists of a wheel in contact with the belt detecting movement. They are only installed in transport conveyors where tracking is required and with a length bigger than 1600mm. Each tracking section has a fixed number of impulses given by the encoder, corresponding to a fixed length. Tracking is valid if the bag enters and exits a conveyor while maintaining a total number of impulses within the tolerance level range programmed in the PLCs.

### 4.3.7 Bag Separation

Metering conveyors before X-Ray machines and other special devices, such as diverters, are used to ensure proper operation and a smooth baggage flow. These conveyors maintain a minimum bag gap with a bag control facility.

The bag gap control is programmed to stop the upstream conveyor if the present gap is inferior to the required. To restart the conveyor it is necessary to achieve the normal bag spacing again. The head end photocells in the conveyors, within the parts of the BHS where the separation of baggage is required, are used to ensure correct bag spacing. This distance parameter is adjustable in all conveying software modules.

The operation sequence can be seen in figure 4.14. When bag A interrupts the end photocell of conveyor C1 an internal timer is initiated. If, before the timer has elapsed, the end photocell in conveyor C1 is interrupted again the bag B is considered to close causing the conveyor C1 to stop. The internal timer continues, while the conveyor remains stopped, and when it has elapsed then the conveyor C1 restarts and proceeds normally.

### 4.3.8 Bag jam detection and reset

The PLC programming logic is prepared to detect the occurrence of bag jams. If the photocell on a conveyor is covered for more than a predefined period of time while that conveyor is running, the PLC generates a jam alarm. The predefined time is calculated with the speed of the conveyor and the maximum allowed length for bags. The conveyor that detected the jam is stopped immediately. The upstream conveyors do a cascade stop, that is the conveyors run until a bag covers their photocell.

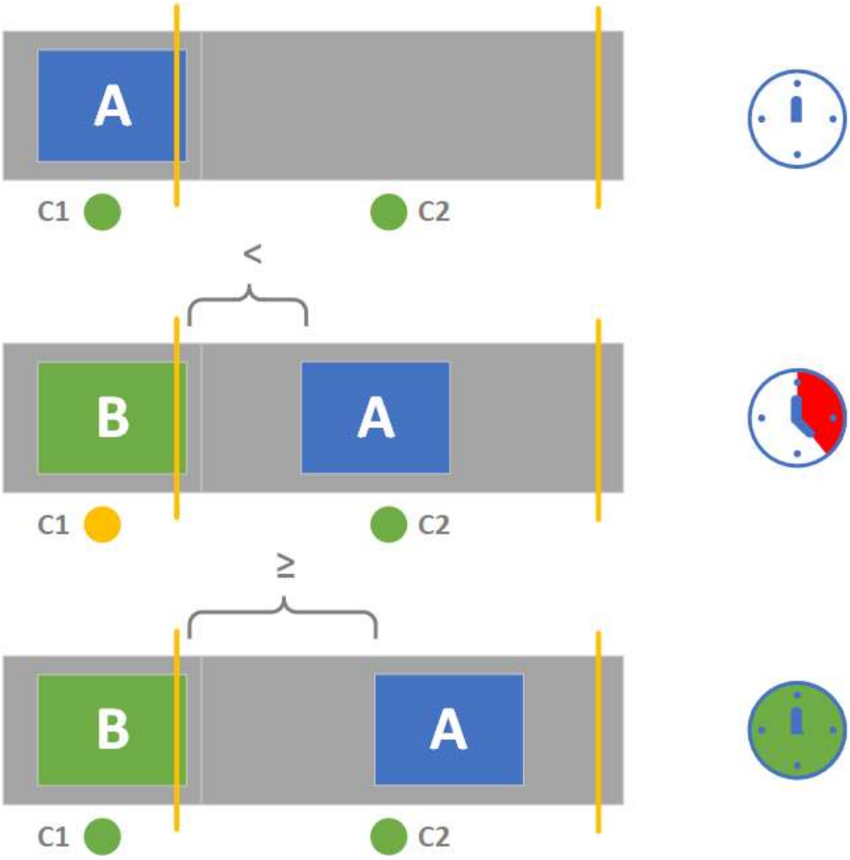



Figure 4.14: Bag separation operation sequence.

To clear and reset a jam it is necessary to follow a procedure. Firstly, switch off the affected conveyor motors. To clear the photocell manually take out the bags causing the jam. Then switch the motors back on. Then the reset can be completed in the HMI or by pressing the "Fault Reset" in the FDB panel. If this is successful the conveyors restart automatically.

## 4.4 Communication

### 4.4.1 Profinet

The communication between the PLC and the field devices is made via PROFINET PN. PROFINET PN also exchanges data with decentralized I/O stations, intelligent field devices, SIEMENS G110M, and SIMATIC Field PG programming units.

The field bus network is a modular structure and so it is easy to implement extensions. The network topology considers spare performance capacity at the field bus level.

### 4.4.2 Ethernet Lan Network

The data exchange is managed by the communication system Ethernet Lan Network. The Lan Network is used for data exchange from the PLC to the HMI. This link is established by a TCP/IP communication processor located in the rack of the PLC panel. Information exchanged includes, but it is not limited to:

- Power bus line availability and conveyor status messages
- Malfunctions due to failures
- E-Stop messages
- Motors and general power supply switch statuses
- Some PLC-hardware components status.
- Manual operations performed on certain conveyors
- Screening results from X-Ray machines
- Baggage tracking data interface

# Chapter 5

# Conclusions

The link between the various topics covered is Industry 4.0, and the way the industrial revolution based on the present digital age has allowed all that has been described. Sensors and actuators have enabled machines to connect to a PLC, among themselves and even the internet, to lessen the human intervention required in industrial processes. The decrease in human labor has also decreased security risks, errors, cost and process time. The present work aimed to use virtual reality software in a process controlled by a PLC, with the objective of being virtually commissioned. In parallel, it was possible to develop an HMI for the connection between users and the modeled system. Virtual commissioning tests allowed the PLC programmers to make the needed corrections more easily before they are problematic in a normal commissioning process, allowing for cost and time savings.

It can be concluded that this work successfully designed the departure bag handling system for the Santorini International Airport in the virtual reality software Emulate3D by Rockwell's. Based on a series of technical drawings with the information necessary a virtual replica of the real system was designed, respecting conveyor lengths, angles, speeds, and accelerations. All this information allowed for a rigorous virtual representation of the system in the study, which is important to achieve the full potential of this technology. The flow of a BHS is an extremely important aspect, and considering the number of different variables present in this system it is necessary to take all the information provided in consideration so that the digital twin has the same behavior as the real-life system.

The HMI constructed to accompany the system was really helpful it gave a new perspective of what is behind a real BHS and it allowed for a virtual commission closer to the real commission. Not only was it used as a tool to help with the process of virtual commissioning, but it was also commissioned at the same time. Using a touch screen was a lot more helpful, it reduced the peripherals needed to interact with the system and provided a more user-friendly interface for any operator that has to use it. The way that the BHS was divided into several pages has pros and cons, less information in each screen helps to keep them clean and easy to understand, on the other hand, this can lead to a more complicated and compartmentalized HMI where information can get lost between the different screens.

Using the virtual BHS model and a PLC control program written in TIA Portal it was possible to virtually commission the process. The virtual commission allowed the PLC and SCADA team to correct smaller problems in their code. Ultimately, those corrections will lead to a shorter real commission in the airport, each correction made in the VC is one less correction delaying the process of real commission and therefore delaying the turn over to the client.

## 5.1 Future Work

The next logical step to continue this work would be to complete the BHS by modeling the arrivals in Emulate3D. The arrivals are composed of a few conveyors and two claim carousels. After the system has been modeled it can be commissioned virtually with the PLC code, an HMI can also be constructed to house that part of the system.

The state of the art mentions immersion. However, during the length of this work, it was not possible to use it. Being able to be fully integrated into the virtual world provides different advantages that should be explored for future work. It gives a better perspective to every member involved in the process of designing even if they are not experts in CAD software. Adding walls and other infrastructures can help to include even more departments in the virtual commissioning, for example, the safety department as it can evaluate other parts in that focus.

The HMI can also be revised. The system can be divided in a different way keeping it with fewer pages so that the operator doesn't have to lose a lot more time looking for information, but also keeping each screen clean and concise. This is not a priority and can be made later on the timeline of a BHS project.

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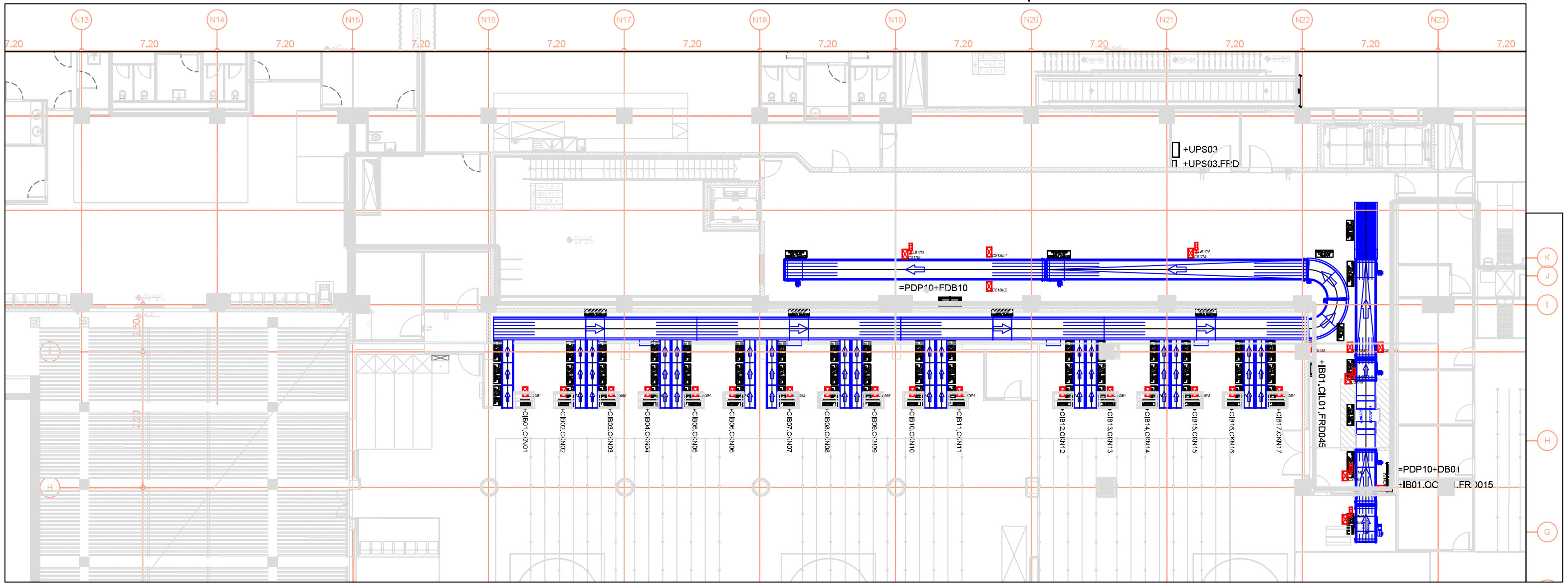
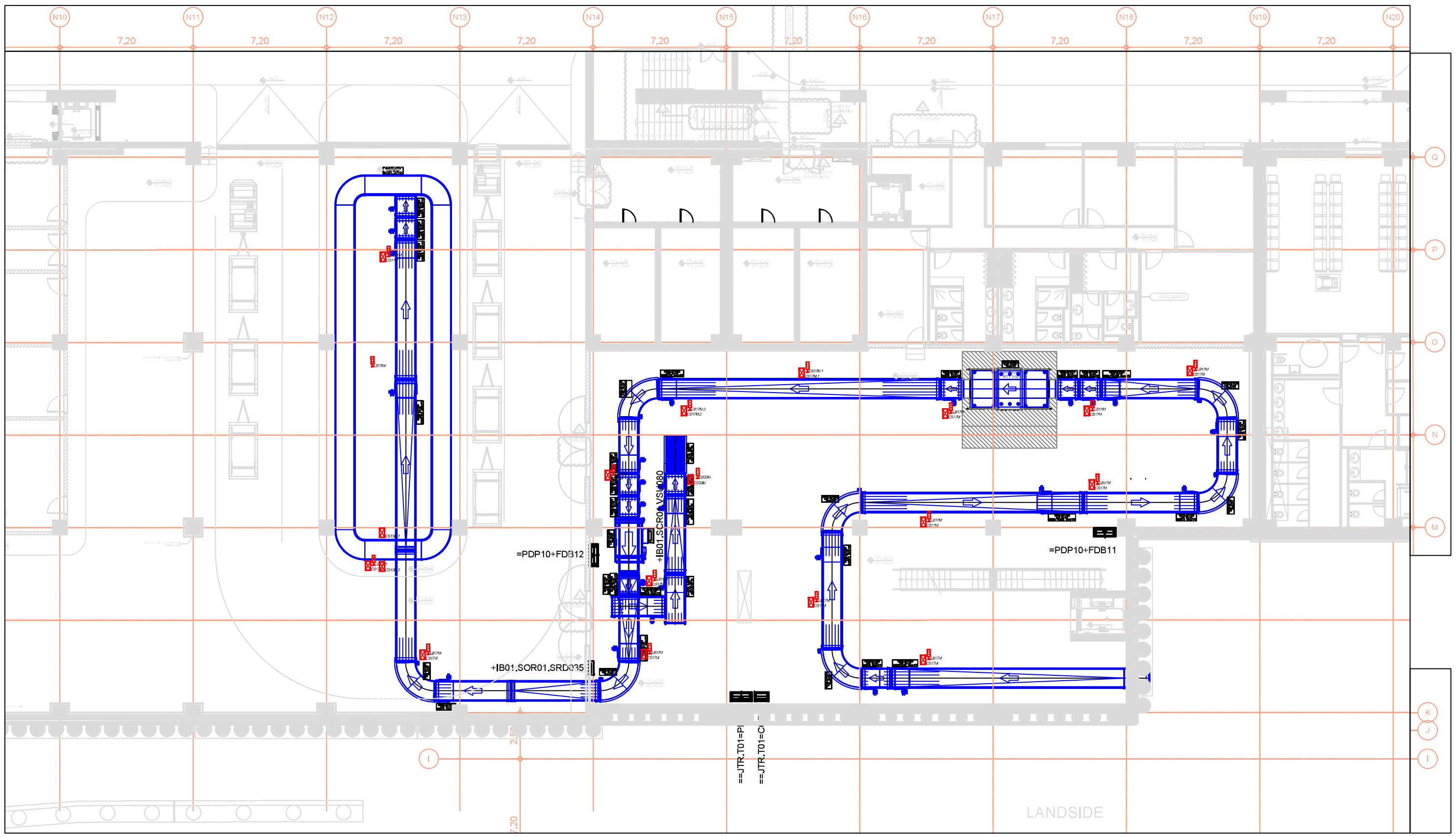
# Appendix A

# Mechanical Project

In this appendix the Mechanical Project for the Bag Handling System in the departures is presented.




Gen GND




Gen BAS

## SYMBOLOGY

- Fault Reset Light Beacon
- Fault Reset Control Station
- Departures Make-up Light Beacon
- Check-in Control Station
- Pier Conveyor Light Beacon
- Pier Conveyor Control Station
- Level 2 Light Beacon
- Level 2 Control Station
- Passage Way Control Station
- Fire Door Control Station

P60115-JTR-V074 0.0

# Appendix B

# Technical Datasheets

In this appendix the datasheet for the PLC and the HMI used in this project are presented.

## B.1 PLC Datasheet

SIEMENS

## Data sheet 6ES7516-3AN01-0AB0

SIMATIC S7-1500, CPU 1516-3 PN/DP, Central processing unit with Work memory 1 MB for program and 5 MB for data, 1st interface: PROFINET IRT with 2-port switch, 2nd interface: PROFINET RT, 3rd interface: PROFIBUS, 10 ns bit performance, SIMATIC Memory Card required

| General information | |
|---|---|
| Product type designation | CPU 1516-3 PN/DP |
| HW functional status | FS03 |
| Firmware version | V2.6 |
| Product function | |
| • I&M data | Yes; I&M0 to I&M3 |
| Engineering with | |
| • STEP 7 TIA Portal configurable/integrated as of version | V15.1 (FW V2.6)/V13 SP1 Update 4 (FW V1.8) or higher |
| **Configuration control** | |
| via dataset | Yes |
| **Display** | |
| Screen diagonal [cm] | 6.1 cm |
| **Control elements** | |
| Number of keys | 6 |
| Mode selector switch | 1 |
| **Supply voltage** | |

| | |
|---|---|
| Type of supply voltage | 24 V DC |
| permissible range, lower limit (DC) | 19.2 V |
| permissible range, upper limit (DC) | 28.8 V |
| Reverse polarity protection | Yes |
| Mains buffering | |
| • Mains/voltage failure stored energy time | 5 ms |
| • Repeat rate, min. | 1/s |
| **Input current** | |
| Current consumption (rated value) | 0.85 A |
| Inrush current, max. | 2.4 A; Rated value |
| $I^2t$ | 0.02 $A^2 \cdot s$ |
| **Power** | |
| Infeed power to the backplane bus | 12 W |
| Power consumption from the backplane bus (balanced) | 6.7 W |
| **Power loss** | |
| Power loss, typ. | 7 W |
| **Memory** | |
| Number of slots for SIMATIC memory card | 1 |
| SIMATIC memory card required | Yes |
| Work memory | |
| • integrated (for program) | 1 Mbyte |
| • integrated (for data) | 5 Mbyte |
| Load memory | |
| • Plug-in (SIMATIC Memory Card), max. | 32 Gbyte |
| Backup | |
| • maintenance-free | Yes |
| **CPU processing times** | |
| for bit operations, typ. | 10 ns |
| for word operations, typ. | 12 ns |
| for fixed point arithmetic, typ. | 16 ns |
| for floating point arithmetic, typ. | 64 ns |
| **CPU-blocks** | |
| Number of elements (total) | 8 000; Blocks (OB, FB, FC, DB) and UDTs |
| DB | |
| • Number range | 1 ... 60 999; subdivided into: number range that can be used by the user: 1 ... 59 999, and number range of DBs created via SFC 86: 60 000 ... 60 999 |
| • Size, max. | 5 Mbyte; For DBs with absolute addressing, the max. size is 64 KB |
| FB | |

| | |
|---|---|
| • Number range | 0 ... 65 535 |
| • Size, max. | 1 Mbyte |
| FC | |
| • Number range | 0 ... 65 535 |
| • Size, max. | 1 Mbyte |
| OB | |
| • Size, max. | 1 Mbyte |
| • Number of free cycle OBs | 100 |
| • Number of time alarm OBs | 20 |
| • Number of delay alarm OBs | 20 |
| • Number of cyclic interrupt OBs | 20; With minimum OB 3x cycle of 250 µs |
| • Number of process alarm OBs | 50 |
| • Number of DPV1 alarm OBs | 3 |
| • Number of isochronous mode OBs | 3 |
| • Number of technology synchronous alarm OBs | 2 |
| • Number of startup OBs | 100 |
| • Number of asynchronous error OBs | 4 |
| • Number of synchronous error OBs | 2 |
| • Number of diagnostic alarm OBs | 1 |
| Nesting depth | |
| • per priority class | 24 |

## Counters, timers and their retentivity

| | |
|---|---|
| S7 counter | |
| • Number | 2 048 |
| Retentivity | |
| — adjustable | Yes |
| IEC counter | |
| • Number | Any (only limited by the main memory) |
| Retentivity | |
| — adjustable | Yes |
| S7 times | |
| • Number | 2 048 |
| Retentivity | |
| — adjustable | Yes |
| IEC timer | |
| • Number | Any (only limited by the main memory) |
| Retentivity | |
| — adjustable | Yes |

## Data areas and their retentivity

| | |
|---|---|
| Retentive data area (incl. timers, counters, flags), max. | 512 kbyte; In total; available retentive memory for bit memories, timers, counters, DBs, and technology data (axes): 472 KB |

| | |
|---|---|
| Extended retentive data area (incl. timers, counters, flags), max. | 5 Mbyte; When using PS 6 0W 24/48/60 V DC HF |
| Flag | |
| • Number, max. | 16 kbyte |
| • Number of clock memories | 8; 8 clock memory bit, grouped into one clock memory byte |
| Data blocks | |
| • Retentivity adjustable | Yes |
| • Retentivity preset | No |
| Local data | |
| • per priority class, max. | 64 kbyte; max. 16 KB per block |

| Address area | |
|---|---|
| Number of IO modules | 8 192; max. number of modules / submodules |
| I/O address area | |
| • Inputs | 32 kbyte; All inputs are in the process image |
| • Outputs | 32 kbyte; All outputs are in the process image |
| per integrated IO subsystem | |
| — Inputs (volume) | 8 kbyte |
| — Outputs (volume) | 8 kbyte |
| per CM/CP | |
| — Inputs (volume) | 8 kbyte |
| — Outputs (volume) | 8 kbyte |
| Subprocess images | |
| • Number of subprocess images, max. | 32 |

| Hardware configuration | |
|---|---|
| Number of distributed IO systems | 64; A distributed I/O system is characterized not only by the integration of distributed I/O via PROFINET or PROFIBUS communication modules, but also by the connection of I/O via AS-i master modules or links (e.g. IE/PB-Link) |
| Number of DP masters | |
| • integrated | 1 |
| • Via CM | 8; A maximum of 8 CMs/CPs (PROFIBUS, PROFINET, Ethernet) can be inserted in total |
| Number of IO Controllers | |
| • integrated | 2 |
| • Via CM | 8; A maximum of 8 CMs/CPs (PROFIBUS, PROFINET, Ethernet) can be inserted in total |
| Rack | |
| • Modules per rack, max. | 32; CPU + 31 modules |
| • Number of lines, max. | 1 |
| PtP CM | |
| • Number of PtP CMs | the number of connectable PtP CMs is only limited by the number of available slots |

| Time of day | |
|---|---|
| **Clock** | |
| • Type | Hardware clock |
| • Backup time | 6 wk; At 40 °C ambient temperature, typically |
| • Deviation per day, max. | 10 s; Typ.: 2 s |
| **Operating hours counter** | |
| • Number | 16 |
| **Clock synchronization** | |
| • supported | Yes |
| • to DP, master | Yes |
| • in AS, master | Yes |
| • in AS, slave | Yes |
| • on Ethernet via NTP | Yes |

| Interfaces | |
|---|---|
| Number of PROFINET interfaces | 2 |
| Number of PROFIBUS interfaces | 1 |

| 1. Interface | |
|---|---|
| **Interface types** | |
| • Number of ports | 2 |
| • integrated switch | Yes |
| • RJ 45 (Ethernet) | Yes; X1 |
| **Protocols** | |
| • IP protocol | Yes; IPv4 |
| • PROFINET IO Controller | Yes |
| • PROFINET IO Device | Yes |
| • SIMATIC communication | Yes |
| • Open IE communication | Yes |
| • Web server | Yes |
| • Media redundancy | Yes; MRP Automanager according to IEC 62439-2 Edition 2.0 |
| **PROFINET IO Controller** | |
| Services | |
| — PG/OP communication | Yes |
| — S7 routing | Yes |
| — Isochronous mode | Yes |
| — Open IE communication | Yes |
| — IRT | Yes |
| — MRP | Yes; as MRP redundancy manager and/or MRP client; max. number of devices in the ring: 50 |
| — MRPD | Yes; Requirement: IRT |
| — PROFIenergy | Yes |
| — Prioritized startup | Yes; Max. 32 PROFINET devices |

| | |
|---|---|
| — Number of connectable IO Devices, max. | 256; In total, up to 1 000 distributed I/O devices can be connected via AS-i, PROFIBUS or PROFINET |
| — Of which IO devices with IRT, max. | 64 |
| — Number of connectable IO Devices for RT, max. | 256 |
| — of which in line, max. | 256 |
| — Number of IO Devices that can be simultaneously activated/deactivated, max. | 8; in total across all interfaces |
| — Number of IO Devices per tool, max. | 8 |
| — Updating times | The minimum value of the update time also depends on communication share set for PROFINET IO, on the number of IO devices, and on the quantity of configured user data |
| Update time for IRT | |
| — for send cycle of 250 µs | 250 µs to 4 ms; Note: In the case of IRT with isochronous mode, the minimum update time of 375 µs of the isochronous OB is decisive |
| — for send cycle of 500 µs | 500 µs to 8 ms |
| — for send cycle of 1 ms | 1 ms to 16 ms |
| — for send cycle of 2 ms | 2 ms to 32 ms |
| — for send cycle of 4 ms | 4 ms to 64 ms |
| — With IRT and parameterization of "odd" send cycles | Update time = set "odd" send clock (any multiple of 125 µs: 375 µs, 625 µs ... 3 875 µs) |
| Update time for RT | |
| — for send cycle of 250 µs | 250 µs to 128 ms |
| — for send cycle of 500 µs | 500 µs to 256 ms |
| — for send cycle of 1 ms | 1 ms to 512 ms |
| — for send cycle of 2 ms | 2 ms to 512 ms |
| — for send cycle of 4 ms | 4 ms to 512 ms |
| PROFINET IO Device | |
| Services | |
| — PG/OP communication | Yes |
| — S7 routing | Yes |
| — Isochronous mode | No |
| — Open IE communication | Yes |
| — IRT | Yes |
| — MRP | Yes; as MRP redundancy manager and/or MRP client; max. number of devices in the ring: 50 |
| — MRPD | Yes; Requirement: IRT |
| — PROFIenergy | Yes; per user program |
| — Shared device | Yes |
| — Number of IO Controllers with shared device, max. | 4 |
| — Asset management record | Yes; per user program |

| 2. Interface | |
| --- | --- |
| Interface types | |
| • Number of ports | 1 |
| • integrated switch | No |
| • RJ 45 (Ethernet) | Yes; X2 |
| Protocols | |
| • IP protocol | Yes; IPv4 |
| • PROFINET IO Controller | Yes |
| • PROFINET IO Device | Yes |
| • SIMATIC communication | Yes |
| • Open IE communication | Yes |
| • Web server | Yes |
| • Media redundancy | No |
| PROFINET IO Controller | |
| Services | |
| — PG/OP communication | Yes |
| — S7 routing | Yes |
| — Isochronous mode | No |
| — Open IE communication | Yes |
| — IRT | No |
| — MRP | No |
| — MRPD | No |
| — PROFIenergy | Yes |
| — Prioritized startup | No |
| — Number of connectable IO Devices, max. | 32; In total, up to 1 000 distributed I/O devices can be connected via AS-i, PROFIBUS or PROFINET |
| — Number of connectable IO Devices for RT, max. | 32 |
| — of which in line, max. | 32 |
| — Number of IO Devices that can be simultaneously activated/deactivated, max. | 8; in total across all interfaces |
| — Number of IO Devices per tool, max. | 8 |
| — Updating times | The minimum value of the update time also depends on communication share set for PROFINET IO, on the number of IO devices, and on the quantity of configured user data |
| Update time for RT | |
| — for send cycle of 1 ms | 1 ms to 512 ms |
| PROFINET IO Device | |
| Services | |
| — PG/OP communication | Yes |
| — S7 routing | Yes |
| — Isochronous mode | No |

| | |
|---|---|
| — Open IE communication | Yes |
| — IRT | No |
| — MRP | No |
| — MRPD | No |
| — PROFIenergy | Yes; per user program |
| — Prioritized startup | No |
| — Shared device | Yes |
| — Number of IO Controllers with shared device, max. | 4 |
| — Asset management record | Yes; per user program |

## 3. Interface

| | |
|---|---|
| **Interface types** | |
| • Number of ports | 1 |
| • RS 485 | Yes; X3 |
| **Protocols** | |
| • PROFIBUS DP master | Yes |
| • PROFIBUS DP slave | No |
| • SIMATIC communication | Yes |

## Interface types

| | |
|---|---|
| **RJ 45 (Ethernet)** | |
| • 100 Mbps | Yes |
| • Autonegotiation | Yes |
| • Autocrossing | Yes |
| • Industrial Ethernet status LED | Yes |
| **RS 485** | |
| • Transmission rate, max. | 12 Mbit/s |

## Protocols

| | |
|---|---|
| **Number of connections** | |
| • Number of connections, max. | 256; via integrated interfaces of the CPU and connected CPs / CMs |
| • Number of connections reserved for ES/HMI/web | 10 |
| • Number of connections via integrated interfaces | 128 |
| • Number of S7 routing paths | 16 |
| **Redundancy mode** | |
| • H-Sync forwarding | Yes |
| **SIMATIC communication** | |
| • S7 communication, as server | Yes |
| • S7 communication, as client | Yes |
| • User data per job, max. | See online help (S7 communication, user data size) |

| | |
|---|---|
| Open IE communication | |
| • TCP/IP | Yes |
| — Data length, max. | 64 kbyte |
| — several passive connections per port, supported | Yes |
| • ISO-on-TCP (RFC1006) | Yes |
| — Data length, max. | 64 kbyte |
| • UDP | Yes |
| — Data length, max. | 2 kbyte; 1 472 bytes for UDP broadcast |
| — UDP multicast | Yes; Max. 5 multicast circuits |
| • DHCP | No |
| • SNMP | Yes |
| • DCP | Yes |
| • LLDP | Yes |
| Web server | |
| • HTTP | Yes; Standard and user pages |
| • HTTPS | Yes; Standard and user pages |
| PROFIBUS DP master | |
| • Number of connections, max. | 48; for the integrated PROFIBUS DP interface |
| Services | |
| — PG/OP communication | Yes |
| — S7 routing | Yes |
| — Data record routing | Yes |
| — Isochronous mode | Yes |
| — Equidistance | Yes |
| — Number of DP slaves | 125; In total, up to 1 000 distributed I/O devices can be connected via AS-i, PROFIBUS or PROFINET |
| — Activation/deactivation of DP slaves | Yes |
| OPC UA | |
| • Runtime license required | Yes |
| • OPC UA client | Yes |
| — Application authentication | Yes |
| — Security policies | Available security policies: None, Basic128Rsa15, Basic256Rsa15, Basic256Sha256 |
| — User authentication | "anonymous" or by user name & password |
| — Number of connections, max. | 10 |
| — Number of nodes of the client interfaces, max. | 2 000 |
| — Number of elements for one call of OPC_UA_NodeGetHandleList/OPC_UA_ReadList/OPC_UA_WriteList, max. | 300 |
| — Number of elements for one call of OPC_UA_NameSpaceGetIndexList, max. | 20 |

| | |
|---|---|
| — Number of elements for one call of OPC_UA_MethodGetHandleList, max. | 100 |
| — Number of simultaneous calls of the client instructions per connection (except OPC_UA_ReadList,OPC_UA_WriteList,OPC_UA_MethodCall), max. | 1 |
| — Number of simultaneous calls of the client instructions OPC_UA_ReadList,OPC_UA_WriteList and OPC_UA_MethodCall, max. | 5 |
| — Number of registerable nodes, max. | 5 000 |
| — Number of registerable method calls of OPC_UA_MethodCall, max. | 100 |
| — Number of inputs/outputs when calling OPC_UA_MethodCall, max. | 20 |
| • OPC UA server | Yes; Data access (read, write, subscribe), method call, custom address space |
| — Application authentication | Yes |
| — Security policies | Available security policies: None, Basic128Rsa15, Basic256Rsa15, Basic256Sha256 |
| — User authentication | "anonymous" or by user name & password |
| — Number of sessions, max. | 48 |
| — Number of accessible variables, max. | 100 000 |
| — Number of registerable nodes, max. | 20 000 |
| — Number of subscriptions per session, max. | 20 |
| — Sampling interval, min. | 100 ms |
| — Publishing interval, min. | 200 ms |
| — Number of server methods, max. | 50 |
| — Number of inputs/outputs per server method, max. | 20 |
| — Number of monitored items, max. | 2 000; for 1 s sampling interval and 1 s send interval |
| — Number of server interfaces, max. | 10 |
| — Number of nodes for user-defined server interfaces, max. | 5 000 |
| **Further protocols** | |
| • MODBUS | Yes; MODBUS TCP |
| **Media redundancy** | |
| • Switchover time on line break, typ. | 200 ms; For MRP, bumpless for MRPD |
| • Number of stations in the ring, max. | 50 |

## Isochronous mode

| | |
|---|---|
| Isochronous operation (application synchronized up to terminal) | Yes; Distributed and central; with minimum OB 6x cycle of 375 µs (distributed) and 1 ms (central) |
| Equidistance | Yes |

| S7 message functions | |
|---|---|
| Number of login stations for message functions, max. | 32 |
| Program alarms | Yes |
| Number of configurable program messages, max. | 10 000; Program messages are generated by the "Program_Alarm" block, ProDiag or GRAPH |
| Number of loadable program messages in RUN, max. | 5 000 |
| Number of simultaneously active program alarms | |
| • Number of program alarms | 600 |
| • Number of alarms for system diagnostics | 200 |
| • Number of alarms for motion technology objects | 160 |

| Test commissioning functions | |
|---|---|
| Joint commission (Team Engineering) | Yes; Parallel online access possible for up to 8 engineering systems |
| Status block | Yes; Up to 8 simultaneously (in total across all ES clients) |
| Single step | No |
| Number of breakpoints | 8 |
| Status/control | |
| • Status/control variable | Yes |
| • Variables | Inputs/outputs, memory bits, DBs, distributed I/Os, timers, counters |
| • Number of variables, max. | |
| — of which status variables, max. | 200; per job |
| — of which control variables, max. | 200; per job |
| Forcing | |
| • Forcing, variables | Peripheral inputs/outputs |
| • Number of variables, max. | 200 |
| Diagnostic buffer | |
| • present | Yes |
| • Number of entries, max. | 3 200 |
| — of which powerfail-proof | 500 |
| Traces | |
| • Number of configurable Traces | 4; Up to 512 KB of data per trace are possible |

| Interrupts/diagnostics/status information | |
|---|---|
| Diagnostics indication LED | |
| • RUN/STOP LED | Yes |
| • ERROR LED | Yes |
| • MAINT LED | Yes |
| • Connection display LINK TX/RX | Yes |

| Supported technology objects |
|---|

| | |
|---|---|
| Motion Control | Yes; Note: The number of axes affects the cycle time of the PLC program; selection guide via the TIA Selection Tool or SIZER |
| • Number of available Motion Control resources for technology objects (except cam disks) | 2 400 |
| • Required Motion Control resources | |
| — per speed-controlled axis | 40 |
| — per positioning axis | 80 |
| — per synchronous axis | 160 |
| — per external encoder | 80 |
| — per output cam | 20 |
| — per cam track | 160 |
| — per probe | 40 |
| • Positioning axis | |
| — Number of positioning axes at motion control cycle of 4 ms (typical value) | 7 |
| — Number of positioning axes at motion control cycle of 8 ms (typical value) | 14 |
| Controller | |
| • PID_Compact | Yes; Universal PID controller with integrated optimization |
| • PID_3Step | Yes; PID controller with integrated optimization for valves |
| • PID-Temp | Yes; PID controller with integrated optimization for temperature |
| Counting and measuring | |
| • High-speed counter | Yes |

## Ambient conditions

| | |
|---|---|
| Ambient temperature during operation | |
| • horizontal installation, min. | 0 °C |
| • horizontal installation, max. | 60 °C; Display: 50 °C, at an operating temperature of typically 50 °C, the display is switched off |
| • vertical installation, min. | 0 °C |
| • vertical installation, max. | 40 °C; Display: 40 °C, at an operating temperature of typically 40 °C, the display is switched off |
| Ambient temperature during storage/transportation | |
| • min. | -40 °C |
| • max. | 70 °C |
| Altitude during operation relating to sea level | |
| • Installation altitude above sea level, max. | 5 000 m; Restrictions for installation altitudes > 2 000 m, see manual |

## Configuration

| | |
|---|---|
| Programming | |
| Programming language | |
| — LAD | Yes |
| — FBD | Yes |

| | |
|---|---|
| — STL | Yes |
| — SCL | Yes |
| — GRAPH | Yes |
| Know-how protection | |
| • User program protection/password protection | Yes |
| • Copy protection | Yes |
| • Block protection | Yes |
| Access protection | |
| • Password for display | Yes |
| • Protection level: Write protection | Yes |
| • Protection level: Read/write protection | Yes |
| • Protection level: Complete protection | Yes |
| Cycle time monitoring | |
| • lower limit | adjustable minimum cycle time |
| • upper limit | adjustable maximum cycle time |

| Dimensions | |
|---|---|
| Width | 70 mm |
| Height | 147 mm |
| Depth | 129 mm |

| Weights | |
|---|---|
| Weight, approx. | 845 g |

**last modified:** 08/03/2019

## B.2 HMI Datasheet

SIEMENS

## Data sheet 6AV2124-0MC01-0AX0

SIMATIC HMI TP1200 Comfort, Comfort Panel, Touch operation, 12" widescreen TFT display, 16 million colors, PROFINET interface, MPI/PROFIBUS DP interface, 12 MB configuration memory, Windows CE 6.0 (Microsoft Support included Security updates discontinued) configurable from WinCC Comfort V11


| General information | |
|---|---|
| Product type designation | TP1200 Comfort |

| Display | |
|---|---|
| Design of display | TFT |
| Screen diagonal | 12.1 in |
| Display width | 261.1 mm |
| Display height | 163.2 mm |
| Number of colors | 16 777 216 |
| Resolution (pixels) | |
| • Horizontal image resolution | 1 280 Pixel |
| • Vertical image resolution | 800 Pixel |
| Backlighting | |
| • MTBF backlighting (at 25 °C) | 80 000 h |
| • Backlight dimmable | Yes; 0-100 % |

| Control elements | |
|---|---|
| Keyboard fonts | |
| • Function keys | |
| — Number of function keys | 0 |

| | |
|---|---|
| — Number of function keys with LEDs | 0 |
| • Keys with LED | No |
| • System keys | No |
| • Numeric keyboard | Yes; Onscreen keyboard |
| • alphanumeric keyboard | Yes; Onscreen keyboard |
| Touch operation | |
| • Design as touch screen | Yes |
| Expansions for operator control of the process | |
| • DP direct LEDs (LEDs as S7 output I/O) | |
| — F1...Fx | 0 |
| • Direct keys (keys as S7 input I/O) | |
| — F1...Fx | 0 |
| • Direct keys (touch buttons as S7 input I/O) | 40 |

| Installation type/mounting | |
|---|---|
| Mounting position | vertical |
| Mounting in portrait format possible | Yes |
| Mounting in landscape format possible | Yes |
| maximum permissible angle of inclination without external ventilation | 35° |

| Supply voltage | |
|---|---|
| Type of supply voltage | DC |
| Rated value (DC) | 24 V |
| permissible range, lower limit (DC) | 19.2 V |
| permissible range, upper limit (DC) | 28.8 V |

| Input current | |
|---|---|
| Current consumption (rated value) | 0.85 A |
| Starting current inrush $I^2t$ | 0.5 $A^2 \cdot s$ |

| Power | |
|---|---|
| Active power input, typ. | 20 W |

| Processor | |
|---|---|
| Processor type | X86 |

| Memory | |
|---|---|
| Flash | Yes |
| RAM | Yes |
| Memory available for user data | 12 Mbyte |

| Type of output | |
|---|---|
| Info LED | No |
| Power LED | No |
| Error LED | No |
| Acoustics | |

| | |
|---|---|
| • Buzzer | No |
| • Speaker | Yes |
| **Time of day** | |
| Clock | |
| • Hardware clock (real-time) | Yes |
| • Software clock | Yes |
| • retentive | Yes; Back-up duration typically 6 weeks |
| • synchronizable | Yes |
| **Interfaces** | |
| Number of industrial Ethernet interfaces | 1; 2 ports (switch) |
| Number of RS 485 interfaces | 1; RS 422 / 485 combined |
| Number of RS 422 interfaces | 0; together with RS 485 |
| Number of RS 232 interfaces | 0 |
| Number of USB interfaces | 2; USB 2.0 |
| • USB Mini B | 1; 5-pole |
| Number of 20 mA interfaces (TTY) | 0 |
| Number of parallel interfaces | 0 |
| Number of other interfaces | 0 |
| Number of SD card slots | 2 |
| With software interfaces | No |
| Industrial Ethernet | |
| • Industrial Ethernet status LED | 2 |
| • Number of ports of the integrated switch | 2 |
| **Protocols** | |
| PROFINET | Yes |
| Supports protocol for PROFINET IO | Yes |
| IRT | Yes; As of WinCC V12 |
| PROFIBUS | Yes |
| MPI | Yes |
| Protocols (Ethernet) | |
| • TCP/IP | Yes |
| • DHCP | Yes |
| • SNMP | Yes |
| • DCP | Yes |
| • LLDP | Yes |
| WEB characteristics | |
| • HTTP | Yes |
| • HTTPS | Yes |
| • HTML | Yes |
| • XML | Yes |
| • CSS | Yes |

| | |
|---|---|
| • Active X | Yes |
| • JavaScript | Yes |
| • Java VM | No |
| Redundancy mode | |
| • MRP | Yes; As of WinCC V12 |
| Further protocols | |
| • CAN | No |
| • EtherNet/IP | Yes |
| • MODBUS | Yes |

| EMC | |
|---|---|
| Emission of radio interference acc. to EN 55 011 | |
| • Limit class A, for use in industrial areas | Yes |
| • Limit class B, for use in residential areas | No |

| Degree and class of protection | |
|---|---|
| IP (at the front) | IP65 |
| Enclosure Type 4 at the front | Yes |
| Enclosure Type 4x at the front | Yes |
| IP (rear) | IP20 |

| Standards, approvals, certificates | |
|---|---|
| CE mark | Yes |
| cULus | Yes |
| RCM (formerly C-TICK) | Yes |
| KC approval | Yes |
| Use in hazardous areas | |
| • ATEX Zone 2 | Yes |
| • ATEX Zone 22 | Yes |
| • IECEx Zone 2 | Yes |
| • IECEx Zone 22 | Yes |
| • cULus Class I Zone 1 | No |
| • cULus Class I Zone 2, Division 2 | Yes |
| • FM Class I Division 2 | Yes |
| Marine approval | |
| • Germanischer Lloyd (GL) | Yes; As of product version: 10 |
| • American Bureau of Shipping (ABS) | Yes; As of product version: 10 |
| • Bureau Veritas (BV) | Yes; As of product version: 10 |
| • Det Norske Veritas (DNV) | Yes; As of product version: 10 |
| • Lloyds Register of Shipping (LRS) | Yes; As of product version: 10 |
| • Nippon Kaiji Kyokai (Class NK) | Yes; As of product version: 10 |
| • Polski Rejestr Statkow (PRS) | No |

| Ambient conditions |
|---|

| | |
|---|---|
| Ambient temperature during operation | |
| • Operation (vertical installation) | |
| — For vertical installation, min. | 0 °C |
| — For vertical installation, max. | 50 °C; (55 °C, see entry ID: 64847814) |
| • Operation (max. tilt angle) | |
| — At maximum tilt angle, min. | 0 °C |
| — At maximum tilt angle, min. | 40 °C |
| • Operation (vertical installation, portrait format) | |
| — For vertical installation, min. | 0 °C |
| — For vertical installation, max. | 40 °C |
| • Operation (max. tilt angle, portrait format) | |
| — At maximum tilt angle, min. | 0 °C |
| — At maximum tilt angle, min. | 35 °C |
| Ambient temperature during storage/transportation | |
| • min. | -20 °C |
| • max. | 60 °C |
| Relative humidity | |
| • Operation, max. | 90 %; no condensation |

## Operating systems

| | |
|---|---|
| proprietary | No |
| pre-installed operating system | |
| • Windows CE | Yes |

## Configuration

| | |
|---|---|
| Message indicator | Yes |
| Alarm system (incl. buffer and acknowledgment) | Yes |
| Process value display (output) | Yes |
| Process value default (input) possible | Yes |
| Recipe management | Yes |
| Configuration software | |
| • STEP 7 Basic (TIA Portal) | No |
| • STEP 7 Professional (TIA Portal) | No |
| • WinCC flexible Compact | No |
| • WinCC flexible Standard | No |
| • WinCC flexible Advanced | No |
| • WinCC Basic (TIA Portal) | No |
| • WinCC Comfort (TIA Portal) | Yes; from V11 |
| • WinCC Advanced (TIA Portal) | Yes; from V11 |
| • WinCC Professional (TIA Portal) | Yes; from V11 |

## Languages

| | |
|---|---|
| Online languages | |
| • Number of online/runtime languages | 32 |

| | |
|---|---|
| **Project languages** | |
| • Languages per project | 32 |
| **Functionality under WinCC (TIA Portal)** | |
| Libraries | Yes |
| Applications/options | |
| • Web browser | Yes |
| • Pocket Word | Yes |
| • Pocket Excel | Yes |
| • PDF Viewer | Yes |
| • Media Player | Yes |
| • SIMATIC WinCC Sm@rtServer | Yes |
| • SIMATIC WinCC Audit | Yes |
| Number of Visual Basic Scripts | Yes |
| Task planner | |
| • time-controlled | Yes |
| • task-controlled | Yes |
| Help system | |
| • Number of characters per info text | 70 |
| **Message system** | |
| • Number of alarm classes | 32 |
| • Bit messages | |
| — Number of bit messages | 4 000 |
| • Analog messages | |
| — Number of analog messages | 200 |
| • S7 alarm number procedure | Yes |
| • System messages HMI | Yes |
| • System messages, other (SIMATIC S7, Sinumerik, Simotion, etc.) | Yes |
| • Number of characters per message | 80 |
| • Number of process values per message | 8 |
| • Acknowledgment groups | Yes |
| • Message indicator | Yes |
| • Message buffer | |
| — Number of entries | 1 024 |
| — Circulating buffer | Yes |
| — retentive | Yes |
| — maintenance-free | Yes |
| **Recipe management** | |
| • Number of recipes | 300 |
| • Data records per recipe | 500 |
| • Entries per data record | 1 000 |

| | |
|---|---|
| • Size of internal recipe memory | 2 Mbyte |
| • Recipe memory expandable | Yes |
| **Variables** | |
| • Number of variables per device | 2 048 |
| • Number of variables per screen | 400 |
| • Limit values | Yes |
| • Multiplexing | Yes |
| • Structures | Yes |
| • Arrays | Yes |
| **Images** | |
| • Number of configurable images | 500 |
| • Permanent window/default | Yes |
| • Global image | Yes |
| • Pop-up images | Yes |
| • Slide-in images | Yes |
| • Image selection by PLC | Yes |
| • Image number in the PLC | Yes |
| **Image objects** | |
| • Number of objects per image | 400 |
| • Text fields | Yes |
| • I/O fields | Yes |
| • Graphic I/O fields (graphics list) | Yes |
| • Symbolic I/O fields (text list) | Yes |
| • Date/time fields | Yes |
| • Switches | Yes |
| • Buttons | Yes |
| • Graphic display | Yes |
| • Icons | Yes |
| • Geometric objects | Yes |
| **Complex image objects** | |
| • Number of complex objects per screen | 20 |
| • Alarm view | Yes |
| • Trend view | Yes |
| • User view | Yes |
| • Status/control | Yes |
| • Sm@rtClient view | Yes |
| • Recipe view | Yes |
| • f(x) trend view | Yes |
| • System diagnostics view | Yes |
| • Media Player | Yes |
| • HTML browser | Yes |

| | |
|---|---|
| • PDF display | Yes |
| • IP camera display | Yes |
| • Bar graphs | Yes |
| • Sliders | Yes |
| • Pointer instruments | Yes |
| • Analog/digital clock | Yes |
| **Lists** | |
| • Number of text lists per project | 500 |
| • Number of entries per text list | 500 |
| • Number of graphics lists per project | 500 |
| • Number of entries per graphics list | 500 |
| **Archiving** | |
| • Number of archives per device | 50 |
| • Number of entries per archive | 20 000 |
| • Message archive | Yes |
| • Process value archive | Yes |
| • Archiving methods | |
| — Sequential archive | Yes |
| — Short-term archive | Yes |
| • Memory location | |
| — Memory card | Yes |
| — USB memory | Yes |
| — Ethernet | Yes |
| • Data storage format | |
| — CSV | Yes |
| — TXT | Yes |
| — RDB | Yes |
| **Security** | |
| • Number of user groups | 50 |
| • Number of user rights | 32 |
| • Number of users | 50 |
| • Password export/import | Yes |
| • SIMATIC Logon | Yes |
| **Logging through printer** | |
| • Alarms | Yes |
| • Report (shift log) | Yes |
| • Hardcopy | Yes |
| • Electronic print to file | Yes; PDF, HTML |
| **Character sets** | |
| • Keyboard fonts | |
| — US English | Yes |

| | |
|---|---|
| Transfer (upload/download) | |
| • MPI/PROFIBUS DP | Yes |
| • USB | Yes |
| • Ethernet | Yes |
| • using external storage medium | Yes |
| Process coupling | |
| • S7-1200 | Yes |
| • S7-1500 | Yes |
| • S7-200 | Yes |
| • S7-300/400 | Yes |
| • LOGO! | Yes |
| • WinAC | Yes |
| • SINUMERIK | Yes; with SINUMERIK option package |
| • SIMOTION | Yes |
| • Allen Bradley (EtherNet/IP) | Yes |
| • Allen Bradley (DF1) | Yes |
| • Mitsubishi (MC TCP/IP) | Yes |
| • Mitsubishi (FX) | Yes |
| • OMRON (FINS TCP) | No |
| • OMRON (LINK/Multilink) | Yes |
| • Modicon (Modbus TCP/IP) | Yes |
| • Modicon (Modbus) | Yes |
| • OPC UA Client | Yes |
| • OPC UA Server | Yes |
| Service tools/configuration aids | |
| • Backup/Restore manually | Yes |
| • Backup/Restore automatically | Yes |
| • Simulation | Yes |
| • Device switchover | Yes |

## Peripherals/Options

| | |
|---|---|
| Peripherals | |
| • Printer | Yes |
| • SIMATIC HMI MM memory card: Multi Media Card | Yes; Up to 128 MB |
| • SIMATIC HMI SD memory card: Secure Digital memory card | Yes; Up to 2 GB |
| • SIMATIC HMI CF memory card Compact Flash Card | No |
| • USB memory | Yes |
| • SIMATIC IPC USB Flashdrive (USB stick) | Yes; Up to 16 GB |
| • SIMATIC HMI USB stick | Yes; Up to 8 GB |

| | |
|---|---|
| • Network camera | Yes |

| Mechanics/material | |
|---|---|
| Enclosure material (front) | |
| • Plastic | No |
| • Aluminum | Yes |
| • Stainless steel | No |

| Dimensions | |
|---|---|
| Width of the housing front | 330 mm |
| Height of housing front | 241 mm |
| Mounting cutout, width | 310 mm |
| Mounting cutout, height | 221 mm |
| Overall depth | 65 mm |

| Weights | |
|---|---|
| Weight without packaging | 2.8 kg |
| Weight incl. packaging | 3.5 kg |

**last modified:** 08/02/2019

# Appendix C

# Bag Handling System(Adapt. [45])

For a better understanding of the virtual reality model created for the purpose of this master thesis this chapter aims to explain the equipment used in the real bag handling system. It's divided in three sections.

The first one, Electrical Equipment, describes the cabinets present around the system and the PLC controlling it. The second section, Conveyor, describes the type of conveyors used and why they are used. Lastly, the third section, Special Equipment, describes how more specific equipment is used.

## C.1 Electrical Equipment

### C.1.1 PLC

The PLC responsible for the control of the field equipment is a SIEMENpS SIMATIC S7-1516F (Figure C.1). The PLC, its central processing unit and other modules are installed in a rack in the PLC CC. The main modules are:

1. Power supply unit;
2. Central processing unit (CPU);
3. Fast Ethernet communication modules;
4. Digital input/output modules;
5. Memory module.

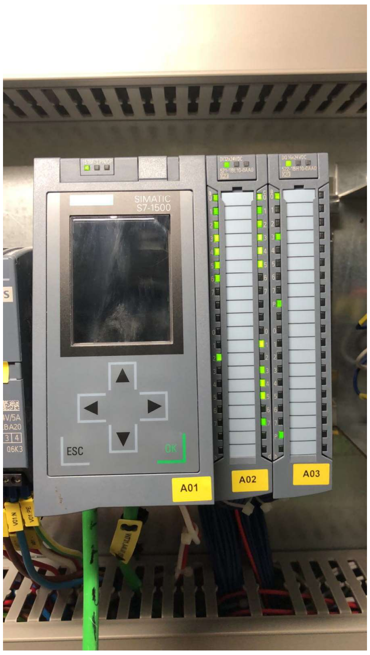



Figure C.1: SIEMENS SIMATIC S7-1516F.

The CPU was selected keeping in mind the processing speed and memory size required. The communication with the HMI and other control levels is expected to be of high-speed for that fast Ethernet communication modules are needed.

### C.1.2 Central Control Panel

The Central Control Panel houses the PLC responsible for the control of field equipment in the BHS (Figure C.2). The cabinet door has a HMI, a lamp test, general reset and E-Stop reset push buttons, a busbar voltage, incoming voltage and auxiliary voltage OK signalization lights, main switch and a light beacon with a red, yellow and green signalization.

Figure C.2: Central Control Panel cabinet door.

Pressing the lamp test push button illuminates all the lamps at the CCP, this allows for a quick check if any lamp needs to be replaced. The general reset push button resets all fault conditions at the PLC. Clicking the E-Stop reset push button resets the emergency stops in the PLC stored in that CCP. The main switch turns off the power for the CCP cabinet. The busbar voltage signalization light when on indicates that the CCP cabinet has electrical power and is entirely powered. The incoming voltage signalization light indicates that the CCP has an electrical connection even if not completely powered. The Auxiliary voltage OK signalization shows if the voltage feeding the PLC is OK.

In the beacon if the red light is flashing there has occurred a fault situation. The yellow light indicates the installation was manually stopped. The green light shows that the installation is ready to start and operate.

Located inside the CCP are two illuminated push buttons. A green one that if pressed places all equipment controlled by the PLC in ready to operate mode, the light is on when the PLC is ready to operate. The red light when pressed stops all equipment controlled by the PLC, the light is on when the PLC is not ready to operate.

### C.1.3 Power Distribution Panel

The Power Distribution Panel is responsible for feeding all the secondary panels with low tension energy trough a radial network. While the PDP gets energy from one of the posts at the airport.

The PDP has two modules, one is the entry point for the electricity, where there is one network analyzer, an UPS and a main switch. The second module has the busbars to each power line.

### C.1.4 Field Distribution Board

The Field Distribution Board (Figure C.3) is used to feed and control all field equipment. The FDB door, similarly to the CCP cabinet's door, has a busbar voltage, incoming voltage and auxiliary voltage ok signalization lights, a main switch and a lamp test and e-stop reset push buttons. It also has a fault reset and buzzer acknowledge push buttons, an UPS supply light, an emergency stop push button and a beacon with a warning buzzer, emergency stop and general fault signalization.

The fault reset push button resets all fault conditions at the FDB. The buzzer acknowledge push button silences the buzzer while the fault is still active. The emergency stop push button activates the emergency stop of the FDB.


Figure C.3: Field Distribution Board.

The warning buzzer in the light beacon starts in case of a fault or emergency stop. The red emergency stop signalization indicates that at least one equipment under the FDB cabinet control has an an emergency stop active. The orange general fault signalization indicates if any equipment controlled by the FDB cabinet has a fault.

### C.1.5 Distribution Box

All the field equipment in the OOG line are controlled and feed by the Distribution Board. Similarly to the FDB cabinet's door, the Distribution Board cabinet door has an UPS supply light, a fault reset, a lamp test, e-stop reset and buzzer acknowledge push buttons, a main switch and incoming voltage and auxiliary voltage ok signalization lights.

### C.1.6 Check-In Interface Box

The Check-In Interface Box (CIB) (Figure C.4) is used to control and feed the Check-Ins, every Check-In has a specific Interface Box. The Interface Box has a main switch, a remote/local switch, three inching/-continuous switches, as well as three forward/backward switches one for each conveyor, an incoming voltage and auxiliary voltage OK signalization lights.

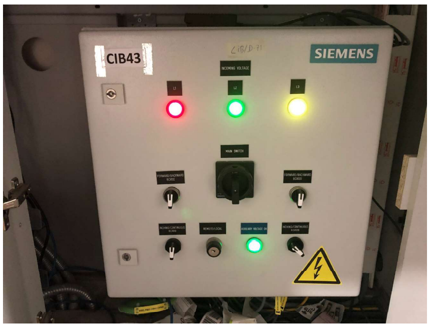



Figure C.4: Check-In Interface Box.

The main switch turns off the power. The remote/local switch allows changes the operation mode from PLC control to local mode and vice-versa. The inching/continuous switch while in manual operation mode changes between continuous or inching, when in continuous mode the respective conveyor runs forward. The forward/backward switch, when in local inching mode runs the conveyor forward or backward. The incoming voltage signalization light indicates that the CIB has an electrical connection. The Auxiliary voltage OK signalization shows if the voltage feeding the CIB is OK.

### C.1.7 Vertical Sorter Unit Interface Box

The Vertical Sorter Unit Interface Box (VSU IB) (Figure C.5) is used to feed and control the VSU. The Interface Box cabinet's door has a automatic/manual switch, a down and a up push buttons, a main switch, a reset light and an emergency stop push buttons.

Figure C.5: Vertical Sorter Unit Interface Box

The automatic/manual switch changes the VSU from automatic mode to manual mode. When in manual mode the down push button changes it to the inferior position, the up push button on the other hand changes to the superior position. The main switch turns off the power. The reset light push button flashs to indicate an emergency stop on the VSU, by clicking it the emergency stops are reseted. The emergency stop push button activates the emergency stop.

### C.1.8 Fire Door Cabinet

The Fire Door Cabinet (Figure C.6) is used to control the fire doors. Similarly to the FDB cabinet's door, the Fire Door Cabinet door has a emergency stop, a fault reset and e-stop reset push button, a main switch, incoming voltage and auxiliary voltage ok signalization lights.


Figure C.6: Fire Door Cabinet.

## C.2 Conveyor and Conveying

### C.2.1 Straight and Curve conveyors

Straight and curve conveyors (Figure C.7) are used when there is the need to transport baggage in a single direction. Straight conveyors represent the greater part of the conveyors in this project. Curve conveyors work in the same way, the only difference being in their 45 or 90 degrees angles.

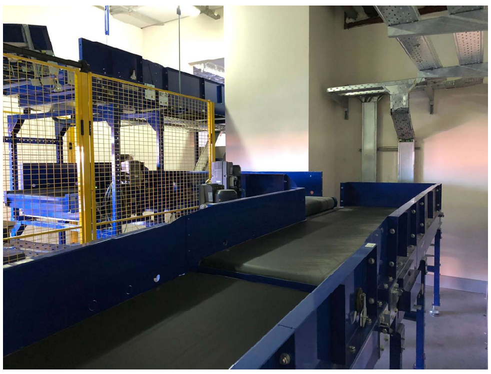


Figure C.7: Straight Conveyors.

The behavior of one conveyor influences the two in front of it. The interruption of the end photocell on the first conveyor causes the next two to start running. They go into idle mode after 2 minutes, unless the end photocell in the first conveyor is interrupted again.

If for any reason the third conveyor encounters a fault and as to stop the interruption of it's photocell causes the second conveyor to stop to and enter ”dieback mode”. In dieback mode for the second conveyor start the third conveyor as to start running first.

### C.2.2 Metering conveyors

Metering conveyors are smaller, they are meant to only hold one baggage at a time, and are controlled by the PLC functions bag separation and spacing (Chapter 4.3.7). Metering conveyors also have special equipped motors to handle the frequent starting and stopping.

In this project they are placed before the VSU, before and after each X-Ray machine and any other point where there might be a high volume of queued baggage.

### C.2.3 Induction

Induction conveyors are at any point where baggage must be transferred from one conveyor to another with a 90 degree intersection. They transport baggage in a controlled way from the delivery to the receiving conveyor or carousel (the carousel doesn't have a upstream sensor).

The bag reaches the photocell of the delivery conveyor and receives permission to transit onto the receiving conveyor. If no bag as reached the maximum delay point, even if it already passed the upstream track sensor, the delivery conveyor still transition an approaching bag. Once the bag on the receiving line has crossed the maximum delay point the delivery conveyor stops, triggering an internal timer which judges the time needed for the bag to pass. If the maximum delay point is crossed before the previous one has reached the passage point the internal timer is reseted. When the delivery conveyor has been given authorization to dispatch the bag onto the receiving conveyor it does so with no regard to the authorization status during transit.

If a bag is injected and doesn't pass the downstream sensor an alarm is triggered in the HMI and both conveyors stop. The reset is possible in the HMI or in the closest control station.

### C.2.4 Make-up Carousel

The Make-up Carousel (Figure C.8) is the only carousel on the departures. It receives bags from the feeding lines and accumulates them until they are removed by the handlers.

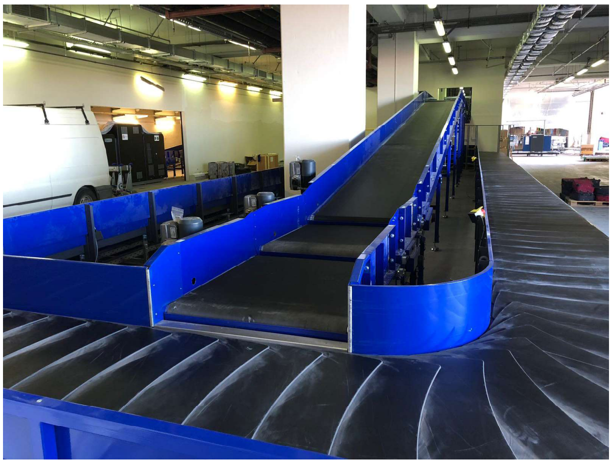


Figure C.8: Make-up Carousel.

The carousel has a light beacon LB19M. Three illumination elements and one buzzer element. The buzzer is black and sounds as a startup alarm for the carousel's initial startup or in case of a jam in the anti-crush photocell. If an emergency stop is pressed the red signalization light starts flashing. The orange light turns on if the carousel is full or if there is a jam in the anti-crush photocell. Lastly, the green light flashes during the startup alarm and is turned on while the carousel is running.

### C.2.5 Roller Table

Roller tables (Figure C.9) are used to accommodate bags. The bags are transported to the end of the roller table as a result of the gravity rollers.

Figure C.9: Roller table.

If the bags are not removed they will accumulate until they cover the initial photocell located in the beginning of the roller table. If the photocell stays covered for more than 5 seconds an alarm is triggered in the HMI and the system stops sending bags to the roller table, stopping in the conveyor before this position.

After the bags are removed and the photocell is free the alarm is automatically reseted and the PLC resumes normal operation.

## C.3 Special Equipment

### C.3.1 Vertical Sorter Unit

Following a security screening result the VSU (Figure C.10) routes baggage upwards or downwards to another conveyor line. The decision is made when a bag reaches the photocell, the function control of the VSU checks the tracking data to decide which route the bag must follow. If the VSU is in the same direction as the direction the bag must travel, then it maintains said position. If the direction is not the same as the direction the bag must travel, then the diverter changes it's position to the right one.

Figure C.10: Vertical Sorter Unit.

### C.3.2 X-Ray Machines

X-Ray machines (Figure C.11) scan bags looking for dangerous items. This type of machine is able to make a preliminary evaluation. To track the bag inside, the PLC generates a unique dummy bag-id and sends it to the X-Ray machine. After the bag leaves, the PLC receives the tracking information back and the preliminary evaluation. All statuses available in the X-Ray machine are visible in the HMI.

Figure C.11: X-Ray Machine.

### C.3.3 Fire Doors

The principal purpose of a fire door is in the event of a fire to create a barrier between different areas of the airport maintaining distinct fire compartments. After receiving the fire alarm signal the PLC activates a relay in the shutter door, due to gravity it closes triggering the Stop Installation Mode in the corresponding PLC putting all the equipment in stop mode. In case of a PLC failure the fire alarms triggers the automatic descent device and releases the shutter break.

Before the conveyor over which the door has closed can restart it needs to be ensured that the fire door has been opened. Once the upstream photocell has been interrupted the PLC orders the fire door to open. The selection of the photocell based on the speed of the fire door assures conveying continuity.

### C.3.4 Security doors

Security doors prevent the circulation of people from one side to the other by creating a barrier between walls. The way a security door operates is similar to the fire doors (Chapter C.3.3.)

### C.3.5 Emergency Stop Push Button

The emergency stop push buttons (Figure C.12) are placed beside the conveyors. In the event of an emergency, they are pressed to stop all equipment's in that area, cutting off the power supply. In the departures there are four different e-stop zones (Figure C.13). The first zone is comprised by the check-ins, cil conveyors and the first conveyor from the OOG line. The second zone starts after the first zone and includes the rest of the OOG line an up to the fortieth conveyor on the transport part. The third zone starts after the second zone and goes to the thirty third conveyor on the sorting part of the system. The fourth and last zone goes from the third zone and includes the rest of the system. The zones are separated by either fire or security doors.


Figure C.12: Emergency Stop push button.

Each emergency stop is illuminated and close to a light beacon 17M that also turn on when that e-stop is pressed for easy identification. When activated all conveyors within the same zone stop immediately.

The main functions of the emergency stops are detecting an emergency stop, managing the interlocking of zones and distributing the trip commands to the individual conveyor FDB, through the PROFIsafe layer.

Activating an emergency stop device also immediately stops all conveyors in the zones adjacent to the E-Stop. Each emergency stop zone is controlled by a Failsafe PLC.

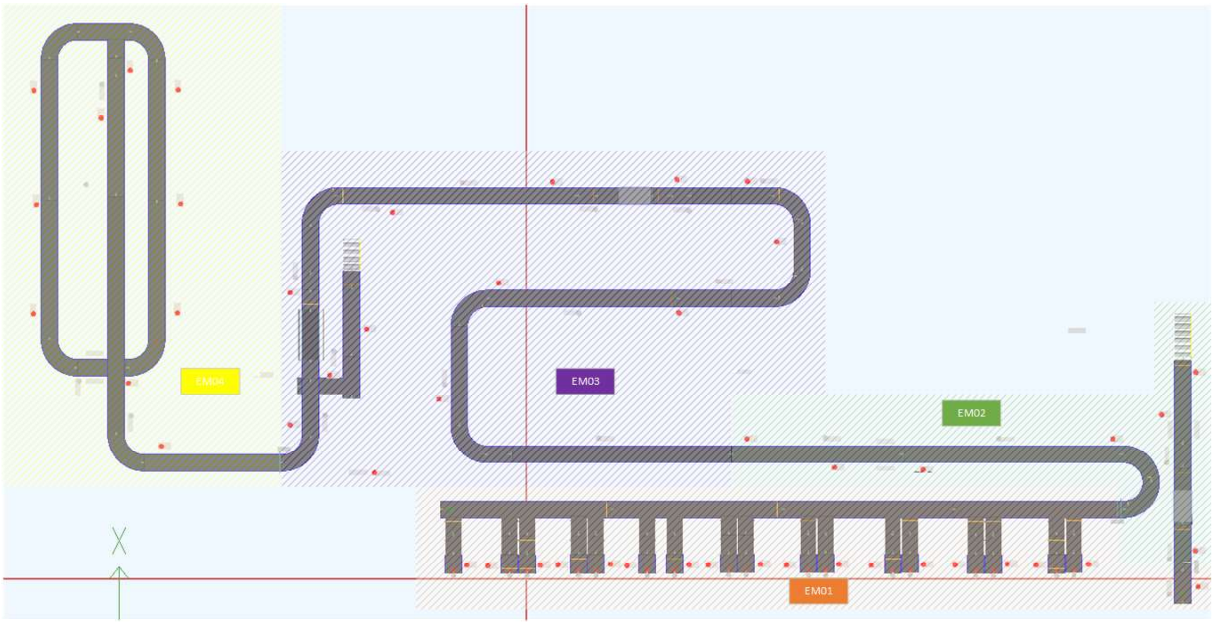



Figure C.13: Representation of the different emergency stop zones.

### PROFIsafe

PROFIsafe is the first communication standard based on the safety standard IEC 61508, allowing standard and safety related communication on the same bus cable. It is certified by IEC 61508, IEC 62061, EN ISO 13849-1:2006, EN 954, NFPA 79-2012 and NFPA 85.

PROFIsafe uses PROFINET real-time communications for fail-safe communication. It is exchanged between a fail-safe CPU and a fail-safe field device or drive, as well as, user data, status and control information.

### Activation and Reset of E-Stop

Emergency stop devices are activated by pressing the red push buttons alongside the conveyors. They are located on both sides of the conveyors where access is provided.

For safety reasons, any pressed E-Stop device must only be released and acknowledge by authorized personnel. The procedure to clear such E-stop is to firstly release the emergency stop device pressed and then reset it in the FDB panel with the emergency stop reset key switch. Conveyor movement only restarts after an authorized operator uses this switch.

### Messages and Indications Related to E-Stop System

All emergency stop signals are divided in zones and collected in the FDB. When an E-Stop is activated a signal is sent to that conveyor's PLC. The signal sent allows the PLC to identify E-Stop events or a power shutdown.

The E-Stop indicator in the HMI is a symbol showing which emergency stop device is activated. The event is written in a message line indicating the name of the device. And all the conveyors affected are highlighted in red. An indication light on the PLC panel and FDB is provided.

### C.3.6 Passage Way

The installation is equipped with several CS13M passage way control station, it is used when there is the need to cross the conveyors. There is a control station installed in both sides of the conveyor this allows starting and stopping the system from both sides. When the red stop push button is activated it requests the conveyor where the control station is located to stop. When the system is safe to be crossed a green illuminated push button lights up. After the operator as crossed they must press the green illuminated push button to resume normal operation.

Figure C.14: Passage Way.

# Appendix D

# HMI Faceplates and Color Codes

## D.1 Check-In

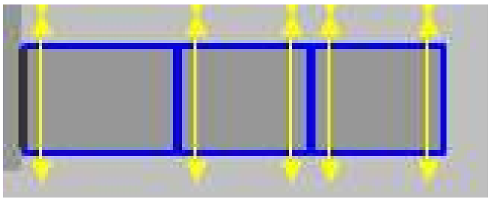


Figure D.1: Detail of check-in counter faceplate.

The check-in counter faceplate represents the status of the three motors through the following color code:

Table D.1: Check-in Counter Status Color Code.

| Priority | Color Code | Description |
|---|---|---|
| 1 | (red) | Emergency Stop Active |
| 2 | (yellow) | Fault (Bag Jam/Overload Fault/Failure to Run/Oversize) |
| 3 | (blue) | Manual Mode Active |
| 4 | (green) | Running in Automatic Mode |
| 5 | (grey) | Idle and Ready to Run |

## D.2 Conveyor

Figure D.2: Detail of straight conveyor faceplate.

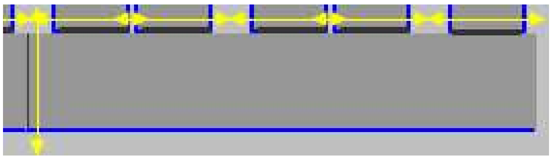


Figure D.3: Detail of loading conveyor faceplate.

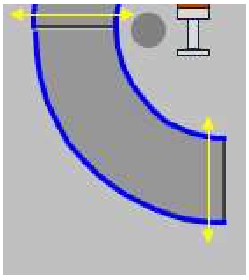


Figure D.4: Detail of curve conveyor faceplate.

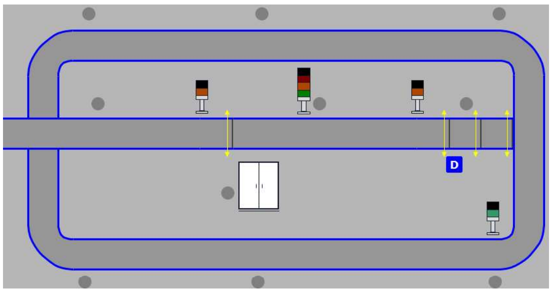



Figure D.5: Detail of carousel faceplate.

The conveyor equipment faceplate (straight, loading, curve and carousel) represents the status of the motor and photocell status (when applicable) through the following color code:

Table D.2: Straight Conveyor Status Color Code.

| Priority | Color Code | Description |
|---|---|---|
| 1 | (red) | Emergency Stop Active |
| 2 | (purple) | Communication Fault |
| 3 | (yellow) | Fault (Bag Jam/Overload Fault/Failure to Run/Oversize) |
| 4 | (orange) | Queuing Mode |
| 5 | (blue) | Manual Mode Active |
| 6 | (green) | Running in Automatic Mode |
| 7 | (black) | Maintenance Mode |
| 8 | (grey) | Idle and Ready to Run |

## D.3 Vertical Sorter Unit

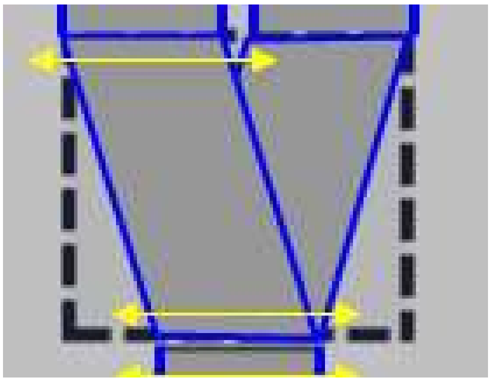


Figure D.6: Detail of VSU faceplate.

The VSU equipment faceplate represents the status of the motors through the following color code:

Table D.3: VSU Status Color Code.

| Priority | Color Code | Description |
|---|---|---|
| 1 | (red) | Emergency Stop Active |
| 2 | (purple) | Communication Fault |
| 3 | (yellow) | Fault (Bag Jam/Overload Fault/Failure to Run/Oversize) |
| 4 | (orange) | Queuing Mode |
| 5 | (blue) | Manual Mode Active |
| 6 | (green) | Running in Automatic Mode |
| 7 | (black) | Maintenance Mode |
| 8 | (grey) | Idle and Ready to Run |

## D.4 X-Ray Machine

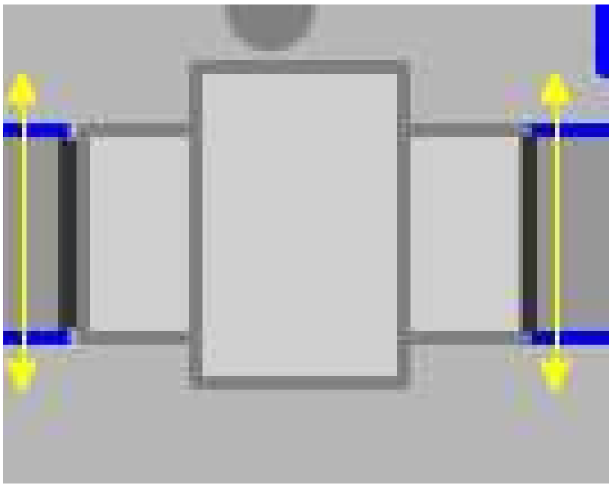


Figure D.7: Detail of X-Ray Machine faceplate.

The X-Ray machine faceplate represents the status of the X-Ray machine through the following color code:

Table D.4: X-Ray Machine Status Color Code.

| Priority | Color Code | Description |
|---|---|---|
| 1 | | Emergency Stop Active |
| 2 | | Communication Fault |
| 3 | | Fault (Equipment Fault) |
| 4 | | Local Mode |
| 5 | | Conveyor Running (Screening Mode) |
| 6 | | Bypass Mode |
| 7 | | Idle and Ready to Run with no Faults |

## D.5 Fire and Security Shutter

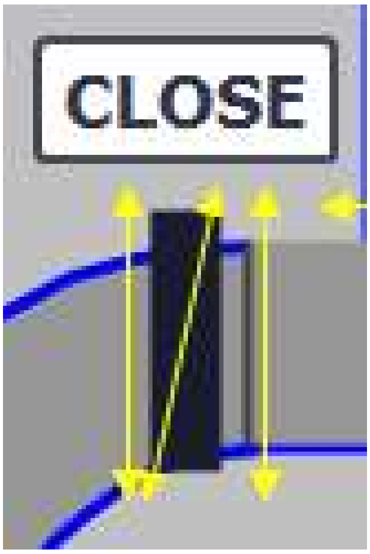



Figure D.8: Detail of Fire and Security Shutter faceplate.

The Fire or Security Shutter faceplate represents the status of the fire or security shutter through the following color code:

Table D.5: Fire and Security Shutter Status Color Code.

| Priority | Color Code | Description |
|---|---|---|
| 1 | | Emergency Stop Active |
| 2 | | Communication Fault |
| 3 | | Fault (Equipment Fault) |
| 4 | | Manual Mode Active |
| 5 | | Open |
| 6 | | Closed |

## D.6 Cabinet

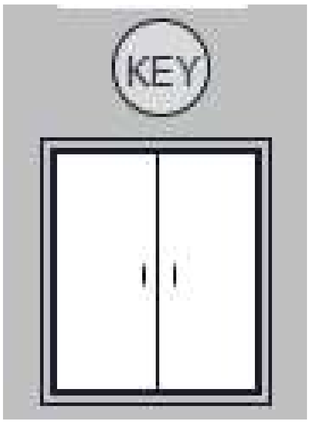



Figure D.9: Detail of CCP faceplate.

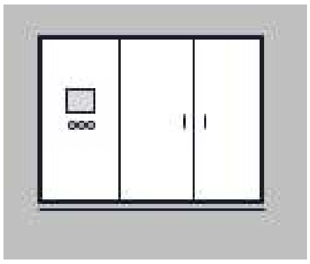


Figure D.10: Detail of PDP faceplate.

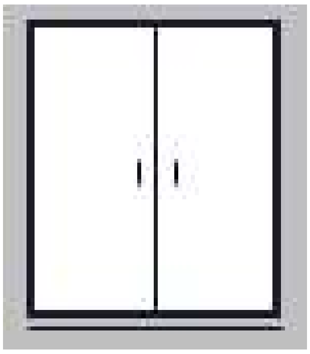


Figure D.11: Detail of FDB faceplate.

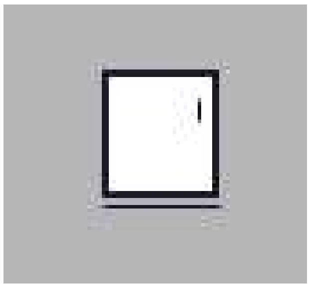


Figure D.12: Detail of UPS faceplate.

The PLC Cabinet faceplate (CCP, PDP, FDB, UPS) represents the status of the PLC's status through the following color code:

Table D.6: PLC Cabinet Status Color Code.

| Priority | Color Code | Description |
|---|---|---|
| 1 | | Emergency Stop Active |
| 2 | | Communication Fault |
| 3 | | Fault (Equipment Fault) |
| 4 | | Working with no Faults |

## D.7 Emergency Stop

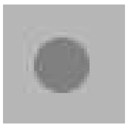


Figure D.13: Detail of Emergency Stop Equipment faceplate.

The Emergency Stop faceplate represents the status of the emergency stop pushbutton through the following color code:

Table D.7: Emergency Stop Status Color Code.

| Priority | Color Code | Description |
|---|---|---|
| 1 | | Emergency Stop Pushbutton Active |
| 2 | | Emergency Stop Pushbutton not Active |