NOVA SCHOOL OF SCIENCE & TECHNOLOGY

DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

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BSc in Electrotechnical Engineering

DIGITAL TWIN CONCEPT APPLIED TO SIMULATION AND PERFORMANCE REPORTING FOR PRINTED CIRCUIT BOARD MANUFACTURING

INTEGRATION OF PRODUCTION LINE DATA FOR SIMULATION AND PERFORMANCE REPORTING PURPOSES

MASTER IN ELECTRICAL AND COMPUTER ENGINEERING

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MASTER IN ELECTRICAL AND COMPUTER ENGINEERING
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Digital Twin concept applied to simulation and performance reporting for printed circuit board manufacturing

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For me and for my loved ones.

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"Carpe Diem" (Quintus Horatius Flaccus)

Abstract

This industrial revolution, also known as Industry 4.0, is now taking place due to technology requirements. With an ever growing world population, new demands rise, henceforth better, more optimized, more customized, and faster product manufacturing must be achieved. A way to do this is by implementing Smart Manufacturing methods in industrial environments, which can be accomplished by using a Digital Twin solution.

This dissertation focuses on expanding an already existing Digital Twin, developed by Visteon Corporation, which purpose is to modulate the productive capacity of Visteon's PCB (Print Circuit Board) production lines. This extension consists of achieving one of the key advantages of using a Digital Twin solution, making predictions regarding a system's real performance, that in this case, are the production lines. The extension further allows better planning for future changes.

Keywords: Digital Twins, Digital, Physical, Smart Manufacturing, Industry 4.0, PCB, SMT

Resumo

A atual revolução industrial, também conhecida como Indústria 4.0, está a ocorrer devido a necessidades tecnológicas. Com um aumento constante da população mundial, surgem novas exigências, por isso é necessário alcançar uma melhor, mais otimizada, mais customizada e mais rápida manufatura de produtos. Uma maneira de o fazer é implementando métodos de Smart Manufacturing em ambientes industriais, que pode ser alcançado através de uma solução de Digital Twin.

O foco desta dissertação é expandir um Digital Twin já existente, que foi desenvolvido pela Visteon Corporation, cujo objetivo é modular a capacidade produtiva das linhas de produção de PCB (Print Circuit Board) da Visteon. Esta extensão tem como objetivo atingir uma das vantagens mais significativas do uso de uma solução de Digital Twin, fazer previsões da performance real de um sistema, que neste caso, são as linhas de produção. A extensão permite também fazer planeamentos mais rigorosos para o futuro.

Palavras-chave: Digital Twins, Digital, Physical, Smart Manufacturing, Industry 4.0, PCB, SMT

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1 Introduction

1.1 Motivation

The Digital Twin concept has been increasing in popularity in the last years by playing an important role in Smart Manufacturing and consequently, Industry 4.0. It brings a whole new breadth of possibilities and advantages when implemented in manufacturing environments but can also prove to be valuable in a variety of other topics such as medicine or even space exploration.

Another technology, Cyber Physical Systems, also plays an important role in Smart Manufacturing, establishing the value that can be obtained from connecting Digital-Physical devices around the world. This technology can be used in conjunction with a Digital Twin to further enhance Smart Manufacturing's potential and opportunities.

Visteon has developed a Digital Twin with the goal of modeling the production capacity of its PCB (Print Circuit Board) production lines. The Digital Twin is currently being used and modules more than seventy lines across the world that aid in future decisions regarding investments or equipment transport between lines.

1.2 Objectives

The first aim of this dissertation is to connect the Digital Twin to CIMPLE, Visteon's MES (Manufacturing Execution System), that contains the real performance data of the SMT (Surface Mount technology) production lines. This connection is expected to integrate, in the Digital Twin, the benefits of making predictions concerning the real performance of the productive equipment.

To accomplish this, four milestones were specified:

- Starting with extending the Digital Twin data model to support the integration of live production data.
- Designing and developing the integration between the MES system CIMPLE and the Digital Twin.
- Designing and developing reports that compare theoretical to the real SMT placement machines' performance.
- Implementing the solution for one production line in Palmela's plant.

This integration of the real performance data will ultimately allow Visteon to detect lines with inferior performance and act to improve that performance so that the contracts' requirements are assured to be met.

The second project of this work, the Plant Simulator, has the goal of further extending the Digital Twin, by allowing the creation of a whole customized plant scenario, were changes and tests can be simulated without changing real values.

This project was previously structured by Visteon's engineers, so the rest of the purposed work is as follows:

- The first step will be studying the already existing plan and architecture for this project.
- Then, it will be required to review the Plant Simulator's goals, and seeing if the existing plan meets the requirements to reach those goals.
- After that, the layout of the Plant Simulator in the Digital Twin will be completely revised and, if necessary, changes to the layout will be conducted.
- Finally, the project's development will be pursued.

The simulator is expected to help the plant engineers to make important decisions, by planning for the future in a controlled environment and with more accurate results.

1.3 Dissertation Structure

This dissertation is structured into six different chapters.

Firstly, it is displayed an introduction to the document, specifying its motivation and objectives.

Then, on the second chapter, a state of the art research and analyses is presented, containing the key concepts of this work. PCB and SMT, are the initial notions to be shown, followed by a brief introduction to Visteon Corporation, as well as its now being used technologies and being manufactured products, then, modern and of high importance concepts in the manufacturing industry that are related to this project are also mentioned, Industry 4.0, Smart Manufacturing and Cyber Physical Systems, and lastly, an introduction to the Digital Twin concept, a way of developing a solution for its design, creating and implementation and a brief summary of Visteon's Digital Twin, are also exhibited.

On the following two chapters, it is presented the developed work, by showing a detailed view of the two projects established for this dissertation, the Real Performance Data project and the Plant Simulator project. The view of each project is organized in three subsections, the respective project's Architecture, Implementation and Validation.

Afterwards, on the fifth chapter, a summary of the work is presented as well as ideas for possible further improvements on the work developed during this dissertation.

Lastly, on the sixth chapter, the paper, web and books references are displayed.

2

A Review of Previous Works

Before anything else, it is important to have a good understanding of the key concepts, PCB and SMT, Visteon's production plants and lines, Visteon's manufacturing methods and used technologies, Industry 4.0, Smart Manufacturing and Cyber Physical Systems, Digital Twins and Visteon's Digital Twin. To this extent, the subjects will be explained individually and how they are related. Finally, a method to develop a Digital Twin solution will also be described.

2.1 Print Circuit Board (PCB) and Surface Mount Technology (SMT)

Besides the Digital Twin, PCB and SMT are two concepts that are crucial to the work to be developed, since the Digital Twin expansion is to be applied to the SMT placing machines that produce the PCBs, so they need to be covered and briefly explained.

Before PCBs, electronic components were connected manually with lose wires. This composes not only a difficult, but also time-consuming task that facilitates committing errors. PCBs radically improves and simplifies these connections by designing a layout (normally made from copper) on a non-conductive material on to which the components are attached. This removes the numerous wires problem, and also makes repairing and monitoring electronic circuits a much easier task.

SMT refers to the process of directly attaching a component to a PCB [2]. The attached component is designated SMD (Surface Mount Device), and this is how most PCB production lines operate, including the ones in Visteon Corporation.

Logically, the SMT is not perfect, therefore errors may occur timely that can severely impact production capabilities. Utilizing a Digital Twin solution to smoothen this problem as proposed in this dissertation objective by using its predictive capabilities to detect any upcoming problem on PCB production, can optimize manufacturing, preventing lucrative consequences.

Although having some similarities, Digital Twins and Cyber Physical Systems are different notions, however, they can be put together to form a powerful tool of a physical to

digital integration method. This can be applied, as demonstrated in [3], to SMT production lines, providing an extra motive for the implementation of a Digital Twin solution, as proposed in this paper.

2.2 Overlook at Visteon Corporation

Visteon Corporation produces and supplies cockpit electronics and it is "The leading automotive technology company focused exclusively on cockpit electronics" [4].

With thirteen plants all over the world located in Chihuahua in Mexico, Reynosa in Mexico, Manaus in Brazil, Palmela in Portugal, Námestovo in Slovakia, Bir el Bey in Tunisia, Vladimir in Russia, Chennai in India, Rayong in Thailand, Changchun in China, Shanghai in China and Hiroshima in Japan, Visteon has approximately seventy three SMT production lines. There are also engineering centers scattered around the world, to help the plants with their work and attend other topics. The following image (figure 2.1) shows the approximate location of Visteon's Work centers and plants.

Figure 2.1: Visteon work centers and plants [4]

Visteon's market is directed to automotive manufacturers all around the world, such as Audi, BMW, Mercedes, Renault, Volkswagen, Ford and many more. The company produces around one million products per week, with the essential help of its approximately ten thousand employees, of which four thousand are engineers.

Products like Analog / Hybrid Clusters or separated audio devices were initially the most manufactured in Visteon. Due to technology advancements, the production volume of these got progressively lower, being replaced with other products, such as Digital Clusters. Currently, these are the most requested product in Visteon, and consequently, the most manufactured. Nevertheless, innovating, state of the art and environmentally friendly devices like Cockpit Domain controllers and the Battery management system, take part in the new generation of products in Visteon and are rapidly growing in popularity. The latter product takes part in the electrification project, this will be covered in the following chapter.

2.2.1 Visteon's Manufacturing Products and Used Technologies

Visteon offers a variety of cockpit electronics related products.

Starting with the Instrument Clusters, Visteon is actively producing all-digital clusters that provide all the required information for a stressless drive. The all-digital clusters also work with the vehicle infotainment system, providing an interactable way of managing multimedia, browsing a phone book, making calls, or selecting destination addresses for navigation. With this Visteon helps car manufacturers transitioning from analog to digital clusters.

Following, the Infotainment system offers access to cloud services in the cockpit. This can be done through the user's smartphone or through embedded Android or HTML5 technologies, with the last two method only being provided by Visteon.

Cockpit displays are another focus of the company. Visteon provides High resolution, curved, bigger and immersive displays. Whilst providing these key advantages over regular displays, when designing these displays, Visteon also takes into consideration other long know factors and possible issues such as extreme temperatures, vibrations, and reflectivity, in order to go around them.

The Telematics theme is another mandatory aspect for the future of the automotive industry. Being continuously connected to the internet and the cloud is a key aspect for the Digital Era we are now transitioning in to. Visteon offers automobile companies solutions for this matter by providing the latest generation of wireless technologies such as LTE/5G, Wi-Fi/Bluetooth and V2X (DSRC and cellular).

Next up there are the Domain controllers that server as the main controller for the previously mentioned products that allow managing those from a single entity.

Finally, Visteon is also investing into producing software that provides car with the self-driving ability. This is only usable in certain conditions, such as when the road is well-marked and in traffic jams. The self-driving car software "analyzes input from multiple sensors such as cameras, radar, Lidar and map to understand the environment and determine appropriate action to steer, break and accelerate the vehicle". The continuous improvement and expansion of the connectivity between cars joined with the self-driving feature allows safer trips as well as more comfort in doing those [4].

In order to successfully design and develop the previously mentioned products, Visteon uses a variety of modern technologies.

Of these technologies takes part the Artificial Intelligence (AI) that, for example, plays a big role in the self-driving car due to the large amount of data collected by the sensor of the car to perform this being too large for normal algorithms to solve and therefore the need for AI.

Another major technology is the Connected Car which is the one that supports the infotainment products. Nowadays, connectivity is one of the most important aspects of vehicles and to this extent, it is crucial for a user to be connected in the vehicle as much as

he is connected outside of the vehicle.

A subject that cannot be missed is security. Security is probably one of the most important if not the most important aspects of developing and working with product like the ones mentioned before. Without security these can't be reliable, so it is mandatory to give maximum attention to this theme. Visteon incorporates end-to-end cybersecurity from design to development to manufacturing to final product to ensure top level security. Also, it keeps the security system up to date.

Visteon pays attention to the User Experience when interacting with their products. By giving the user the ability to customize, for instance, the digital cockpit in more ways than usual, the experience of being in a car with Visteon's technologies whether it is for the driver or the other passengers in greatly enchased. Part of this work is done by co-creating with costumers and gathering their opinion and experiences to build the best possible version of this technology.

Lastly, Visteon offers an innovating system of Driver Monitoring, this for ensuring a safe and autonomous future. This technology allows the identification of drowsiness and the distraction level of the driver to decide if the driver is prepared or not to drive [4].

2.3 Industry 4.0

The fourth industrial revolution (Industry 4.0) is currently taking place and it consists of the integration of cyber-physical Systems in the current Industry. Improvements on the systems that were designed to support Industry 4.0 technologies consist of the complete automatization of systems by having the ability to monitor, change, optimize and enhance themselves. This will allow for better resource and energy management and efficiency as well as using co-creation to reach mass customization and lastly, will take part in helping various time consuming and complex decisions, lessening the need for human interaction [5].

An example of the impact of Industry 4.0 technologies, referring its benefits stated previously, can be found in [6].

In achieving the fourth industrial revolution milestone, various concerns must be assured. Among them, there is the need for factories having the abilities of self-awareness, self-prediction, self-comparison, self-recognition and self-maintenance [7]. Moreover, there is also the need for sharing information across all different types of devices so that data collected by them can be taken advantage of across the cyber-network. Also, the gathered information must be organized, studied, and rearranged to maximize the value obtained from it.

A Digital Twin solution can provide a framework to implement this requirements on a manufacturing environment, as covered in [8].

Another of the challenges when dealing with Industry 4.0 matters, are the vast amount of simultaneously connected devices, and to the extent of correctly and efficiently controlling them, it is necessary to study this subject extensively.

Providing as an example all of the machines and robots necessary to make a production line work efficiently on a plant with Industry 4.0 technology, these must be controlled in a structured way so that everything runs smoothly. An example option to guarantee this is to use as a base model RAMI 4.0 (Reference Architectural Model Industry 4.0). RAMI 4.0 is a three-dimensional model that provides an approach on how to properly develop a system in Industry 4.0 in a structured manner, ensuring that all of the "participants" communicate and understand each other(in this case the robots and other machines). RAMI 4.0 is a Service Oriented Architecture (SOA) [9] [10].

It is possible to use a Digital Twin solution supported by RAMI 4.0 to protype a connected device network, as presented in [11].

Although IoT (Internet of Things) and Big Data, will not be directly covered in this paper, they still play a major role in Industry 4.0, so they might be of interest. Detailed views of IoT and Big Data as well as some of their applications can be found in [12] and [13], respectively.

2.4 Smart Manufacturing and Cyber Physical Systems

Smart Manufacturing can be described as a "Manufacturing Paradigm based on a collaborative ecosystem" [14] where product manufacturing is achieved through co-creation. This means that in the creation of a product, costumer opinion and demands are taken into consideration, establishing this way an association between the producer and the client. A Smart Manufacturing system has cognitive intelligence, which can be provided through e.g., the implementation of a Digital Twin solution, allowing it to close the loop of continuous system optimization.

Smart Manufacturing implementation in modern production environments is a necessary development to meet today's requirements and challenges, therefore, a self-improving system that can adapt to dynamic changes in its ecosystem is vital.

A suggestion of an Implementation of Sustainable Smart Manufacturing using a process-driven maturity model: Smart Manufacturing Kaizen Level (SMKL) achieved with a KPI (Key Performance Indicator) [15], can be found at [16].

Paper [17] provides three concepts to better understand how Smart Manufacturing methods operate and can be a better option, rather than regular manufacturing, in terms of efficiency, flexibility, economy and environmental and social impacts:

• The term Smart Production differs from regular production by being more organized and constantly connected to monitoring and optimization devices, granting it cognitive intelligence.

• Smart Production Network refers to a set of production systems that are cyber-physically connected, forming a network. This unlocks the potential to acknowledge at almost real-time, dynamic changes in any individual system and external supply chain.

• Lastly, Mass Personalization corresponds to the ability to sell different versions of the same product to clients, depending on their demands, by interacting with them. This way, a better relationship with the client is developed, enchasing sales overall.

The characteristics of Smart Manufacturing that were described by these notions, allow the utilization of the benefits listed previously.

Another benefit of using Digital Twin Solutions is that it can also be used in the design phase of a system, and in this case, a manufacturing system. As presented in [13], designing a manufacturing system involves "back-and-forth interactions" to achieve the best possible outcome. Utilizing a Digital Twin solution to assist in this stage can prove to be extremely useful by allowing the designer to interactively optimize, customize, simulate, and experiment on functionalities at a faster rate and by having more options. This allows for the improved quality and more customized design of a System.

Then, throughout the produced System's lifecycle, the ability to supervise and optimize

Systems and the other benefits of using a Digital Twin solution, are a key factor that differentiates Regular Manufacturing Systems from Smart Manufacturing Systems.

Due to this, the Digital Twin can be considered the one of the main technologies for sustaining Smart Manufacturing [18] and [19]. Paper [20] purposes a method on how to build and utilize a Digital Twin solution for an example of a Smart Manufacturing System.

On another hand, although being quite different in many aspects, Big Data can be an alternative solution to the Digital Twin when implementing Smart Manufacturing Systems.

Whilst the Digital Twin has the abilities previously mentioned, Big Data has access to enormous amount of information and can make decisions, prediction and optimizations based on smart algorithms that select and analyze carefully the data gathered. This can also prove to be a viable solution, as explained with more detail in [13].

Big Data also has the possibility to use the same algorithms on the information gathered from the system to monitor it and detect possible anomalies.

One of the main subjects in Industry 4.0 are the Cyber Physical Systems (CPS), these are elaborate digital systems that are connected to physical devices. There is a large variety of uses for these systems, ranging in all Industries. They can be viewed as an integration of the digital and physical world, providing an interconnection between them, that allows manipulation from one side to another [21].

Examples of Cyber Physical Systems applications are Smart cities [22], automobile electrification [23] and [24], smart manufacturing, but also in other completely different sectors such as agriculture [25], public health [26], entertainment and education [27], or environment protection [28].

Cyber Physical Systems can play an important role in manufacturing production lines, such as PCB production lines, as in Visteon. The ability to connect several components to different sectors the line, to the whole line, to a digital interface, storing the data locally and online, brings immense possibilities such as facilitating the line's monitoring.

A more in-depth look at the advantages of Cyber Physical Systems in production lines can be found at [29].

2.5 Digital Twins

The person that introduced the Digital Twin concept was Professor Michael Grieves in 2003, whilst researching product life-cycle management [30]. Grieves's definition of Digital Twin presented in the referenced paper consists of a model composed of three components, first, a physical element that exists in the real world, then, a virtual counterpart that resides in the virtual world and lastly the connections between these two parts that allow information transfer between them. An overview of a high-level Digital Twin representation is displayed in figure 2.2.

As an example, a Digital Twin solution for a robotic arm would consist of the robotic arm itself, in the real world, a digital replica of that robotic arm in a digital environment (that could reside in a computer and be visualized in its interface) and the data transitions from the robotic arm to the computer and from the computer to the robotic arm, whether this is performed using a wire or wireless connection, transferring any necessary data.

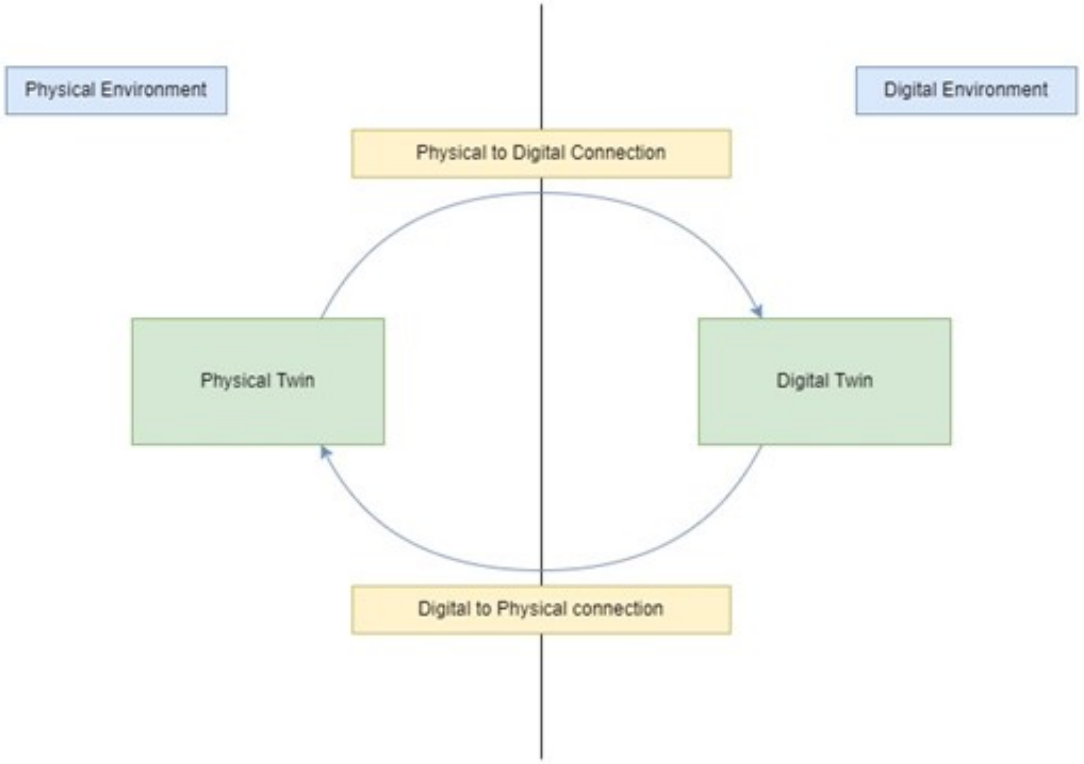


Figure 2.2: Digital Twin elements overview

Grieves also proposes a few more concepts regarding the Digital Twin idea in [31], that can be advantageous when mentioning it, Digital Twin Prototype, Digital Twin Instance and Digital Twin Environment.

The Digital Twin Prototype is defined as a description of what is necessary to create a

fully functional physical twin that can be replicated in the digital space. Much like there are blueprints for buildings, the Digital Twin Prototype is a blueprint for a Digital Twin Solution, which includes everything that is necessary to develop it.

The Digital Twin instance refers to a physical or real object to which a digital twin remains connected until the end of the real object's lifecycle.

There is also the Digital Twin environment that is the multi-domain physics application environment where the Digital Twin takes effect.

Now it will be presented the reasons why a Digital Twin solution has the potential to better any kind of system.

Having an exact copy of a physical system in a digital environment can prove to be a vast advantage since one can have easy access to all the data corresponding to that system in real time. This fact alone already provides an easy, more reliable, and fast access to the system, reducing its chances of having issues due to a lack of, or poor monitoring. The thing about the Digital Twin is that it brings even more opportunities besides that. The ability to couple Digital Twins with algorithms and computer programs, unlocks a whole new level of possibilities, an example of this is being able to process the data received from a physical system, optimizing its parameters according to that information, and automatically adjusting them in the physical system which can be done in many ways that are of use to the system, building this way, a completely automated system optimization cycle. Being the focus of this paper, the Digital Twin also has the potential to predict a system's performance and behaviors, with this characteristic being similar to monitoring the device. Also, when joined with a simulation algorithm, it has the ability to perform tests to any changes regarding the system and identifying its outcome, without changing the real system in the first place. This last example likely consists of one of the prevalent benefits of Digital Twins, imagine being able to know what will happen to something when performing anything to it, before doing it.

A practical example of a use of a Digital Twin solution for Production Optimization on production lines can be found in [32].

It is important to keep in mind that since Digital Twin solutions can also be applied to other themes besides the ones focused on this paper, as in healthcare or smart cities [33], the benefits mentioned, can also be applied to these or other subjects.

This way, if done correctly, the implementation of a Digital Twin solution in an industrial manufacturing environment can bring many and awarding benefits, but it is also a complex task that must be done carefully and attentively. To this extent, I consider that some of the presented concepts in [34] are of importance and should be used and understood when it comes to developing or working with a Digital Twin solution, namely Physical Entity, Virtual Entity, Physical Environment, Virtual Environment, Parameters, Fidelity, State, Physical-to-Virtual Connection, Virtual-to-Physical Connection, Twinning and Twinning Rate, Physical Processes and Virtual Processes:

• Starting with the Physical Entity, any object that influences or is a physical component that has potential to be twinned and exists in the real world can be considered a physical entity. One or various connected Physical Entities can constitute the Physical Twin.

• Next there is the Virtual Entity, which is basically the same as the Physical Entity, but in the virtual realm. Elaborately, it is the virtual representation of a Physical Entity, residing in a virtual environment. One or various connected Virtual Entities can constitute the Digital Twin.

• The Physical and Virtual Environments are the places or spaces where all the Physical and Virtual Entities reside, respectively, along with all the Parameters that may influence them.

• The Parameters consists of the categories of information that take part in describing and changing the states of the Physical Entities and Digital counterparts and are also the data that is transmitted through the previously mentioned connections concerning them.

• Fidelity refers to the number of Parameters transferred among the Physical and Virtual Environment, and their exactness, and level of abstraction. This allows for a better understanding and processing of that information.

• The Concept State, meaning the state of the Physical and Digital Twins, gives a perspective of their current condition. This perspective involves various types of information depending on the system type or anything else important to the system monitoring, e.g., considering a Digital Twin solution applied to an engine, overviewing its state could be gathering information about its speed, temperature, remaining lifetime, components health, etc. This overview is usually given by the Parameter values.

• After that, there are the Physical-to-Virtual and Virtual-to-Physical connections. These concepts are used to specify which way is being accounted for when mentioning the third component of the Digital Twin, the connection between the Physical and Virtual realms. The main function of the Physical-to-Virtual connection is to update the Digital Twin with any changes to the system whereas the Virtual-to-Physical connection is used to optimize the system with any parameters recalculated by algorithms to improve the system or to perform any necessary action that could only be realized in the virtual environment e.g., an emergency stop due to a malfunction on a component.

• Twinning is the term used in the synchronizing of states of the Physical and Digital Twins, and Twinning Rate, determines how fast this occurs. What this describes is the process of a change that occurs or is realized in one of the sides, is transferred, realized, and updated on the other side. This is particularly important when dealing with e.g., mass production, where lost time or bad synchronization can lead to significant penalties in various topics, or when working with highly sensitive equipment, where a slight change may cause big errors.

• Finally, Physical and Virtual Processes consist of the tasks executed by the Digital or Physical entities. It is during this procedure when the change on the parameters of the

respective entity happens.

A simplified version of the Physical and Digital Twins tasks are shown in figures 2.3 and 2.4 respectively.

It is crucial to emphasize that although in some cases, a Digital Twin solution in which there is only a physical to digital connection and not contrariwise can be developed and proven to work well, there should always be a digital to physical connection as well because a big part of the benefits regarding the use of a Digital Twin solution come from the ability to use the studied and arranged data in the virtual realm to adjust the physical counterpart to any changes that may need to be done, whether it is to avoid any consequences or to make the system better.

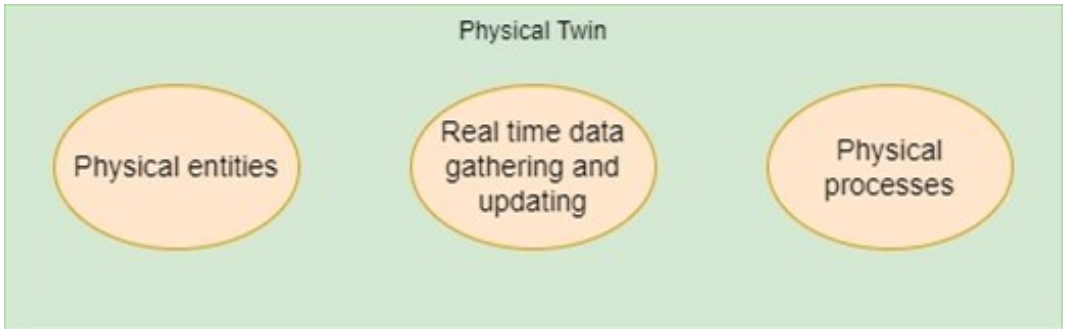


Figure 2.3: Physical Twin components and tasks

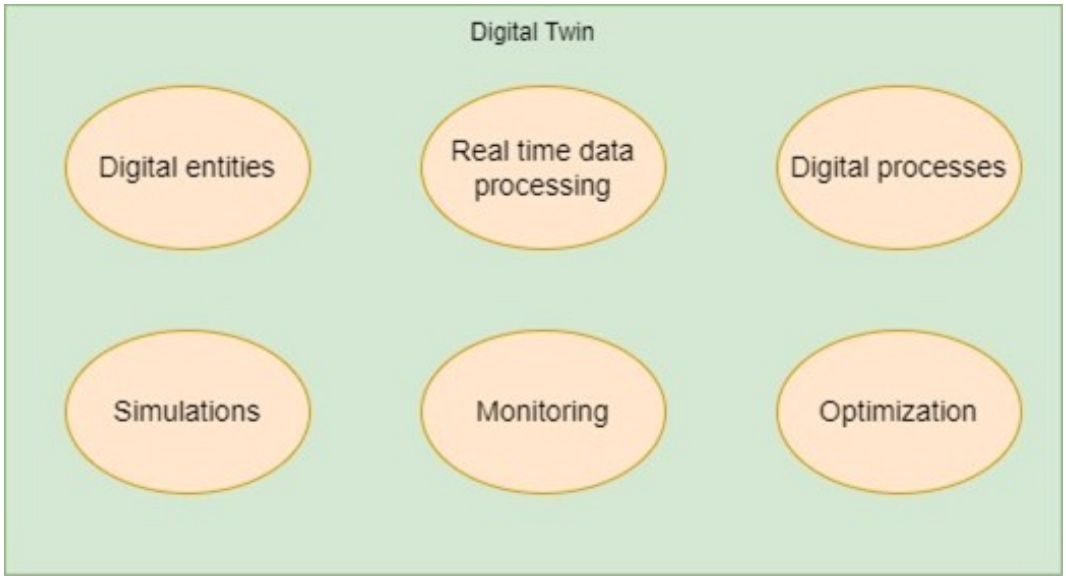


Figure 2.4: Digital Twin components and tasks

2.5.1 How to develop a Digital Twin solution

Since the objective of this paper is to extend an already existing Digital Twin solution, it is important to understand how one is created so it will now be presented an approach on how to implement a Digital Twin solution for Manufacturing Systems on an Industrial environment, based on paper [35].

The method to develop a Digital Twin solution is divided in five stages, Planning, Requirements and Analyses, Design, Development and lastly, Testing. The outputs of each stage are identified in the figures following the stage explanation.

Starting with the Planning stage, the very first thing to do is finding what motivates the use of a Digital Twin Solution and if it's worth the investment. This is an important question to answer because in some cases using a Digital Twin might not be the ideal approach. An example where a Digital Twin solution could be viable would be in a mass-production environment, where small down-times or non-optimized assembly lines could severely impact production. The best way to check if a Digital Twin solution is viable is to cope its advantages and disadvantages against one's needs and available resources.

At least one solution should be presented, although multiple solutions are recommended. These are based of the identified requirements for a Digital Twin solution, mainly targeting them e.g., real time monitoring, optimizations, simulations.

Next, the Digital Twin output and quality-of-output metrics needs to be recognized. The output is simply a way to describe and/or visualize the assigned function of the Digital Twin, for example, the output of a Digital Twin solution that is intended to monitor an engine, could be the value of its temperature, fuel and its consumption rate, energy output or the components health. With this in mind, the quality-of-output analyses the presented output and gives information regarding its condition, this is, it evaluates the quality of the output based on a scale and concludes if it good or bad. Given a scale from 0 to 100 fuel percentage where the value for the fuel output would be shown ranging from 0 to 100, the quality-of-output could be classified as "low", if the fuel was below 20%, "medium", if the fuel output was between 20 and 80%, and as "full", if the fuel output value was larger than 80%.

The last step of the Planning stage is determining if the chosen Digital Twin solutions are feasible. To accomplish this, a review of the planning stage must be performed, confirming that the chosen methods to execute the necessary task are able to meet the requirements necessary to achieve it. The resulting outputs of this stage are represented in figure 2.5.

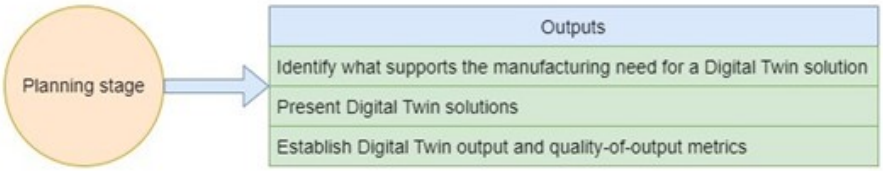


Figure 2.5: Planning stage outputs

The second stage is Requirements and Analyses. Firstly, a qualitative analysis is performed on each of the purposed Digital Twin solutions, by utilizing Big Data's "four V's" attributes, as well as veracity. This step also evaluates the needed resources, data, data quality and security requirements to implement the recognized Digital Twin solutions. Already existing assets are also detected, so that they can be used if needed, however, these must be selected. The selection occurs by directly implementing available resources, combining, or enhancing them. If this selection fails, brand new resources must be introduced.

A quantity evaluation is then performed, quantifying the value of information that will be gathered from the real system. The quality range of the Digital Twin solution is determined by the measurement of characteristics of quality of information resources in terms of availability, accuracy, consistency, context richness, integrity, and timeliness. The quality of information resources also affects the quality range of the Digital Twin output.

This assessment is also responsible for increasing the value of the Digital Twin solution output and searching data to try finding any information that is useful to assist in the Digital Twin development.

The quantity evaluation is additionally responsible for establishing the financial profit for the Digital Twin solutions. This is of substantial importance due to the project development depending on it. If the profits from implementing a Digital Twin solution are not significant enough comparatively to the profits without a digital twin solution, also having in mid the costs to implement it, then it should not be implemented. Besides that, remembering that the Digital Twin is not perfect and may have some flaws in its processes that may negatively influence profits, it is important to note that those reductions must be studied if the Digital Twin solution was considered profitable and recalculate its profitability based on that information.

After that, from the presented Digital Twin solution alternatives, are selected the ones that satisfy the restrictions and requirements imposed by the qualitative and quantitative evaluations.

Now, taking the chosen Digital Twin solutions, a comparison that should be done between at least two of those solutions, but it's ideal to compare all of them, targeting key parameters, such as costs, profits, security, or technology used. The solution that scores the highest among them is recommended. The following figure (figure 2.6) displays the outputs of the described stage.

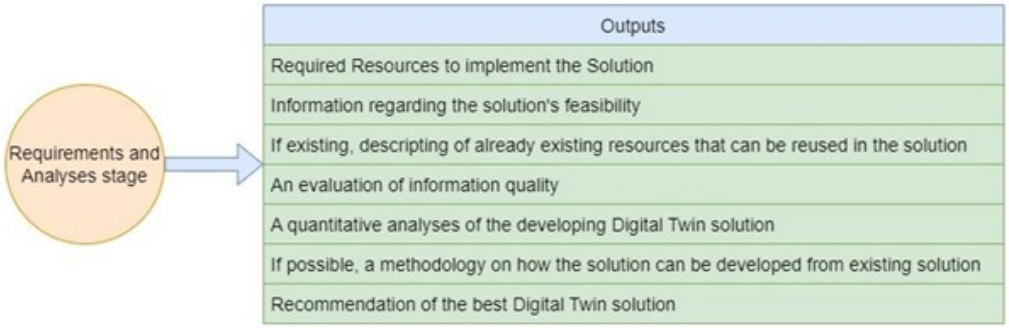


Figure 2.6: Requirements and analyses stage outputs

The following stage, Design, which outputs can be seen in image 2.7, can be viewed as the development of a blueprint for the Digital Twin recommended solution. Here is where the connections between the components are designed. These are organized through a hierarchy model that establishes the Digital Twin's classes, attributes, operation, methods, and relationships. In this model is also specified how the resources used in the Digital Twin solution are combined and shared, and how they can be extended and reused.

After defining the classes and hierarchy and having a "schematic" for building and implementing the Digital Twin solution, everything must be rechecked. A Digital Twin solution must be as accurate and flawless as possible, especially when working in a production intensive manufacturing environment, where small errors can originate large problems or less profits, so revising the design phase of the project is a high importance task. Common errors in this stage involve giving distinct names to classes that perform the same tasks or correspond to the same idea or giving equal names to classes that perform different tasks or correspond to different ideas.

Figure 2.7: Design stage outputs

Next up, there's the Development phase. In this stage, the "blueprint" created in the design phase is implemented. That means both the physical and digital parts as well as the connection constituting the whole Digital Twin solution are created practically. At the end of this stage, a fully functional version of the Digital Twin solution exists and is ready to operate. This stage has a single output, visible in figure 2.8.

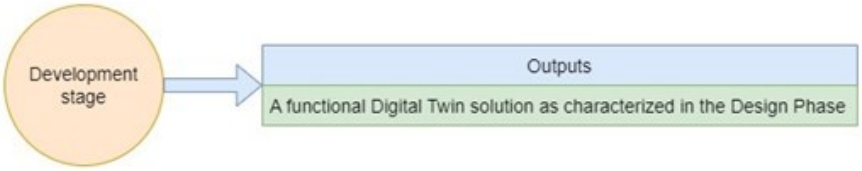


Figure 2.8: Development stage outputs

Last of all, the Testing stage involves using the Digital Twin to perform its intended task, by putting it against the requirements. This can be accomplished by used the "V&V" method which stands for Verification and Validation, with verification confirming if everything is working according to the requirements without any complications and checking for any defects in the system's design, whilst Validation tests the system under different circumstances (this can be achieved through simulation) and takes conclusions concerning its behavior. If an error that could compromise the system is detected while testing, the current Digital Twin solution project must go back to phase 3 (Design phase) and must be redesigned. Another possibility consists of picking another solution previously validated. After successfully completing this stage the Digital Twin solution is ready to be used. Figure 2.9 shows the output for this final stage.

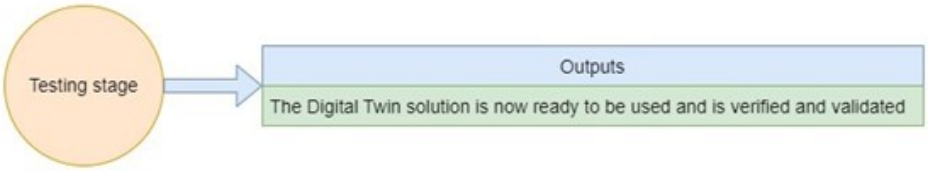


Figure 2.9: Testing stage outputs

2.5.2 Visteon's Digital Twin

Visteon's requirement for having a tool that modulates the productive capacity of its PCB production lines lead to the development of a Digital Twin, the SMT Load Forecast.

The SMT Load Forecast is connected to a local database and contains all the information and statistics of the production lines of all the plants in Visteon. A database is usually a structured digital entity that allows storing, retrieving, and organizing information electronically [36]. Throughout the developed work, databases were valuable assets that were used in almost all the tasks.

This tool allows its users to view, change and analyze their plant's lines, machines, and programs as well as their plant's generic parameters and capacity, among other useful information. Moreover, the Digital Twin provides a simulator for the lines of each plant, that allows the creation of a custom scenario where all the previously referred capabilities are possible to be implemented. Also, it is possible to visualize the loads of each line in a bar graph. Having a simulator with these functionalities is a major asset because it allows predicting any change's consequences before implementing the change, providing this way the necessary information for optimizing future investments or carrying out machine changes among the lines.

As displayed in figure 2.10, the Digital Twin's homepage is the first interface that is presented after logging in. Here, by clicking the "Submit" button, the users can navigate to one of the selected pages with information regarding their plant that will be covered next.

In the page the button "OTO CPH Standards" takes the user to another page where there is a list of all the machines of all the plants. It is possible to edit these machines, delete, or add new ones. The next button, "All Plants Status" provides an interface that allows visualizing the current status of the plant validation process (that includes the validation of both machines and boards in each line). Following, there is the "All Plants Program" button, that is a generalization for all the plants of the "Program info section". Finally, the "What's New" button, reveals recently added features and updates regarding the tool.

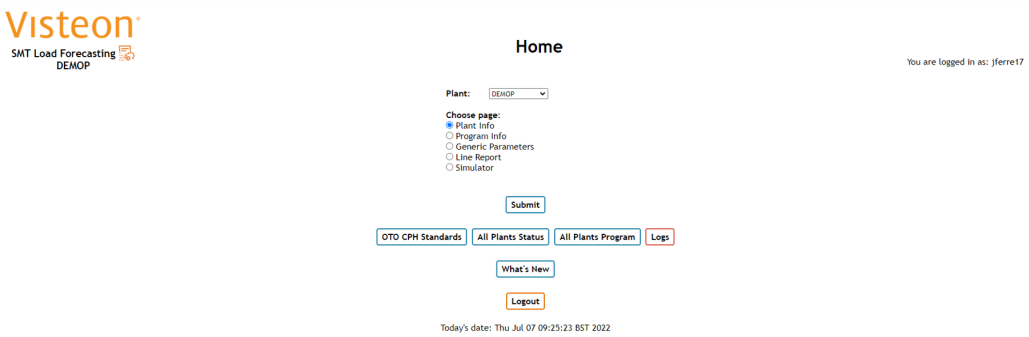


Figure 2.10: The Digital Twin's Homepage

In the "Plant Info" page the user is able to select one of the lines in his plant and hit "search". This action will display the line, the type (line shape), and CPH (line Capacity of boards Per Hour). It will also show both in side 1 and side 2 (if the selected line has a secondary side), information regarding the machines currently present on the line as well as possible changes in the future to those machines. This page is presented in the following image (figure 2.11).

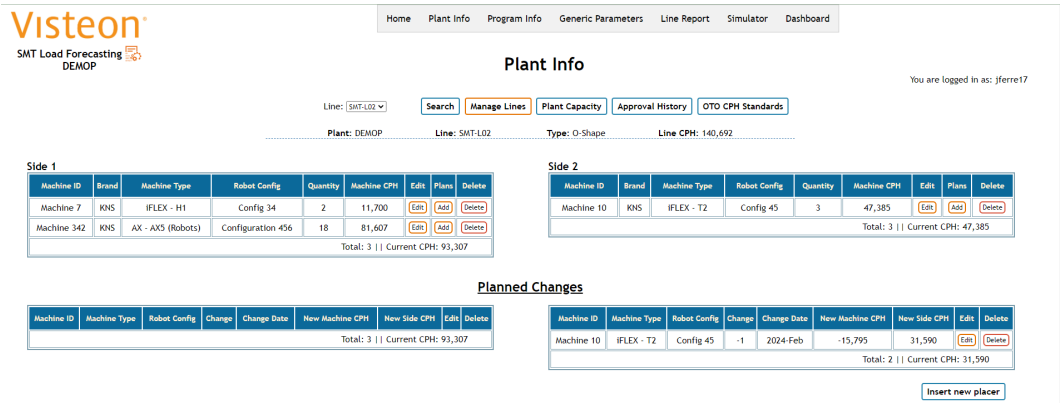


Figure 2.11: Digital Twin's "Plant info" page

The "OTO CPH Standards" button, explained before is also accessible in this page. The "Approval History" button allows the user to visualize the history of the Plant validations.

This tab also gives the possibility to the user to Manage the Plant's lines, with that meaning adding lines, changing their type, or deleting them, by clicking the "Manage Lines" button, as shown in the next image (figure 2.12).

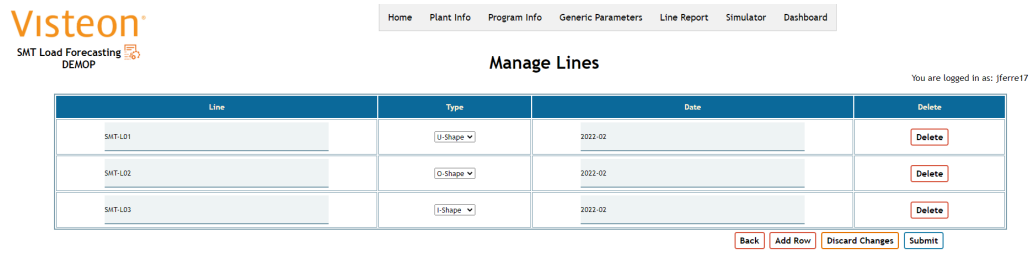
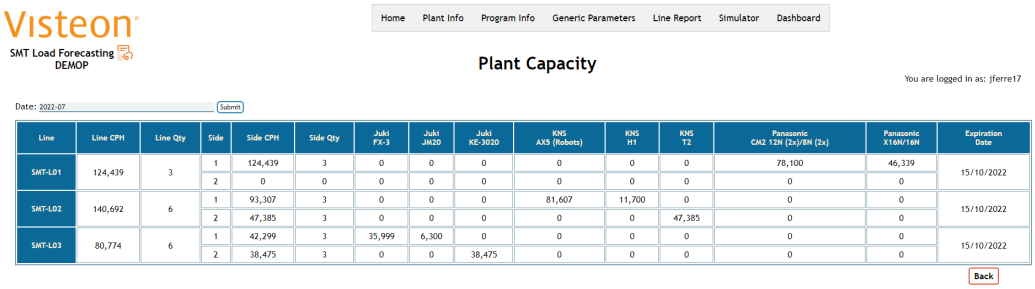


Figure 2.12: Digital Twin's "Manage Lines" page

Lastly, the "Plant Capacity" button, takes the user to another page, as in figure 2.13, where it is displayed the CPH of the Plant for each line, the CPH of each line separated by side and the CPH of each line separated by side and separated by machine.



Line	Line CPH	Line Qty	Side	Side CPH	Side Qty	Juki FX-3	Juki JM20	Juki KE-3020	KNS AX5 (Robots)	KNS H1	KNS T2	Panasonic CM2 12N (2x)/8N (2x)	Panasonic X16N/16N	Expiration Date
SMT-L01	124,439	3	1	124,439	3	0	0	0	0	0	0	78,100	46,339	15/10/2022
			2	0	0	0	0	0	0	0	0	0	0	
SMT-L02	140,692	6	1	93,307	3	0	0	0	81,607	11,700	0	0	0	15/10/2022
			2	47,385	3	0	0	0	0	0	47,385	0	0	
SMT-L03	80,774	6	1	42,299	3	35,999	6,300	0	0	0	0	0	0	15/10/2022
			2	38,475	3	0	0	38,475	0	0	0	0	0	

Figure 2.13: Digital Twin's "Plant Capacity" page

On the top of most pages there is a section that allows the user to change tabs, with the "Home" tab redirecting the user to the Digital Twin's Homepage.

Next up there is the "Program Info" page, displayed in figure 2.14. Here is displayed all the programs of all lines on the plant along with useful information regarding them. Some filtering buttons are provided to help necessary searches, "New", "Pending" and "Valid", "Production", "Awarded" and "Pursuit". The last three filters refer, respectively, to the variants currently in production, the variants that will be produced, and the variants that are still being negotiated to be produced. The buttons "Clear" and "Clear All" are used to remove those filters and "Show Volume" display the Total Volume separately by years. There is the "Excel" button that allows the exportation of the table to Microsoft Excel while the "Download Programs Boards – Excel" Button exports information about the boards that are part of those programs to Microsoft Excel. The last button on this page is the "Non-IFS Programs" that takes the user to a separate page that shows all of the programs that can be added manually (normally programs come from IFS whilst manual programs are created manually due to adjustments by the plant engineers of what is going to be produced).

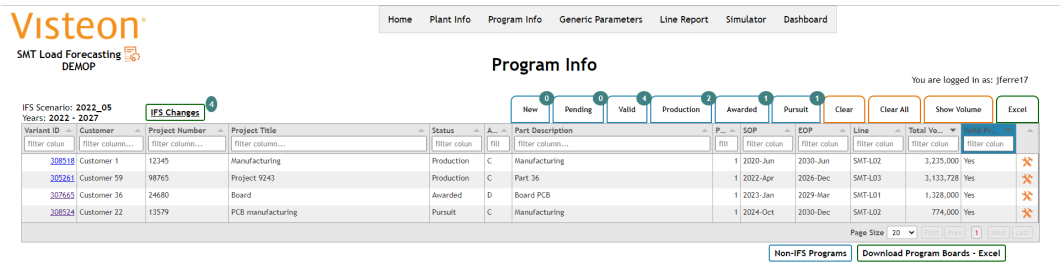


Figure 2.14: Digital Twin's "Program Info" page

By clicking on the orange tool icon on the last column, the user is redirected to the "Manufacturing Details" page (figure 2.15), where a more detailed look at a program can be analyzed, including all the boards contained in that program. Almost all the fields in the boards are changeable, giving users the ability to modify, add or remove boards from the programs.

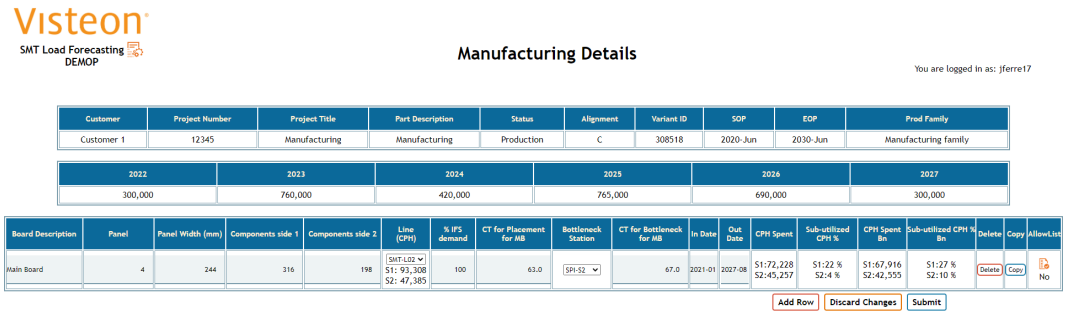


Figure 2.15: Digital Twin's "Manufacturing Details" page

The "Generic Parameters" tab provides an overview and the ability to change some key parameters of the current plant, the OEE (the coefficient allows taking into consideration the inefficiencies of the line while changing board models), the Efficiency of the Placer machines, the average available hours per day that the plant is producing and the average available days per month that the plant is producing. This page is shown in the next image (figure 2.16).

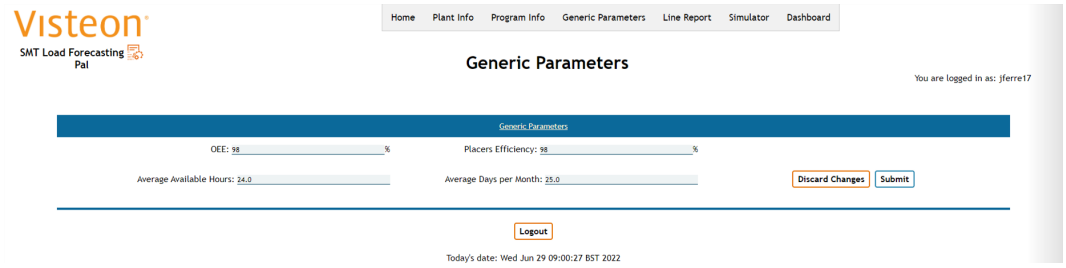


Figure 2.16: Digital Twin's "Generic Parameters" page

In the "Line Report" page, represented by figure 2.17, a joined version of the "Plant Info" and "Program Info" pages is displayed, it is shown the current machines in the selected line as well as the planned machine changes, and also the programs of that line. There is a section for commentaries if desired and a validation method for certain users to make sure the data is correct. The "Exceptions" button displays a categorized list of boards and/or programs that are considered to have problems.

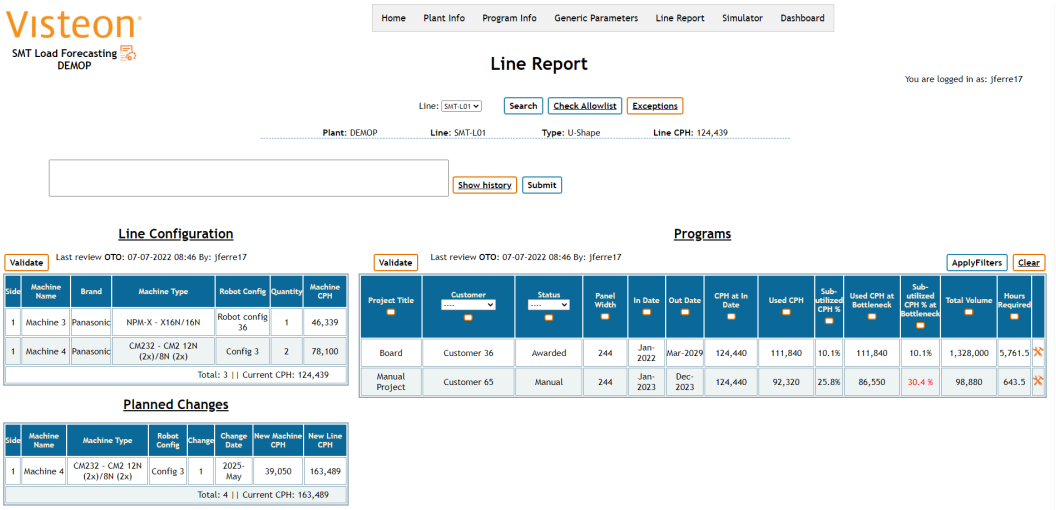


Figure 2.17: Digital Twin's "Line Report" page

The Last tab, "Dashboard" redirects the user to a page that has the dashboards with plant data to further enlightenment, as it can be visualized in the following image (figure 2.18). These are the Dashboards that use QlikView, including the Manufacturing Ops Excellence, the Data Analyses, the Prod Analyses and the SMT LoadCharts Dashboards. QlikView is a virtual tool used for dashboard creation and interaction, used by Visteon [37].

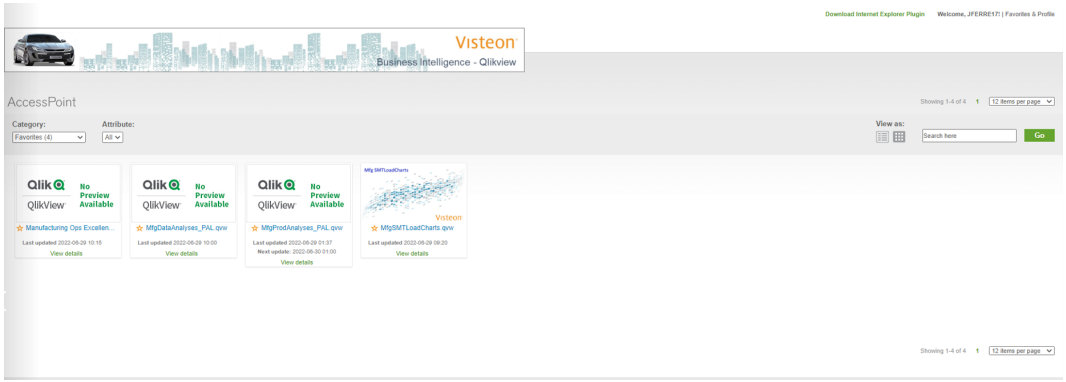


Figure 2.18: Digital Twin's Dashboard list page

The "Simulator" page brings up an interface that allows the user to create new line scenarios, that copies the selected line load to the new scenario. When a scenario already exists, there are the possibilities to Load and Simulate it, that will take the user to new pages that will be show briefly, as well as copying, deleting, or renaming that scenario (figure 2.19).

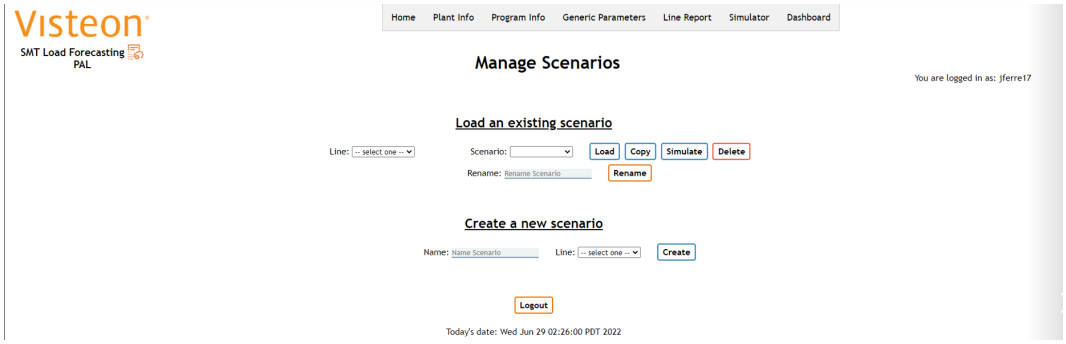


Figure 2.19: Digital Twin's "Manage Scenarios" page

When loading or after the creation of a custom scenario, the user is redirected to the "Scenario Homepage" page, shown in figure 2.20. Here it is possible to add, change and delete machines and boards, by using the "edit" buttons on both the boards and line configurations, giving the user a way to make any changes on the line. The "Non-IFS Programs" displays a list of the programs that can be added manually (these can also be created, changed and deleted). If the user clicks the "Simulate" button, he is redirected to the Load Simulator page.

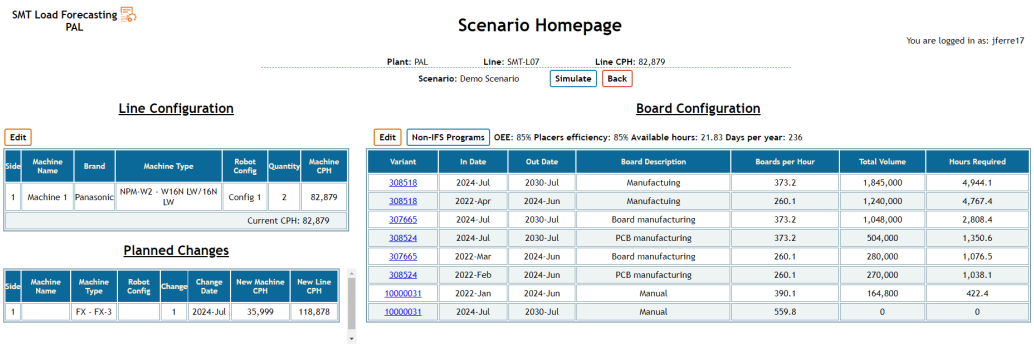


Figure 2.20: Digital Twin's "Scenario Homepage" page

As displayed in figure 2.21, in the "Load Simulator" page it is possible to test the changes made in the Scenario Homepage to the custom line scenario and study its impact. To this extent, it is displayed in a bar graph, "Average Daily Placements (M)", the total line load, separated by the loads that are considered to be production, awarded, pursuit or manual, for the next six years. The load capacity that each shift is able to produce is also shown in this graph.

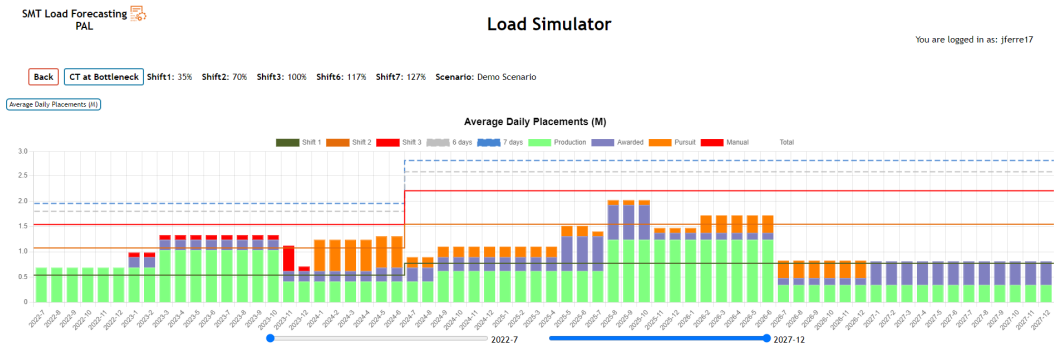


Figure 2.21: Digital Twin's "Load Simulator" page (part 1)

There are two other graphs (figure 2.22) with a similar structure to the last one. The "Utilization (%)" shows the percentage of the line capacity that is being used whilst the "Utilization (Hours)" is populated with the same data, but its value is presented in hours.

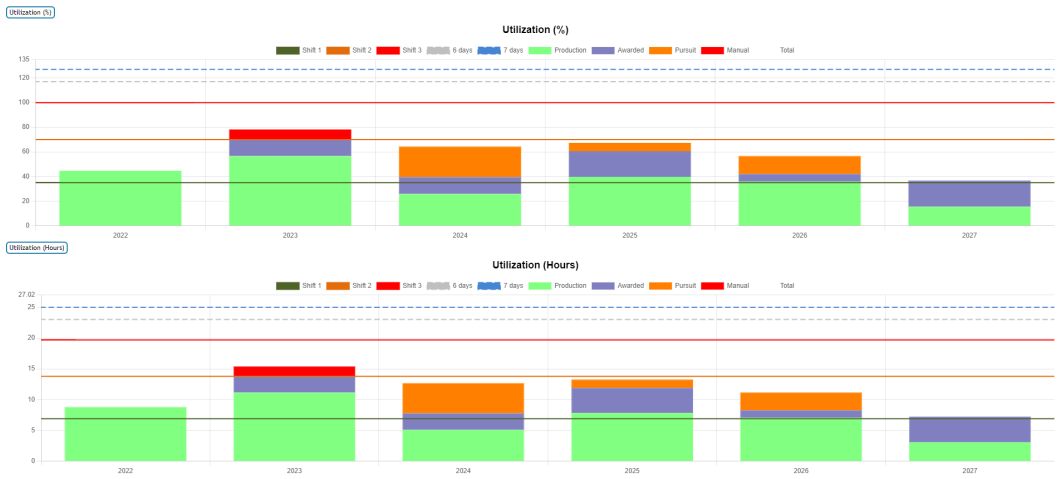


Figure 2.22: Digital Twin's "Load Simulator" page (part 2)

In bottom of the page, as displayed in figure 2.23, are displayed the programs in that line and the respective information about them. It has a filtering button that, by selecting and clicking the "Apply" button, allows choosing a different set of boards and visualizing the changes in the graphs. Lastly there are two buttons with green borders, "Excel - Yearly" and "Excel - Monthly" that allow exporting the program's table to Excel, with the volumes by each year and by each month, respectively.

Back Apply Excel - Yearly Excel - Monthly OEE: 85% Placers efficiency: 85% Available hours: 21.83 Days per year: 236

Program Title	Customer	Variant	Board Description	Panel Width	Status	Total Volume		2022	2023	2024	2025	2026	2027	
Manufacturing	Costumer 1	308518	Manufactuing	100	Production	1,845,000	Volume	0	0	240,000	765,000	690,000	150,000	☑
							Utilization	0 %	0 %	12.46 %	39.72 %	35.83 %	7.79 %	
Manufacturing	Costumer 1	308518	Manufactuing	100	Production	1,240,000	Volume	300,000	760,000	180,000	0	0	0	☑
							Utilization	44.7 %	56.62 %	13.41 %	0 %	0 %	0 %	
Board	Costumer 36	307665	Board manufacturing	100	Awarded	1,048,000	Volume	0	0	120,000	400,000	120,000	408,000	☑
							Utilization	0 %	0 %	6.23 %	20.77 %	6.23 %	21.19 %	
PCB manufacturing	Costumer 22	308524	PCB manufacturing	100	Pursuit	504,000	Volume	0	0	90,000	132,000	282,000	0	☑
							Utilization	0 %	0 %	4.67 %	6.85 %	14.64 %	0 %	
Board	Costumer 36	307665	Board manufacturing	100	Awarded	280,000	Volume	0	180,000	100,000	0	0	0	☑
							Utilization	0 %	13.41 %	7.45 %	0 %	0 %	0 %	
PCB manufacturing	Costumer 22	308524	PCB manufacturing	100	Pursuit	270,000	Volume	0	0	270,000	0	0	0	☑
							Utilization	0 %	0 %	20.12 %	0 %	0 %	0 %	
Manual Project	Costumer 65	10000031	Manual	100	Manual	164,800	Volume	0	164,800	0	0	0	0	☑
							Utilization	0 %	8.19 %	0 %	0 %	0 %	0 %	
Total						5,351,800	Volume	300,000	1,104,800	1,000,000	1,297,000	1,092,000	558,000	
							Utilization	44.7 %	78.22 %	64.34 %	67.35 %	56.7 %	28.98 %	

Back Apply Top

Figure 2.23: Digital Twin's "Load Simulator" page (part 3)

2.5.3 Visteon's LoadCharts Dashboard

From the Dashboards list it is important to highlight the SMT LoadCharts Dashboard. In general, this Dashboard serves as an interactive tool to visualize SMT Production Lines data graphically, in contrary to the denser way in the SMT Load Forecast.

The Dashboard is organized in eleven different tabs, with each one displaying different ways of looking at the data. Noting that all of the pages, except the "CPH Over Time" page, have the ability to filter the data by Plant, Status (production, awarded, pursuit or manual), Panel width (panel width of the boards), Line and Source (IFS (production, awarded or pursuit) or Manual), the tabs are as follows:

• In the first tab, "Main", the objective is to give the user an overview of the selected plant's board volumes per line, facing the installed capacity. To achieve this, it is shown in figure 2.24 the average daily placements (in millions) of components in the boards, for each of the lines of the selected plant. It is also shown, left of the previous graph, the average daily placements for all the lines. Lastly, at the bottom of the page, is represented the current installed capacity per side, for each of the lines in the plant.

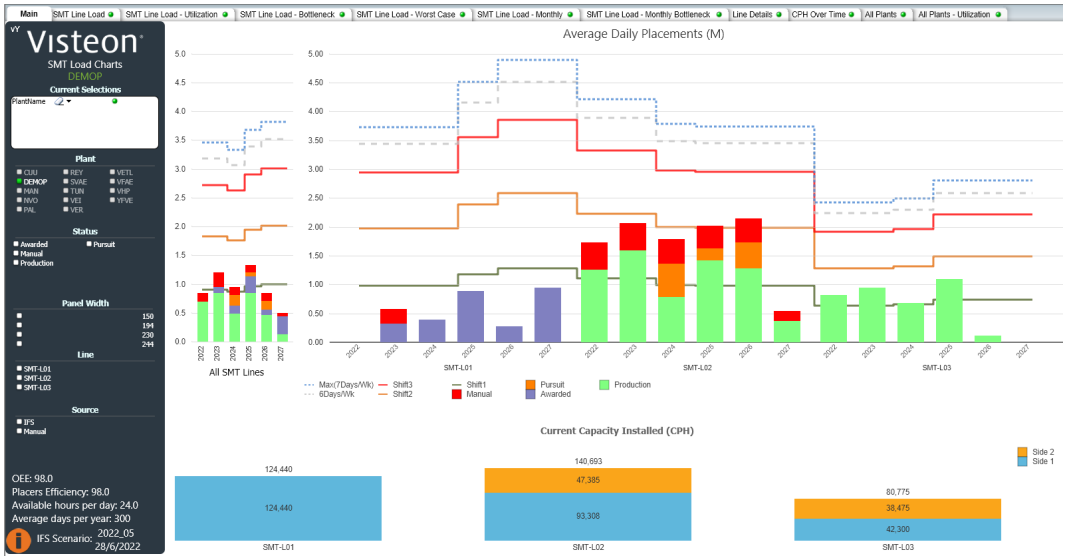


Figure 2.24: LoadCharts "Main" tab

• The following tab, "SMT Line Load", allows the comprehension of the volumes in comparison to the customers, in addition to the first tab. This time, in the graph, it is displayed in figure 2.25 the lines' utilization instead of average daily placements and there is also an extra chart where it can be seen the forecast of the volume of boards per costumer.

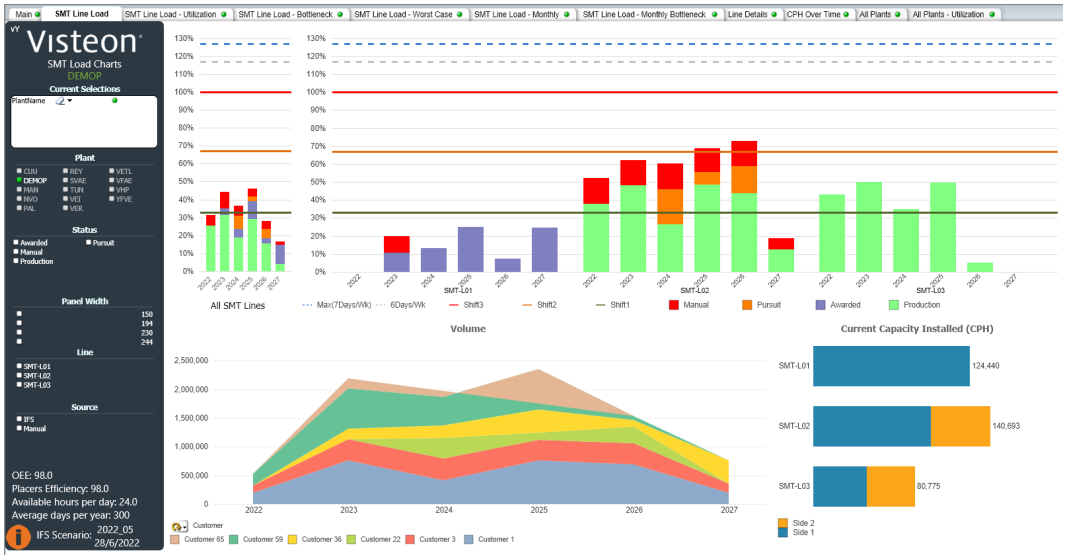


Figure 2.25: LoadCharts "SMT Line Load" tab

• Then, in the tab, " SMT Line Load – Utilization", the main goal is to analyze the line loads with the shift's capacity. As it can be in the following image (figure 2.26), the bottom graph is the same as the second graph in the last page and the top graph is also similar, except its values are presented in hours instead of percentage.

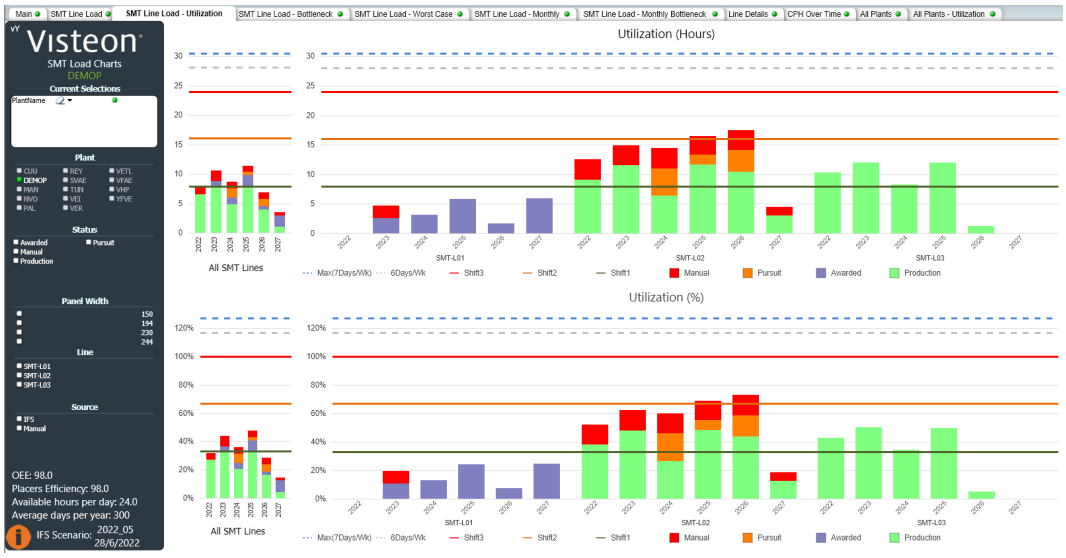


Figure 2.26: LoadCharts "SMT Line Load - Utilization" tab

• The fourth tab, shown in figure 2.27, has the exact same structure as the "Main" tab, except the data is displayed based on the bottleneck station's tycle times, so its aim is to visualize the bottleneck data.

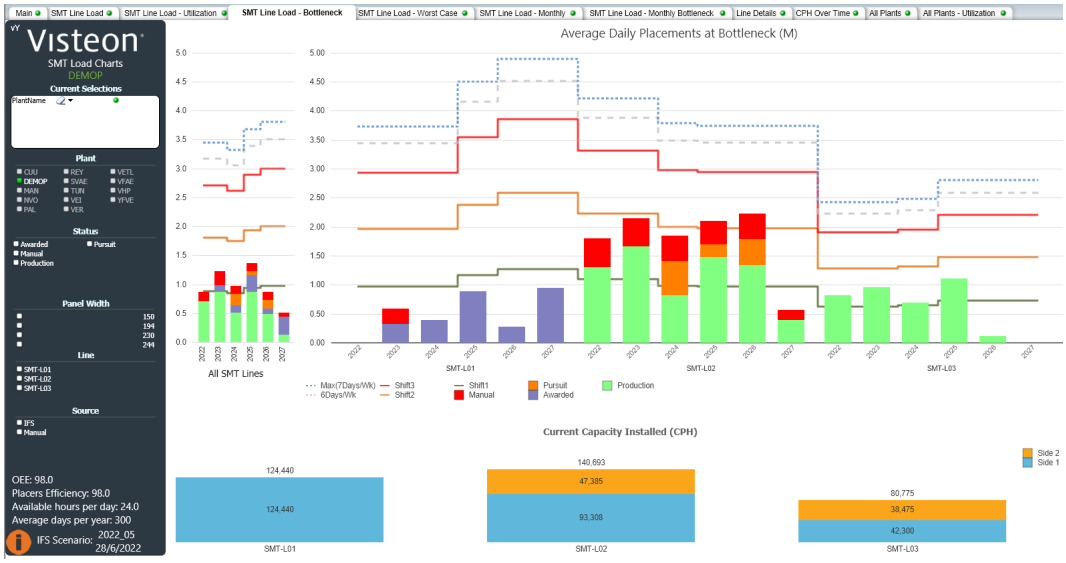


Figure 2.27: LoadCharts "SMT Line Load - Bottleneck" tab

• After, in the “SMT Line Load - Worst Case” tab, is exhibited the worst case scenario, this is the worst month of the year, with the goal of reporting the peak line load for that year. This data reporting, represented in the next image (figure 2.28), is accomplished by presenting the average daily placements, both in number (millions) and percentage, on all of the lines. To the left of each of this graphs there are two more graphs that report the worst case of all the lines.

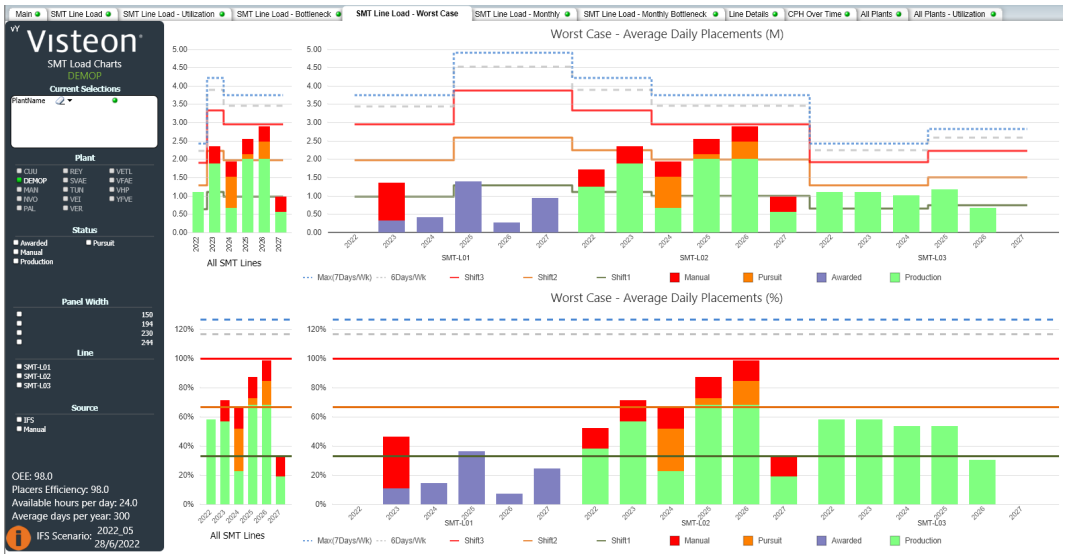


Figure 2.28: LoadCharts "SMT Line Load – Worst Case" tab

• The “SMT Line Load – Monthly” tab displays, as in figure 2.29, the average daily placements, in millions, for all of the lines. This time this data’s granularity is monthly and there is also a month filter on the bottom of the page, so this will allow the users a more detailed view of the data. If the user clicks on the “Programs” tab (figure 2.30), a popup

table will show up with the programs. The programs contains information regarding what is manufactured, and in this case, the variant (number that identifies a group of boards), the project number (or the program number), the line name and project status (program status. Can be production, awarded, pursuit or manual).

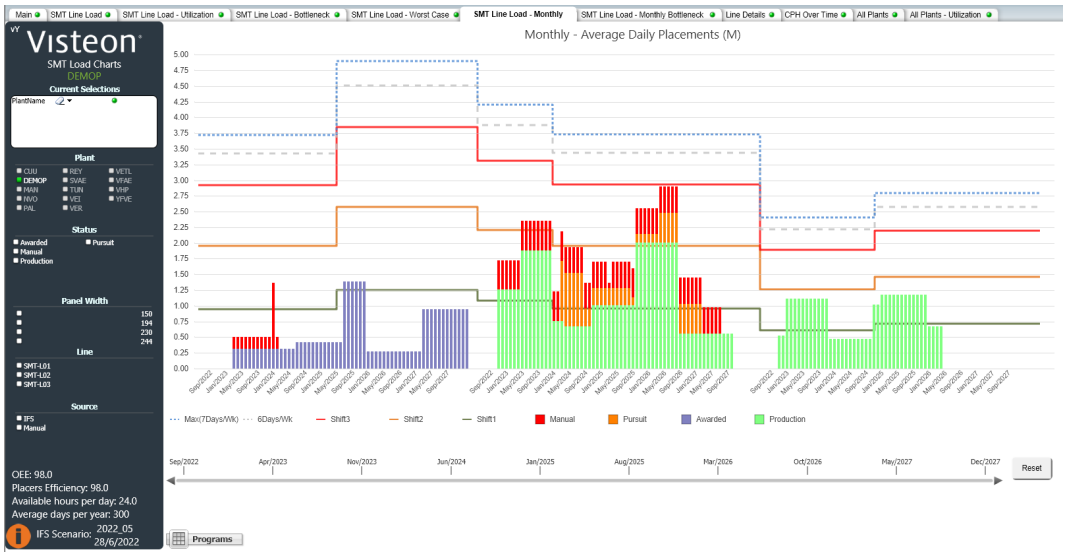


Figure 2.29: LoadCharts "SMT Line Load - Monthly" tab

Programs

Variant	ProjectNumber	LineName	ProjectStatus
305261	98765	SMT-L03	Production
307665	24680	SMT-L01	Awarded
308518	12345	SMT-L02	Production
308524	13579	SMT-L02	Pursuit
10000031	43241	SMT-L01	Manual
10000143	12345	SMT-L02	Manual
-	-	SMT-L02	-
-	-	SMT-L03	-

Figure 2.30: LoadCharts "SMT Line Load - Monthly" tab's Programs table

• The subsequent tab (figure 2.31) has the exact same structure as the last tab, except the data is displayed based on the bottleneck station's cycle times, so its goal is to visualize the bottleneck data.

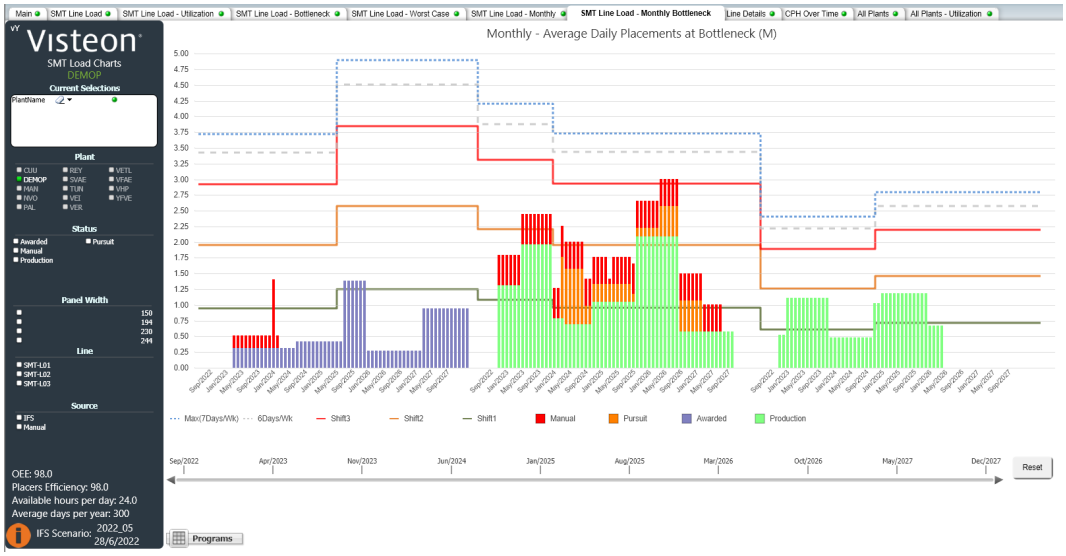


Figure 2.31: LoadCharts "SMT Line Load - Monthly Bottleneck" tab

• The "Line Details" tab has a slightly different body than all the other tabs because its main component is a table. It is used to report detailed information regarding the presented graphs in the other tabs. The next image (figure 2.32) represents this tab.

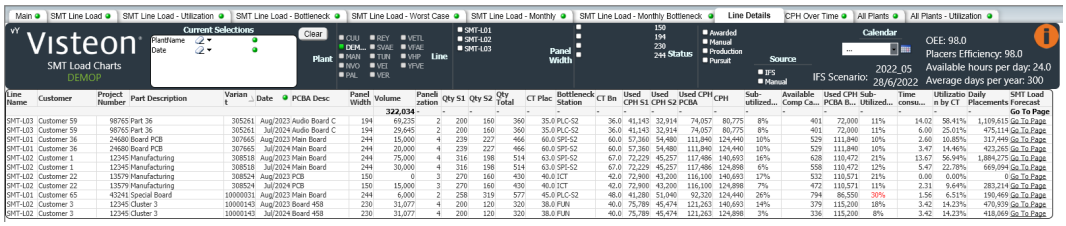


Figure 2.32: LoadCharts "Line Details" tab

• Afterwards, the "CPH Over Time" tab (figure 2.33) shows, for all of the lines, the total installed capacity (total CPH) of the machines per side, in thousands, and it is also possible to filter the date interval. This information's granularity is monthly. This tab is utilized to observe the line CPH change overtime, and consequently, machine changes.

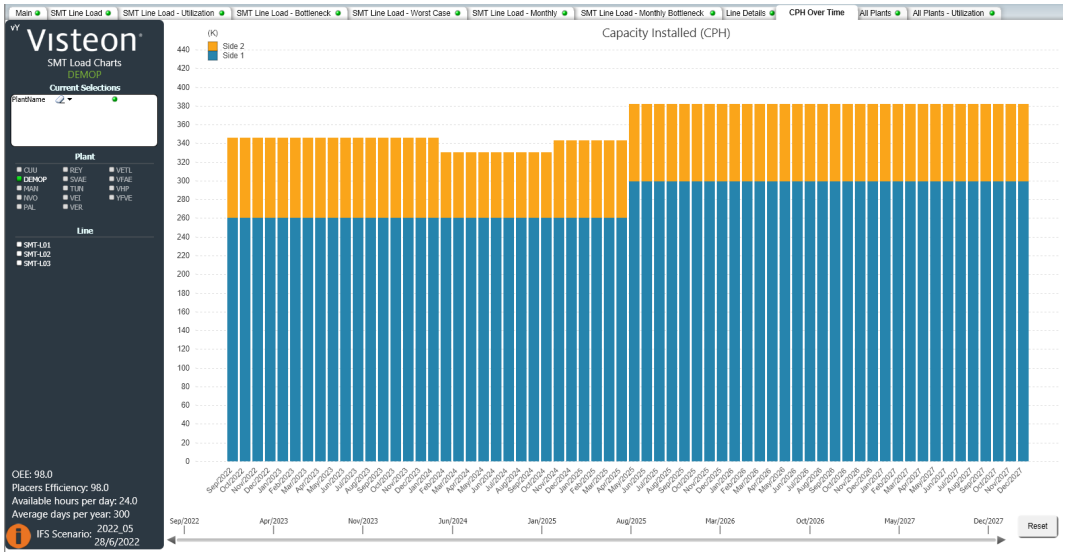


Figure 2.33: LoadCharts "CPH Over Time" tab

• The second to last tab “All Plants”, shows the average daily placements for all of the lines in each plant and also shows the number of lines in each plant, as in figure 2.34.

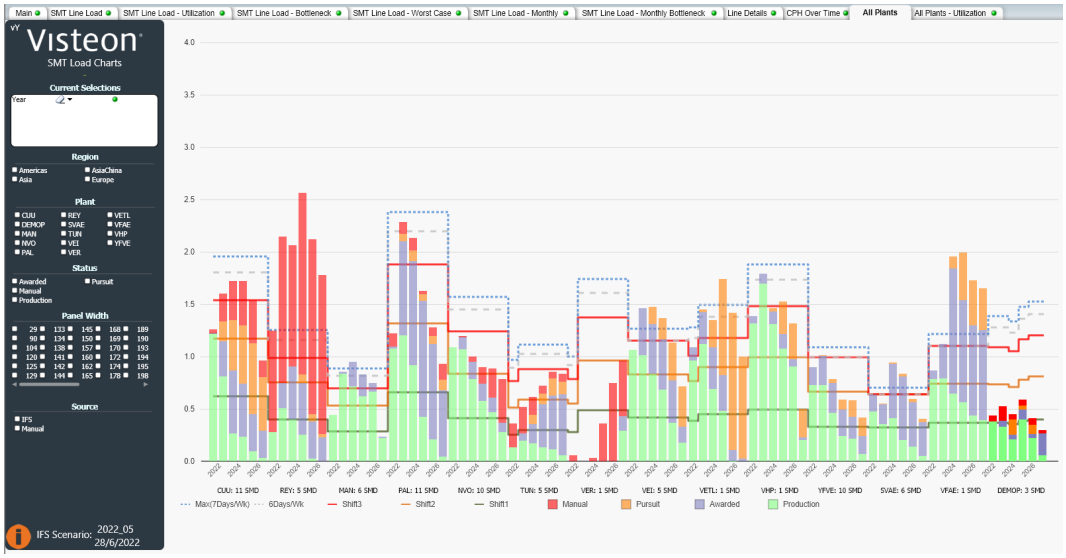


Figure 2.34: LoadCharts "All Plants" tab

• The last tab, represented in the following image (figure 2.35), has the exact same structure as the third tab (SMT Line Load - Utilization), except the displayed data is the average for all the lines of each plant. Its main goal is to analyze the plant loads with the shift’s capacity.

Figure 2.35: LoadCharts "All Plants - Utilization" tab

3

Real Performance Data Integration

3.1 Architecture

One of the sections of the proposed expansion for the Digital Twin is Integrating live performance data from the SMT production lines directly in to the Digital Twin. This is expected to enchase the predictive skill of the Digital Twin that allows better decision making and planning regarding the SMT production lines.

This project involves gathering real performance data to use in the Digital Twin, so the theoretical CPH and CT (cycle time of a board in a mandatory station) of the boards regarding that process currently in use, are planned to be updated. This can be done by implementing a connection between the SMT Load Forecast and CIMPLE, with the latter containing the real CT which can then be used to calculate the real CPH.

The following image (figure 3.1) presents the diagram of the mentioned logic of gathering the necessary information and implementing the connection between SMT Load Forecast and CIMPLE. The IRIS Database will be explained later on this dissertation.

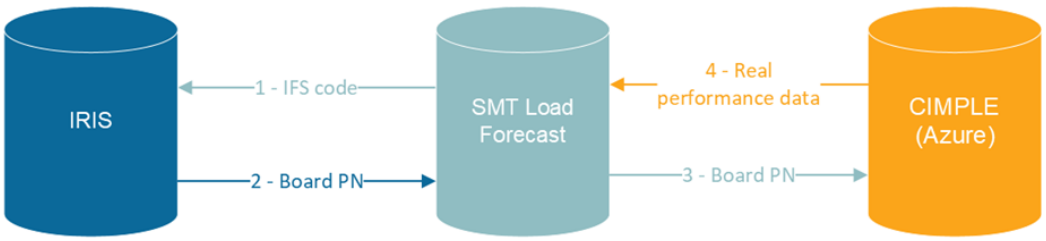


Figure 3.1: Real Performance Data project's Diagram

To report the new real data and its comparison to the theoretical data, it will be created a new section on the Digital Twin as well as in the LoadCharts Dashboard.

To help displaying this data in graphs and other charts, a few ideas were procured on the book "The Big Book of Dashboards" [38].

To better understand the parameters and data that exists on each of the databases, and

how they are organized, the following scheme is presented (figure 3.2).

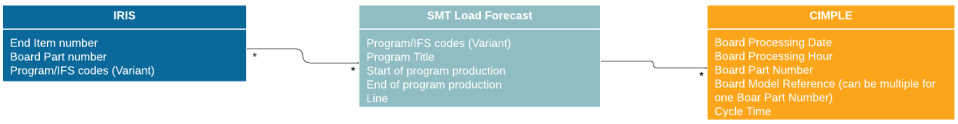


Figure 3.2: Real Performance Data project's Scheme

3.1.1 Digital Twin

Regarding the section on the Digital Twin, it is purposed to be added a new tab, named Real Performance Data, that will redirect the user to a page with his assigned plant. As the goal of this dissertation is to test the real performance data addition just in one line in Palmela plant, only this part will be implemented, however, when planning the layout of the page, it was already taken into consideration that this exercise would be expanded to this whole plant and also to the other plants.

The first page of the Real Performance Data section is dedicated to displaying the values of the real CT and CPH and comparing those to their theoretical values in a plant environment, with that meaning that these values will reflect the average values of all lines of that plant combined.

There were a few drafts that were made for data reporting regarding this subject before a final version, and as such, those will be shown.

Firstly, it is shown the overview for the new Digital Twin section in the next diagram (figure 3.3).

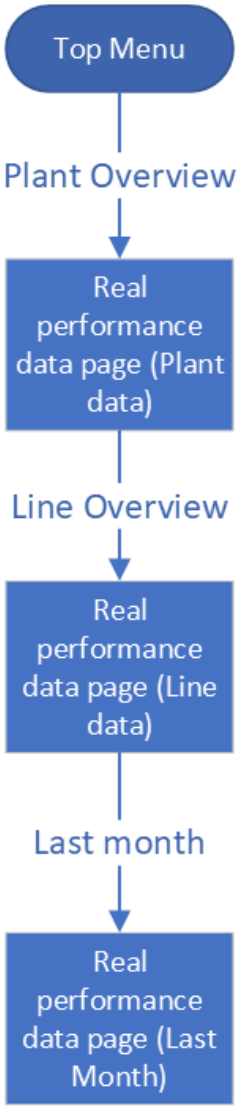


Figure 3.3: Digital Twin Real Performance Data Section Layout

Starting with the first version of the purposed architecture, at the top of the first page, as it can be seen in figure figure 3.4, it would be shown in text the values and differences in percentage of the Real and Theoretical CT and CPH in the placement machines and bottleneck machine.

Then it would be displayed the Real And Theoretical Line loads forecast for the following six months, in separate graphs, per line.

Lastly and at the bottom of the page, there would be a table with key data regarding the new and theoretical values, ordered by the lines. To go to the second page, one of the lines must be clicked on.

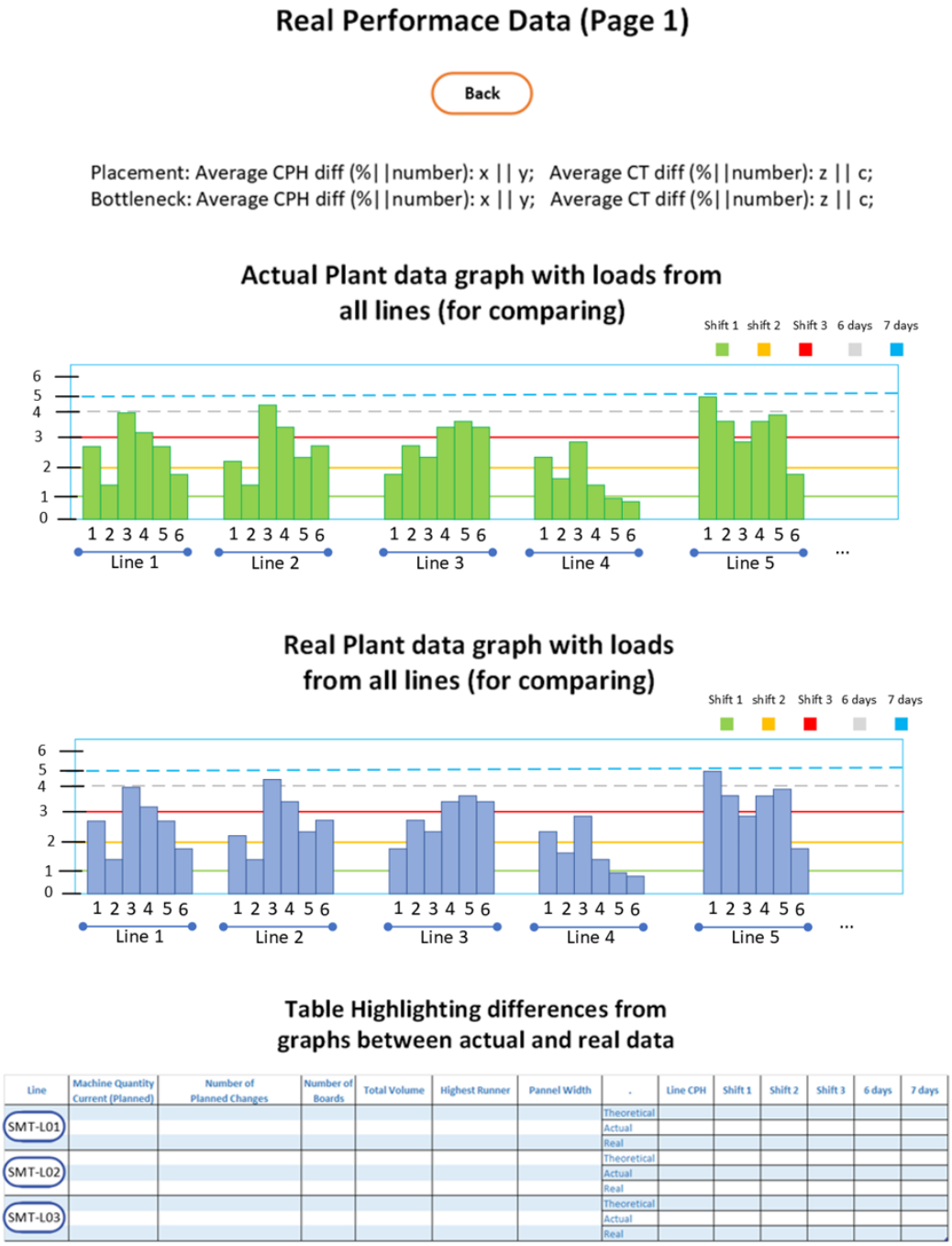


Figure 3.4: Draft 1 - Real Performance Data Page 1

The following page is regarding a line. Here is both shown the values of the real CT and CPH and the comparison between them to their Theoretical values, but this time in a line environment.

With this in mind, on the first draft of this page, on the upper part, it will be presented in text the values and difference in percentage of the Real and Theoretical CT and CPH in the placement machines and bottleneck machine.

After, two graphs (one with real data and another with theoretical data) with the line

loads forecast for the next six months, by week, are purposed to be drawn.

And lastly, the lower part of the page would contain a table with all of the programs in production in that line, ordered by variant. The idea here would be getting to the third page to view detailed information about each variant by clicking on it. This page is represented in the next image (figure 3.5).

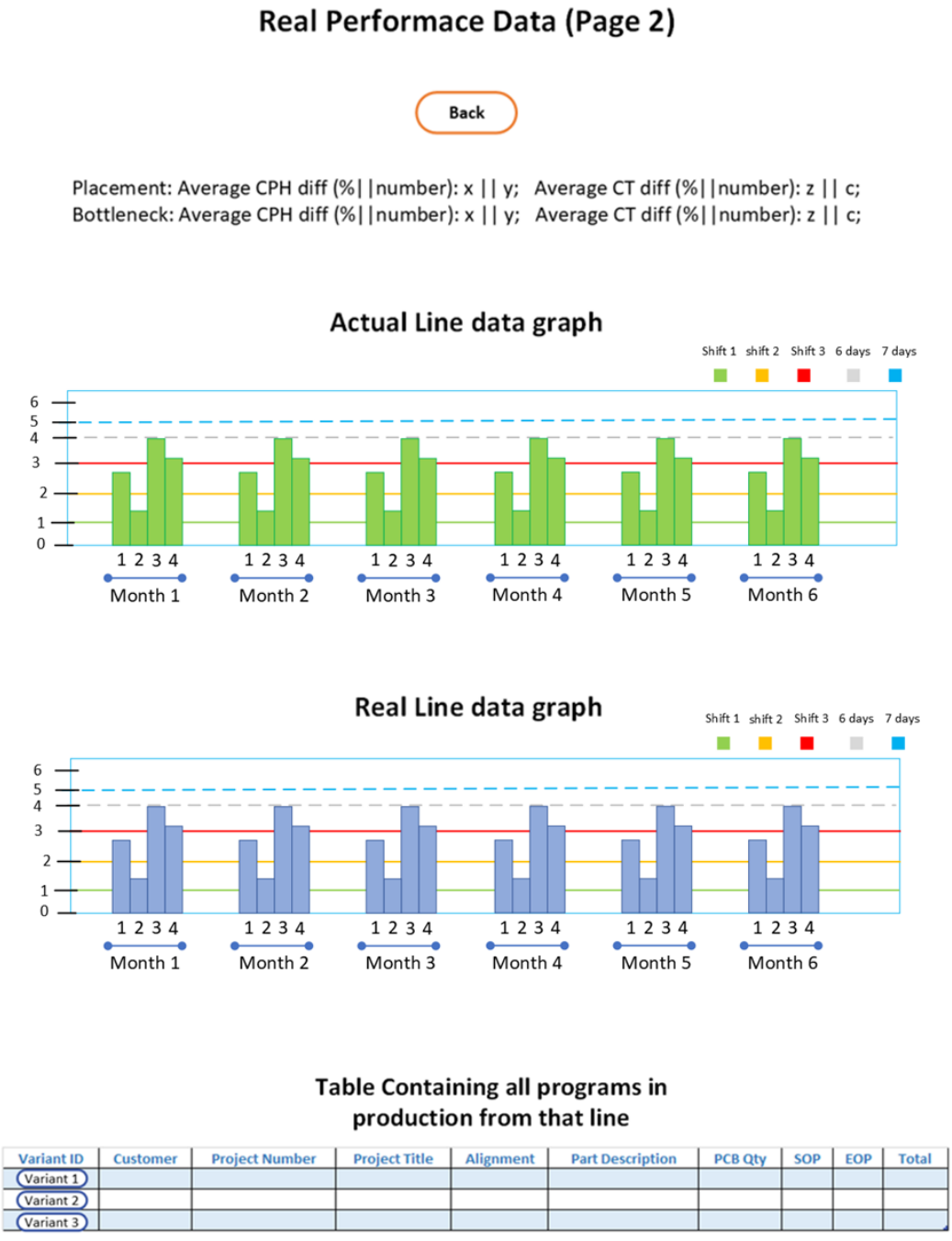


Figure 3.5: Draft 1 - Real Performance Data Page 2

The last page of the new Digital Twin section was firstly thought of containing the

comparison between the Real and Theoretical data of each of the existing variants in the former page.

On the first draft, and as it is presented in the Manufacturing Details page of the Digital Twin, this page would have general information about the program variant, as well as its associated boards and with the correspondent volumes, for the year in question and the following six years.

Then for the comparison there would be a table (for each of the boards) with the values of the Real and Theoretical CT on the Bottleneck Station.

Figure 3.6 displays this page.

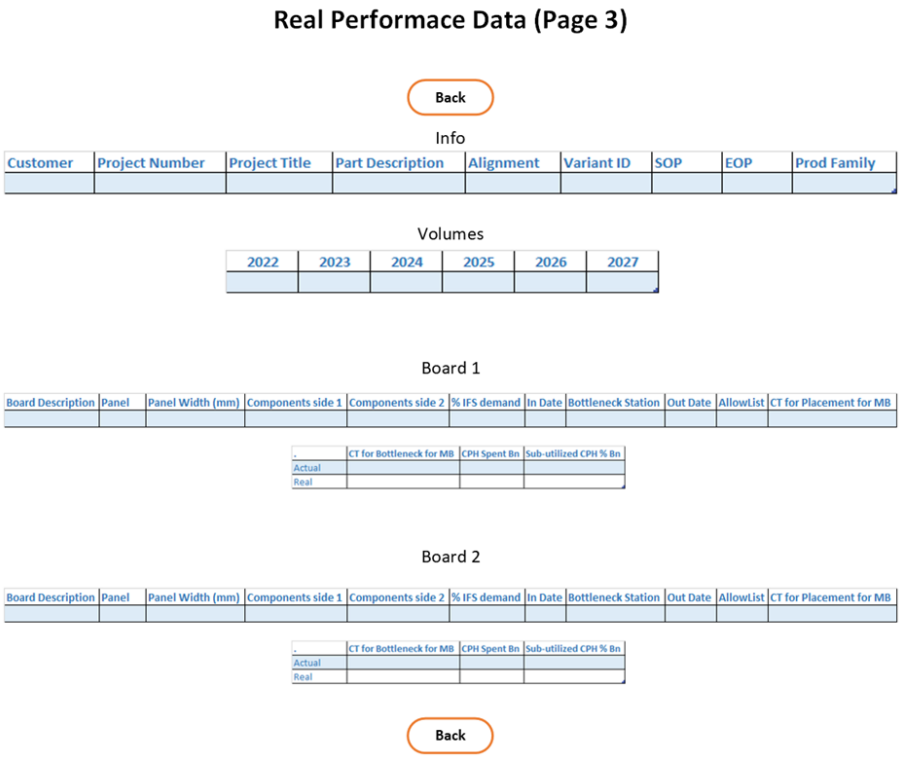


Figure 3.6: Draft 1 - Real Performance Data Page 3

After analyzing this first draft of the three pages, it rapidly came to conclusion that there were some issues with the data visualization.

To the extent of correcting this issues, a second draft was purposed for the new Digital Twin section.

On the first page of the second draft there were two main changes. Firstly, to display the difference and values of the real CT and CPH, it was only considered the placement machines, because only these were considered in the Theoretical calculation on the Digital Twin, so it was more correctly to only include these. Then although the values for the real and Theoretical CT and CPH were still written in text, the difference between those was

now purposed to be displayed in a one dimension horizontal bar graph, with overlapping data.

After, the plant load graphs in this page would still contain the same data with the same restrictions, but now the two graphs (The Theoretical data and the Real data graphs) will be joined in the same chart, by putting the data side by side. The updated draft can be visualized in the next image (figure 3.7).

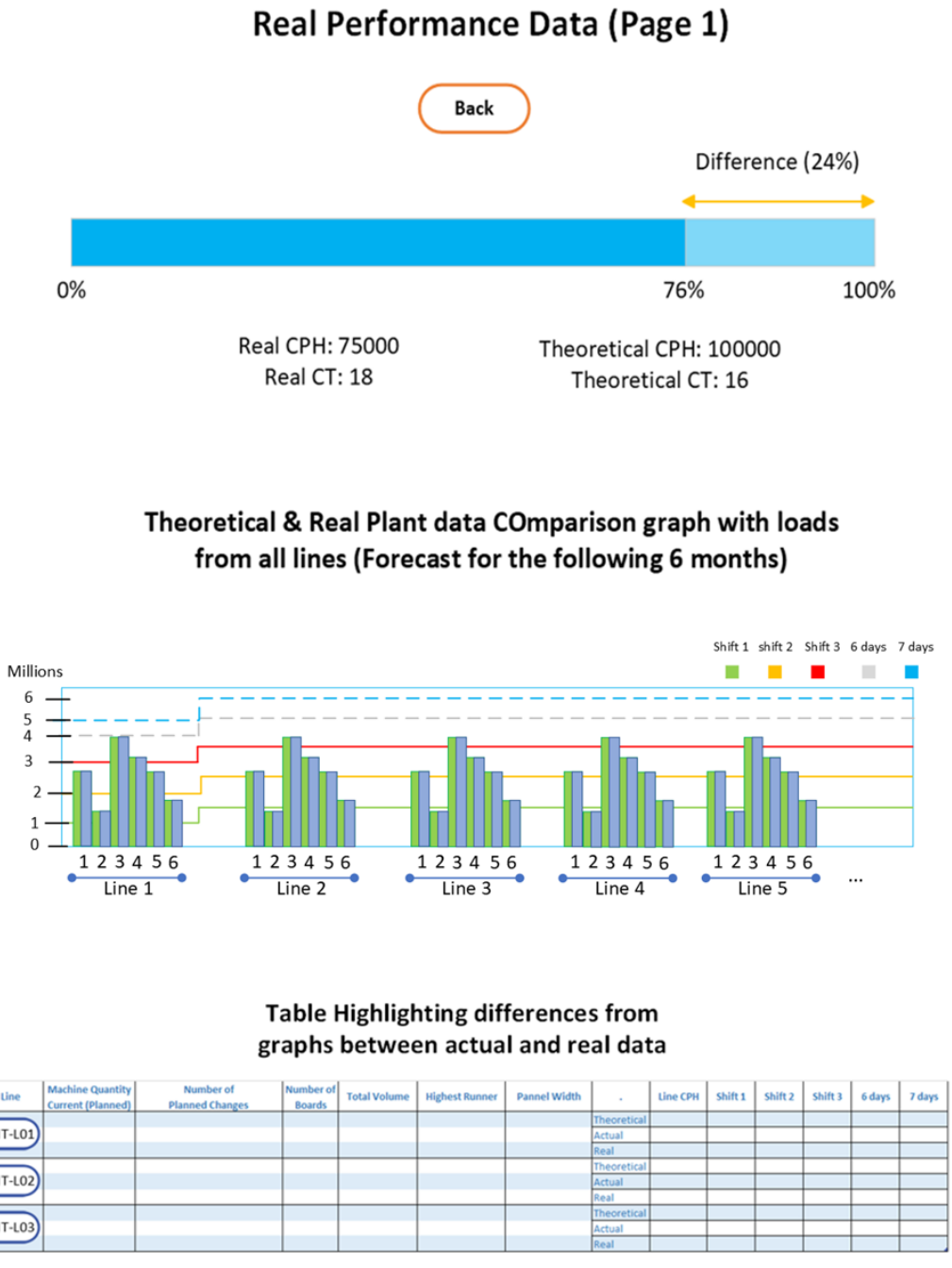


Figure 3.7: Draft 2 - Real Performance Data Page 1

The second page (figure 3.8) would now have a similar interface to display the Real and Theoretical CT and CPH, as explained before in the first page, on the top.

The weekly line load graph consists of a joined version of the Theoretical and Real data graphs and now displays only one month at a time and comes with the ability to filter by each month (to a cap of the next six months) by clicking on the blue buttons with the different months. The purple buttons with the week have the function of redirecting the user to the third page, which now contains detailed information regarding the selected week on the selected month.

The table on the bottom of the page is now divided in two tables and has a different format. The first table contains key information about all the boards, separated by board part number, as well as a comparison in a small chart between the CTs of that board, Real, Theoretical and Target, all this on the selected month, with the Target CT being the desired CT to have on the line to reach peak optimization.

As some of the data that will be brought to the Digital Twin is regarding the last month's real data it was thought that that data could be interesting and useful to be displayed for the users as well. The second table was created with this in mind. It was thought of containing that data as well as the Target CT.

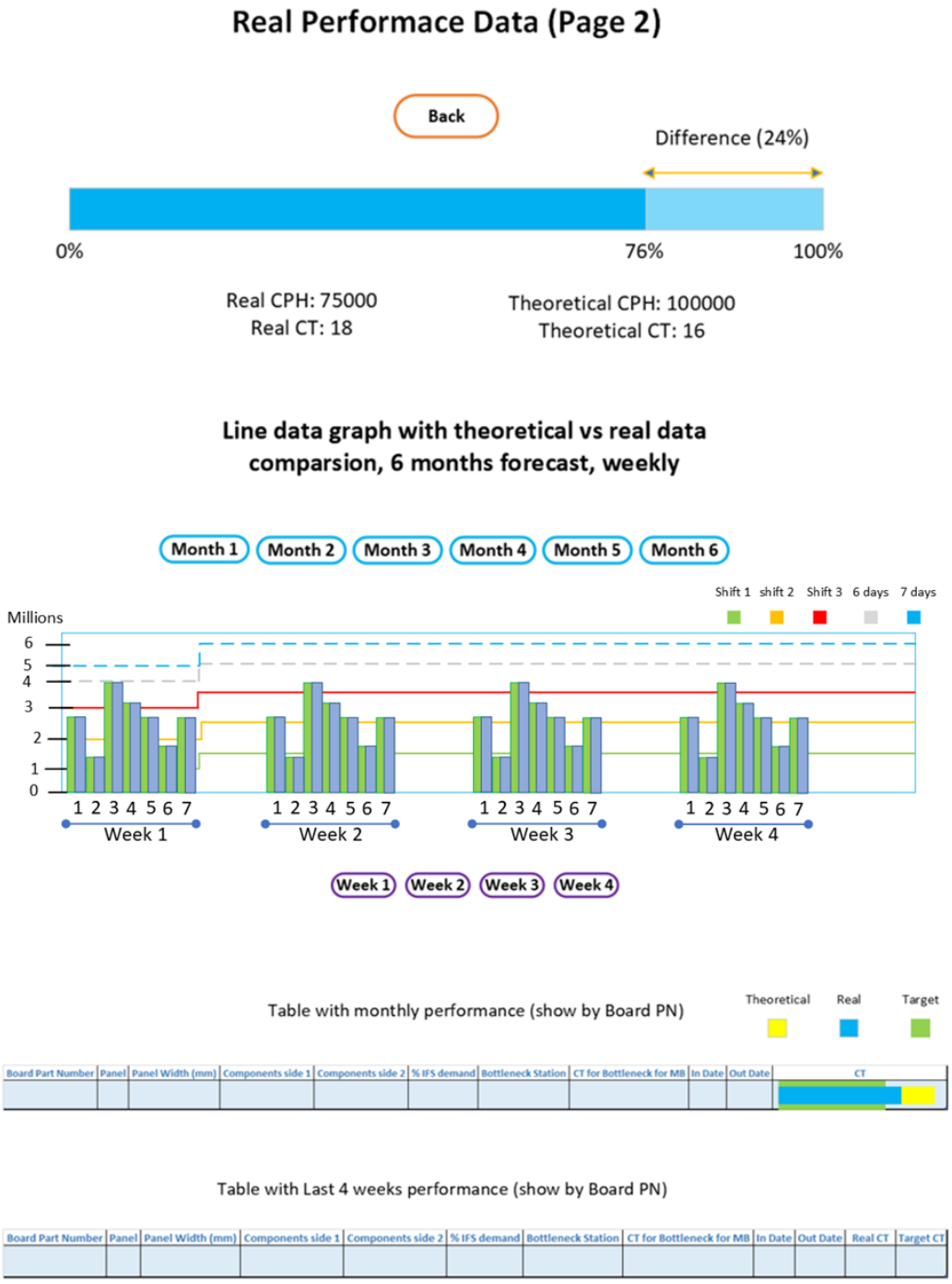


Figure 3.8: Draft 2 - Real Performance Data Page 2

Now, the third page (figure 3.9) was focused on displaying the selected week's detailed data. First there would be a chart with the Theoretical line load vs Real line load with warnings on the possible overloads of the shift's capacity when considering the real data.

And at the bottom a table was positioned with key information about all the boards, exactly like the first table on the last page, but now applied only to one week.

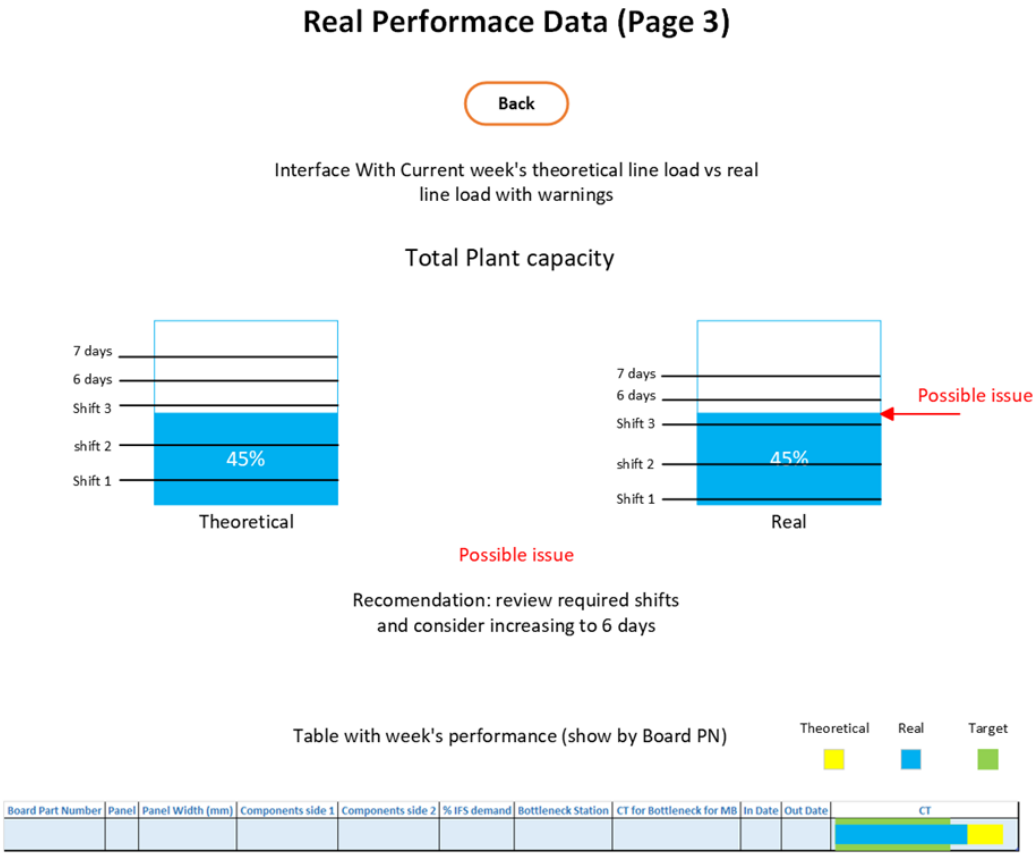


Figure 3.9: Draft 2 - Real Performance Data Page 3

After this second draft there were still issues with data visualization and also even with some data displaying conflicts due to having the intention of displaying non-existing data.

On the third draft, the first page only had one difference, visible in figure 3.10, which was the fact that now the values of the Theoretical and real CT and CPH displayed on the top of the page had both their own graph.

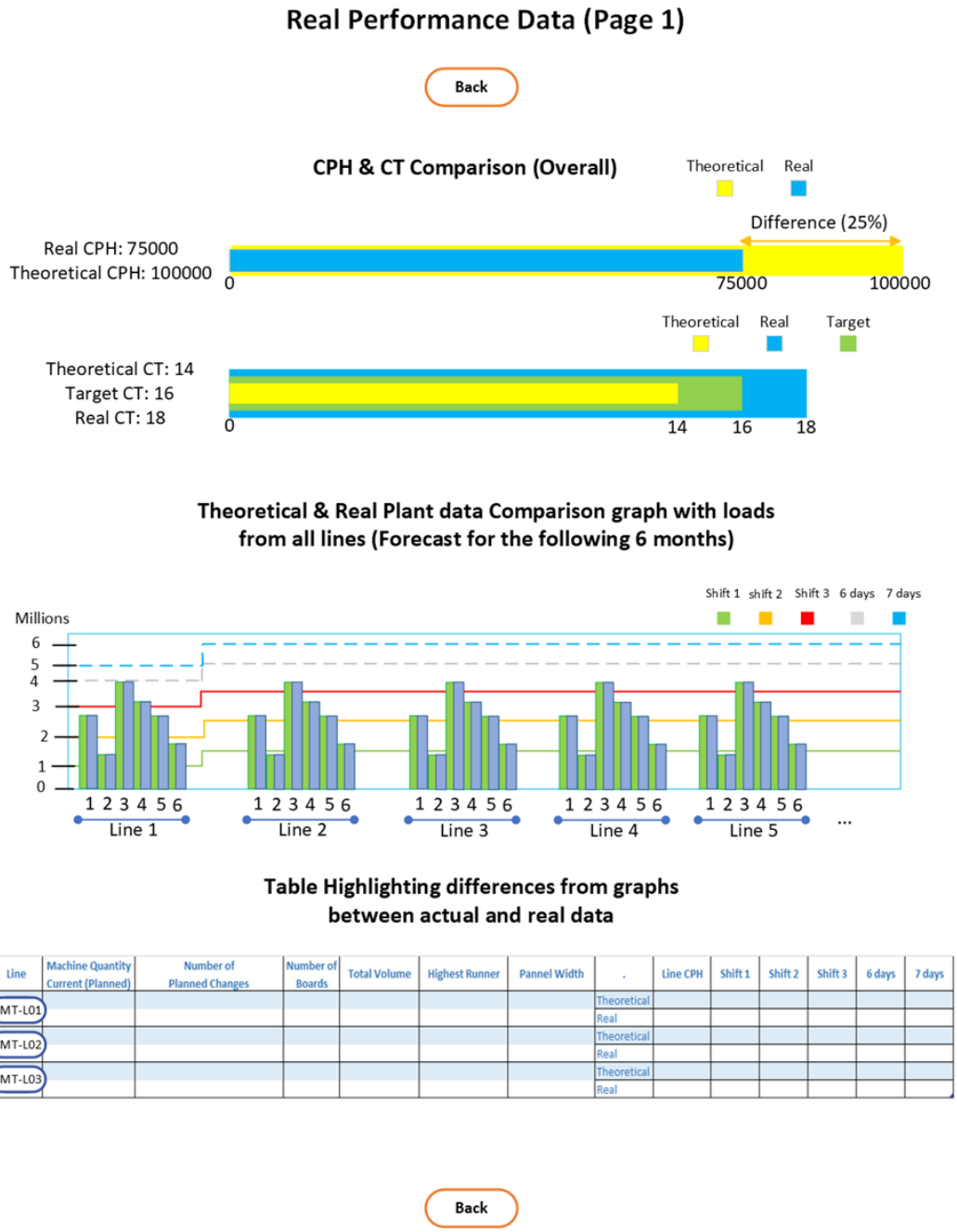


Figure 3.10: Draft 3 - Real Performance Data Page 1

It was purposed that on the second page that the comparison between the Theoretical and Real CT and CPH would be implemented the same way as in the former page.

Now, in the graph presented in figure 3.11, the data comparison would be seen by month, instead of by week, and after that, there would be an interface with warnings regarding the line shift's capacity.

On the bottom of the page, the last table on the previous draft was removed, with the first one remaining the same.

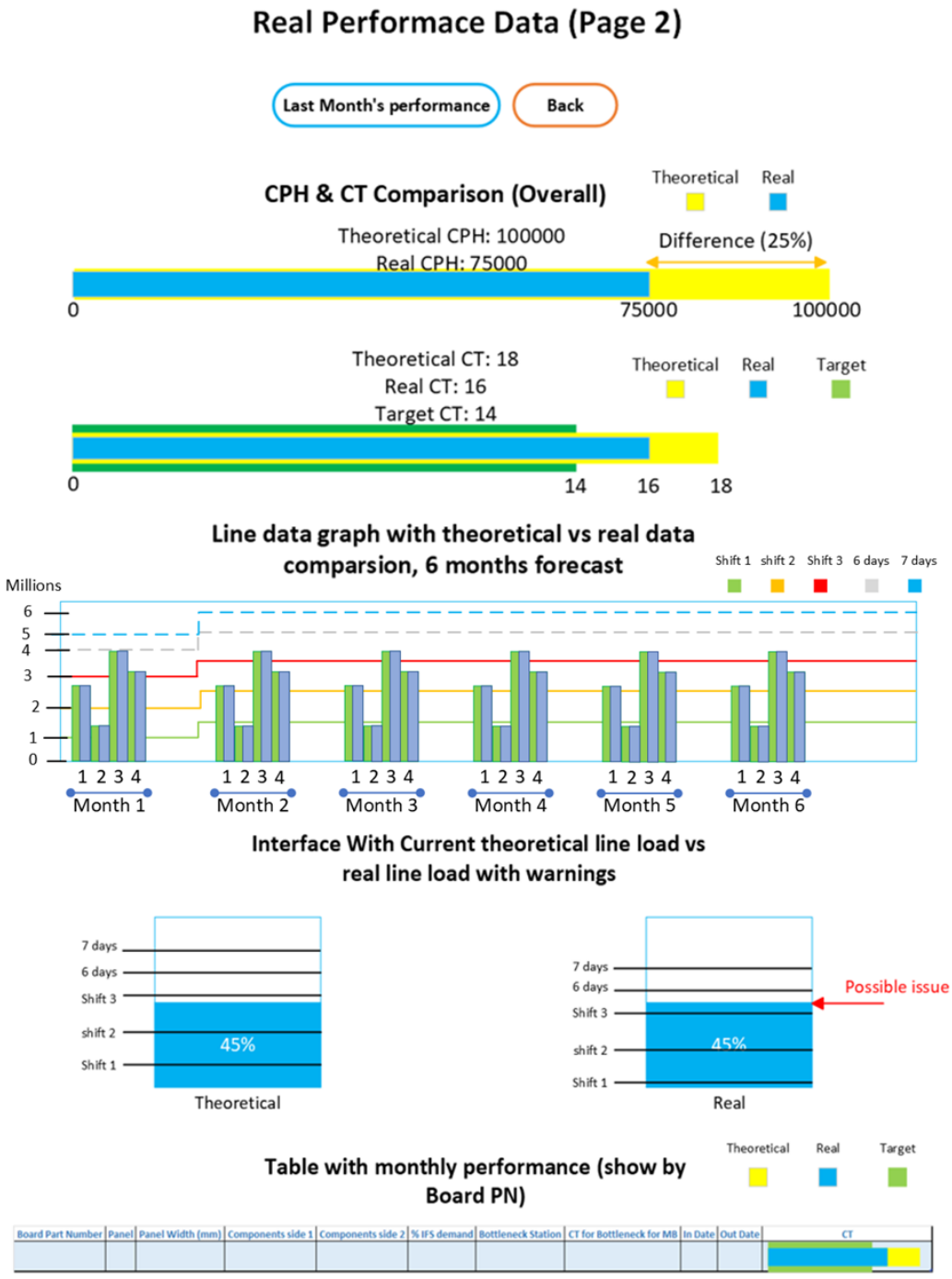


Figure 3.11: Draft 3 - Real Performance Data Page 2

This time the last page was focused on displaying the last month's performance data, accessible by clicking the "Last Month's Performance" button in the last page.

This page starts with a graph that displays the daily number of boards made in the last month as well as the shift capacity used and cycle time.

Then, after the graph there would be a table, filterable by week, containing general information about the boards, separated by Board part number.

This draft is presented in the following image (figure 3.12).

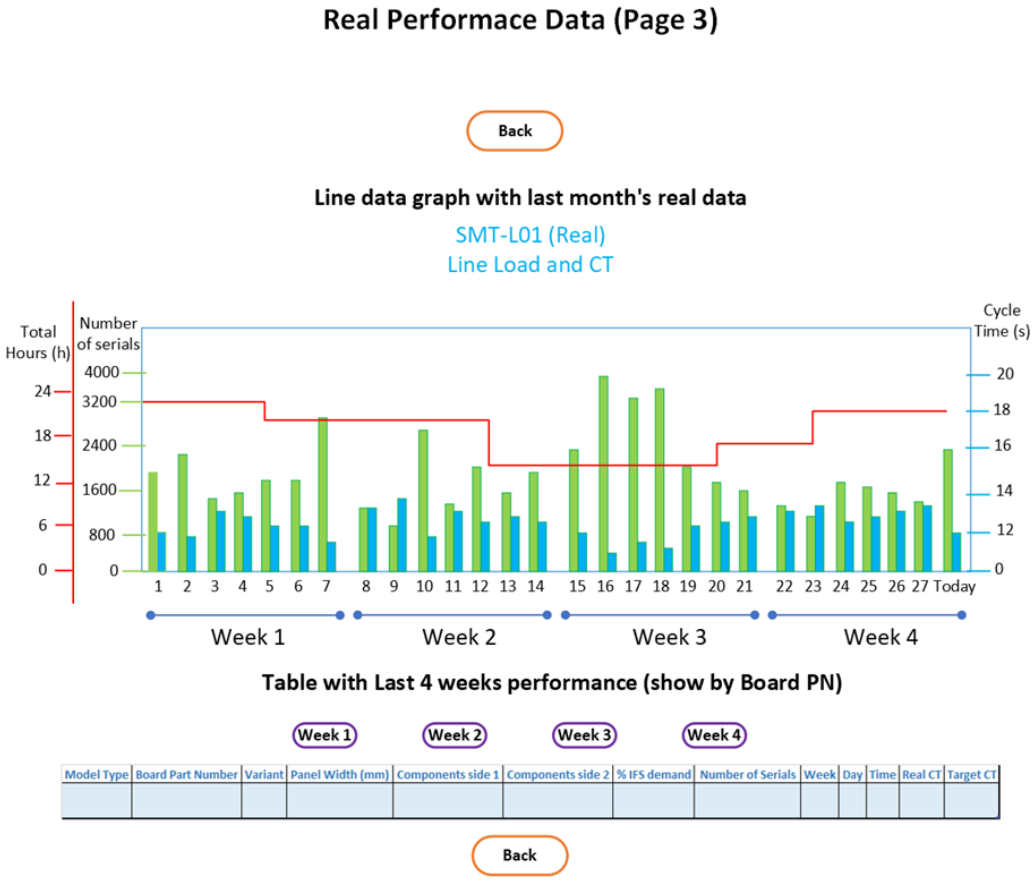


Figure 3.12: Draft 3 - Real Performance Data Page 3

After the correction of a few visual and data errors, the final and fourth draft was created as follows:

On the first and third pages, there are no changes relative to the former draft.

However, on the second page (figure figure 3.13), the real and theoretical graphs were separated, and now instead of line loads, it is demonstrated the line's utilization. The graph has been changed for better visualization of its contents and now the table contains board data with only the placement machine's CT, instead of bottleneck machine's CT. There is no longer a chart with the comparison between the Theoretical, Real and Target CTs in the table, but there are now two more columns that show the difference from the Theoretical and Target CTs to the Real CT, for detailed comparison. This removal and addition are thought to be better than the small chart in each row of the table.

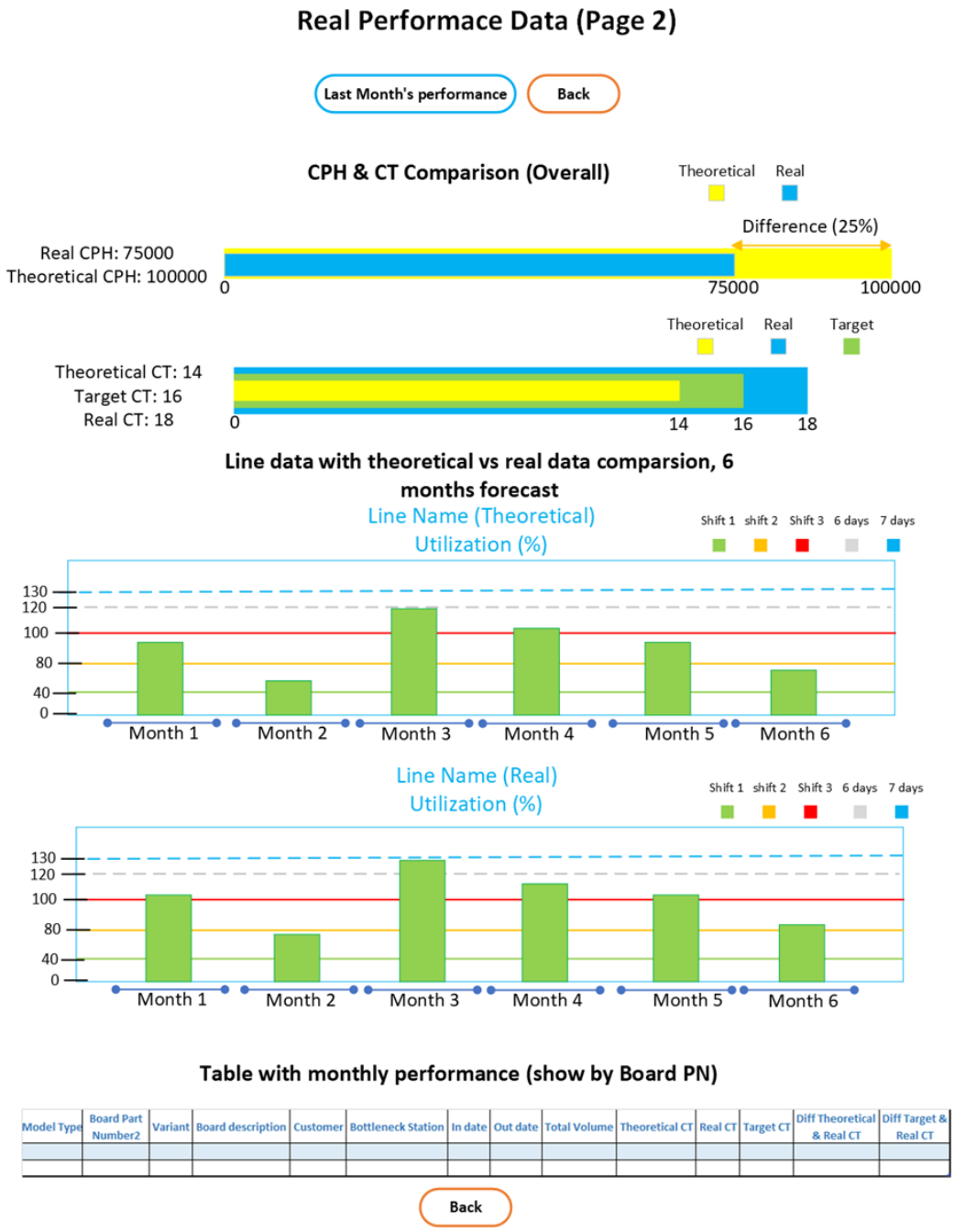


Figure 3.13: Draft 4 - Real Performance Data Page 2

3.1.2 LoadCharts dashboard

Now, regarding the LoadCharts reporting, the Data and structure that is expected to be presented in the Digital Twin is similar to this one, although the layout is slightly different.

The layout of the LoadCharts reporting addition is presented in the following diagram (figure 3.14).

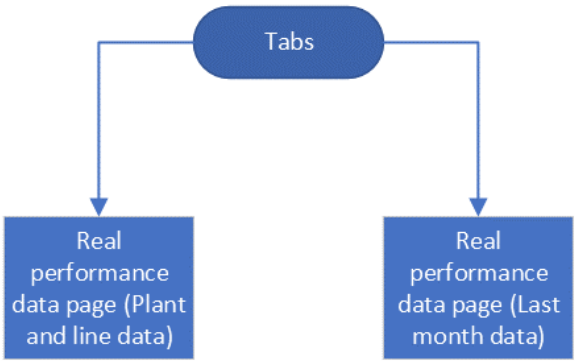


Figure 3.14: LoadCharts Dashboard Real Performance Data Section Layout

It consists of only two pages, shown in the next two images (figures 3.15 and 3.16), as the first page is expected to have both plant and line data, and the second page, the last month's performance data.

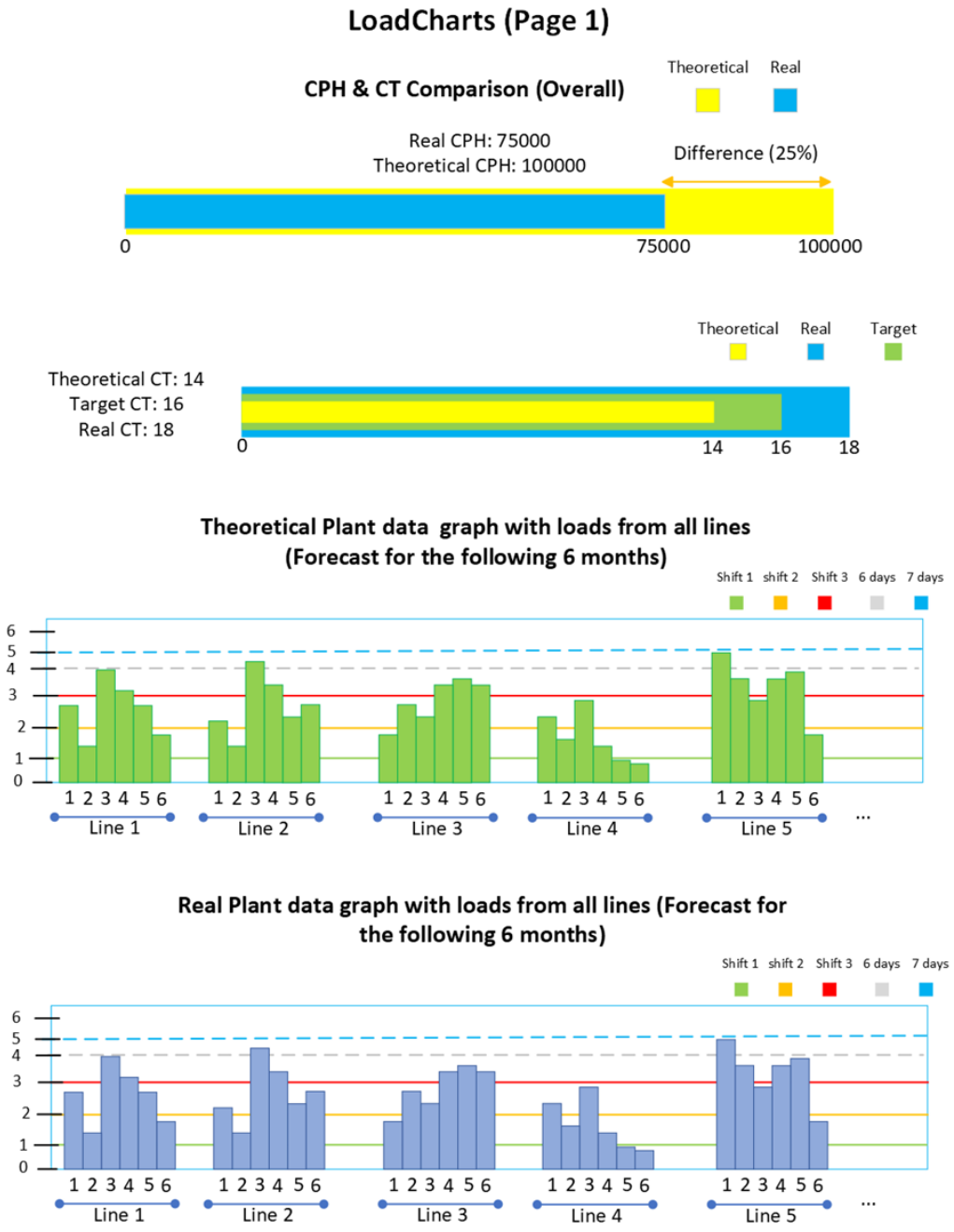


Figure 3.15: Real Performance Data LoadCharts Draft - Page 1

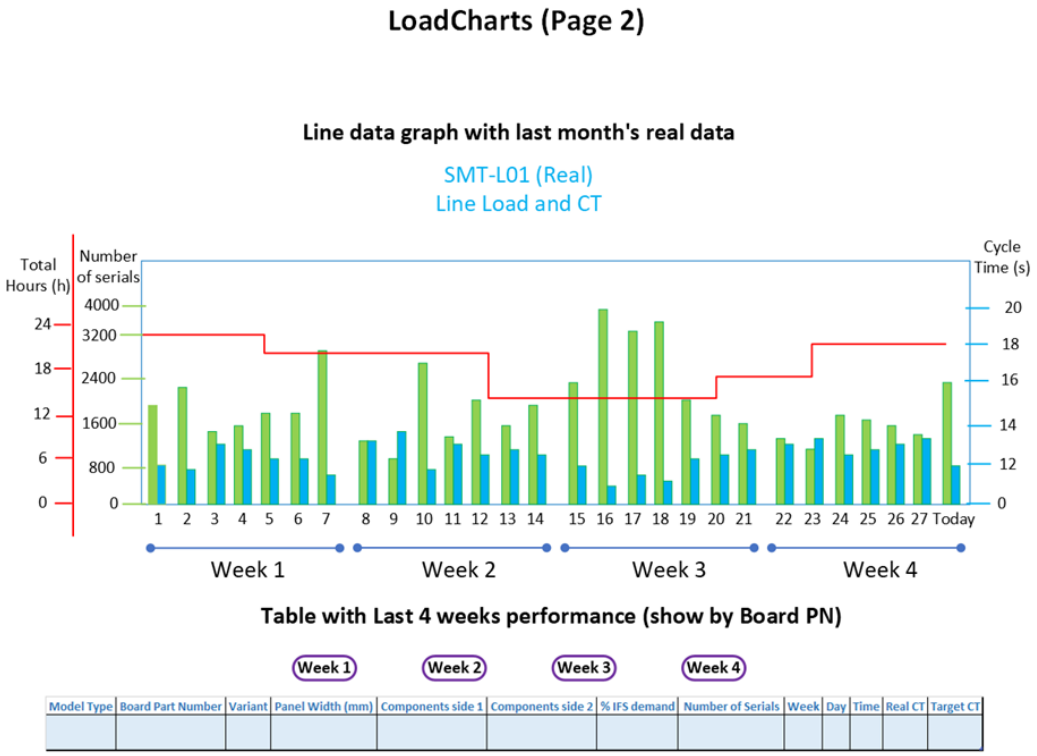


Figure 3.16: Real Performance Data LoadCharts Draft - Page 2

3.2 Implementation

In this section it will be presented the implementation for the real performance data integration project that connects SMT Load Forecast to CIMPLE.

The first part included accounting for the unavailable data that could eventually be used in the required task, so it was concluded that it was necessary to gather the end item numbers, that could be matched with the variants or IFS codes already contained in the Digital Twin and the board part numbers to be matched with the end part numbers. The board part numbers could then be matched in CIMPLE to get the real CT (cycle time).

After searching for a while, it was found that the required end item numbers and board part numbers were both contained in QAD. QAD is an ERP (Enterprise Resource Planning) that provides manufacturing and supply chain solutions. Regardless, an easier and faster way to gather this information was found by accessing IRIS, a database that contains a section of QAD's data, including the end item numbers and board part numbers.

3.2.1 Exercise 1

To gather proof of concept a first exercise was performed for a variant example, with two tables directly from QAD with sample data being provided for experimentation on. With this, a generic variant that was being produced in Palmela plant in SMT line 6, was retrieved from SMT Load Forecast and matched with the corresponded IFS code in one of the provided tables (Sales Order) to get the correspondent end part numbers. The diagram of this step is presented in the following image (figure 3.17).

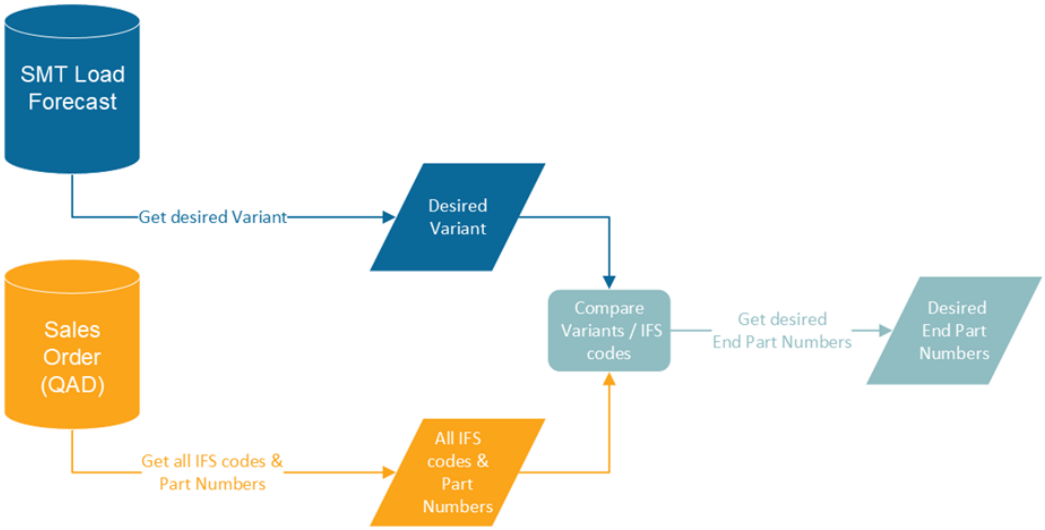


Figure 3.17: Using SMT Load Forecast and Sales Order table to get end part numbers Diagram

Then, as shown in figure 3.18, one of the end part numbers was selected and compared in the other table (Product Structure Browse) in order to obtain the matching Component numbers. To get the board part numbers, from the Component numbers obtained, the ones containing the string "14B115" (the code used to identify Boards) were selected. After that, the Model Types were acquired by searching one of the board numbers in the Manufacturing Ops Excellence dashboard.

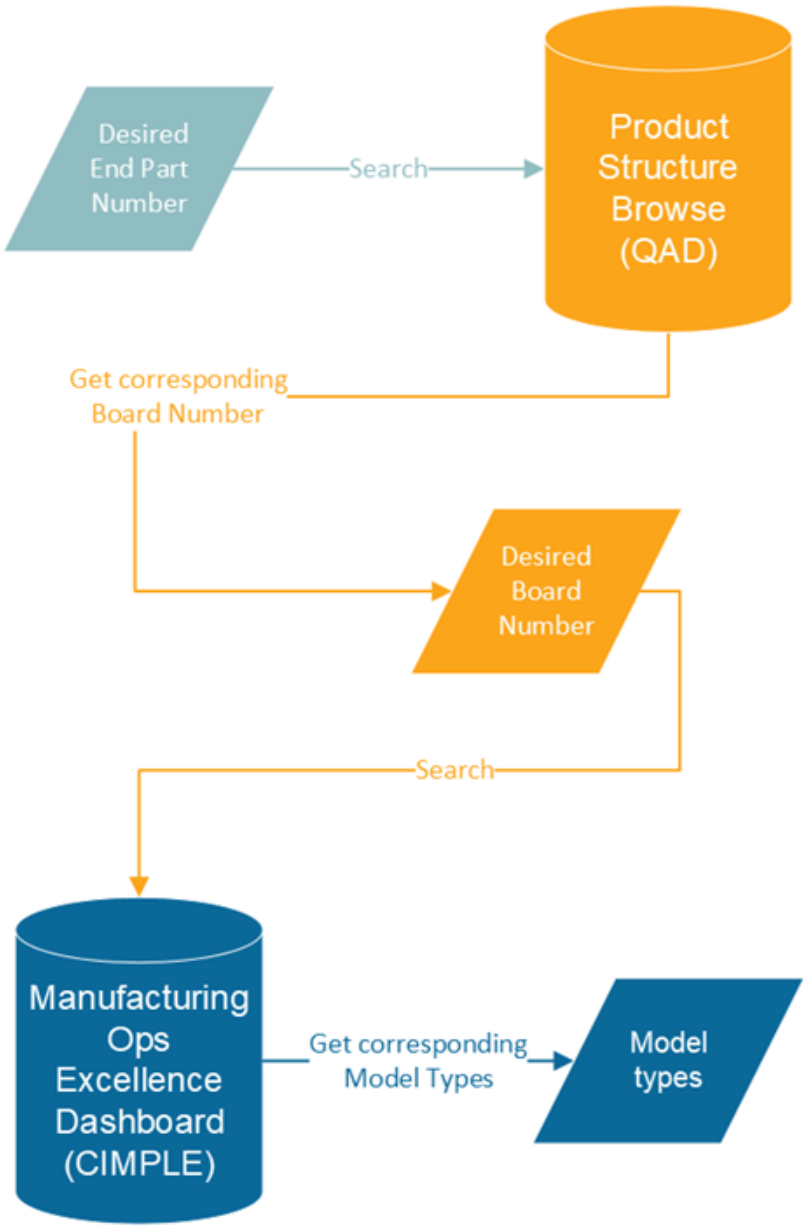


Figure 3.18: Using end part numbers to get Model Types Diagram

With this information and by accessing the Data Analyses dashboard, the number of produced units of those Model Types was retrieved (figure 3.19). It was still required the number of components per unit per side, so this was easily observed by searching the initial variant in the Digital Twin.

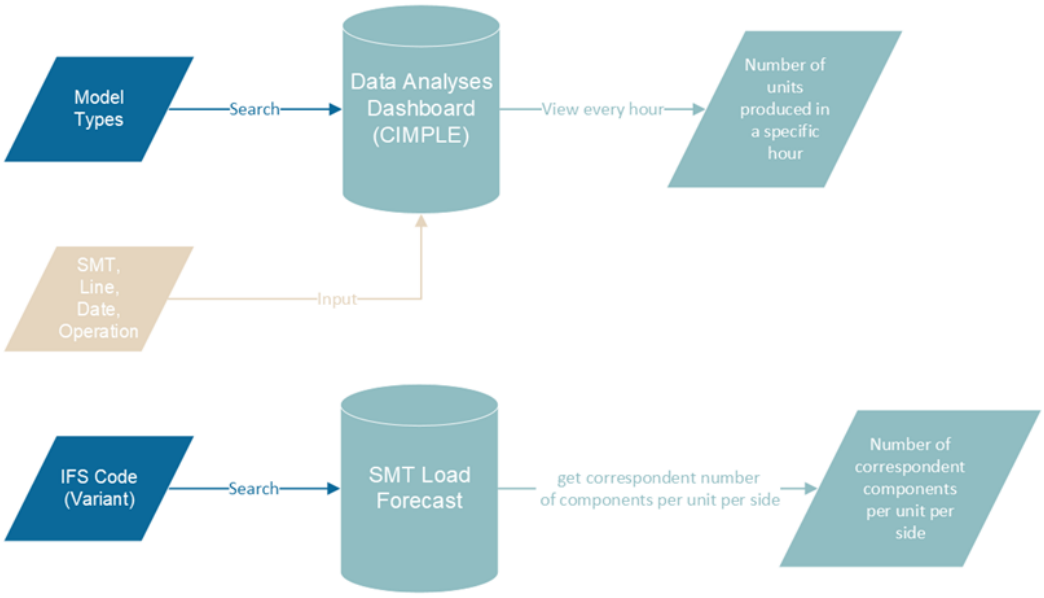


Figure 3.19: Using Model Types and IFS Code to get number of produced units and number of components Diagram

Finally, as it can be observed in the following image's diagram (figure 3.20), the real CPH and CT were calculated.

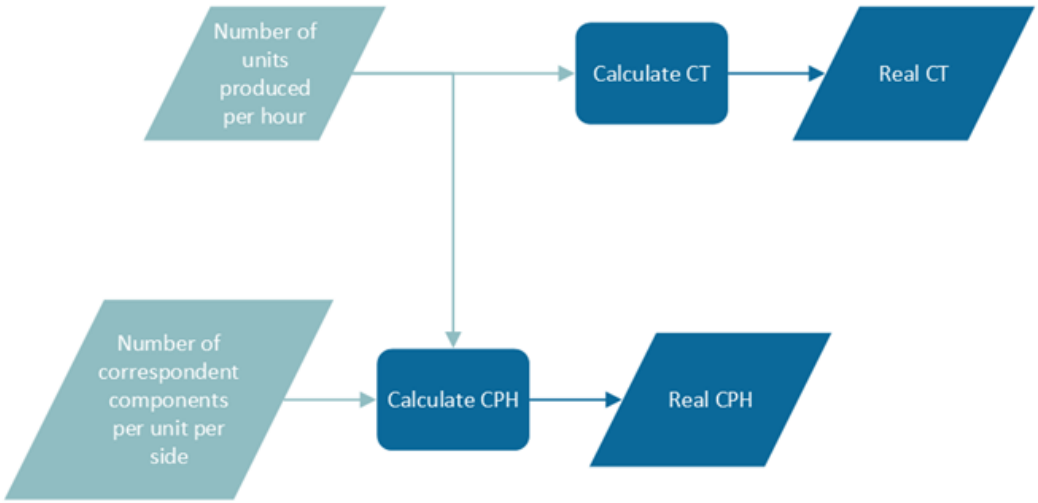


Figure 3.20: Using number of produced units and number of components to get real CT and CPH Diagram

This first exercise proofed that the project's primary idea was indeed possible to implement, the results of the Comparison between the real CPH and theoretical CPH that is currently in use in SMT Load Forecast (Board CPH at Bottleneck) are as follows (figure 3.21).

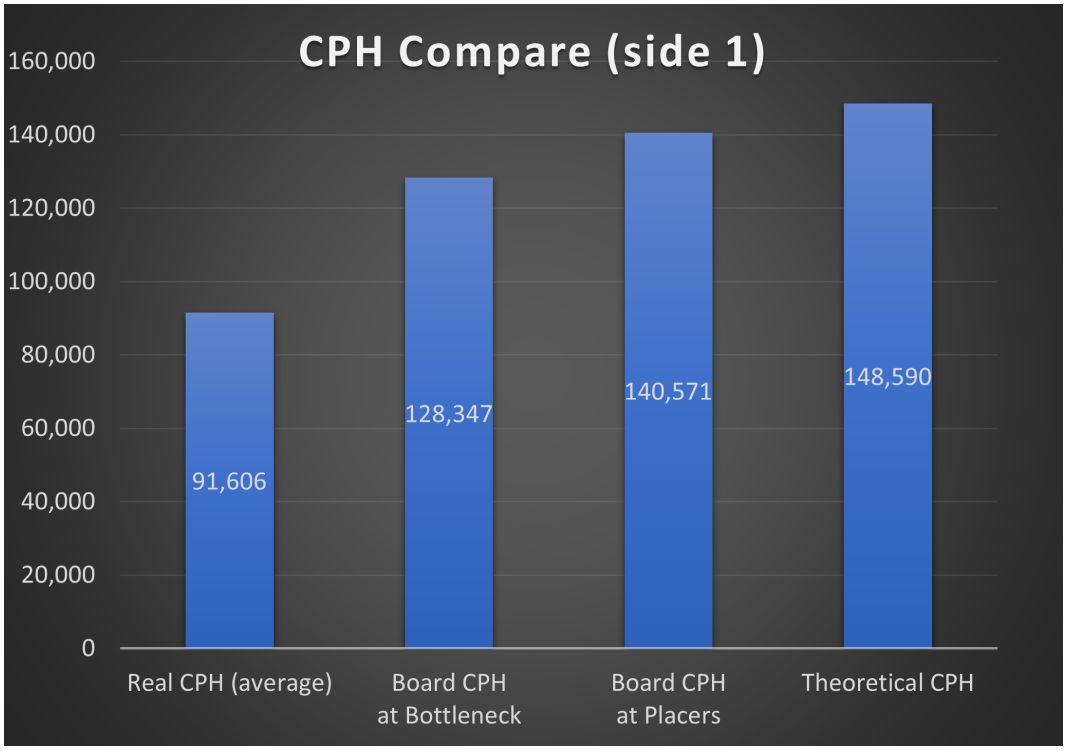


Figure 3.21: First exercise's real, at Bottleneck, at Placers and theoretical CPH comparison graph

As it can be seen in the graph (figure 3.21), there is a discrepancy between the value of the obtained real CPH and the CPH currently being used in SMT Load Forecasting. This means that there is value to the purposed work. Starting to use the real CPH will allow more accurate prediction making and planning.

It is important to keep in mind that the Manufacturing Ops Excellence dashboard contains the values of the real CT, organized by board part number, and that the obtained CT, which was compared with this value, was not correct. This meant having to repeat the exercise, exploring this time a different method of calculation of the CT as well as more optimized pathways to reach the desired goal.

3.2.2 Exercise 2

With this in mind, another method was studied.

Granting the first and last parts were done the same way as the first exercise, instead of retrieving Model Types from the Manufacturing Ops Excellence dashboard, this time that information was retrieved from the table "Traceability.SerialHistory" in Azure database.

This method still did not give accurate results, so in a third exercise, the model types were retrieved from the Data Analyses dashboard, as exhibited in the following image (figure 3.22).

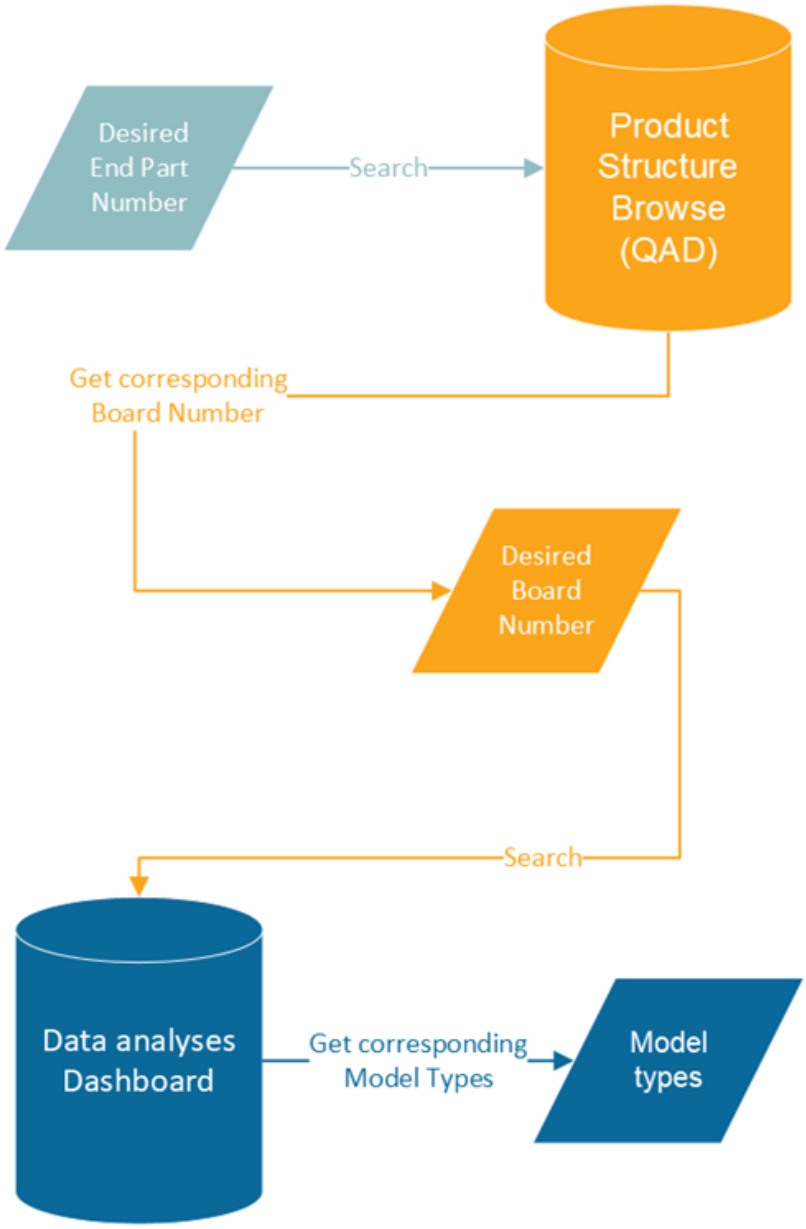


Figure 3.22: Using end part numbers to get Model Types Diagram

Then, on the table "Reporting.CTHistory" in Azure database, the real CTs corresponding to those model types were found and saved (figure 3.23).

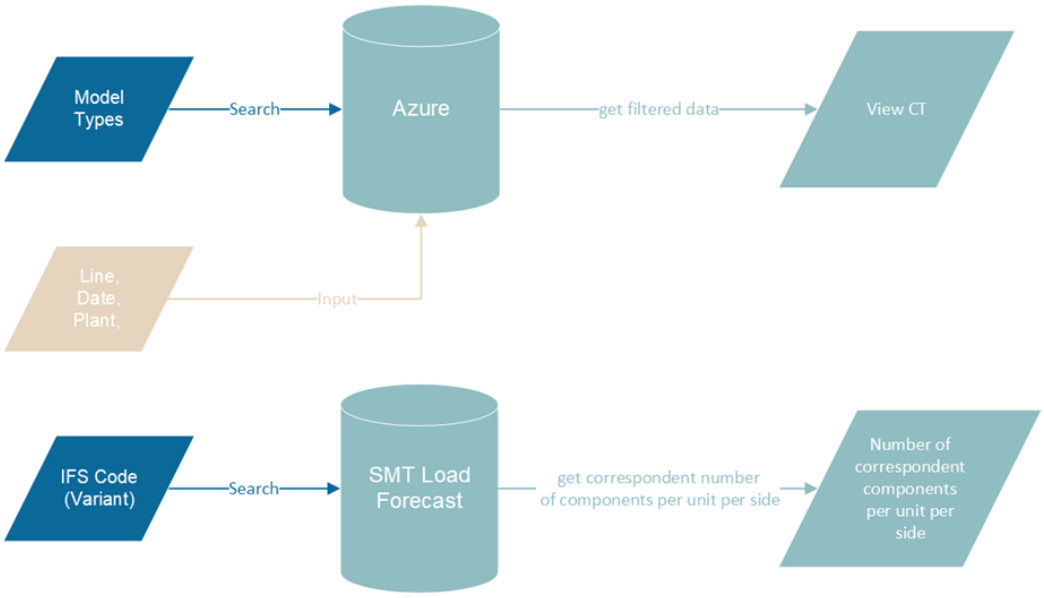


Figure 3.23: Using Model Types and IFS Code to get real CT and number of components Diagram

Finally, with the data retrieved from this table, the calculation method was changed to obtain the real CPH from the real CT (figure 3.24).

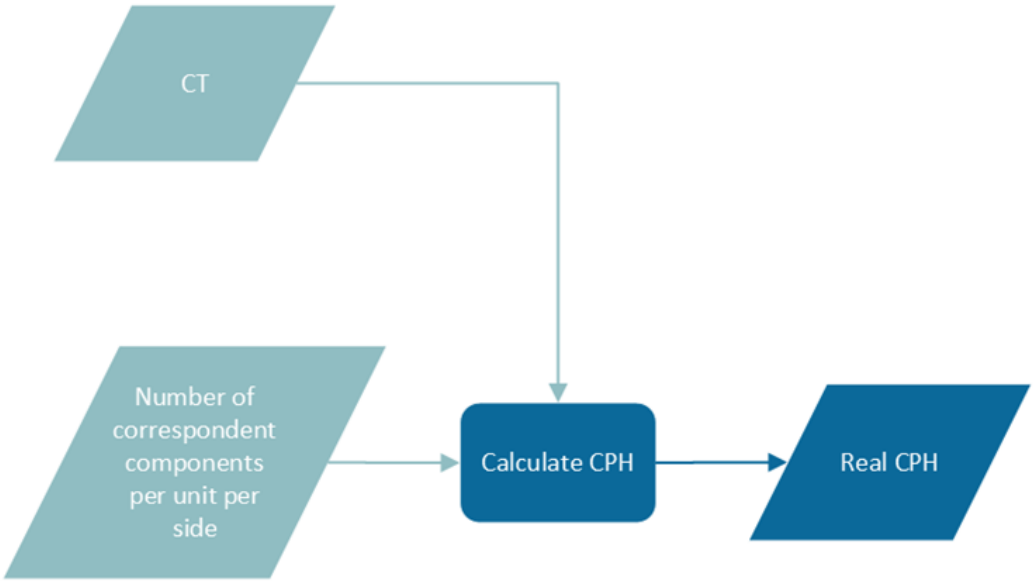


Figure 3.24: Using real CT and number of components to get real CPH Diagram

In this exercise it was concluded that obtained value for the real CT (and consequently

the real CPH) was equal to the CT presented in the Manufacturing Ops Excellence dashboard. The values can be seen in the following two tables (3.1 and 3.2).

Parameter	Data Source	Station	Value	Number of produced units
AVG CPH (side 1)	Azure	AOI	79655	2802
AVG CPH (side 2)	Azure	AOI	98111	2802
AVG CT	Azure	AOI	18.53	2802

Table 3.1: Azure data extraction method: values table

Parameter	Data Source	Station	Value	Number of produced units
AVG CPH (side 1)	Man. Ops Excellence	AOI	79655	2802
AVG CPH (side 2)	Man. Ops Excellence	AOI	98111	2802
AVG CT	Man. Ops Excellence	AOI	18.53	2802

Table 3.2: Manufacturing Ops Excellence Dashboard data extraction method values table

With these new values, the same comparison with the theoretical CPH in use in SMT Load Forecast was made (figure 3.25).

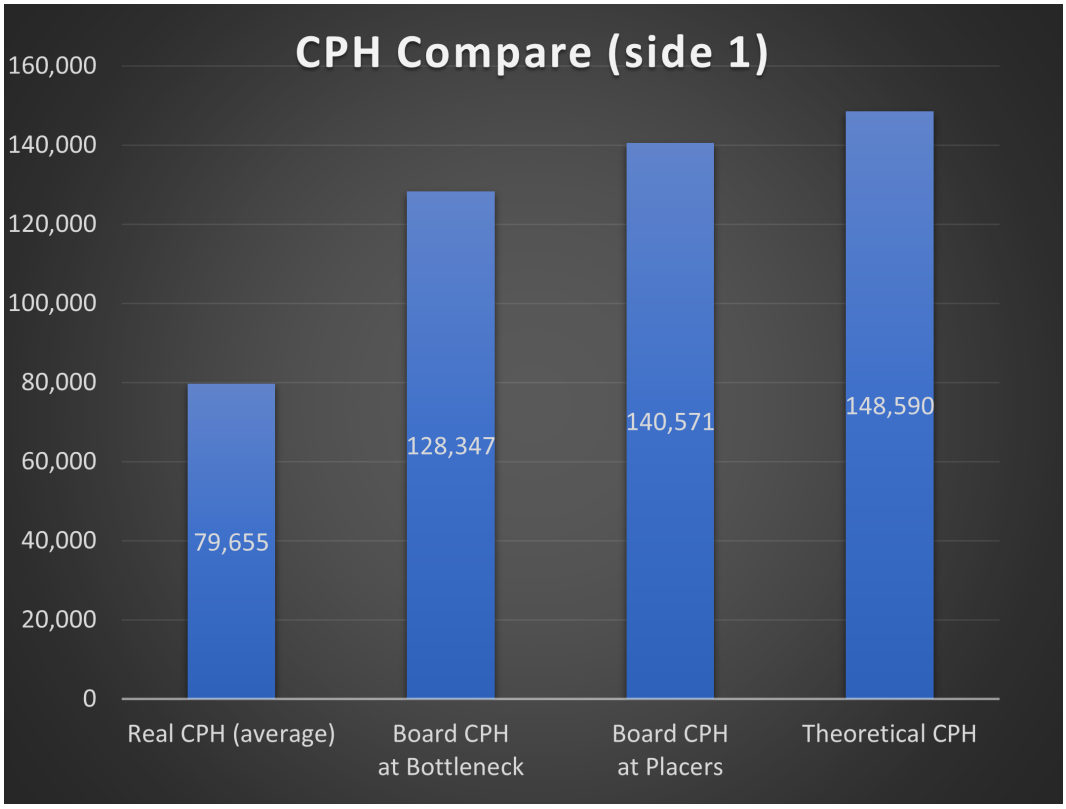


Figure 3.25: Second exercise's real, at bottleneck, at placers and theoretical CPH comparison graph

The results are similar to the obtained previously, where the Real CPH is lower than the theoretical CPH in use.

3.2.3 Exercise 3

Although a correct methodology for the connection between the Digital Twin and CIMPLE had already been discovered and ready to be implemented, another exercise with the objective of optimizing the path was performed.

Now, after obtaining the Model Types, the CT was retrieved from the same table. This can be visualized the in the following diagram (figure 3.26).

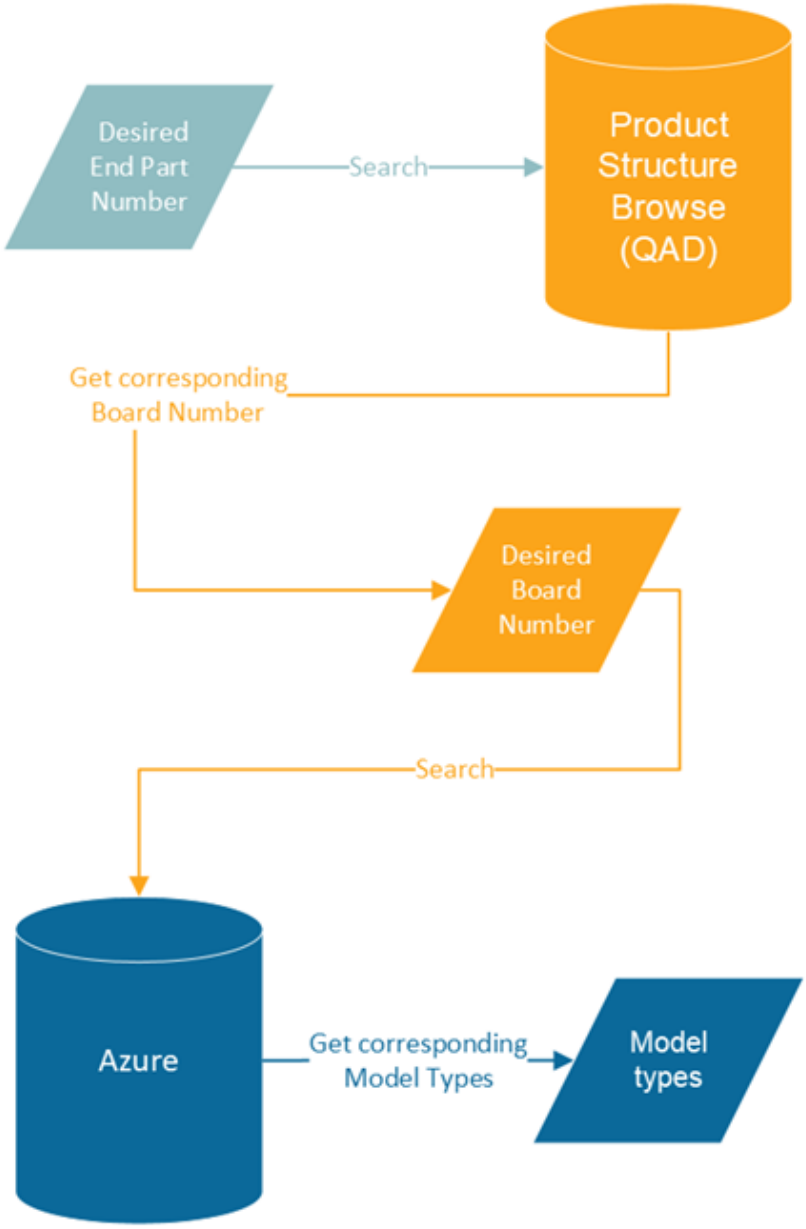


Figure 3.26: Using end part numbers to get model types Diagram

Connecting the Digital Twin to CIMPLE this way is more optimized than still having to access the Data Analyses dashboard.

Before beginning the project's implementation there was still the need for making sure that all the necessary data from the different databases was available. After gaining access and trying out a few methods to gather information from IRIS, the most accurate method of connecting SMT Load Forecast to CIMPLE was remade to test the data retried from IRIS.

Then, following making sure that the retrieved new data was usable, it was developed a method to directly retrieving data from IRIS and writing it on the local database.

Then, with the information on the local database, the project was ready to be taken to the next step, where firstly it was studied and debated a few ways to display and report the newly acquired data on the Digital Twin and also on the LoadCharts Dashboard.

3.3 Validation

After having a feasible reporting architecture and carrying-out its development, the obtained results are as follows (figures 3.27, 3.28 and 3.29):

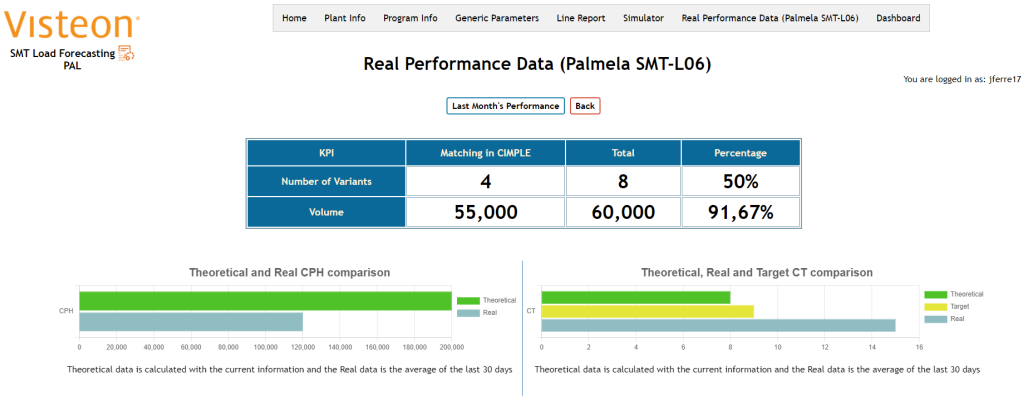


Figure 3.27: Real Performance Data Page 2 Part 1

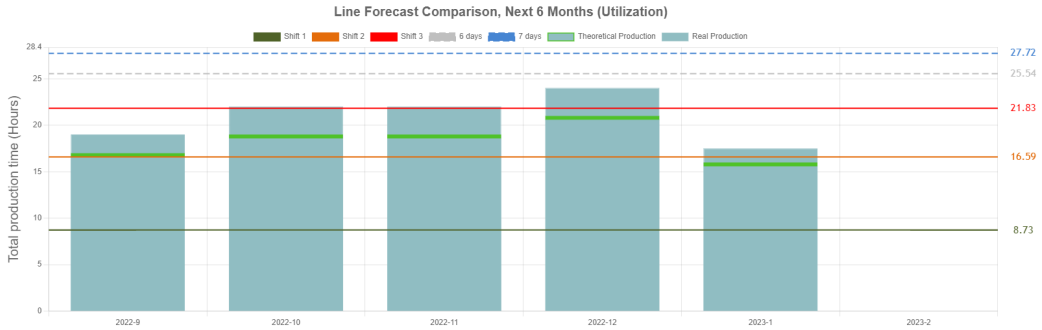


Figure 3.28: Real Performance Data Page 2 Part 2

Model Type	Board Part Number	Variant	Board Description	Customer	Bottleneck Station	In Date	Out Date	Total Volume (Next 6 months)	Theoretical CT	Real CT	Target CT	Difference (Real-Theoretical) Absolute | | Percentage	Difference (Real-Target) Absolute | | Percentage
A1A	ABCDEF-14B115-ABC	123456	PCB Board	Costumer 1	Station 1	2022-09-01	2023-11-01	300,000	7	16	9	9 | | 56.25%	7 | | 43.75%
B2B	FEDCBA-14B115-CBA	654321	Board PCB v2	Costumer 2	Station 2	2021-12-01	2024-04-01	290,000	8	15	9	7 | | 46.67%	6 | | 40%
A1A	ABCDEF-14B115-ABC	123456	PCB Board	Costumer 1	Station 1	2022-09-01	2023-11-01	280,000	7	16	9	9 | | 56.25%	7 | | 43.75%
B2B	FEDCBA-14B115-CBA	654321	Board PCB v2	Costumer 2	Station 2	2021-12-01	2024-04-01	270,000	8	15	9	7 | | 46.67%	6 | | 40%
A1A	ABCDEF-14B115-ABC	123456	PCB Board	Costumer 1	Station 1	2022-09-01	2023-11-01	260,000	7	16	9	9 | | 56.25%	7 | | 43.75%
B2B	FEDCBA-14B115-CBA	654321	Board PCB v2	Costumer 2	Station 2	2021-12-01	2024-04-01	250,000	8	15	9	7 | | 46.67%	6 | | 40%
A1A	ABCDEF-14B115-ABC	123456	PCB Board	Costumer 1	Station 1	2022-09-01	2023-11-01	240,000	7	16	9	9 | | 56.25%	7 | | 43.75%
B2B	FEDCBA-14B115-CBA	654321	Board PCB v2	Costumer 2	Station 2	2021-12-01	2024-04-01	230,000	8	15	9	7 | | 46.67%	6 | | 40%
A1A	ABCDEF-14B115-ABC	123456	PCB Board	Costumer 1	Station 1	2022-09-01	2023-11-01	220,000	7	16	9	9 | | 56.25%	7 | | 43.75%
B2B	FEDCBA-14B115-CBA	654321	Board PCB v2	Costumer 2	Station 2	2021-12-01	2024-04-01	210,000	8	15	9	7 | | 46.67%	6 | | 40%
A1A	ABCDEF-14B115-ABC	123456	PCB Board	Costumer 1	Station 1	2022-09-01	2023-11-01	200,000	7	16	9	9 | | 56.25%	7 | | 43.75%
B2B	FEDCBA-14B115-CBA	654321	Board PCB v2	Costumer 2	Station 2	2021-12-01	2024-04-01	190,000	8	15	9	7 | | 46.67%	6 | | 40%
A1A	ABCDEF-14B115-ABC	123456	PCB Board	Costumer 1	Station 1	2022-09-01	2023-11-01	180,000	7	16	9	9 | | 56.25%	7 | | 43.75%
B2B	FEDCBA-14B115-CBA	654321	Board PCB v2	Costumer 2	Station 2	2021-12-01	2024-04-01	170,000	8	15	9	7 | | 46.67%	6 | | 40%

Figure 3.29: Real Performance Data Page 2 Part 3

Now, comparing the developed page to the last draft, two main differences can be pointed out. These include, on one side, two KPIs (Key Performance Indicators) located at the top of the page and then also displaying both the Utilization graphs, of the Real

and Theoretical Data, in the same graph.

As a reminder, the goal of this project is to extract real performance data from the SMT Production Lines (stored in CIMPLE) and utilize it to improve prediction and decision making. As a large part of this predictions and decisions are done in the Digital Twin, it is required for the extracted data to be put in the Digital Twin and, in a later stage, to start being used.

With this in mind, starting with the KPIs, these can be seen as the deciding factor for the credibility of the data that is displayed on the page. The "number of variants" KPI tells the number of variants that had a match in Digital Twin that came from CIMPLE, facing the total number of variants in Digital Twin, and also that number in percentage. On the other hand, the "Volume" KPI shows the volume of boards that the matching variants represent, facing the total Volume, and it also displays that number in percentage. From the example seen in the last figures, only 4 out of 8 boards in the Digital Twin, had a match, making up for only 50% of the variants. By itself this value can make the data is poor and that 50% of the variants is not a percentage big enough to take conclusions. However, only looking at this KPI in not enough to see if the data is or is not poor. Also considering the volume KPI, it can be seen that the initial 50% of the matching variants make up for 91.67% of the total volume of boards. This means that the concern for the mismatching 4 boards is almost completely surpassed by this value because now the calculations are based on 91.67% of the total volume of boards.

Moving on not the graphs, the first one, that represents the values of the Theoretical and Real CPH, has the goal of calling out the difference between those values. As it can be seen in the images, the CPH currently in use in the Digital Twin (Theoretical CPH) is fairly higher than the Real CPH.

The second graph displays the values of the Theoretical, Real and Target CT, which is the CT milestone for having an optimized production line. In the figure, the Theoretical CT in smaller the Target CT, so it is assumed that the line has beyond peak optimization. However, the real CT tells a different story, it is larger than the Target CT and this means that there is still room for further optimization. I rush to refer again that this values are based on 91.67% of the volume of the board, so with very good data quality.

Both of this graphs highlight the discrepancies in the current Theoretical values for the CT and CPH being used, meaning that there could possibly be line overload problems due to the actual smaller capacity than the initially thought of.

The third graph, Utilization, displays the total production time forecast, in hours, monthly, in the following six month, both the Theoretical and Real values. Here the possible overload issues can actually be visualized when comparing the Real with the Theoretical Data.

Finally, there is a table that shows the detailed information about each of the Model types, and consequently, board part numbers, in the next six months on that line, with the goal of getting a detailed comparison between the Theoretical, Real and Target CTs.

The third page of the Real Performance data project, that displayed the information regarding the Real Performance from the last month (figures 3.30 and 3.31), was also developed.

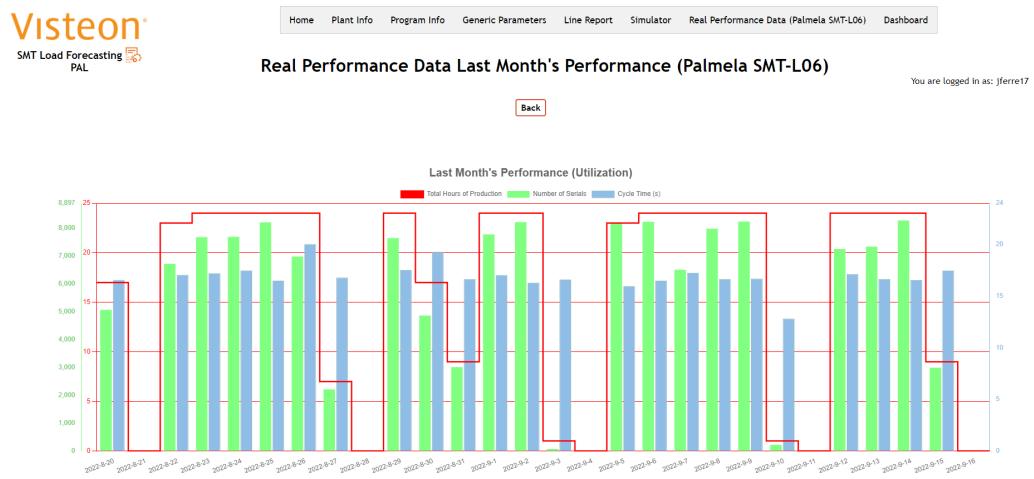
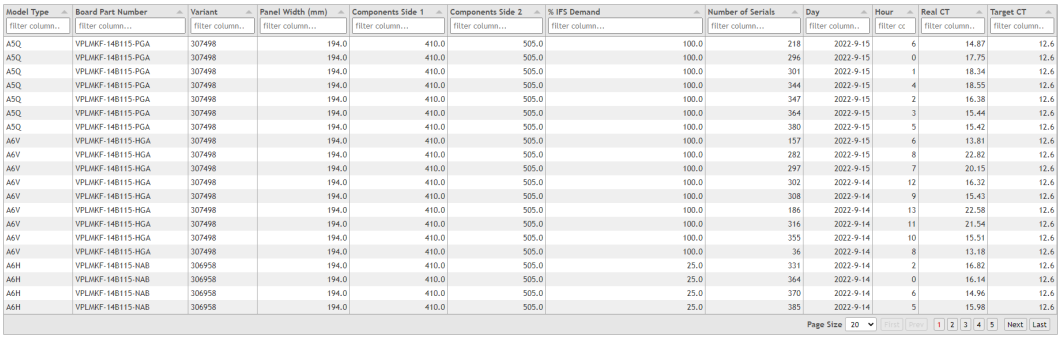


Figure 3.30: Real Performance Data Page 3 Part 1



Model Type	Board Part Number	Variant	Panel Width (mm)	Components Side 1	Components Side 2	% IFS Demand	Number of Serials	Day	Hour	Real CT	Target CT
A5Q	VPLMKF-14B115-PGA	307498	194.0	410.0	505.0	100.0	218	2022-9-15	6	14.87	12.6
A5Q	VPLMKF-14B115-PGA	307498	194.0	410.0	505.0	100.0	296	2022-9-15	0	17.75	12.6
A5Q	VPLMKF-14B115-PGA	307498	194.0	410.0	505.0	100.0	301	2022-9-15	1	18.34	12.6
A5Q	VPLMKF-14B115-PGA	307498	194.0	410.0	505.0	100.0	344	2022-9-15	4	18.55	12.6
A5Q	VPLMKF-14B115-PGA	307498	194.0	410.0	505.0	100.0	347	2022-9-15	2	16.38	12.6
A5Q	VPLMKF-14B115-PGA	307498	194.0	410.0	505.0	100.0	364	2022-9-15	3	15.44	12.6
A5Q	VPLMKF-14B115-PGA	307498	194.0	410.0	505.0	100.0	380	2022-9-15	5	15.42	12.6
A6V	VPLMKF-14B115-HGA	307498	194.0	410.0	505.0	100.0	157	2022-9-15	6	13.81	12.6
A6V	VPLMKF-14B115-HGA	307498	194.0	410.0	505.0	100.0	282	2022-9-15	8	22.82	12.6
A6V	VPLMKF-14B115-HGA	307498	194.0	410.0	505.0	100.0	297	2022-9-15	7	20.15	12.6
A6V	VPLMKF-14B115-HGA	307498	194.0	410.0	505.0	100.0	302	2022-9-14	12	16.32	12.6
A6V	VPLMKF-14B115-HGA	307498	194.0	410.0	505.0	100.0	308	2022-9-14	9	15.43	12.6
A6V	VPLMKF-14B115-HGA	307498	194.0	410.0	505.0	100.0	186	2022-9-14	13	22.58	12.6
A6V	VPLMKF-14B115-HGA	307498	194.0	410.0	505.0	100.0	316	2022-9-14	11	21.54	12.6
A6V	VPLMKF-14B115-HGA	307498	194.0	410.0	505.0	100.0	355	2022-9-14	10	15.51	12.6
A6V	VPLMKF-14B115-HGA	307498	194.0	410.0	505.0	100.0	36	2022-9-14	8	13.18	12.6
A6H	VPLMKF-14B115-NAB	306958	194.0	410.0	505.0	25.0	331	2022-9-14	2	16.82	12.6
A6H	VPLMKF-14B115-NAB	306958	194.0	410.0	505.0	25.0	364	2022-9-14	0	16.14	12.6
A6H	VPLMKF-14B115-NAB	306958	194.0	410.0	505.0	25.0	370	2022-9-14	6	14.96	12.6
A6H	VPLMKF-14B115-NAB	306958	194.0	410.0	505.0	25.0	385	2022-9-14	5	15.98	12.6

Figure 3.31: Real Performance Data Page 3 Part 2

As in the last case, there are also few differences between this page's draft and the implemented solution. These are the fact that the table data is now filterable by any column's field, instead of by each of the weeks and also now the table can be ordered by any column.

The graph at top of this page displays daily, in the last 28 days, the average cycle time, total number of serials and hours of production of all the boards in the line. It is important to note that the days that have no value for all the three parameters are days without

production, such as Sundays or holidays.

This page's table is similar to the last page's table, showing detailed information about the boards, but this time the table refers to the Last month's real performance rather than the following month's forecast.

With this pages the users will be able to visualize the differences between the currently in use Theoretical values and the Real values and determine the value that can be taken by implementing the new Real values.

4

Plant Simulator

4.1 Architecture

This is the second project that takes part in the proposed expansion of the Digital Twin. Its objective is to give the engineers the opportunity of planning for the future with accuracy, by allowing the simulation of a customized scenario of the company's plants, where the user will be able to test different machine and program configurations.

Now, looking in detail, at the Plant Simulator's functionalities and benefits, first there is the ability to move boards between lines, that will allow studying the effects of different program setups. This feature is an instrument to balancing the loads between lines.

The implementation of this feature will also allow the visualization of the effects of changes in any line on the whole plant scenario, and with this the benefits of better planning, prediction making, and line optimization are easily accessible.

This project allows visualizing the results of the actions described previously without changing the real values eliciting it to be a big asset in making changes in the production lines. This is one of the most important aspects of a Digital Twin, allowing the simulation and experimentation of new methods before putting them to use.

The Plant Simulator project consists of four main pages:

- The Plant Scenario homepage, where a table with an overview of the plant will be displayed, showcasing important information for each of the lines
- The Line Scenario homepage, containing the detailed overall data of a line in the plant scenario.
- The Plant Simulator page, that shows two graphs, one with the theoretical plant data and another with the scenario plant data, as well as a table with information regarding all the boards in all the lines in the plant scenario.
- The Line Simulator page, in which three graph are presented with that line's data the plant scenario as well as a table with information of that line. This page is more is more detailed than the Plant Simulator page.

These pages will be covered in detail in the "Validation" sub-chapter of the Plant Simulator.

as mentioned before, this project already structured by Visteon's engineers, and was also documented. with this, to revise and confer the approach on the project's development, a meeting was setup to exchange ideas, give suggestions and define new requisites.

The purposed architecture of the Plant Simulator project is presented in the following diagram (figure 4.1), with the respective legend (figure 4.2).

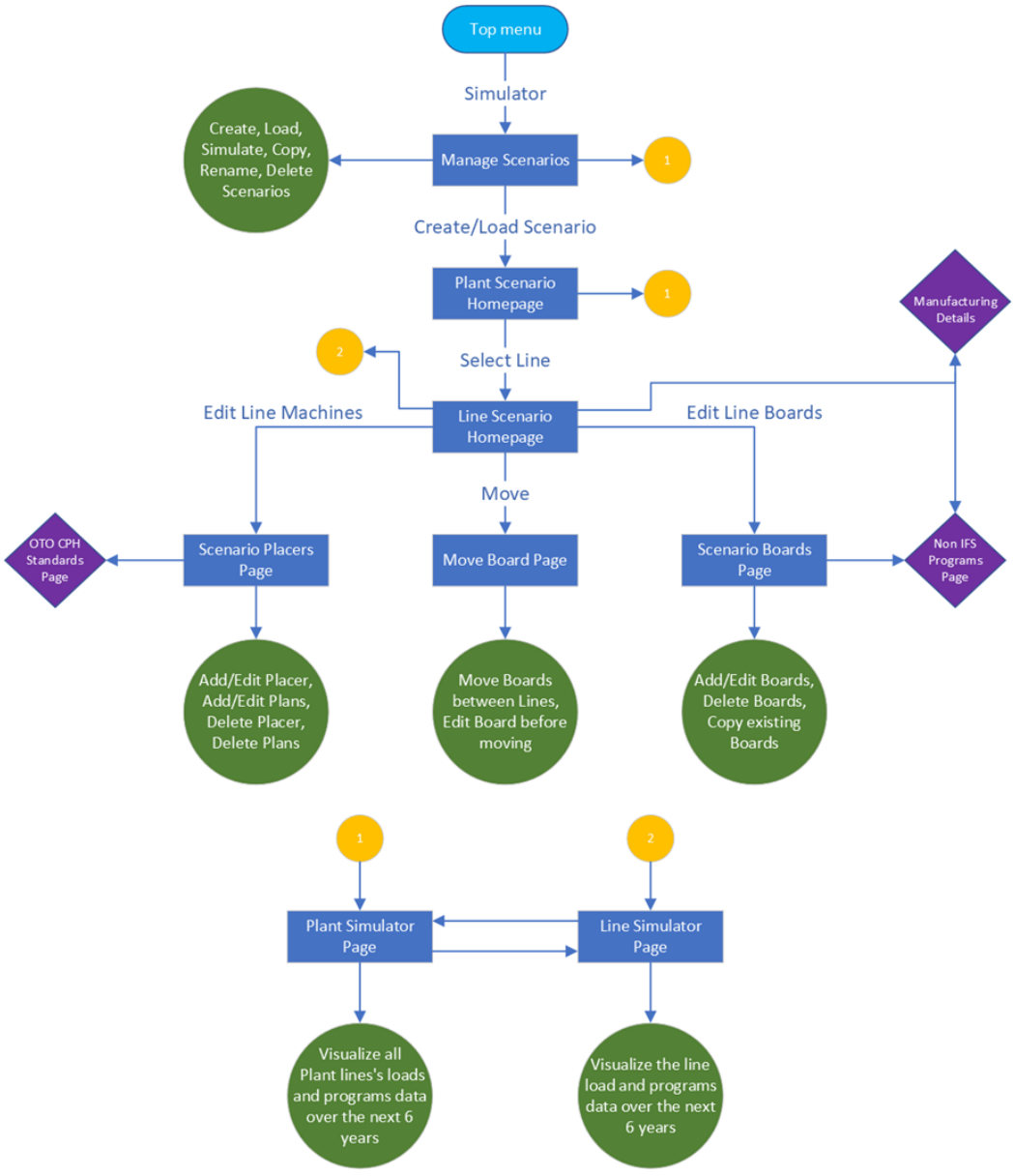


Figure 4.1: Plant Simulator's architecture

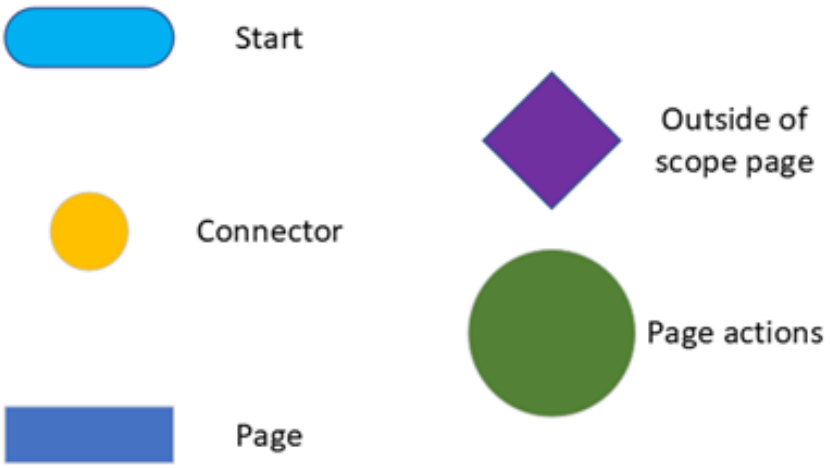


Figure 4.2: Plant Simulator's architecture legend

4.2 Implementation

This project is based on the "Line Simulator" already implemented in the Digital Twin, expanding it to a Plant point of view.

To this extent, the implementation of this project consisted of taking the "Line Simulator" pages and adapting them to be used in conjunction with the "Plant Simulator" and adding pages to allow a complete plant simulation.

The Plant Simulator project was designed to be used by both the engineers and the decision makers from all the plants of the company. For this reason, the focus while developing the project is that its interface is intuitive, and that the displayed data is correct and meets the required specifications.

Because of this, it was beneficial to gather the user's feedback so that the project's interface would be more user friendly.

4.3 Validation

After finishing the development of the project and before releasing it to the plants, some time was dedicated to testing it. In these tests a few bugs were found that were later resolved. Only then and after training the plant's personnel to use the Plant Simulator, it was released for testing purposes.

After a few days of testing from the user's part, more bugs were found and communicated. Also, the users gave their opinion on new features that they wanted to see implemented and thought that could be helpful in data manipulation. Finally, after fixing the bugs and discussing and reviewing the user's suggestions, and implementing some of those, such as adding extra information to the tables or changing the button positioning, the Plant Simulator was completely released to all the plant of Visteon.

As expected, this section of The Digital Twin has the ability to perform the initially desired goals and with it being a simulator, by creating a custom scenario, it is possible to manipulate data and acknowledge its results without disrupting the current theoretical data. This gives the possibility of planning with more accuracy due to the users having the knowledge of likely effects of certain actions in the production lines in the future.

A complete overview of the plant can be visualized on the main page of the Plant Simulator and also in the Simulation page. This includes all of the lines in that scenario, the current quantity of placement machines as well as the quantity of planned changes for those machines, the line CPH, the number of individual boards that are currently being produced, the total volume of boards (whether it is categorized as production, awarded, pursuit or manual), the highest running program and the minimum and maximum panel width. A comparison between the scenario line loads and the actual line loads with the addition of some information from all the programs can also be seen.

To optimize the production line's utilization, a common task within Visteon is to partially or completely moving board production between lines, transferring this way, loads between lines to try reaching balance. This feature was successfully implemented.

The first change when implementing this project was in the interface of the "Simulator" page. Now, as it can be visualized in figure 4.3, line scenarios can no longer be created, with the objective of being completely substituted by the Plant simulator in the near future. Also, there has been created a new section for creating plant scenarios, as well as loading, copying, simulating, deleting and renaming them.

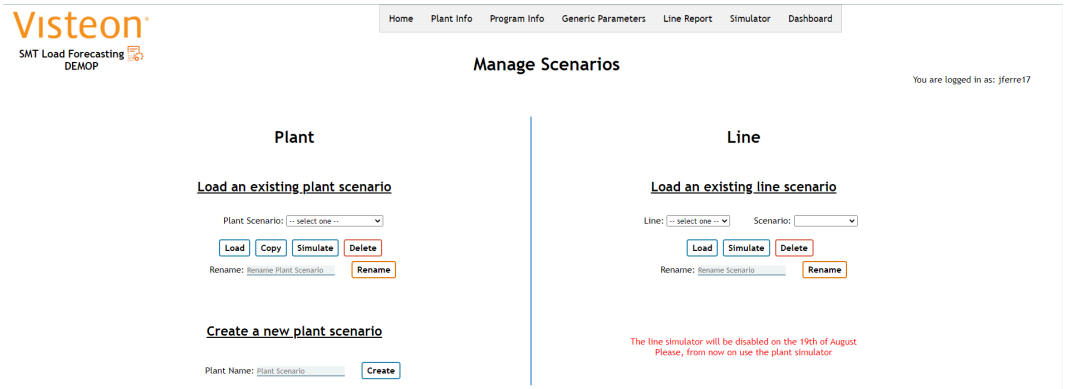


Figure 4.3: Digital Twin's new "Manage Scenarios" page

The main page of a custom plant scenario is the "Plant Scenario Homepage" (figure 4.4), where an overview of the plant scenario can be visualized. This view contains all the lines in the plant as well as generic information regarding them. It is possible to directly simulate the plant scenario by clicking the "Simulate" button. Each of the lines can be analyzed and edited separately by clicking them. Doing this will redirect the user to a similar interface to the previous "Scenario Homepage" page, that consists of a detailed version of the selected line.

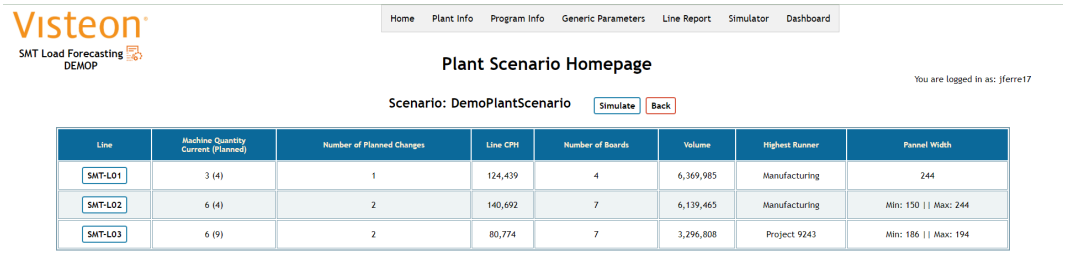


Figure 4.4: Plant Simulator's Homepage

In "Scenario Homepage" it is possible to see and edit the selected line's current machines and boards. The "Edit" button on the "Line Configuration" table redirects the user to the "Scenario Placers" page, whilst the one on the "Board Configuration" redirects the user to the "Scenario Boards" page. Both these pages allow editing, deleting and adding machines and boards to the line. A list of the manual programs that are available can be seen by clicking the "Non-IFS Programs" button. Lastly, the "Simulate" button, brings up a page similar to the previous "Load Simulator." This page in presented in the following image (figure 4.5).

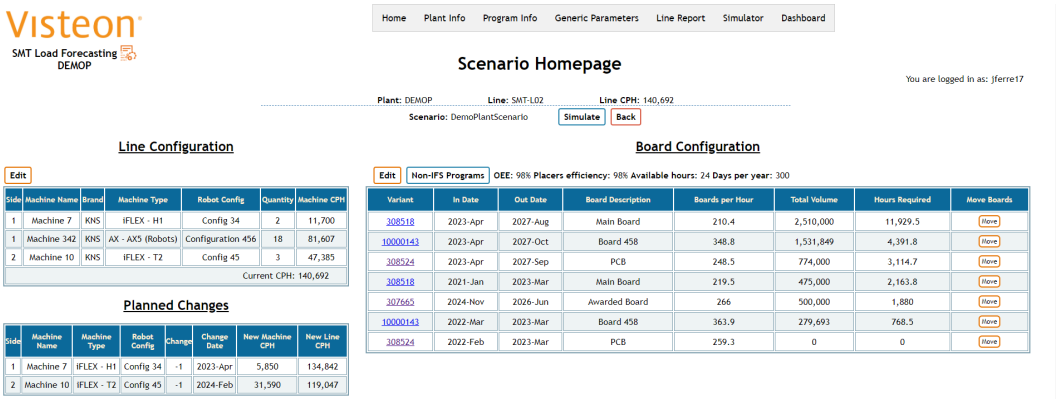


Figure 4.5: Plant Simulator's "Scenario Homepage" page

As expected, in the "Scenario Placers" page, shown on figure figure 4.6, there are displayed, from both sides, the machines currently active in the lines as well as their correspondent planned changes, whether it is to remove or add new machines. It is possible to edit, add and delete machines, by clicking on the respective buttons. If a user wishes to consult the list of all the machines of all the plants along with some information about it, he must click the "OTO CPH Standards" button.

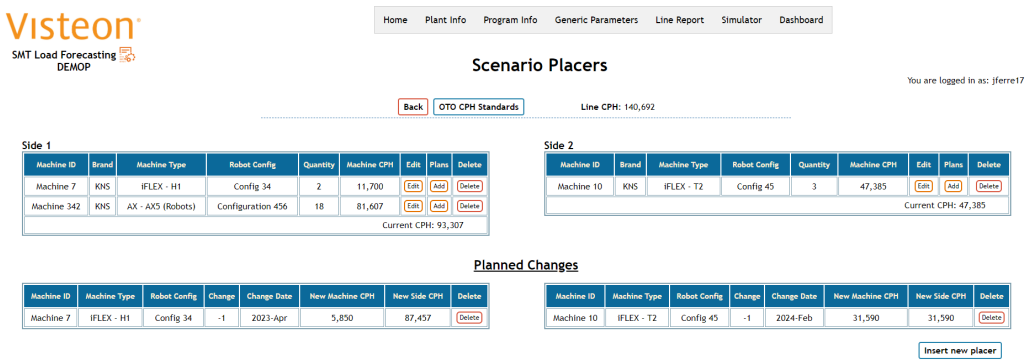


Figure 4.6: Plant Simulator's "Scenario placers" page

To manipulate boards and their data in a custom scenario, the "Scenario Boards" page must be accessed. Here, it is possible to edit all fields of the boards, as displayed in the figure, and also manipulate the rows as desired. The available manual programs are also visible by clicking on the "Non-IFS Programs" button on this page. When all the changes are done the user must click the "Submit" button to save the changes made. The layout of this page is shown in the following image (figure 4.7).

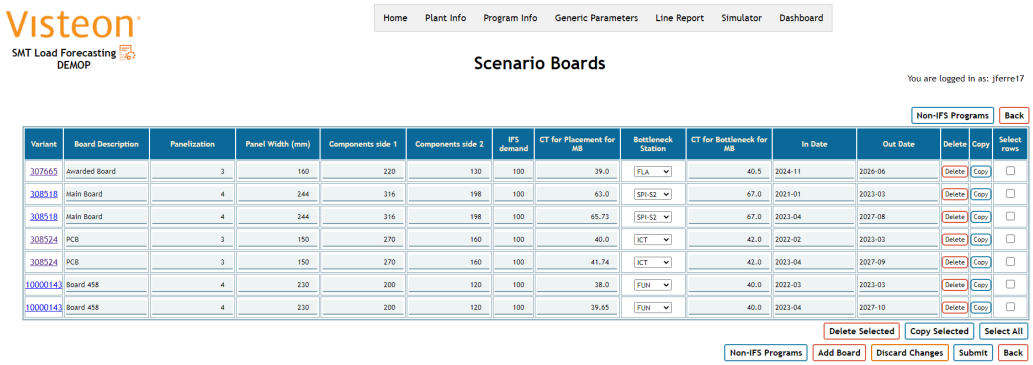


Figure 4.7: Plant Simulator's "Scenario Boards" page

The "Non-IFS Programs" page (figure 4.8) displays a list of all of the manual programs associated with the current plant and it also offers the ability to create additional manual programs by clicking the "Create program" button. The column headers allow row filtering. To this extent, the "Clear All" button removes all of the filters previously applied, if any, whilst the "Show Volume" button, displays the volume, by year, throughout the next six years of each of the shown programs. The "Excel" button exports a table with the manual programs along with their information, as displayed in the page, to an excel file. The last three columns of the table are for checking the "Manufacturing Details" page, which displays information about the program, for editing the program and for deleting the program, respectively.

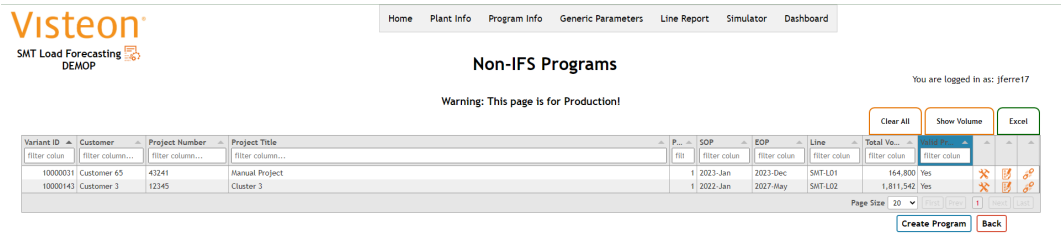


Figure 4.8: Plant Simulator's "Non-IFS Programs" page

The main difference in the "Scenario Homepage" tab is the new "Move" button in each row of the "Board configuration" section. Clicking this button will redirect the user to a new page, presented in figure 4.9, where information about the program and the board is displayed. Still in this page it is possible to move boards completely or partially to a different line in the same plant scenario. Some of the parameters can be changed in the last table, as presented in the figure. To move the board, the user must click the "Submit" button.

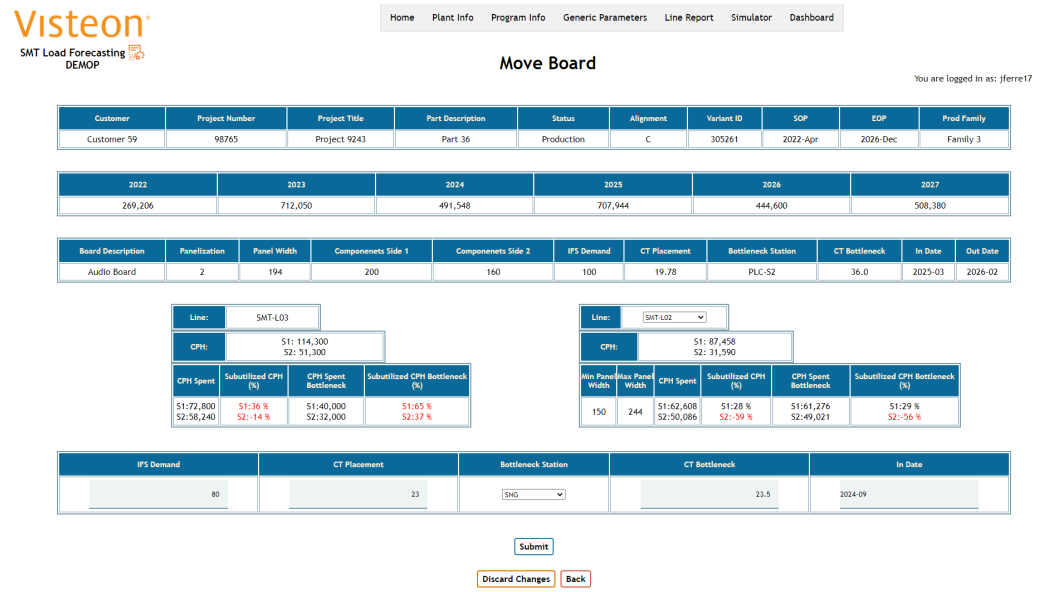


Figure 4.9: Plant Simulator's "Move Board" page

On the top of the line simulator page (figure 4.10), it is shown a bar graph with the line loads throughout the next six years, by month. The graph also shows the capacity of each shift and has four categories, the boards that are in production, are awarded, are being pursued and are manual. It also has a filtering option that allows visualizing different periods of time during the six-year time span. The "CT at Bottleneck" button allows the recalculation of the graph with the Bottleneck station's cycle time instead of the placement machine's cycle time.

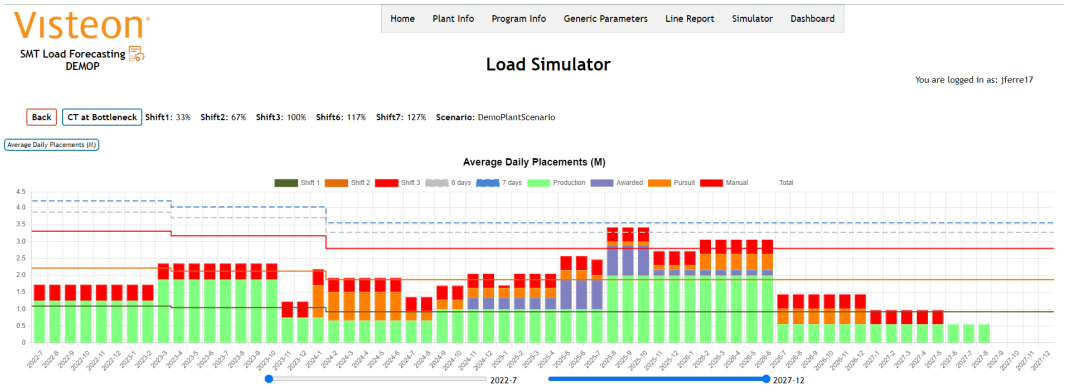


Figure 4.10: Plant Simulator's Line "Load Simulator" page (part 1)

The next two graphs, displayed in figure 4.11, have a similar structure. Here it is shown utilization of the line in percentage and in hours.

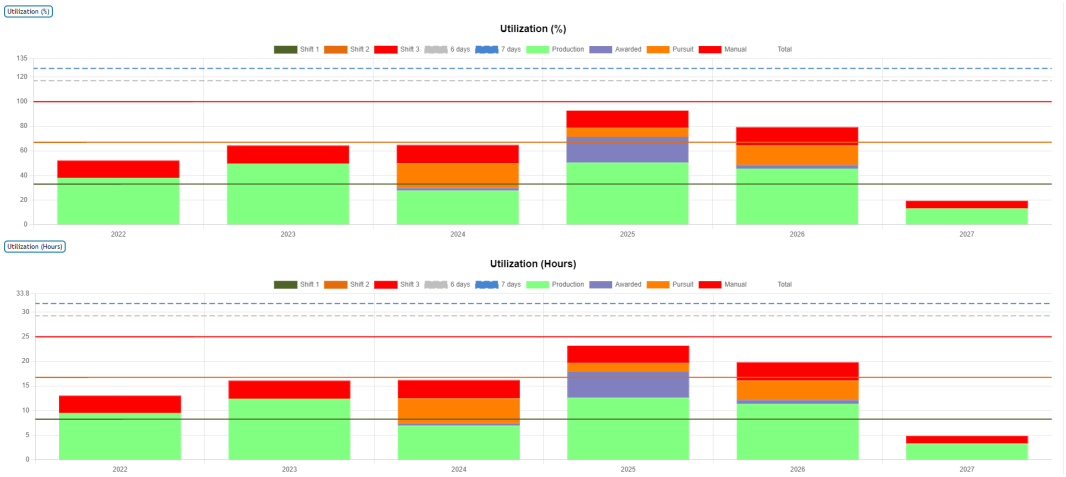


Figure 4.11: Plant Simulator's Line "Load Simulator" page (part 2)

At the bottom of the page and as it is displayed in the following image (figure 4.12), some relevant program information is show along with the volumes and utilization per year for the following six years. It has the option of choosing to calculate the graphs with only certain programs, by deselecting them and clicking the "Apply" button. The two green outlined buttons allow the exportation of the presented table to Microsoft Excel, showing the volumes by year or by month, respectively. Lastly, the "Plant Simulator" button allows a direct redirect to the plant simulator page.

Back | Apply | Excel - Yearly | Excel - Monthly | Plant Simulator | **OEE:** 98% **Placers efficiency:** 98% **Available hours:** 24 **Days per year:** 300

Program Title	Customer	Variant	Board Description	Panel Width	Status	Total Volume		2022	2023	2024	2025	2026	2027	
Manufacturing	Customer 1	308518	Main Board	244	Production	2,510,000	Volume	0	585,000	420,000	765,000	690,000	50,000	☑
							Utilization	0 %	38.62 %	27.72 %	50.5 %	45.55 %	3.3 %	
Cluster 3	Customer 3	10000143	Board 458	230	Manual	1,531,849	Volume	0	279,693	372,934	350,913	372,924	155,385	☑
							Utilization	0 %	11.14 %	14.85 %	13.97 %	14.85 %	6.19 %	
PCB manufacturing	Customer 22	308524	PCB	150	Pursuit	774,000	Volume	0	0	360,000	132,000	282,000	0	☑
							Utilization	0 %	0 %	20.12 %	7.38 %	15.76 %	0 %	
Board	Customer 36	307665	Awarded Board	160	Awarded	500,000	Volume	0	0	40,000	400,000	60,000	0	☑
							Utilization	0 %	0 %	2.09 %	20.89 %	3.13 %	0 %	
Manufacturing	Customer 1	308518	Main Board	244	Production	475,000	Volume	300,000	175,000	0	0	0	0	☑
							Utilization	37.96 %	11.07 %	0 %	0 %	0 %	0 %	
Cluster 3	Customer 3	10000143	Board 458	230	Manual	279,693	Volume	186,462	93,231	0	0	0	0	☑
							Utilization	14.23 %	3.56 %	0 %	0 %	0 %	0 %	
PCB manufacturing	Customer 22	308524	PCB	150	Pursuit	0	Volume	0	0	0	0	0	0	☑
							Utilization	0 %	0 %	0 %	0 %	0 %	0 %	
Total						6,070,542	Volume	486,462	1,132,924	1,192,934	1,647,913	1,404,924	205,385	
							Utilization	52.19 %	64.38 %	64.78 %	92.74 %	79.29 %	9.49 %	

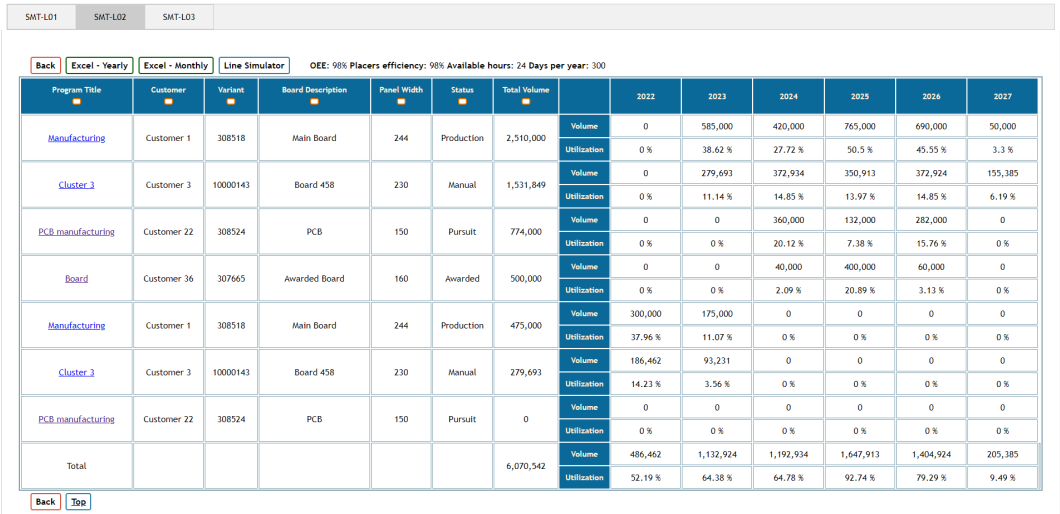
Back | Apply | Top

Figure 4.12: Plant Simulator's Line "Load Simulator" page (part 3)

In the plant simulator page (figure 4.13), the loads from all the lines can be observed throughout the next six years, along with the plant shifts capacity, in a graph, and it is populated with the current scenario data. An equal graph is also displayed, but this time with the real plant data, for comparison. This allows visualizing the distribution of the line loads on the plant for appropriate decision making.

Figure 4.13: Plant Simulator's Plant "Load Simulator" page (part 1)

Finally, as it can be seen in figure 4.14, the bottom of the page is similar to the one in line simulator, it presents more detailed information regarding the lines, and it also has two green outlined buttons allow the exportation of the presented table to Microsoft Excel, showing the volumes by year or by month, respectively. However, this time there is a tab that allows switching between lines, and it is possible to go directly to the line simulator of the selected line by clicking on the "Line Simulator" button.



Program Title	Customer	Variant	Board Description	Panel Width	Status	Total Volume		2022	2023	2024	2025	2026	2027
Manufacturing	Customer 1	308518	Main Board	244	Production	2,510,000	Volume	0	585,000	420,000	765,000	690,000	50,000
							Utilization	0 %	38.62 %	27.72 %	50.5 %	45.55 %	3.3 %
Cluster 3	Customer 3	10000143	Board 458	230	Manual	1,531,849	Volume	0	279,693	372,934	350,913	372,924	155,385
							Utilization	0 %	11.14 %	14.85 %	13.97 %	14.85 %	6.19 %
PCB manufacturing	Customer 22	308524	PCB	150	Pursuit	774,000	Volume	0	0	360,000	132,000	282,000	0
							Utilization	0 %	0 %	20.12 %	7.38 %	15.76 %	0 %
Board	Customer 36	307665	Awarded Board	160	Awarded	500,000	Volume	0	0	40,000	400,000	60,000	0
							Utilization	0 %	0 %	2.09 %	20.89 %	3.13 %	0 %
Manufacturing	Customer 1	308518	Main Board	244	Production	475,000	Volume	300,000	175,000	0	0	0	0
							Utilization	37.96 %	11.07 %	0 %	0 %	0 %	0 %
Cluster 3	Customer 3	10000143	Board 458	230	Manual	279,693	Volume	186,462	93,231	0	0	0	0
							Utilization	14.23 %	3.56 %	0 %	0 %	0 %	0 %
PCB manufacturing	Customer 22	308524	PCB	150	Pursuit	0	Volume	0	0	0	0	0	0
							Utilization	0 %	0 %	0 %	0 %	0 %	0 %
Total						6,070,542	Volume	486,462	1,132,924	1,192,934	1,647,913	1,404,924	205,385
							Utilization	52.19 %	64.38 %	64.78 %	92.74 %	79.29 %	9.49 %

Figure 4.14: Plant Simulator's Plant "Load Simulator" page (part 2)

5

Conclusion and subsequent work

5.1 Summary

In this new era of digitization, constant optimization and adaption to state of the art methods and technologies is mandatory to grow and triumph as a Company or as an individual. The same idea applies to Visteon. When speaking of its manufacturing production lines, a constant need for self improvement is one of the most accounted for topics.

Both the developed projects help with this goal by extending the Digital Twin in a way so that optimal prediction, planning and testing can be conducted.

Specifically, the need for a method that predicts the real performance of the production lines and another method that simulates the plant's data for firmer planning is met by the developed projects.

The implementation of the projects is also expected to help prevent line overloads that ultimately helps with this issue's prediction.

The developed work also contributes to helping to further improve the development of Smart Manufacturing in it, by providing powerful methods that can be utilized not only in Palmela, but also in all of the other Visteon plants and establishments across the globe.

Lastly, I want to strengthen the fact that with the developing of these projects, Visteon will have better capability of achieving the goals set in its contracts with its clients.

5.2 Future Work

Subsequent work that can enhance the Digital Twin's potential, regarding the real performance data project, is implementing a way to do the forecasts weekly, or even daily, besides monthly. This will allow better control and understanding of the weekly or daily events and also the ability to plan better for possible exceptions or unexpected occurrences.

The real performance data project was developed for a line in Palmela Plant, however, its value is of interest of being applied to the other lines in Palmela plant and also to all the other Visteon plants in other countries as well, so it is relevant to extend this work to the other lines and plants.

Another important aspect to advance in the future is the implementation of the Real Performance Data page, for the plants and lines, in the LoadCharts Dashboard. This, because not all of the users that have access to the LoadCharts Dashboard, have access to the Digital Twin, and these users may also benefit from the reporting of this data. Furthermore, this will grant an easy way of viewing a simplified and general display of the data when a detailed look isn't required.

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