POLITECNICO DI TORINO

Master Degree
in Electronic Engineering

Master Thesis

Improvement of automation processes along the Supply Chain

Application of Industry 4.0 concepts in managing incoming components, assembling them into a final product and performance testing

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1 Introduction

The first objective of this master thesis consists in a research of the state of art of the characteristics of Industry 4.0, explaining the main features, with a particular focus on the type of technologies exploited. The explanation of the key points of the Industry 4.0 and how a company should be organized according to them, are reported. It is nowadays essential to be aware of these concepts since they make a company competitive and technologically advanced. Once known the main properties of Industry 4.0, an analysis of the as is of the company where the internship has been carried out is reported: some of the projects, already present, are briefly explained in order to have practical examples of what has been learned from the state of art.
Following the concept of continuous improvement, the company is developing more and more projects in order to create its own processes in compliance with the features of Industry 4.0. In particular, *standardization*, *digitalization* and *automatization* of processes, make the organization of a company stronger and more flexible at the same time. Regarding these two concepts, an important project is being developed: the **Smart Incoming**. It is one of the core objectives of this thesis. The project, that involves the incoming of the components in the warehouse, has been followed from the beginning, looking for the weak points and defects of the actual process, and establishing the characteristics of the new process. In particular, it is a project whose aim is to automatize the recording of the information of the incoming components, using a full cloud infrastructure, by exploiting the OCR technology. Since the development of the project required some previous data analysis, the objective of part of this work of thesis is to elaborate different analysis of various software performances in order to properly decide the project solution. For example, the elaboration time and the confidence of the reading are important aspect to investigate.
The second part of work of thesis focuses the attention on the *pro-*

duction lines. The type of product analysed is the **lighting** one: automotive products that mount LEDs. A study of the actual characteristics of the SMT lines where the PCB are produced, with an highlight on the critical points, is carried out. A specific analysis on the testing part, at the end of the line, is performed. Indeed, the aim is to understand and compare the features of the new tester for LEDs with respect to the actual one. The choice of this type of the product derives from the fact that points out the importance of end-to-end integration and digitalization of the data along the supply chain. One of the most critical aspect about LEDs management during the manufacturing process is the Binning, that is at the same time an information which is difficult to deal with from a logistic point of view: it is, therefore, one of the reason why the development of the Smart Incoming became necessary. A proper traceability system, developed at the beginning of the Supply chain, achievable with the Smart Incoming, can assure a leaner management of the LEDs on the production lines.
From a general point of view, the aim of the thesis is to underline the importance for a company of the application of different characteristics of Industry 4.0, like the integration of processes, an high level of automation and digitalization, in order to guarantee a better quality and efficiency of the work.

1.1 The Company: Bitron Group

The interniship, that led to the elaboration of this master thesis, has been held in a company in Grugliasco, called Bitron.
Bitron history starts in 1955 with Mr. Giovanni Bianco and his brothers when thy founded the company called Fratelli Bianco. Today the company, named Bitron Group, is a *global privately* held company with around 8.500 employees and a strong global footprint.
Bitron is leader in research, development and manufacturing of mechatronics devices and systems for **Automotive**, **Home appliance**, **HVAC** and **Energy** industries. One of the core business

activity of the Bitron Group is the **Electronics Division**: it was born in 2012, and since then, it has reached an always wider global presence. Characterized by innovation, flexibility, market knowl-

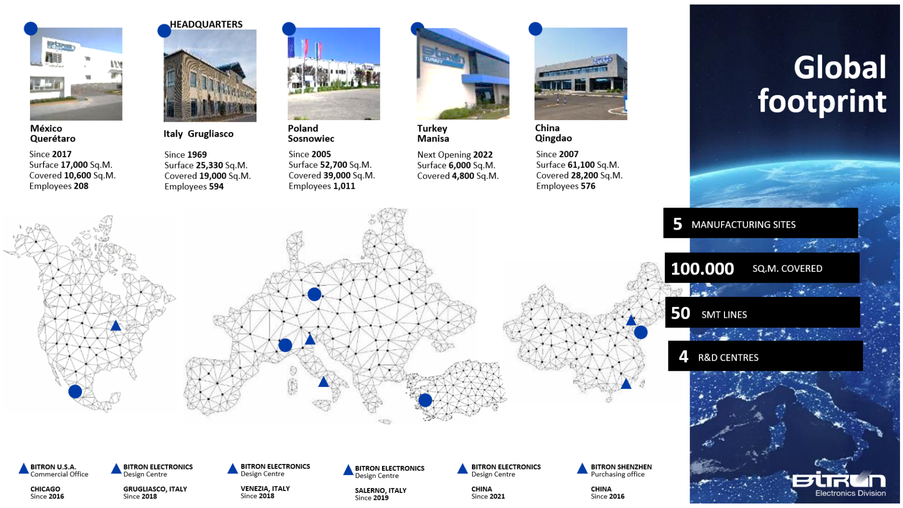


Figure 1: Global presence of Electronic Division

edge and open cooperation, the Electronic division is now responsible of the than 40% of the complete turnover of the Group. The market numbers are the ones reported in the figure 2.

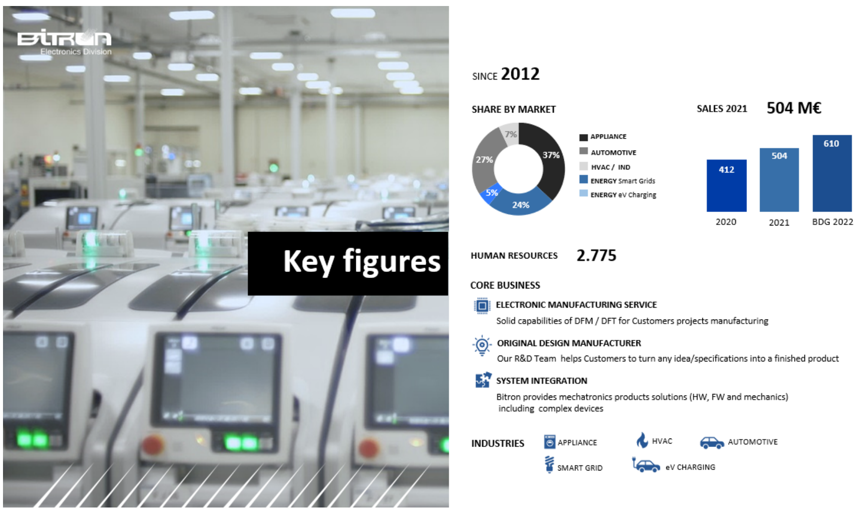


Figure 2: Business characteristics of the company

The industries of reference are then correlated to different kind of products. One of them, for example, is related to the *Smart Grid*

solutions, like smart meter and smart sensor, having as a target utility service providers, energy providers, service companies operating in energy and renewable. Not far from this field, supported by the belief in the future for a reliable, smarter and emission-free mobility, there are the *Ev charging* products, whose target in the market sees charging point operators, car fleet operators, utilities and energy providers. The most spread field of interest, thanks to over than 30 years of experience, consists in the *Home Appliance*, developing solutions for the most important manufacturers on the market. An increasing field is instead the *Automotive* sector, having electronic products devices and system for automotive interiors, powertrain, transmission and lighting. In the end, part of the production involves the *HVAC Solutions*, offering innovative and and energy-saving features for heating and water management.
An important sector is the R&D section, providing an high level of know-how in designing and developing Electronics solutions.
Quality is the fundamental inspiring value of Bitron Electronics. The quality level is guaranteed by using latest techniques and equipments applied by highly-trained and specialized people, especially focusing of Big Data Analytics.

2 Industry 4.0

In this chapter a brief history of industrial revolutions, up to the fourth one, is provided, so that it is clear the overall path that led to the Industry 4.0. A deeper analysis, on the typical features of Industry 4.0 and on the base technologies that actually support the previous ones, is carried in the second part. At the end, the as is of the Company regarding some aspect previous explained are reported, through practical example on how in the company the features of Industry 4.0 are implemented.

2.1 Brief History

In the recent centuries, human kind went through deep scientific and technological progresses that led it to experience different kind of industrial revolutions; according to literature, three of them have been already passed.

Briefly retracing the most important steps up to now, it is possible to see the first one in the Industrial Revolution of the second half of 18th century. A progressive change in the economy, from agriculture and handcraft to industry and machine manufacturing, is the characteristic of that period, chiefly in Britain. This happened mainly due to the use of new materials, like iron and steel; new energy sources such as coal, steam energy; new kind of machines, like the spinning jenny; new transportation, like locomotive and steamship.

It is during the following century that the use of electricity, communication systems like telegraph and telephone, the spreading of mass production and assembly lines led to the Second Industrial revolution. It is easy to deduce how much the manufacturing process has been changed after the installation of the moving assembly line in the automotive factory by Henry Ford: it is the first example of automated production process.

Then, the technology innovation up to the end of 20th century, allowed to enter into the Third Industrial Revolution, also known as

Digital Revolution: the development of electronics, computers and telecommunications permitted the creation of a more connected world and the benefits affected also the industries.
Finally, the ongoing industrial stage is the so called Industry 4.0, that means the Fourth Industrial Revolution, as it has been coined in 2011 by German government with universities and private companies as a strategic program to enhance productivity and efficiency of the industries (1) (2). The key aspects of this new stage consist in *1.* digitalization, optimization, and customization of production; *2.* automation and adaptation. *3.* human machine interaction (HMI); *4.* value-added services and businesses; *5.* automatic data exchange and communication(3). It is clear to see how the evolution of the Information and Communication Technologies (ICT) involves also the progress inside the factories. Moreover, a crucial aspect that the Industry 4.0 must deal with, is the sustainability, in terms of environmental, social and economic dimension (5).

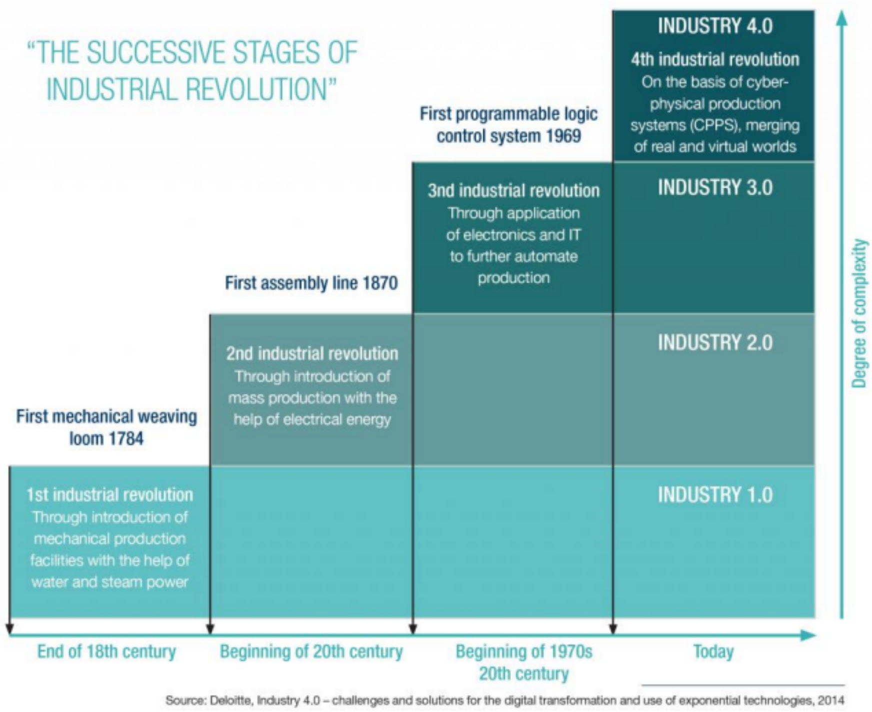


Figure 3: Summary of four industrial revolutions

The manufacturing process is characterized by the use of Cyber-Physical Systems (CPS) production that exploits the Internet of Things (IoT) technologies and the Cloud Computing; the efficiency, the degree of flexibility, the productivity are then highly increased, but also the automation level. It is possible to monitor the physical process and consequently take *smart Decisions* through real-time communications between machines, humans, sensors, and so on (6). This is the beginning of the *Smart Factories* that have to face with the current challenges like shorter product lifecycles, customization and global competition. Another feature that allows to reach the aims of the Industry 4.0 is the *standardization*, useful in order to permit the interaction of different components from different providers (4), it also assures an higher stability and scalability and a better quality of the processes.

2.2 Key points of Industry 4.0

Industry 4.0 is characterized by specific features that need to be deeper explained.
First of all, it is worthy to analyse the theoretical framework of Industry 4.0, as showed in figure 4. In particular, there is a distinction between the Front-end Technologies and the Base Technologies: the first ones refer to the 'smart' dimensions that have an end application on the companies value chain, that means being aware of the operational and market needs; the last ones consist in all the technical instruments that provide the connectivity and intelligence for the front-end part (2).

Smart Manufacturing and Smart Product

The upper part contains the Front-end technologies in which it is possible to distinguish the *Smart Manufacturing* and *Smart Product*: new technologies allow to gain a profound transformation in the production systems but also in the characteristics and potentiality of the product. In fact, an higher flexibility and adaptability to

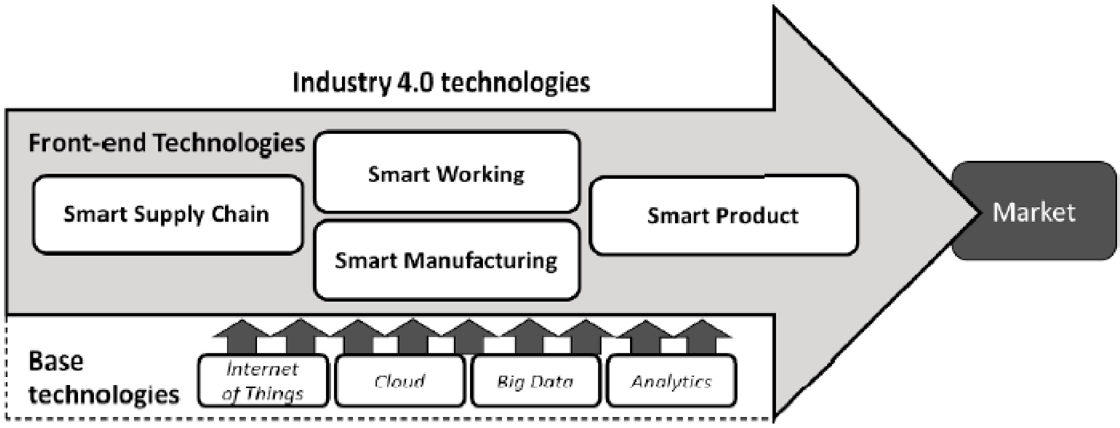


Figure 4: Theoretical framework of the Industry 4.0 technologies

the customer needs, a better quality and productivity are reachable thanks to the technologies exploited by the *Smart Manufacturing*. From (2), six different attributes for the Smart Manufacturing and Smart Product can be identified. They are analyzed in the following part.

Vertical System Integration

This kind concerns the intra-company integration: that means to make possible the sharing of data, real-time information among all levels of the enterprise hierarchy such as corporate planning, production, scheduling or management (7). In particular, as regards the production process, the vertical integration permits to connect the bottom of the process, made by sensors and machines, up to the Enterprise Resource Planning (ERP), generating a flow of information through several stages: from Programmable Logic Computer (PLC), to Supervisory Control and Data Acquisition (SCADA) systems, to have diagnosis and control, to Manufacturing Execution System (MES), to elaborate data for the management.

Obviously, the integration can be gained thanks to the progressive digitalization and automation of the different part of the manufacturing process. The vertical integration is a key aspect of Industry 4.0 since it guarantees a better decision-making process, consider-

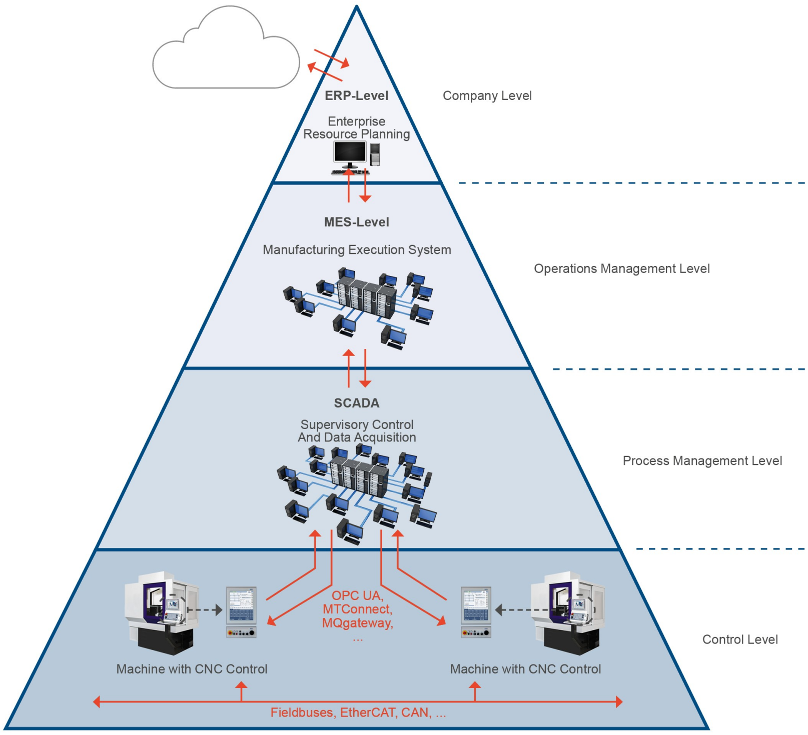


Figure 5: Graphic representation of Vertical Integration

ing the control and the transparency among every steps. It involves not only the manufacture part of the company, but every department and function, enhancing the synergy among them within the entire organization.

Automation and Flexibility

The use of robots, like industrial robots or autonomous guided vehicles (AGV) and so on, in the manufacturing is increasingly spreading, since it assures higher productivity and precision, assuring less effort for the operator. Several parts of the process need to be automatized in order to, also, reduces costs: an example could be the automatic nonconformities identification during the production, thanks to automated functional test or automated optical inspection (AOI). It is essential that the automation is planned considering the flexibility : in this way it is possible guarantee customized

products and eventually, the adaptation of the plant to specific needs. Having the goal of reaching an increasing and higher adaptability, and consequently a facilitation in the production process and a reduction of production costs, the robots are made smarter with the use of Artificial Intelligence (AI) and sensors. An example of this can be found in the Autonomous Industrial Robots, able to make their own decision without the operator intervention and in a constantly changing environment.
There is a promising technology that well fits with the flexibility requirement: Additive Manufacturing. It is a process used for creating complex structures using Computer-Aided Design (CAD) data in a way to reduce time and costs for the design (8). Moreover, it is possible to produce customized product, even with complex geometries, in automatic line, using the same resources. In general, additive manufacturing it also generates less waste, so it is helpful in a sustainable production approach: it is reasonable to believe that AM technology will expand eventually to super-advanced technology areas and substitute current technologies (2) (7).

Traceability

Intended as tracing and tracking of both raw material and final products, this attribute is well connected to the features of *Smart Product*. Manufacturing objects can be equipped with Radio Frequency Identification (RFID) readers and tags, so that it is possible to track them along the entire manufacturing flow(6): the movements inside the factory can be monitored, as well as the operators the work on it (13). The use of sensors in the tracking is particularly important for the warehouse management, too. There is an information flow that is generated thanks to the integration of Big Data and IoT, as it will be more clear in the section 2.2.
The tracing is, instead, indispensable because the information about supplier or manufacturer, date of manufacturing and other specific features, of each component need to be proved: using barcodes or RFID tags all of these data can be read and stored. It is useful, for

example, in case of troubles for a particular finite product: with a good traceability it is possible to go backwards up to the origin of possible non-conformities of any component of the product. It is in this way clear the fact that traceability is strictly connected to quality.
Moreover, in the perspective of flexible automated lines and smart products, it is possible to have machine capable to read the sensors and apply consequently the proper manufacturing actions on the product (2).

Virtualization
Virtualization consists in Virtual commissioning Simulation of processes, Artificial Intelligence for predictive maintenance and planning of production (2). Regarding the simulation, it is an important and helpful technology to understand the dynamics of different systems, it allows experiments for the validation of products and processes. Furthermore, simulation modelling helps on cost reduction, decrease development cycles and increase product quality. Some applications can be the research of maintenance operations, operations planning and scheduling. The simulation modelling with the Digital Twin is so able to provide an ultra-high-fidelity simulation: it is an aspect of increasing importance for the Industry 4.0 (7). Strictly connected to this topic is the use the Virtual Reality in order to have a representation of the factory so that it is possible to obtain a Virtual Factory vision to work with for the simulations.

Energy Management
Another important aspect of the Industry 4.0 is the monitoring and consequently optimization of the energy consumption in order to reach a better energy efficiency. This can be done, for example, with the installation of proper sensors on each part of the equipment of a specific chain (2).

Smart Supply Chain and Smart Working

The Smart Supply Chain provides the technology support for the horizontal integration, explained below, making possible the exchange of real-time data, having access, for example, to the information stored in a cloud (2). Another important aspect is the Smart Working, intended as the various technical solutions that can guarantee a better productivity and more flexibility of the operator. A typical example is the use of collaborative robots, a specific robot designed properly to permit the strict collaboration among human and robots: this means having smoother , security constrains, sensors embedded so that it makes safe the coexistence, the cooperation and the collaboration with human operator. The worker's activity is in this way supported and improved in terms of accuracy, reliability and efficiency.
Another way to make the work smarter is the implementation of the augmented reality: it helps since it can give further information, in real-time, thanks to digitally processed reality and digitally added artificial objects (7). The user's perception of the real world will be altered enabling better performances. Let consider, for example, the use of smart glasses for the vision picking:the glasses can provide information on item location, improving the productivity.

Horizontal and end-to-end System Integration
Thanks to digital platforms, the communications with customers and suppliers becomes flexible, characterized by responsiveness and transparency . The aim of the horizontal integration is to work with the supply chain partners to set business goals, define and carry out common processes, exchange data and information (9). It means that it is an inter-company integration that establish an information network from the supplier to the customer(10).
Finally, the end-to-end digital integration of engineering across the entire value chain is the extension of the horizontal integration of the supply chain and the vertical integration: it is the integration

of the entire product life cycle management. The aim is to link every part, from research, product design, production planning and engineering, manufacturing, to logistic, customer but also services, maintenance and recycle. In this way all the gaps can be filled and the product is followed since the raw material acquisition to its end-of-life.

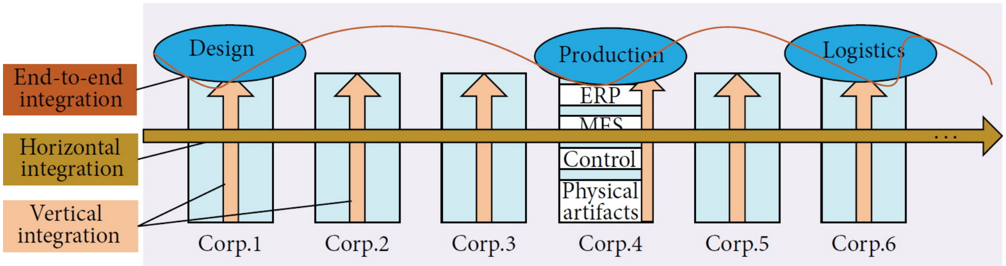


Figure 6: Graphic representation of different kind of integrations (7)

Base Technologies

The ICT technologies that actually assure the different features explained before, consist in the Cyber-Physical Systems, Internet of Things, Cloud Computing, Big-Data and Analytics, and the Cyber-Security, to assure the correct protection for them. They can provide the typical requirements of Industry 4.0 such as autonomous interoperability, agility, flexibility, efficiency and cost reduction (7). As (2) states, the more advanced an industry is, regarding the *Smart Manufacturing*, the stronger the presence of these technologies need to be. A brief explanation of these technologies is reported below.

Cyber-Physical Systems

Among the latest ICT technologies it is possible to identify the Cyber-Physical System:it consists in the integration of different physical objects, like smart machines or smart products, with the virtual dimension of the factory: thanks to the "cyber" component it is possible to interact with the physical world though a virtual copy

of it (7). An essential aspect of the CPS is having embedded systems that allow collecting and process data that can be exchanged with the cloud or among others CPS, in a wired or wireless way. It means that a communication infrastructure can be build: CPS can cooperate with each other but also with humans. Different kind of features can be distinguished like the use of sensors or actuators in order to, respectively, monitor or handle physical component or physical process (3); but also the CPS can collaborate in planning, analysis and maintenance of manufacturing processes. As it can be more clear later, the CPS needs an IoT structure to perform.
To sum up, the CPS consists in the integration of different kind of systems, from physical objects to communication network and computational platforms whose main purpose consists in controlling a physical process by exploiting the provided feedback and easily adapt it to new conditions.
Going into details, the implementation of CPS in a manufacturing environment let to the creation of CPPS (Cyber Physical Production System), characterized by the integration of ICT, automation and all the technologies of the *Smart Factory*. In CPPS are involved not only machines and products but also humans and the use of artificial intelligence and simulation. The aim of this new structure, considered decentralized, is to grant a better cost and time efficiency, higher productivity with better quality, real-time management of the industrial production.

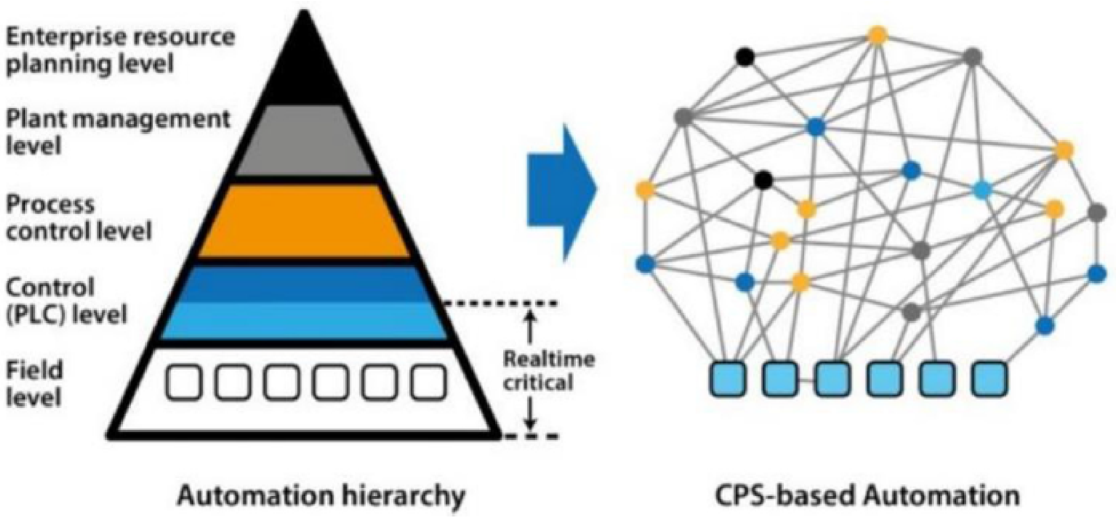


Figure 7: Representation of the the CPPS decentralized structure.

In the figure 7, it is reported the CPS-based Automation: the squares represent inputs/outputs devices, the lines represent service interactions and the blue, yellow, grey and black points represent the corresponding functionalities of the five-layer architecture of the traditional automation pyramid (7).

The Internet of Things

The Internet of Things, or shortly IoT, consists in connecting through the internet, the most widespread network, different type of physical objects like sensors, actuators, machines or terminals. Through this network, information can flow and data can be exchanged with simplicity. Indeed, since Internet is becoming widely available and affordable, also the cost of connecting though internet is decreasing. The interaction and cooperation can be achieved digitalizing all physical systems. The increasing advancement of mobile devices, makes this technology more and more exploited. Some examples of can be Wireless Sensor Network (WSN) or connected RFID.
A significant contribution of IoT is seen in the ease of monitoring and analysing the processes, especially in the production one, that is essential in the quality management, but also support the energy

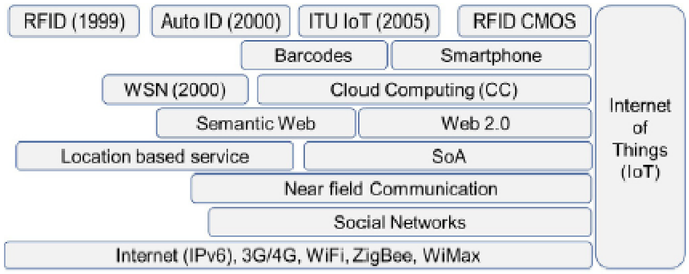


Figure 8: Technologies for IoT

monitoring. Moreover, IoT simplify the supervision, like checking the status or making diagnosis, of the machines(8). It can also help to identify potential risks.
Talking about the industrial environment, it is possible to refer to IIoT (Industrial Internet of Things), in which is more explicit the connection among machines and product: it is clear the use of this technology for commercial purpose, since the product value is increased thanks to analysis, monitoring and optimization.This technology can enhance labor productivity, efficiency and accuracy (14).

Cloud Computing

The Cloud Computing (CC) is, in first place, a technology that provides all the computing services - like servers, database, storage, analytics, software, networking, artificial intelligence. It is a flexible and scalable solution with economical advantages: it can guarantee cost reduction, since it is typical to pay just for the services required. A strong point of the Cloud derives from the fact that it can facilitate the integration of different devices since it is not required to be physically close to share information. Combined with the IoT, it is possible to have communication among objects and systems, that generates data which can be easy to access thanks to the cloud services. In fact, the data from the physical layer can be collected to the cloud and the user can easily interact with them

(11).
In order to summarize, the principal aspects that make convenient the use of the cloud are: better performances, also in terms of speed, and productivity, scalability and lower cost, higher security and reliability since providers can guarantee a strength level of protection, data backup and disaster recovery. In the industrial en-

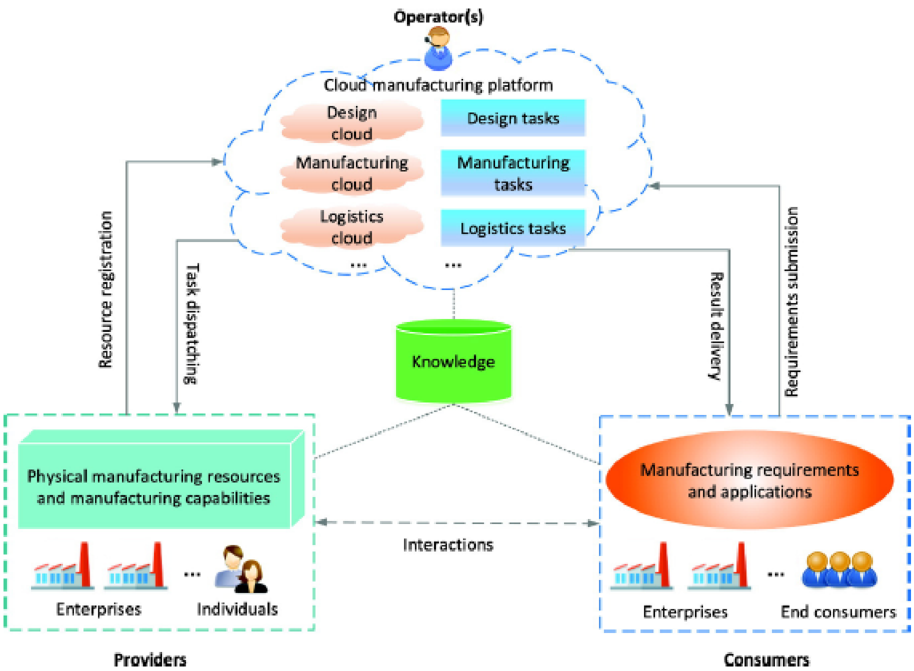


Figure 9: Cloud Manufacturing Example (7)

vironments, it is known as CMfs (Cloud Manufacturing). It refers to the advanced Manufacturing system in which there is a deep collaboration among different technologies like IIoT, virtualization, service-oriented technologies (6), CPPS; obviously all the resources need to be digitalized to be shared. The service provided by CMfg follows the product lifecycle among all the stages, from the design to the management etc.

Big-Data and Analytics

The Big Data refers to, as the same word suggest, the huge amount of data that are generated by the Smart Factory, from systems and objects (like the sensors, as seen for the IoT technology). The Data, that are heterogeneous in terms of volume, variety, velocity and need to be elaborated through data-mining and, above all, data-analitycs. In fact, the core of strength of this technology can be found in the fact that the received data can be converted in useful information: monitoring models, predictive models, prescriptive analytics. The exploitation of machine learning in this field is well clear. A crucial aspect correlated to big data is not only the necessity of cloud computing to analyse the information, but also the ability to understand which are the reasonable data to look for in order to obtain the desired KPI (key performance index) e.g. data of operation time of the machine to know the relative efficiency (11). Thanks to these additional information, that actually are becom-

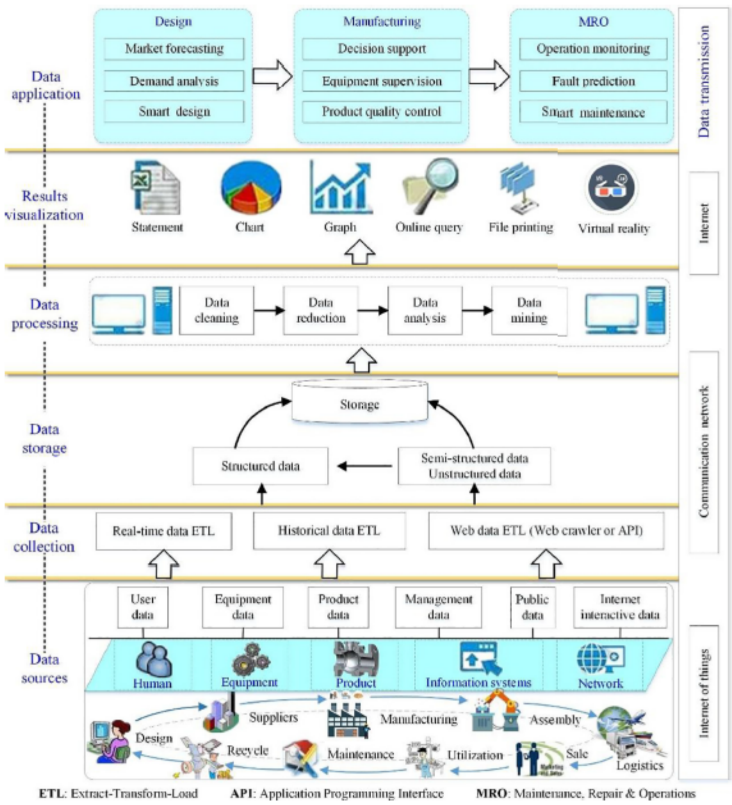


Figure 10: Manufacturing Data Lifecycle

ing more and more indispensable, the decision-making process can optimized. The important contribution can be seen also in the fact that big data facilitates the understanding of the product lifecycle, making easier to discover potential bottleneck along the line (7). Moreover, Big Data become essential, with analytics, in order to create a self-organization of production line and also it can provide to users a clear report of different fields like employee performance, product/machine performance, client feedback etc (8).

CyberSecurity

The protection of information has been always an issue for companies. The Cyber Security refers to the high level information security. Nowadays, the threat of cyber attacks is not negligible, it is then essential that a security system is build. Cyber security can be seen not only from the point of view of the creation of a proper Security Architecture but also from the point of view of the product considering the Security by Design. It is a fundamental aspect to invest in this field since eventual cyber-attacks, can cause shut down in manufacturing operations and this can mean money loss but also eventual risk of safety of operators. The sources of an attack can be multiple: an internal operator that physically have access to data or external sources through wireless transmission (7). In any case, it is also important to well protect the industry in order to, in addiction to what it has already said, maintain customer trust and avoid products' delays.

The objective of the following part is to analyse the **as is** of **Bitron** for what concern some of the aspects of the Industry 4.0 explained before. In particular, some examples about horizontal and vertical integration are reported. For the manufacturing point of view, the importance of flexibility and standardization are put on evidence through two examples.

2.2.1 Examples of Digitalization and Horizontal Integration

The company has built an interesting infrastructure in order to be compliant to the typical features of Horizontal Integration: in fact, this can guarantee a real-time data sharing and an high-level of collaboration with the customer. To preserve the customer privacy, it will be indicated as "Customer" in the following explaination.
In the specific case, the project consists in directly and automatically communicate with the customer database, named *DB Customer*, with the intra-company ones. The architectural solution found is showed in the figure 11. The internal database and the customer one interface each other through the *NN* database thanks to synchronization program that works with APIs (in the figure represented by the arrows). The MES and the ERP indicated are the ones internal in Bitron.
It is useful to observe step by step the data flow. First of all, the orders elaborated by the customer are exchanged from its database to *NN*, including the product code, the quantity and all the information required. At this point, it is still possible to eventually modify the order before it goes to the production. Then, an internal operator is in charge of "freezing" the order so that it is validated and the production can start. When the product arrives on the machine in charge of writing the firmware on the board, a request in order to get the Customer Serial number is sent to NN. This answers with the serial number, that follows the syntactic rules indicated by the customer itself but it is completed with an incremental part of the number obtained by an internal counter, and with various configurations that regards the firmware or the different type of connections the product can support. In fact, these are products that consist in advanced telematics systems used mainly in vehicles. Considering again the production flow, before the production ends, the serial numbers and the relative configuration are stored in the pending table of the NN database. Moreover, it is traced the correlation between the customer serial number and the internal Bitron

label. The outcome of the test are then recorded in the internal MES. After the packaging phase, that is the last one, the information go to the Production table of the NN and only after this step the data are given to the DB Customer database. In this way, the customer has real-time information about the production state of its orders. In fact, the data are updated every 10 minutes. Moreover, the DB Customer receives, always thanks to the synchronization program, the status of the shipments from the ERP of the company, Sigip. In the end, if an order has been closed, the information goes to NN so that the product does not go to the production anymore.

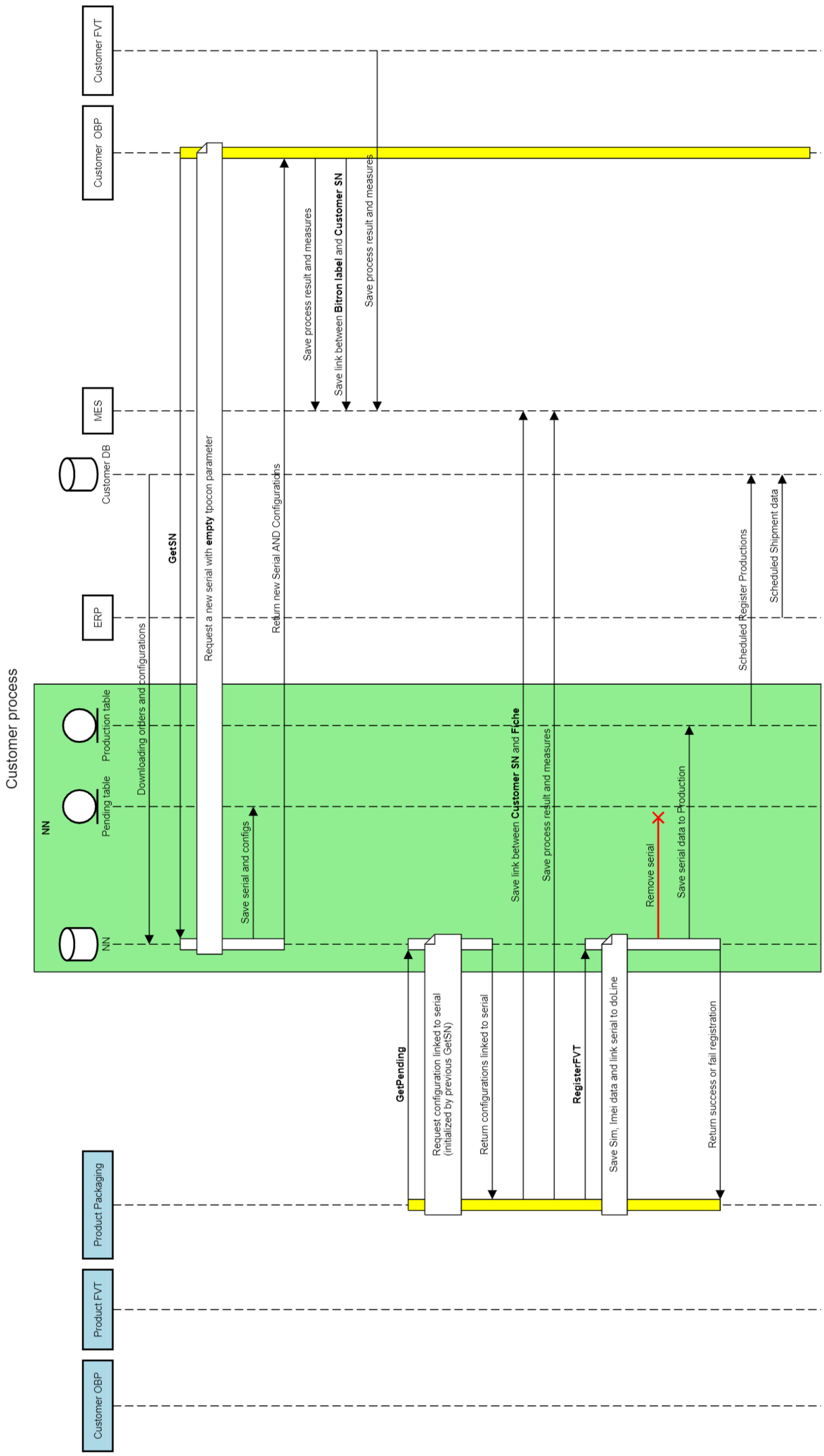


Figure 11: Architecture of the data sharing with the Customer

2.2.2 Examples of Digitalization and Vertical Integration

One of the core part of the business of the company is represented by the production phase. It is for this reason essential to monitor the data coming from the different machine in order to obtain real-time feedback. The data flow starts from the bottom at the SCADA level up to the ERP, as it was theoretically explained in 2.2. As a general organization, the machine are developed considering the possibility to share information with the MES through web services. For example, before starting the manufacturing process on that machine, some information like the program to provide, the state of the previous flux on that product and the other data required according to the specifications are asked to the MES. At the end of the process, the communication happens in the opposite direction since it is the machine that communicate its status to the MES. At the low level there are the so called raw data and going up into the pyramid they are aggregated and abstracted and stored in the ADW, autonomous data warehouse. The infrastructure that represents the flow of data is reported in the figure 12.

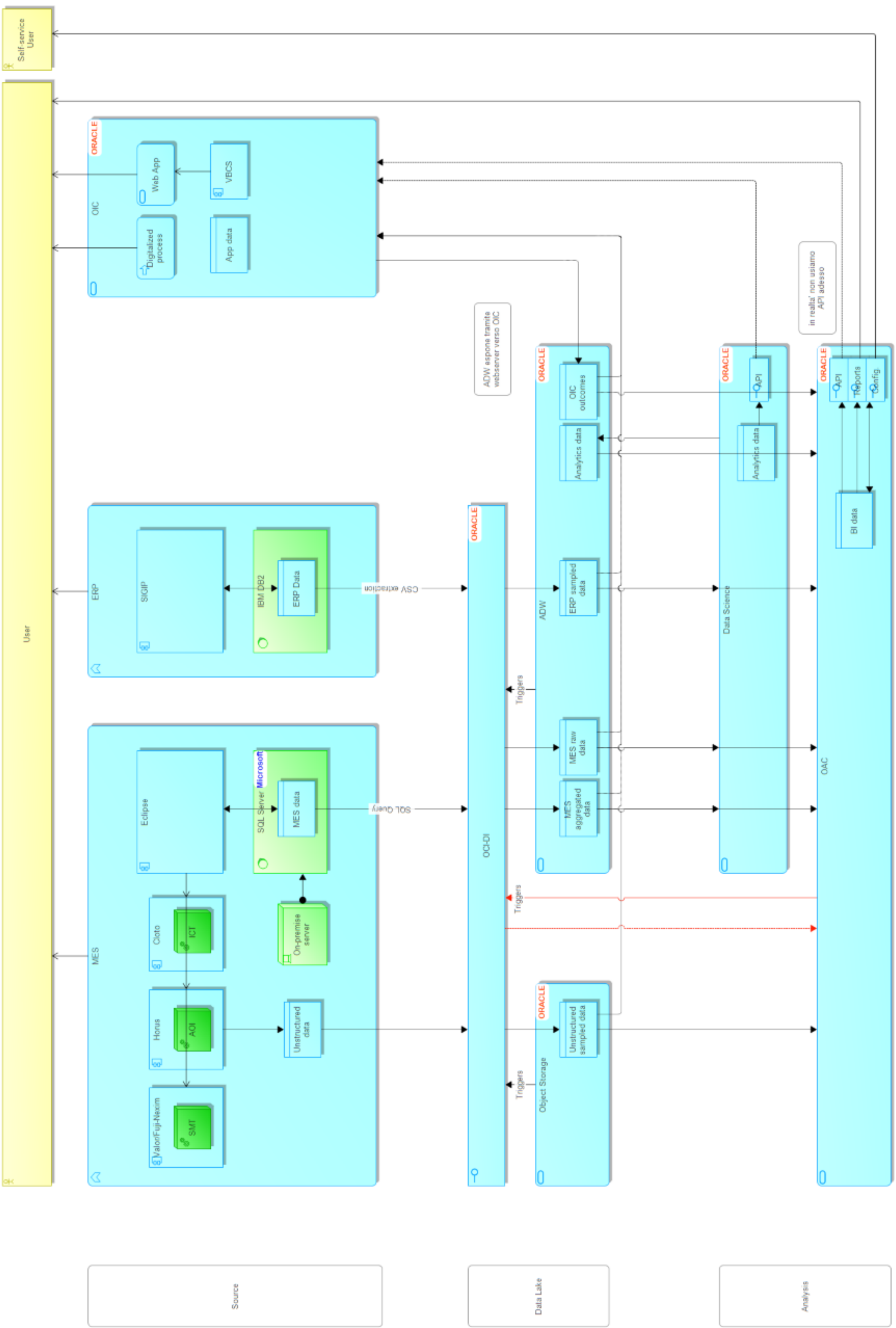


Figure 12: Example data flow inside the company

2.2.3 Example of Standardization in Production: SMT Line

The first part of the production line is a **SMT**, Surface Mount Technology, line. It uses *smd*, surface mounting devices, to be mounted on the PCB. The production process performed by the company for this part is highly standardized among all the plants, with a specific interest into the *real-time control and measure*. In the figure 13 the different modules that form the line are presented. First of all there is the Solder Paste Dispensing, followed by the **SPI**, Solder Paste Inspection: it measures the height, volume, and area on paste deposits. It also computes stencil offsets and finds defects in PCBs. The machine used is characterized by:

- Volume repeatability: less than $\pm$ 1% on 3σ;
- Volume repeatability on average: less than $\pm 3\%$ on 3σ;
- Height accuracy: $2[\mu m]$ on certification target;
- Gage R&R [1]: much less than 10% on 6σ;

Then, there are the SMT modules of pick-and-place machines. They are characterized by: reduced setup time, traceability system, Press-fit (insertion force <90 Nm). This machines are connected with the MES of the company, since each component mounted is traced and connected to the PCB identifier. They are followed by the reflow oven. At this point, for both side of the PCB, the **AOI**, Automated Optical Inspection, is performed: this guarantees a *real-time monitoring* considering data collection for reporting system on hourly base. At the end, **ICT**, In Circuit Tests, are performed, using machines characterized by:

- 700 measure/sec (parallel system);
- Automatic inline system;

[1] Gage repeatability and reproducibility (GR&R) is defined as the process used to evaluate a gauging instrument's accuracy by ensuring its measurements are repeatable and reproducible

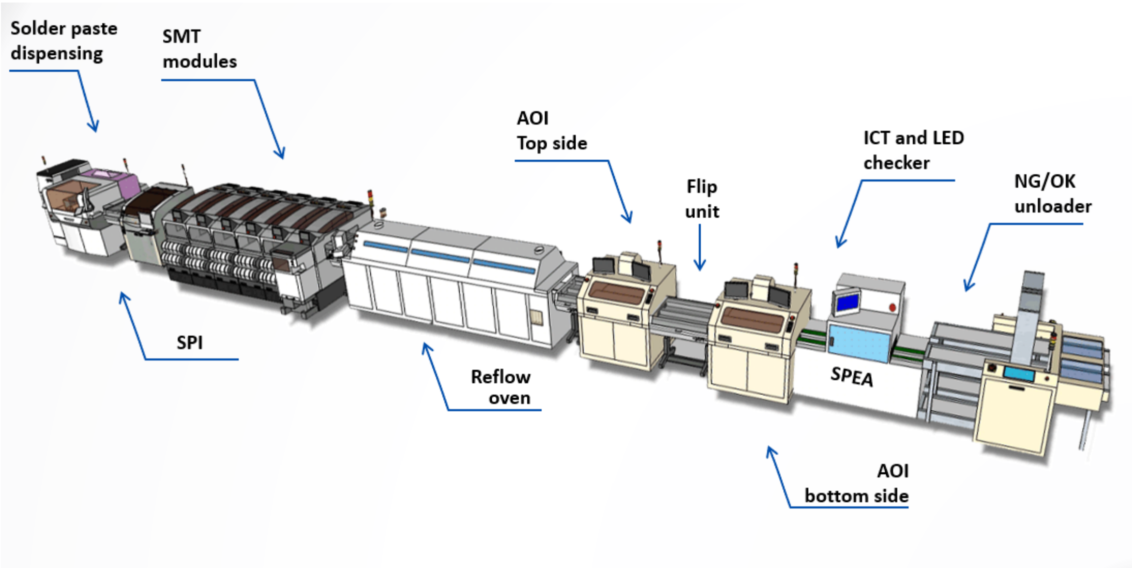


Figure 13: Example of the standardized SMT line inside the production of the company

This solution explained is the same for many products among plants, therefore a *global* standardization has been found. Moreover there is a deep attention on the real-time testing of non-conformities, in order to identify in the early stages possible errors, avoiding further unnecessary operations; these analysis are all automatized, with, however a more careful look of the operator.

2.2.4 Examples of Flexibility of Automation in Production

The first part of the production line is the one explained in the previous paragraph 2.2.3. After this part, it is necessary to cut the panel created into the single PCB, the one actually integrated into the product. For this reason a **Router** is required. This is the first step of the internally called *Backend Line*: the one showed in the figure 14. The main section of this part of the line is the **MAC** : an automated module for assembly lines to assemble electronic devices with actuation method and associated control. It is modular since it is composed by multiple cell that can have different roles. This solution has obtained a patent (patent pending TO2013A0009549).

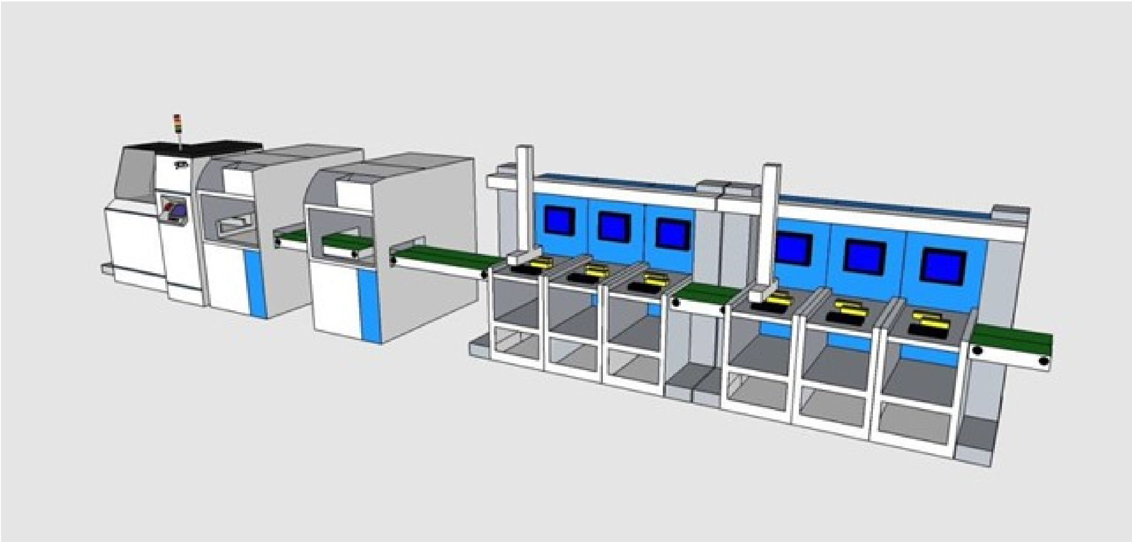


Figure 14: Example of the standardized final phases of the production line: Back-end line

The characteristics of each *cell* of the module are:

- a support structure;
- a control unit;
- at least one actuating system, operatively connected to the control unit, for receiving commands and for transmitting the results obtained.

Each automated *module* is provided with:

- at least one moving device in order to move the devices among the cells;
- a supervising unit that interacts with each control unit, controls the movement of the device;

A very important aspect is that each cell is independent from the others. That means that the cells with the specific operations, listed below, do not have to be placed in a fixed position. In particular, the kind of cell present are:

- *Assembly cell*: assembling at least one portion of at least one electronic device by means of a respective actuation system;

- *Test cell*: used for FVT, functional verification test, on at least one electronic device by means of a respective actuation system, there can be more than one, working in parallel, on different devices;
- *Marking Cell*: for applying at least one distinctive sign onto at least one electronic device

The real implementation is the one showed in the figure 14: as it is possible to see, there are conveyor belts: one used to move the rejected products, another for the good one.

Figure 15: Example of a real MAC line

3 Automated Warehouse Receiving and Digitalization

The solutions explained in the previous chapter involve all the departments of a company, as it can be seen in the figure 16. In this section, the attention will be focused on a specific part: the raw material inventory, with a particular emphasis on the incoming of the components and a short analyses on the warehouse management.

The technologies of Industry 4.0 are present in each step of the

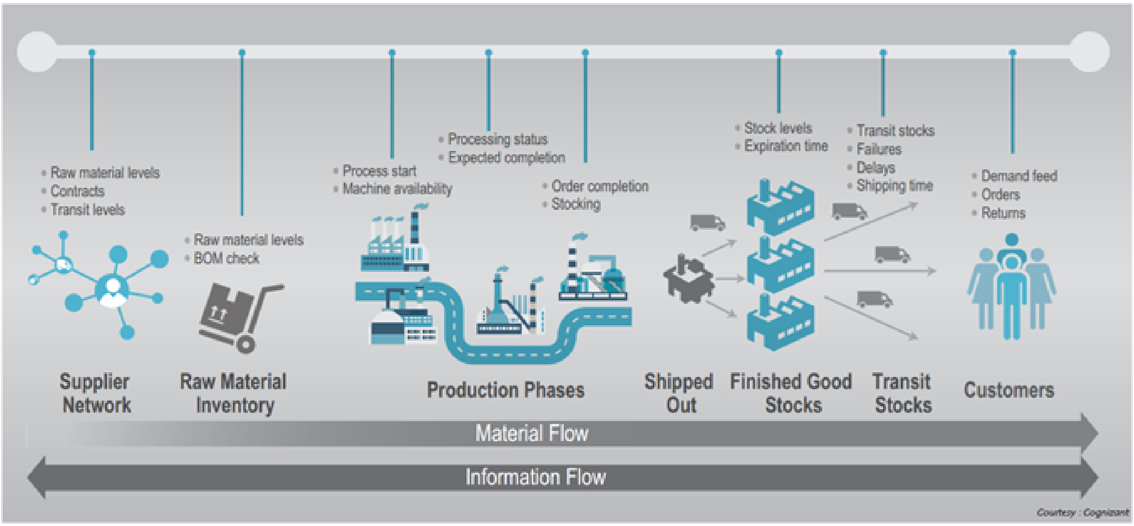


Figure 16: Representation of Industry 4.0 (19)

material flow (fig 16). Starting from the beginning, the first process seen consists in the inbound of the raw material in the inventory. This process is strictly connected to the management of the warehouse. This part of the flow is really important since eventual nonconformities of the component can be already detected, avoiding to waste resources during the production process. In the incoming part there are some aspect to pay attention on: planning of the phases in order to prevent bottle-neck; managing of the warehouse layout: for example, the quantity of material to accept could determine the number of access points; standardization of the procedures to well perform the recording of all the goods in incoming, registering all the information (in this case the use of labels is necessary since all the information seen on them can be stored); determination and managing of the locations in the warehouse.

The material handling is an important aspect that concerns this part of the material flow: optimizing it, means reduction of costs. An interesting role in this intralogistics operation is performed by **AGVs** (Autonomous Guided Vehicles) or **AMRs** (Autonomous Mobile Robots). The last one can be considered an evolution of the previous since they guarantee better performances and an higher level of technology. The AGVs need a central unit that takes control decisions, coordinate the operations of each one that must follow a fixed path with predefined points. The AMRs, instead, form a decentralized system since each one is capable of take its own decisions about the path to follow: the decision making process is way faster since it is distributed and only local factor need to be taken into account. Clearly, this degree of autonomy can be reachable thanks to machine learning and artificial intelligence. From the software point of view, the AMR supports the SLAM (simultaneous location and mapping), a technology for real-time navigation: in fact, it allows to create a detailed area maps of the environment and calculating the position of an AMR on a map. This makes possible to navigate in the operating environment, even though there are no reference points known in advance. Another feature required for the AMR is the motion planning, an essential part of the vision-based guidance systems. Starting from the information obtained by the external environment, it is possible to compute robot's size and dynamics and decide the proper collision-free path to follow, knowing the initial and ending point. In order to reach this result, the algorithm of the motion planning provides commands, such as the speed, to the actuator of the vehicle. Not only from a software point of view, but also the improvement of the hardware made it possible to achieve this more flexible solution. Examples of technologies that support AMR in what concern providing the information about position consist in LiDAR (Light Detection and Ranging), 3D cameras, accelerometers, gyroscopes, and wheel encoders. The amount of data exchanged by the devices is really big, but is essential to allow the adaptation of the path choices to the unknown environment. Specifically, LiDAR laser scanners provide a very precise distance point cloud relative to the AMR in its environment, 3D cameras, instead, provide wide-angle support that enables the visual recognition of obstacles. Another important issue to deal with is the battery management: higher energy capacity and improvements in charging methods can be reached, not only with conventional plug-in connector power supplies but also with wireless power transfer, useful in many case since no wired connection is required. For the AGV, the limited battery capacity and long charging times were weak points in the performances. The new high-capacity batteries (like the lithium-ion one) enable longer operational time and provide more power for the high-level of computation required for autonomous navigation and real-time decisions. This can be affordable thanks to ultra-low-power AI processors: facilitated by hardware developments, AI techniques can be applied to support AMRs in both navigation and providing services. To summarize, it is possible to observe that AGV and AMR are industrial robots that is possible to exploit in different fields, like in manufacturing for the material handling or in the warehousing to pick, localize, sort items. Moreover, the collaboration among them and with humans can be obtained. Two other typical features of these kinds of robots are: scalability, that means that it is possible to increase or decrease the number of AMRs without the need of structural change, and robustness, the systems can easily recover after failure (15).

The automation solutions in the warehouse and logistic management can be found not only in the material handling, as seen before, but also in automatically analyze and store information of the incoming items. Each item has information about manufacturer, supplier, codes, batches, that need to be known if a proper traceability, inside and outside the company, want to be reached.

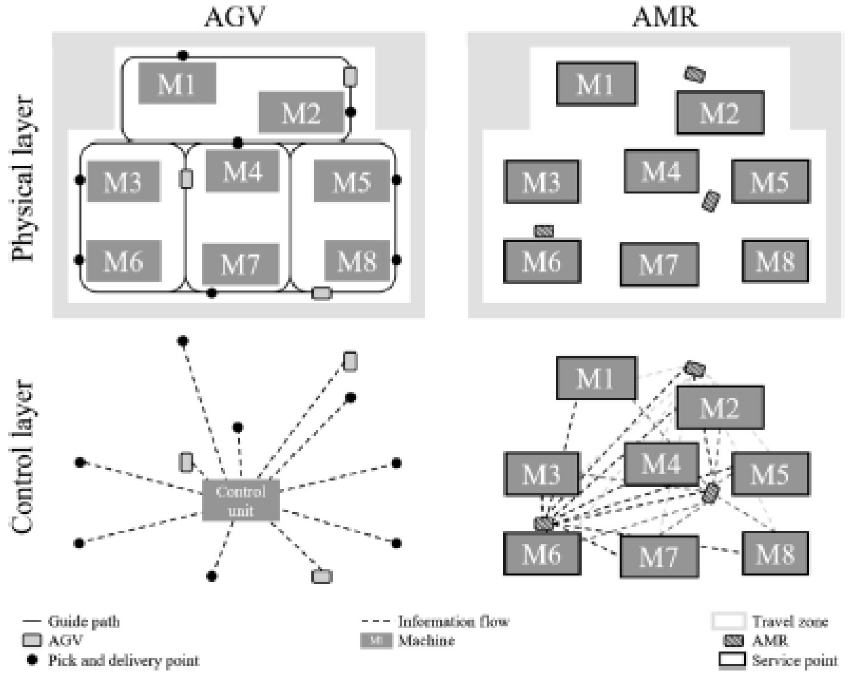


Figure 17: Comparison between AGV and AMR technologies (15)

3.1 Incoming of Components

The field of the incoming components requires more and more attention for many reasons. Firstly, an important aspect regards the *traceability*: for all the components entering in the warehouse, useful information, like the name of manufacturer, supplier, specific codes, quantity or production batch, should be known. Traceability is now one of the main issue correlated to the horizontal integration (consider what is stated in 2.2). In fact, guaranteeing a proper traceability of the components of the product, the distance between customers and manufacturer can be decreased and the connection facilitated, this means having a fully transparent view of the company's supply chain (9). Moreover, it can be exploited in case of recalls of components. The following analysis of the incoming problem has a solution that is **smart** in the sense that it can be considered as a practical example of horizontal *integration* since it can assure a better quality in the *traceability* system, as briefly explained before, but also of vertical integration since, as it will be

clear later, there is an information flow from the hardware up to the ERP of the company. Moreover, it can guarantee a *standardization* of the process among plants and a standard for each kind of electronic component accepted.
A further aspect for which the automated receiving can be exploited consists in the material inspection. The defectiveness of material can cause unnecessary wastage, the need of rework and delays or even recalls and rejection. Having a better control of the material, not only in terms of defectiveness but also in the detection of any kind of non conformities, that enter into the warehouse can assure a better quality and an overall reduction of production costs (12), since identifying any troubles at this stage, decreases overheads.
Going into details, the component analysed for the incoming is the one reported in the figure 18. It is the **reel** that contains the smd devices, exploited during the manufacturing of the PCB performed by the SMT line, explained in the paragraph 2.2.3.

Figure 18: Example of one type of reel present in the warehouse company

3.1.1 Current characteristics and Critical issues of the Warehouse Incoming Management

The current Incoming process is ***not fully standardized***: it means that, according to the type of supplier, different actions need to be performed. In particular, there are two main kinds and the key factor has to be found on the characteristics of the labels.

- *First Type*: It is the most common one. The operator takes the shipping note into the "Receiving goods" office in order to get the GRN (goods receipt note). With this document, after connecting to the ERP, the operator can obtain the generation of each fiche, a *yellow label*, to attach on the reels. The batch information is added to the Reels connected to the GRN, considering that is the same for every reels of the incoming batch. In the yellow label (refer to figure 18), all the information required are repeated and, most important, the *Unique ID* is associated. Once the fiches are put on, those are scanned with a bar-code reader so that the information can be stored into the ERP and MES systems.

- *Second Type*: It regards the components of the suppliers that put on the labels the QrCode in which the data are recorded, even the *Unique ID* (fig 19) is generated by the supplier following rules provided by the Company. In this case, the first step is to read the Qr Code of each reel and, only in a later stage, the operator goes to the "Receiving goods" office to get the GRN associated. For this kind of reels, the yellow fiche is not required since useless.

Looking at this two models of processes, it is reasonable to affirm that the *second* one is more efficient. However, the suppliers that are agree to provide this standard of labels are in a small part. In general, it is really challenging the possibility to reach a standard in the definition of the characteristic of the labels among all the different supplier. For this reason, both process need to be carried

Figure 19: Example of type of reel present in the warehouse company

on in parallel. This is the first critical point identifiable. Another important aspect consists in the fact that both of them are quite time-consuming for the operator point of view. Nevertheless, the most critical points can be found in the ***traceability***, and therefore quality, requirements. For example, the information about the ***manufacturer*** name, that can be different to the supplier one, is lost. Another important issue can be found in the ***batch*** information: up to now, the first reel batch is recorded and considered the same for all the reel in the box. Even if is very likely that this fact is true, it is not completely reliable. It is also useful to underline the fact that those steps explained require attention of the operator: there could be common mistakes, like attaching the fiche on the wrong reel, that means damaging the traceability but also causing issues in the production line. It is then important to

change the process in order to minimize the ***operator's errors***. Another aspect to take into account consists in the fact that all the information about components are registered into the ERP of the Company, however in the ERP it is not possible to store strings longer than 20 digit and it could happen that manufacturers use a larger string to indicate some information, like the *binning* data for LEDs component (the meaning will be clearly explained in the section of the appendix). Additionally, for this type of components, operators need to check the reels one by one to determine whether it can be accepted according to the binning information: up to now, for each bin of the LED there is a different company part number, however it could happen that the supplier does a wrong association between the two data, making necessary a control of the reels received. This process is extremely ***time-consuming***, in fact, it has been computed that on average 4 minutes per reel are spent on this checking phase.
This operation generates another reason of non-standardization since is required only by one type of component.

Production Process issues and Incoming features: an Example of End-to-End Integration

Even though the explanation above has focused the attention on the *logistical* incoming process problems, the real reason why the process has started to be reviewed comes from issues found during the **production** phase. In particular, the manufacturing of **lighting** products, meaning automotive products that mount LEDs, has arisen several issues mainly correlated to the ***LED Bin*** information. This kind of data is important to know since it determines the value of resistance to associate in order to reach the same requirement of brightness for the LED components mounted, despite the fact that different bins are used. It is pertinent to underline the fact that, on the same final product, LEDs with the same bin must be mounted. This is because, otherwise, an undesirable visible effect could be obtained due to slightly varying shades of color because

of different bin values.
The main problem consists in the fact that, having more part number for the same kind of LED according to the bin means having multiple codes of the final product that require distinct machine programs. This organization leads to an excessive amount of *set up time* in the production phase: the code for machine program must be changed every time a reel of LED with a different bin is used, even though the actual program is always the same. What it actually changes between one program and the other is a different association of LED/resistance, required, as previously said, because the same condition of luminosity need to be met, despite the binning. It is clear now, why each LED reel is checked to verify the correct part number/bin association: if there is a mistake on it, the wrong resistance could be mounted and, as a result, the requirements of the customer could not be obtained. Moreover, the amount of documentation to deal with for the same product is unreasonably high, considering the fact that it is always the same project except for the part of the LED bin/resistance association. As well as being a waste of time, those aspects are also a waste of money.

3.1.2 Project Solution: Description of the improvements reachable

The project of the company that focuses its attention on the receiving of components in the warehouse is called **Smart Incoming**. The project developed aims to overcome the critical issue explained above. In general, despite the fact that the digitalization involves various types of processes, the manual data entry is still a common phenomenon in different processes. However, this leads to operator's error, that can mean costly consequences, and slow processing data.
The solution requires an ***automatic reading*** of the labels of the component, focusing on the text part, analyzing them in order

to properly derive the information needed, thanks to a ***machine learning*** *algorithm*, and then store them. As hardware resources, a camera and a bench is required. In order to obtain this result, as a software point of view, a full ***Cloud architecture*** will be implemented. An important aspect to take into account is that the solution found will be the same for all the company's plant, from that, the cloud solution is considered the best one: it allows the ***standardization and synchronization*** among the different plants. Moreover, it is reasonable to consider that the types of item is the same for all plants. As a consequence, the labels read are of the same kind and this allows to better train the algorithm implemented.

According to the architecture of the Smart Incoming, the process will be characterized by the following step:

- Batches arrive in the acceptance location in the entry of the warehouse and the GRN (goods receipt note) is saved in the ERP;

- Each reel of batches is labeled with a tag containing the unique ID.

- Each reel is scanned thanks to the camera: the text of the labels is read using OCR vision technologies;

- Exploiting the machine learning algorithm developed, information in a form of *key-value* are stored in database and compared with the information of the ERP and MES of the company, mainly in real time. The unique ID is also read, in this way all the information are stored are related to that ID.

- The Database is organised so that also the picture is stored;

- The association is automatized but feedbacks from operators can be required;

- Reels are then send to the proper location inside the warehouse or to the acceptance phase;

Organizing the incoming in this way, the error in the association to the unique ID is overcome: the fiche is attached on the reel before the scan and there can not be a mismatch between the content of the label generated with the ID and the content of the reel since the association between the unique ID and the relative information is done after the scan of the text. Moreover, the label with the ID will be smaller since it has to contain only this string. Therefore, the ***traceability*** system can be improved: more detailed information will be recorded with this solution, for example, the proper batch and binning values will be recorded.
It is worthy to notice that these steps will be the same for every kind of reel, this means reaching a ***standard*** in the labelling of reels, making no difference whether the Qr code is present or not, becoming more flexible towards supplier's conditions. Moreover, there will be no differences in the process according to the type of component: the LED will not require additional checking phase.
As a result, Smart Incoming ensures that operator errors will be much lower.

As regards the LED binning, it is precisely because of the improvements in the incoming process that a leaner management of the LEDs in production could be reached, in particular with the development of a dedicated traceability database. First of all, there will not be restriction on the length of the string for the bin. The most important thing is that this architecture facilitate the managing of the bin since the same Part Number for the same type of LED can be used, letting the bin becoming an additional information of the component. Therefore the number of machine codes required for the manufacturing of the same final product is reduced. Simultaneously , there is no need to check each LED reel for the part number/bin association, avoiding waste of time in acceptance phase. This organization also leads to a more secure Led/resistance

association because it is directly connected to the bin information, with the possibility to easily automatize it, reducing the amount of documentation required for each product. Therefore, an improving for both logistic and production processes, mainly in terms of data quality and time reduction, can be met.
Going back to the new incoming process, the mandatory information to obtain from each reel are the following one:

- Unique ID;
- Supplier;
- Manufacturer;
- Bitron Part Number;
- Ordering Code;
- Batch;
- Datacode;
- Quantity;
- MSL;
- Binning;
- Incoming date;

It is now useful to understand the meaning of each point of the list. *Unique ID* is a identification code that is proper, and unique, for each reel, in this way the information of each component that will be mounted on the PCB is known. *Bitron Part Number* is the internal code that identifies that specific type of product, *Ordering Code* is the code with which the type of product is ordered to the Supplier. *Supplier* and *Manufacturer* may differ since the component can be ordered to a supplier that buys from the manufacturer. *Batch* and *Datacode* refer to the production batch, with a more specific indication when the datacode is present. The *Quantity* refers to the number of elements inside the reel. The *Incoming Date* is related to the day when the component arrives in the Warehouse. The last two fields are proper of specific products: the *Binning* is relative to the LEDs, it is the process of grouping LEDs together to maintain a tighter control of the possible output variations and it is expressed with a non-stadardized type of string; the *MSL*, Moisture Sensitive Level, is particularly important for LEDs too and it is the total time period in which the component can be exposed to the moisture in the ambient room condition: this is very important since, during the SMT process, the component can be damaged because it tends to expand because of moisture.

4 Smart Incoming Implementation

The present chapter discuss the implementation of the Smart Incoming process. Each component of the architecture will be explained, considering all the steps of the information flow. The architectural solution is the result of a previous work elaborated by a team of the company. The thesis, in particular, focuses the attention on the performance analyses, explained in the section 4.2 , in order to understand the feasibility of the solution introduced. The software architecture elaborated for the performance analyses is part of the work done for this thesis and it reproduces a great part of the architecture that it will be implemented in the plants: it will not be present, for example, the section that refers to the communication with the ERP and MES systems of the company.

4.1 Architectural Solution

The architecture of the Smart Incoming requires a simple hardware part, that it is mainly composed by a camera and the station for the operator. Instead, the architecture of the software part is way more complicated. In the following picture, the architectural solution is presented. The services of the Cloud, in our case **Oracle**, exploited are more than one. It is important to have clear the characteristics of each service, for this reason a brief explanation is provided below. First of all, **Oracle** is a global corporation that develops and markets computer software applications for business, especially known for its Oracle database software, a relational database management system. The architecture exploits some of the software provided by them. Below, a brief explanation for each one is reported :

- **VBCS**: Visual Builder Cloud Service. It is a cloud-based software development platform and a hosted environment for application development infrastructure. In our case is used to create the User Interface (UI) for the operator: it is possible to access to UI components and WYSIWYG [2] interfaces that uses

[2] WYSIWYG is the acronym for "What You See Is What You Get", a type of editing software

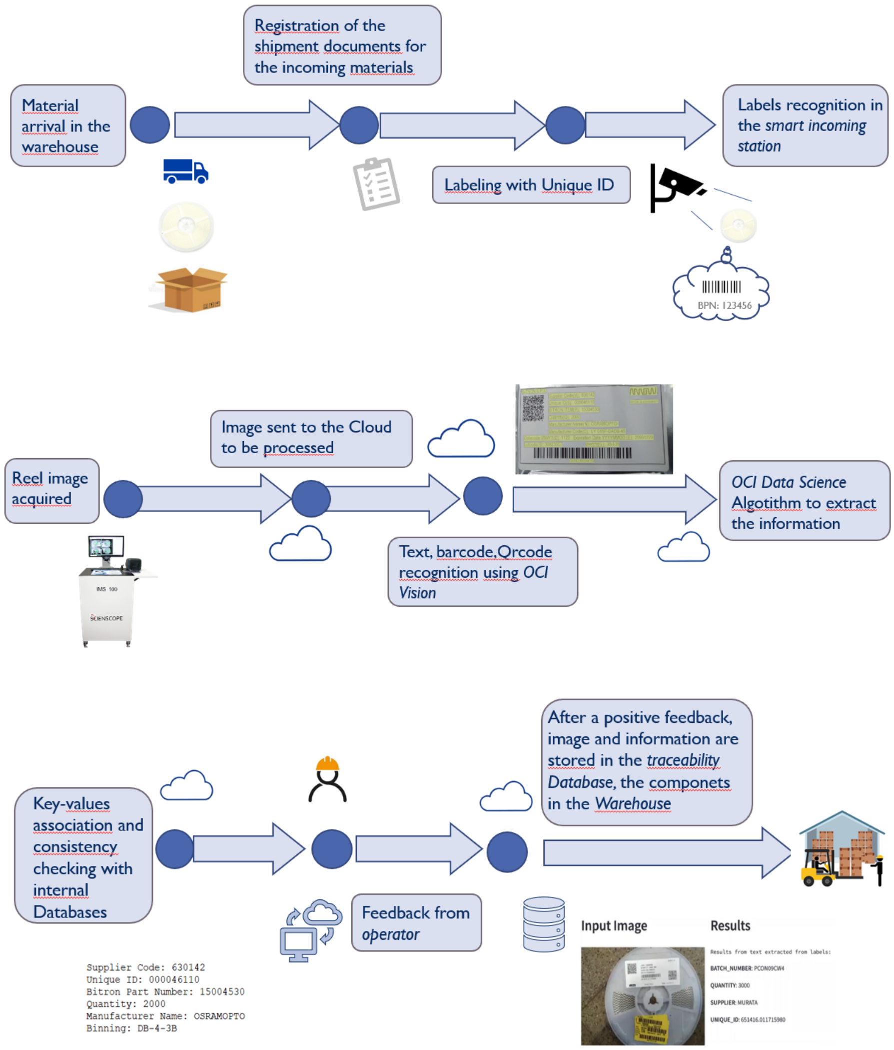


Figure 20: Smart Incoming Process architecture

the open-source Oracle JavaScript Extension Toolkit (JET). That means that the design of a page consists in choosing the desired components among a list and associate the proper actions to carry out once selected. With VBCS, it is also possible to access data through REST-based services [3], both internal and external from Oracle Cloud. It is therefore reasonable to choose this service for our purpose;

that allows users to see and edit content in a form that appears as it would when displayed on an interface.

[3]REST stands for "REpresentational State Transfer". REST is web standards based architecture and uses HTTP Protocol.

- **OCI Vision**: Oracle Cloud Infrastructure Vision is a serverless, multi-tenant service, accessible using the Console, or over REST APIs [4] . It enables you to upload images to detect and classify objects in them. In our case, the interest is just on the detection of text of the labels on the reels and it is accessed by REST API.

- **OCI Data Science**: Oracle Cloud Infrastructure Data Science is a fully-managed platform for teams of data scientists to build, train, deploy, and manage machine learning models using Python and open source tools. In our case, the model developed will work with the JSON file obtained by the Vision analysis and elaborating it, it is possible to associate each of the mandatory field of the information required for each component with the respective value. It is important that the model can have access to databases of the company in order to validate the data obtained.

- **Oracle ADW**: Oracle Autonomous Data Warehouse is the world's first and only autonomous database optimized for analytic workloads, including data marts [5], data warehouses [6], data lakes [7], and data lakehouses [8]. With Autonomous Data Warehouse, data scientists, business analysts, and non-experts can rapidly, easily, and cost-effectively discover business insights using data of any size and type.

- **OAC**: Oracle Analytics Cloud is a scalable and secure Oracle Cloud service that provides a full set of capabilities to

[4] API is the acronym for "Application Programming Interface": a software intermediary that allows two applications to talk to each other.

[5] A data mart is a subset of a data warehouse focused on a particular line of business, department, or subject area.

[6] A data warehouse is a type of data management system designed to enable and support business intelligence (BI), especially analytics. Data warehouses are purely exploited for querying and analyzing and often contain large amounts of historical data.

[7] A data lake is a repository for structured, semistructured, and unstructured data in any format and size and at any scale that can be analyzed easily.

[8] Data lakehouses implement data warehouses' data structures and management features for data lakes, which are typically more cost-effective for data storage.

explore and perform collaborative analytics. It is built on a high-performance platform with flexible data storage, and it provides a complete set of tools to derive and share data insight. In this project this service will be exploited mainly for the *performance analyses*, in particular to analyze the resulting data about elaboration time and confidence.

Going back to the characteristics of the future process, it is useful to recall each step: At first , the transport document information are recorded, the reel located in the station and the image taken. Then, the API of **OCI Vision** is called in order to elaborate the image taken having as aim the reading of the text present on the labels of the reel. The result obtained is elaborated on **Oracle Data Science**. The outcome of the algorithm of Oracle Data Science consists in the associations key-value of the mandatory fields explained in 3.1.2 and they are then stored in the traceability Database and also stored and compared with information present in the MES and ERP of the Company. A web application, that menage all of these operations, is developed with **Visual Builder Cloud Service**. Up to now, the project solution is **full cloud** integrated.

The aim at this point is to understand if it is a feasible solution:

- the **performances** of the vision need to be good since it is essential to have the right codes: a mistake in this part of the process could mean an huge amount of errors, from the traceability to the logistic and warehouse management, and most of all, for the production. In fact, misunderstanding a Bitron Part Number, for example, means mount on the PCB a wrong component and as a consequence the product is irreparably damaged;

- the overall amount of **time required** by each elaboration must stay below a range of few seconds since could cause a bottle neck right at the beginning of the warehouse management. The objective is to be as close as possible to a process like the one at the cash desk.

In order to understand if those constrains are respected, performance analyses are developed.

4.2 Performance Analyses

The aim of this part is to understand if the architectural structure elaborated is effectively applicable in a real implementation and identify eventual improvements.
The software architecture for this analysis is similar to the one of the Smart Incoming, that means that the same various services explained before are used. However, there are some differences: for example, it is not developed the infrastructure that allows to exchange and save data in the ERP and MES systems of the company. The web application is developed on VBCS, as it will be the .
Considering the activity done in order to obtain the desired output some tests have been carried out. In general, a *test* consists in uploading, thorough the VBCS application, a batch of images of reel of the type that will be accepted. Then, all the necessary action are executed and the parameters required analysed.
The below image (fig 21) is the UI page of the web application for the performance analyses.

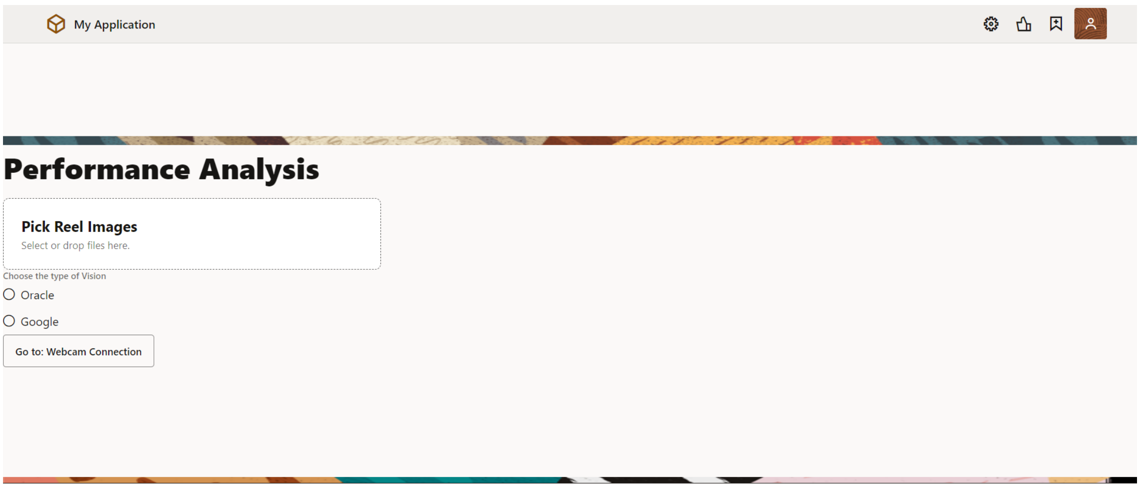


Figure 21: User Interface of web application for performance analyses

In first place, it is useful to underline some features typical of VBCS applications. In particular, the one developed consists in one flow

[9] with just one page. The web application uses:

- Variables: there are different kind of variables according to scope type. There are page, application, flow and action chain scope. In this case, the ones used are *page* variables, that are initialized with default values when the page is entered, and destroyed when the page is exited, and also *action chain* variables that last for the duration of the current action chain. It is possible to assign to them the proper value, that can be, for example, a constant or the result of a function;
- General Components: the most used in this application consist in the "Assign variable", explained before, that allows the correct association or in the "Fire Notification" used when it is useful to display a particular message.
- Call Rest Component: used to connect to the Endpoint of a specific REST API.
- Logic Components: used if logical actions, like 'for' or 'switch' are required;
- JavaScript functions: it is possible to write custom functions in JavaScript code to elaborate values according to the own need and the call to them along the action chain;

Focusing the attention on the interface, it is possible to upload, thanks to the file picker component, a set of images taken from the local memory and store them in a page variable called 'file'. After choosing one option of the radio button, it is generated the Event that consists in the execution of the action chain in the figure 22[10]. Starting from the beginning, the page variable 'valueOptionCase' is assigned with the input value of the chain that consists in the selected option of the radio button. Then, two functions are called.

[9]The flow of a web application is characterized by the systematic organization of web pages, page data, page actions, and mappings to business logic and the interconnection of these components

[10]The behavior of each component in your application is determined by an Action Chain, a sequence of actions started by an event listener when an event occurs in a page.

The first one is used because it is required to take trace of the location of where the analysis is started, for this reason the *Public IP* is saved and stored in the proper variable. Then, as it is possible to observe, for each file image, another action chain is called: in fact it is necessary to memorize different information, like size or time of elaboration, for each image.

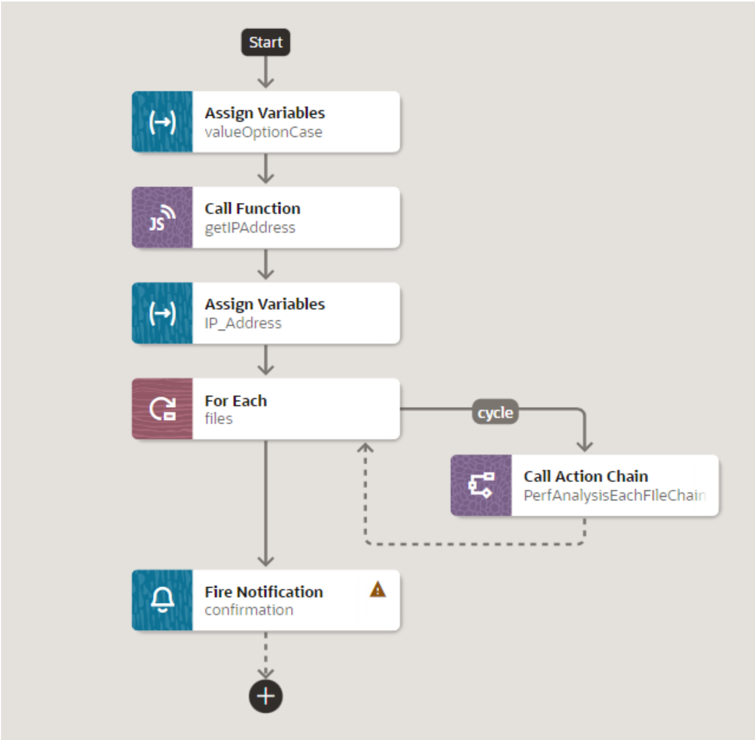


Figure 22: Outer Action Chain

Looking at the fig 23, the first part of the action chain is showed where it is possible to observe the function 'fileToBase64', used to convert the file in base 64 [11], since it is required by the constrains of the Request Body for the Oracle Vision API;
It is then present a 'switch', a logical component, that is used to discriminate among the option of the radio button.
At this point, it is useful to start the explanation considering just the ***Oracle Vision*** branch. First of all, the variable "Request Vision" is assigned. The type of the variable is an object built

[11]Base 64 is a binary-to-text encoding system that is designed to allow binary data to be represented in ASCII string format.

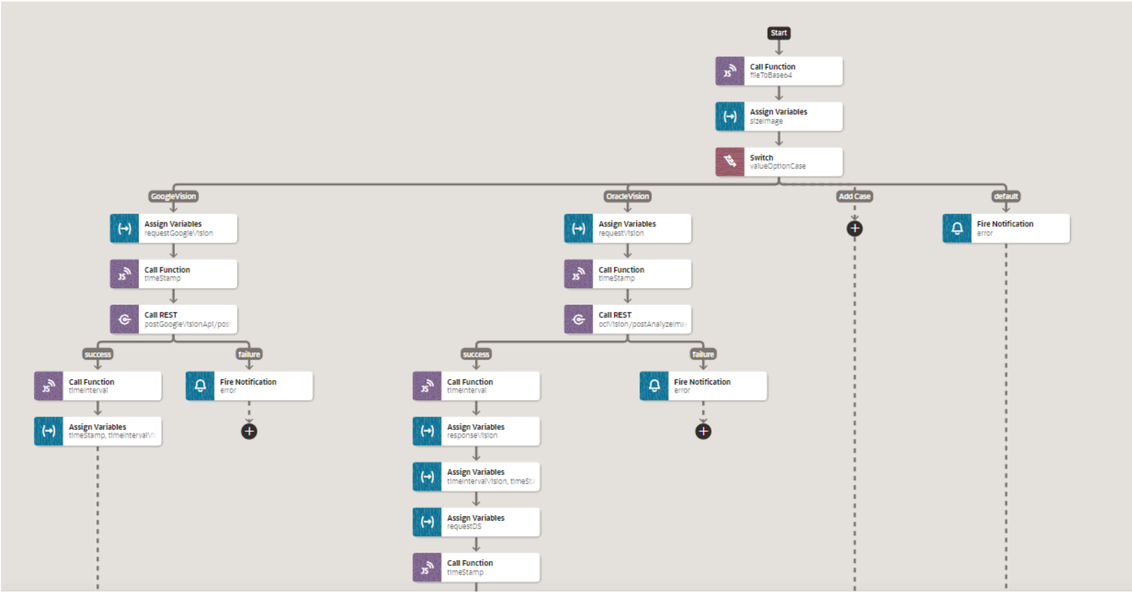


Figure 23: First part of the Action Chain executed for each file

with the various fields mandatory in Request Body for OCI Vision API. It is a POST method whose URL of the Endpoint is https://vision.aiservice.eu-frankfurt-1.oci.oraclecloud.com/20221025/actions/analyzeImage. During the 'Service Connection' operation, the authentication required is of the type "Oracle Cloud Infrastructure API Signature 1.0", where 'Key ID' e 'Private Key' need to be provided. The Request Body fields are the one listed in the table 1:

Compartment ID	Required: no Type: string Min Length: 1 Max Length: 255 The OCID of the compartment that calls the API
feature	Required: yes Type: ImageFeature Min items: 1 The types of image analysis
image	Required: yes Type: ImageDetails

Table 1: Fields of the Request Body for OCI Vision

For the ImageFeature type, there are three different options for the 'featureType' attribute:
`IMAGE_CLASSIFICATION`: Label the image.
`OBJECT_DETECTION`: Identify objects in the image with bounding boxes.
`TEXT_DETECTION`: Recognize text at the word and line level.
In the case of interest, the only features written in the body features is `TEXT_DETECTION` since it is required only to read the text.
Considering instead the ImageDetails the choices for the '*source*' attribute are two:
`INLINE`: The data is included directly in the request payload.
`OBJECT_STORAGE`: The image is in OCI Object Storage.
There is also the attribute '*data*' which contains the image in base 64. In the case of the project, the `INLINE` value is selected, since the image is real-time taken or present in the local memory for the performance analyses.
Going back to the action chain of VBCS, once created the object with all the values for the request body of the API, the Call Rest component for OCI VIsion is present: this accepts as input parameter the variable created.
Here it is the core part of the analysis, in fact right before the calling of the API, the function *timeStamp* is called, that freeze the starting instant, and right after the function *timeInterval* is called in order to compute the total elapsed time from the starting instant of the REST API call to the instant when a Response is obtained.
The Response is still a JSON file with the fields listed in the table 2.
The ImageText type consists in two attributes: 'lines' and 'words'. These are the most important parts since they contain the text read divided into words or entire lines. In fact, this response will be the Request Body for the OCI Data Science API.
Similarly as before, the time elapsed for the elaboration of the response of the second API is computed and stored, as it is possible to observe in the figure 24, that is the following part of the action

errors	Required: no Type:[ProcessingError, ...] The errors encountered during image analysis
imageClassificationModelVersion	Required: no Type:string The image classification model version
imageText	Required:no Type: ImageText
labels	Required:no Type:[Label, ...] The image classification labels
ontologyClasses	Required:no Type:[OntologyClass, ...] The ontologyClasses of image labels
textDetectionModelVersions	Required:no Type:string The text detection model version

Table 2: Fields of the Response Body for OCI Vision

chain seen above.
In order to understand how good the reading has been, in the response file of OCI vision, for each word, a level of confidence is indicated. The average value of the overall file is computed by the algorithm of OCI Data Science and given as one of the attribute of the response body, in addition to the association key-value found.

The end of the action chain executed for each file sent, consists in storing in the ADW the various time intervals computed, the size and the name of the file, the IP address and the timestamp of the starting time of the analysis and the average confidence. This part is performed with a calling to an API that post the results in a database of ADW.

It is now possible to focus the attention on the second branch of the switch: the ***Google Vision*** option. It has been decided to compare the results of elaboration time of OCI Vision with the ones obtained calling the API Vision of Google, one important competi-

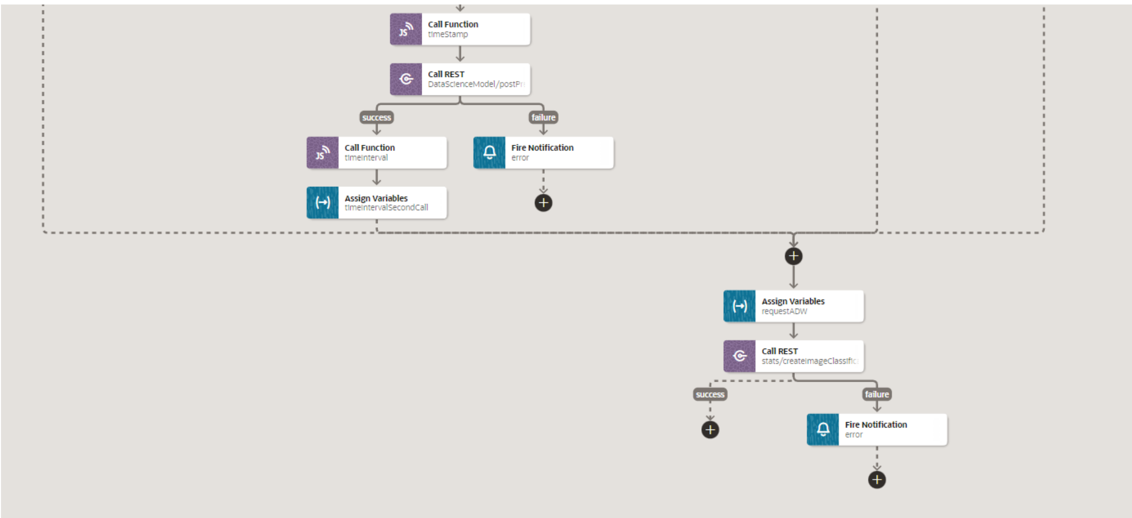


Figure 24: Second part of the Action Chain executed for each file

tor. Since the purpose is just a comparison of the time intervals, it is not necessary to custom the subsequent parts to the google response features. The general setting is actually the same, as it is clearly visible in figure 23. However, the Request Body of the API is different, for this reason another object variable must be used with the following fields:

feature	Required: yes Type: Feature Min items: 1 The types of image analysis
image	Required: yes Type: content Image in base 64

Table 3: Fields of the Request Body for Google Vision

The field **features** is filled with two different 'type':`TEXT_DETECTION` since this allows to extract the text from any image and `IMAGE_PROPERTIES` since it provides the values of confidence for each part of text detected. The confidence values obtained can not be compared with the ones obtained with OCI Vision, for this reason up to now, just the resulting time interval value is stored, in the variable 'timeIntervalVision'.

Oracle Analytics

It is clear, at this point, how the information are taken, through all the process. It is essential now to analyse the results of the tests. The Oracle Analytics has been used for this purpose. The data obtained are stored in the ADW of Oracle. Each line of the database identifies a precise image sent in a specific moment expressed by the timestamp. Each line has therefore an ID associated to the following information:

- IP Address;
- Timestamp;
- Vision Time Interval;
- Data Science Time Interval;
- Confidence: Average Confidence obtained by the Vision;
- Size: size of the image;
- Filename: name of the image;

In order to store those values `SQL| Oracle Database Actions` is exploited; in this environment it has been created a table in which are contained the start and stop time instants of the various test performed. In fact, to better analyze the data, a specific ID related to the number of test is required. The result of the `LEFT JOIN`[12] between this table and the one created during the tests with VBCS is the view actually exploited on OAC. The need of the `ID_TEST` comes from the fact that the data coming from calling to the APIs during, for example, debugging sessions should not be taken into account.

[12]The LEFT JOIN keyword returns all records from the left table (table1), and the matching records from the right table (table2). The result is 0 records from the right side, if there is no match.

It is possible now to comment the results obtained. Firstly, it is worthy to underline the fact that, the values of time intervals obtained as results of the Javascript function are comparable with the one seen observing the Network through the console, that means that there are no delays due to the use of external functions.

Before proceeding in the explanation, for seek of completeness, a summary table of the most used concepts is reported, with the relative definition.

Concepts	**Definition**
OCI Vision Time Interval	Elapsed time from the starting of the elaboration of the image to the getting of the response
Time Threshold	It has been established $4s$ as maximum acceptable time spent on the elaboration of the image
Confidence	Output of the response of OCI Vision related to the reliability of the string read
Results of Confidence	Derive from the evaluation of the responses of the elaboration of several images. According to the characteristic of the string read, three levels have been identified:
Pass	Confidence grater than 95%: all the strings read are correct
Check the result	Confidence between 85% and 95%: it is likely that some characters of the strings are wrong
Do not pass	Confidence below the 85%: it is likely to have different part of the image where the Vision has not recognize any test, even if present. The strings read could be wrong.

Table 4: Summary of the main concepts present in the Performance analysis

4.2.1 OCI Vision Time Intervals Analysis

The first thing analyzed is the average value of the elapsed time to obtain the Response of the **OCI Vision** API and the relative standard deviation. It is important to specify that, for all the further analyses, all the images particularly **out of focus** have been filter out since it has been seen that they have a very low time interval, improving the performances but without considering the fact that the reading result is completely wrong. It is important to underline that, starting from the third trial, the set of image is always the same. In the figure 25 the results are showed. In the x axis the timestamp of the instants at which each image is sent is reported: in this way the image is uniquely identified. The *average value* computed is $3,77s$ with $2,13s$ of *standard deviation*. Even though the average value is actually inside a constrain that want an elaboration time smaller than $4s$, it is worthy to consider that this time value consider only the OCI Vision performance, that means the time required for further analyses need to be added. Nevertheless, the standard deviation is even more critical: the variability of the time intervals is very high and for a real implementation this is not good. In the figure 26 the box plot [13], is showed in order to see the eventual outliers, that are in a large amount. In the same figure, a distribution of the time intervals is reported: the time intervals grouped and the relative number of single IDs is reported.

Each file image has been sent more than once in order to observe the variation of the time elapsed among different trials and the relative standard deviation. The outcome is plotted in the figure 28 and it is particularly interesting: the time required to process each image it is not random but correlated to the own characteristics. The value of *standard deviation* is the result of the average of the different standard deviations computed for each file: it is very low, equal to $0,36s$, and it is possible to affirm that it is a deterministic result for each image.

[13] A box plot is a graphical rendition of statistical data based on the minimum, first quartile, median, third quartile, and maximum. In a typical box plot, the top of the rectangle indicates the third quartile, a horizontal line near the middle of the rectangle indicates the median, and the bottom of the rectangle indicates the first quartile.

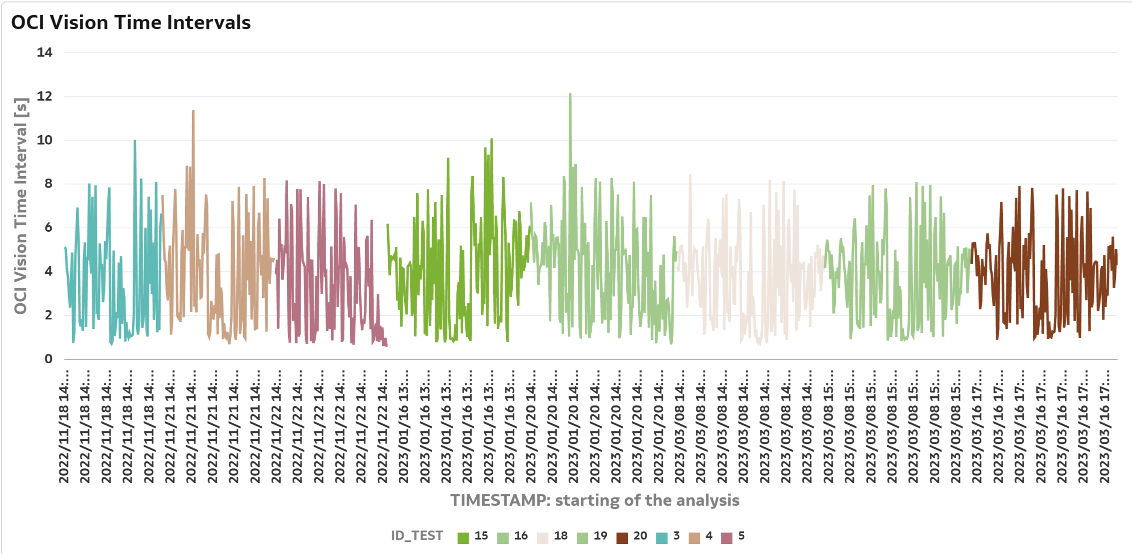
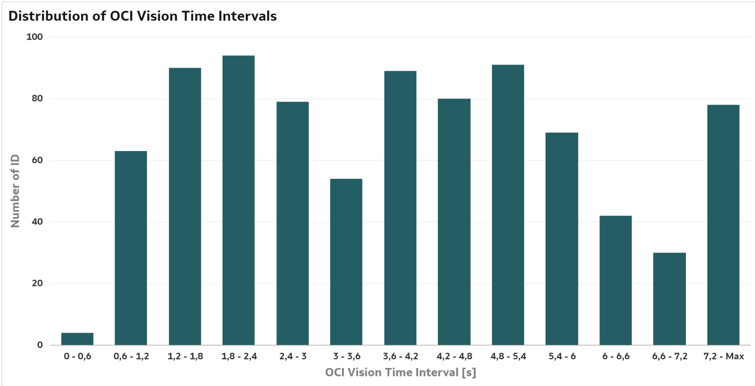


Figure 25: OCI Vision time intervals trend over time

The time intervals required for each file sent which is identified with an unique ID equal to the timestamp of the start time of the analysis

4.2.2 Confidence Analysis

An essential aspect to take into account is not only the elapsed time, but also how reliable is the reading of the labels. The measure that is correlated to this feature is the *Confidence*. The confidence is a specific field of the JSON file Response of OCI Vision for every word present: the value showed for each file is the average of those values. In figure 29, for each file sent, both the value of confidence and interval time of OCI Vision are showed. As it regards the confidence, the variability of the measure for each file is negligible. Since the aim is having a good confidence, a deeper study of it has been performed. First of all, the values have been divided into groups and the number of unique ID that falls in the interval has been computed in order to observe which is the distribution. Moreover, three different levels have been identified: 'Pass' when the confidence is grater than 95%, 'Check again' when it is between 80% and 95%. Often, when the level of confidence is in this range, it means that, if any, just few characters of a string are wrong. In the last case, 'Do not pass', it is very likely that the reading has



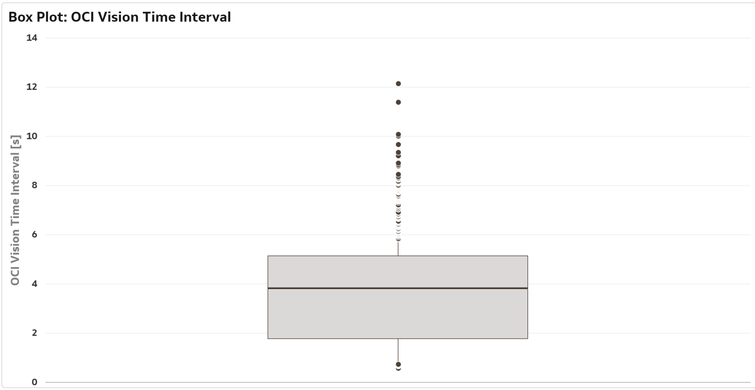


Figure 26: OCI Vision Time Interval Distribution

First Plot: Time intervals divided into groups with the relative number of images that fall in the own range is reported on the ordinate axis; *Second Plot*: box plot for time interval values.

gone completely wrong and the image must be taken again. As it is possible to observe in the figure 30, the greater number is in the middle range. This is, of course, a non-positive outcome: there is also a peak of values in the minimum range.

Another important aspect to evaluate is the correlation between the time interval of OCI Vision and the confidence: the correlation index obtained is $\rho = 0.606$, therefore there is a quite strong *positive correlation* between the two measurements. In order to better analyze these two measures, a scatter plot [14] has been done (fig 31). As it is possible to see, the files (the coloured dots) have been

[14] A scatter plot is a type of plot or mathematical diagram using Cartesian coordinates to display values for typically two variables for a set of data.

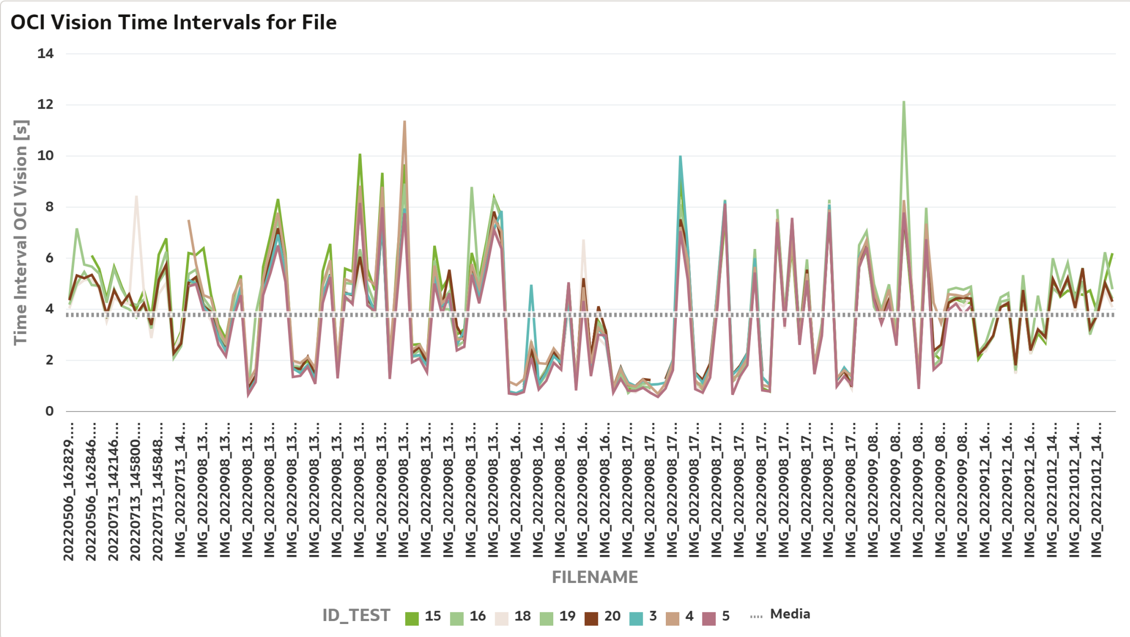


Figure 28: OCI Vision Time interval trend for image file

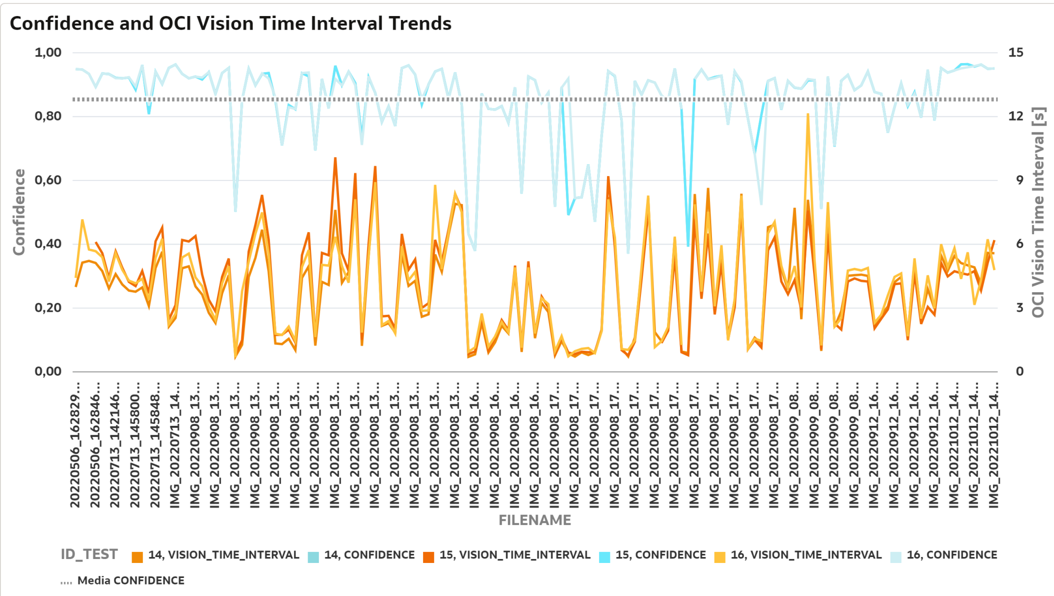


Figure 29: The trend of the confidence and the OCI Vision Time Internal for each file send.

divided into cluster following the k-means algorithm [15] and the re-

[15]K-means clustering algorithm: it is used to divide the observations into k clusters according to an algorithm characterized by the fact that each point has a minimized distance to the centre of the own cluster. The data belonging to each cluster are identified by an iterated process that recalculate the center of each one until the distances of the data and the centers are minimized.

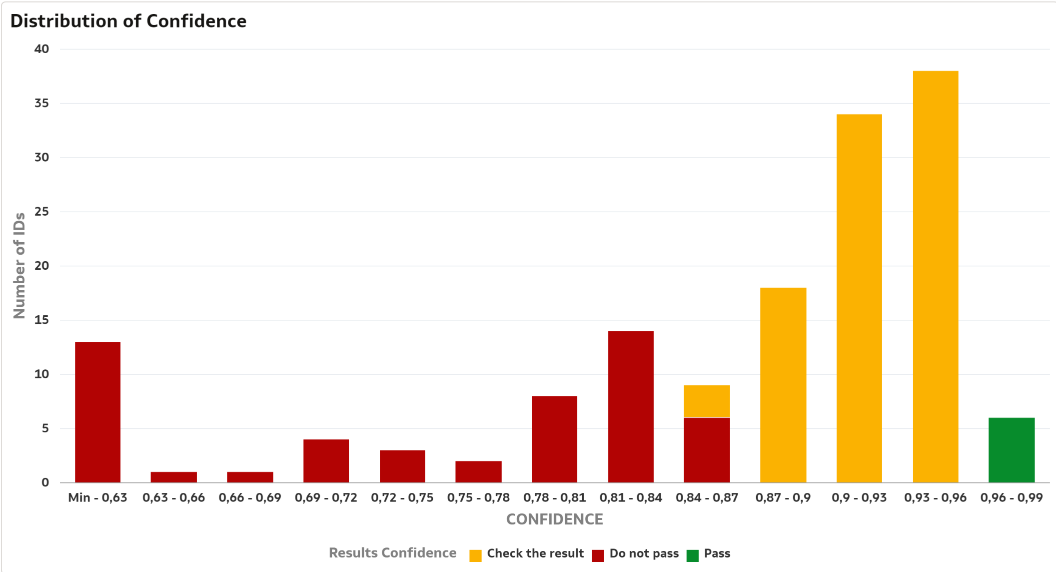


Figure 30: The distribution of the confidence values.

The confidence is divided into three bands: *Pass*, if the confidence is higher than 0.96; *Do not pass*, if the confidence is lower than 0.85; *Check again*, otherwise.

gression line has been subplotted. The value of $R - Squared$ is equal to 0.367, so the linear regression does not well explain the relation between time and confidence. Having divided into clusters makes easier to find the common characteristics of the images that belong to the same cluster. The ones of major importance are the first and the second, since the value of confidence is really low and it is worthy to understand which are the reasons that lead to this outcome. In particular, looking at the images of the first cluster, it can be seen that the text read is almost wrong or often, no words can be detected even if the quality of the image is not excessively low; in this cluster fall also the quite blurred images. For the second cluster, the confidence is still low, even if the quantity of detected words increases. Some of the words, however, are not properly read since OCI Vision is not able to correctly rotate the label: the vision try to interpret a text of an upside down string.

Looking at the remaining clusters, in general, an increasing time interval assures a better quality. It can be deduced that, when the image is clear, the software is able to read properly the text, but the time required is high. It has been quite difficult to observe any differences among the images of other clusters that justify the difference of time interval spent to analyze and of the confidence trend.

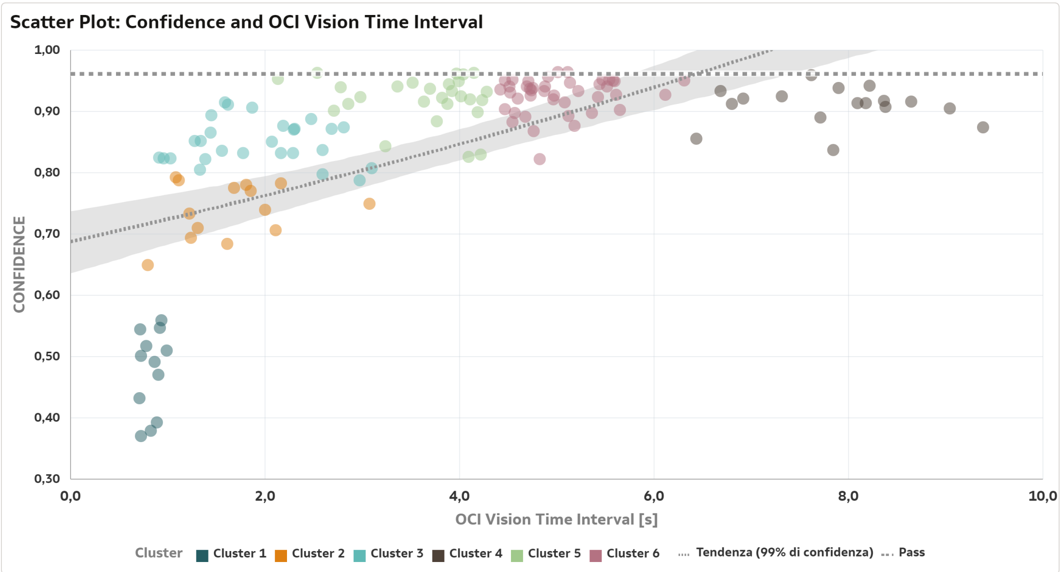


Figure 31: Scatter plot: confidence and OCI Vision time interval

The points are divided into 6 cluster according to the k-means algorithm

4.2.3 Research for variables

It is now necessary to understand which are the reasons that lead to different outcomes. The easiest cause to think about is the **size**. This results are showed in the scatter plot of the figure 32 with a correlation index equal to $\rho = 0,18$. Both of them clearly underline the fact that the size of the image is low positive correlated to the time required to elaborate it.
For further analyses the images with an higher **number of labels** are selected. The outcome is expected: the average OCI Vision Time Interval is higher than the total one found, meaning that an higher amount of text to read requires a more time to be processed (refer to the figure 33). In the real implementation, the standard for the labels will consider, as the internal label, just the *Unique ID* without further information since they are already present in

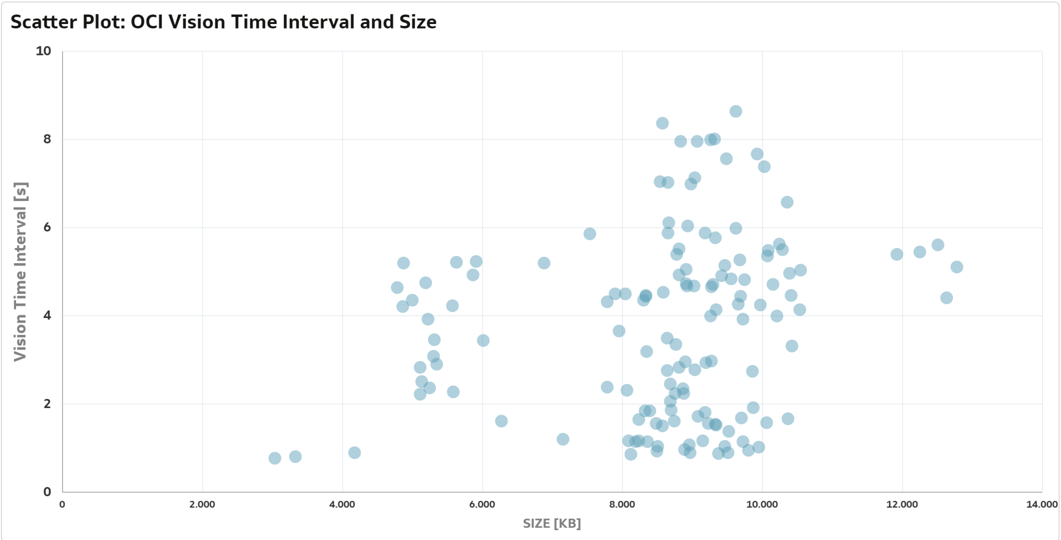


Figure 32: Scatter plot: OCI Vision time interval and size

Each point represents a file: the values of time are the result of the average among more tests

the supplier/manufacturer labels. That means that this should not be an issue in the real implementation. Another aspect seen is the

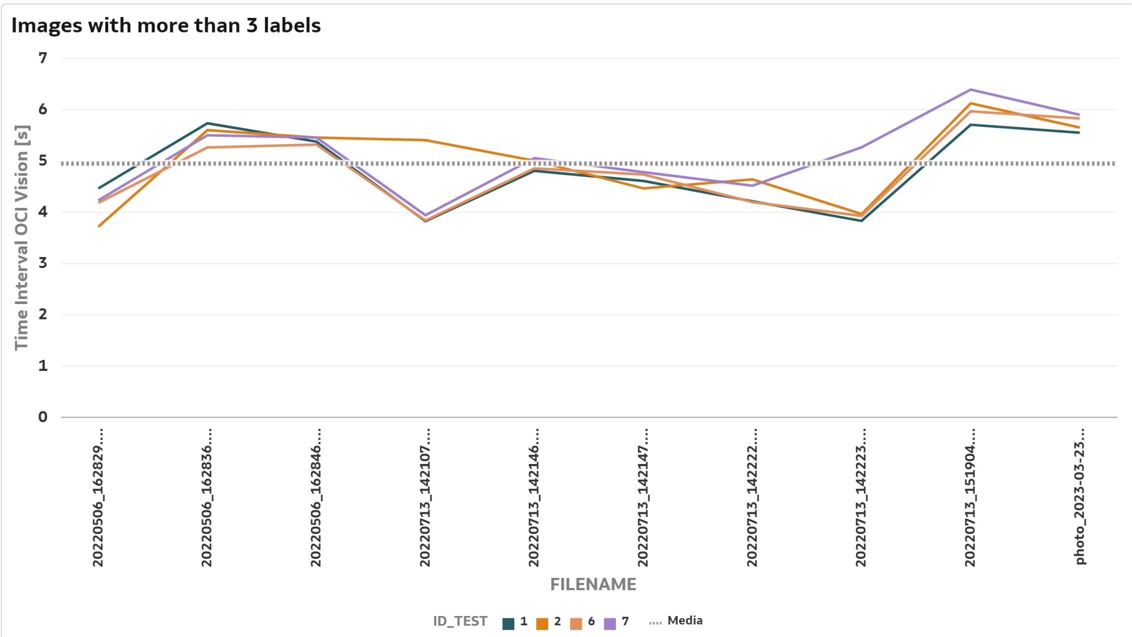


Figure 33: Trend of OCI Vision time interval for the reel that have more than three labels

position of the labels, in the figure 34: the images with labels with different orientations, for example **rotated** of 180°, are chosen. The result tells that this feature seems to improve the time performance since the average time interval is $3,64\ s$. However, this information by itself is not enough to establish how well the Vision read. For this reason, it is interesting to know the confidence too: the average value of the confidence is $0,84$, that is less than $0,89$, the average value of the confidence found for the all samples analysed. This well suits with the result found in the previous paragraph 4.2.2: the second cluster seen in the figure 31 is characterized by images for which OCI Vision is not always able to understand the right orientation of the labels, causing the generation of misread strings and at the same time, being aware of it, the Vision response gives a low level of confidence.

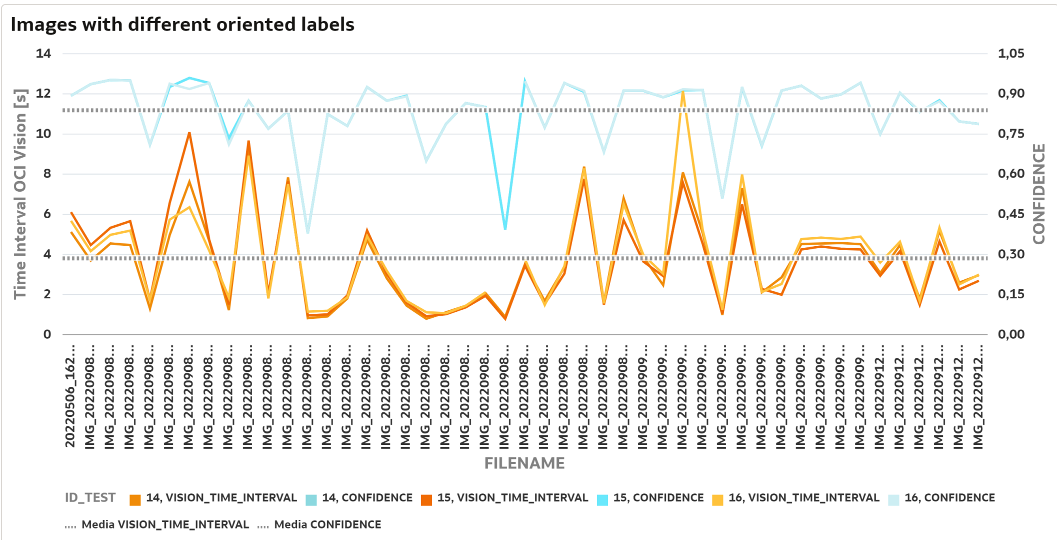


Figure 34: Trend of OCI Vision time interval and confidence for the reel that have labels with different orientation

4.2.4 Luminosity analysis

In order to found other causes for the time interval and confidence, additional analyses have been performed, such as the **luminosity**. The successive analysis consists in modify the images, increasing to the maximum possible the luminosity and decreasing it to the lowest values. Obviously, the luminosity is set in a way that the labels

are still visible and clearly readable. With the aim of performing this analysis, a small subset of the images has been selected and modified with online tools. Then, the modified images, named in a way that it has been possible to easily compare with the relative original ones, have been sent to the API thanks to the VBCS application. The outcome has been indicated with the `ID_TEST` equal to 17 and the resulting time intervals plotted, as it is showed in the figure 35. In both cases, the trials of the images without modification have been plotted, in addition to the black line that represents the test with modified images. Thanks to the horizontal lines of average values, it is easy to observe that for the modified images, in both cases, the time required to process the image increases: for the ones with higher luminosity it increases up to $4,97s$, for the darker ones up to $4,38s$, where the unchanged ones was of $3,95$. At first place, and intuitively, these modification seem to lead a worsening of performances, even for the distribution of confidence, seen in the figure 37, that are all under the 'Pass' threshold.
Nevertheless, comparing the confidence values obtained for the darker and brighter images with the values obtained from one trial with the same ones without modification, the outcome of the figure 39 is obtained. This outcome is not expected: there is actually an increasing of the confidence, in some cases. Going deeper into details, it is possible to find that in those cases, not only the confidence is higher, but also the Vision is able to read more part of the text of the labels, that in the "normal" case was missing. This behaviour is actually counter-intuitive, since, for human eyes, the modified one are a bit more difficult to read.

4.2.5 IP Addresses Analysis

The solution developed for the Smart Incoming should be standardized among different plants of the Company. In particular, apart from the one in Grugliasco, they are located in Poland, China and Mexico. Since the servers of Oracle exploited are located in Frankfurt, the furthest locations are the most interesting to observe. For

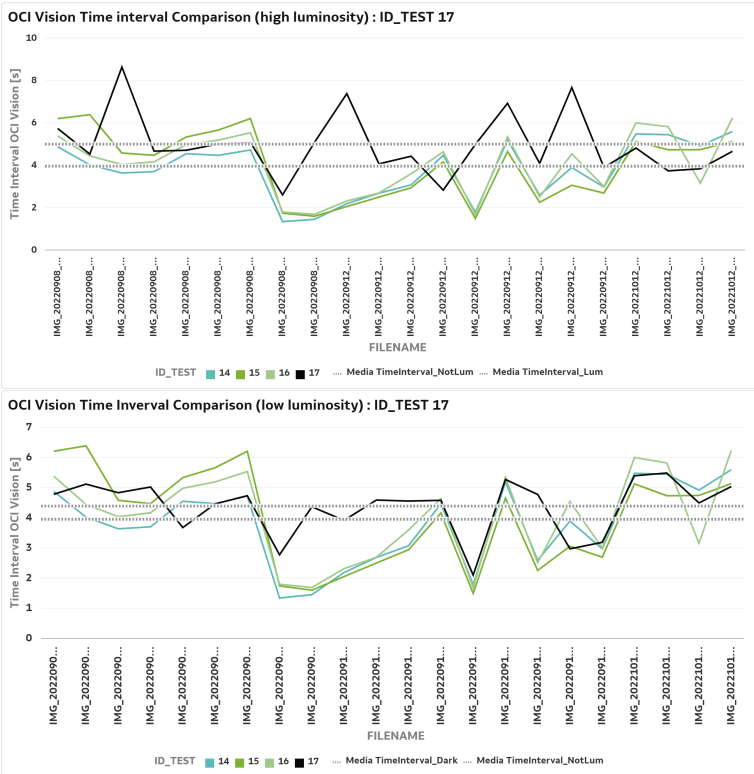


Figure 35: Luminosity analysis: OCI Vision time interval trend

First Plot: OCI Vision Time Intervals for images with very high luminosity; *Second Plot*: OCI Vision Time Intervals for images very low luminosity. The horizontal lines are the average values of time interval for normal images (the lower one in both cases) and the average time interval of the modified images

the sake of convenience, the Mexico's one has been selected to perform the desired analysis. There is an increasing of the time interval required to process the images, as it can be easily seen in the plot of figure 40. However, this result does not exclude the feasibility of the solution since further improvements, like the cropping or the different type of labels with less text that will be used, still have to be applied. In general, the obtained is not discouraging. However, it could be possible, after proper economical evaluation, to adapt and change the API endpoint, according to the plant, by choosing the nearest server. In this way, the standardization of the incoming process an even more feasible solution to pursue.

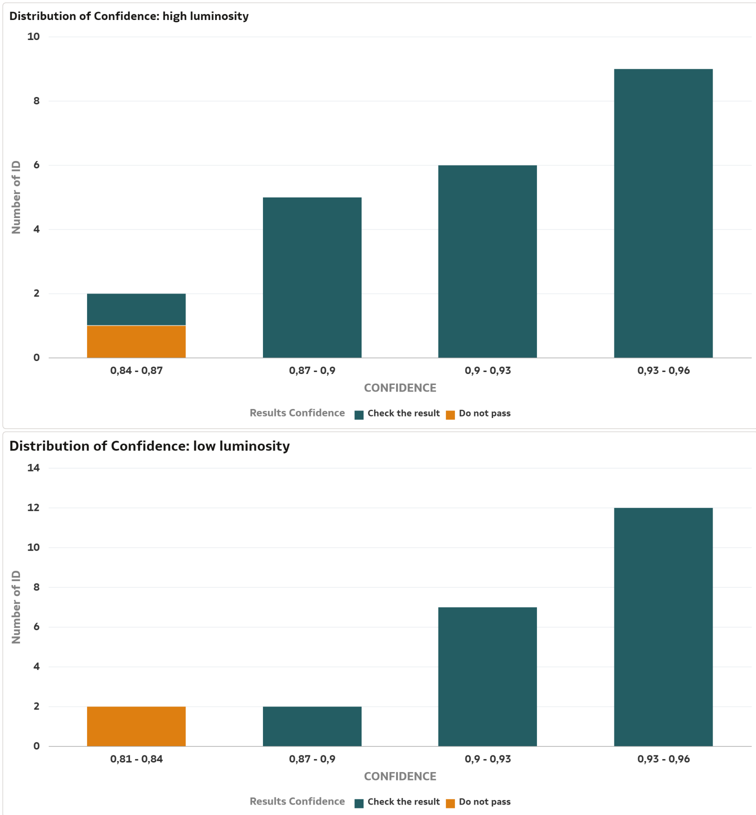


Figure 37: Luminosity analysis: Confidence distribution

First Plot: Confidence distribution of images with very high luminosity; *Second Plot*: Confidence images with very low luminosity.

4.2.6 Comparison with Google Vision

In order to observe the reliability of the system and the quality of it, it has been decided that a good way to know it is the comparison with one of the most important competitor in the OCR field: *Google Vision*. The data are obtained thanks to the fact that two option of analysis are provided (see the paragraph 4.2). The aim of the analysis, up to now, is just to know the difference in time performance. Indeed the extraction of the average confidence would require a specific API on Data Science since the Response JSON file is different from the one of OCI Vision. For this reason, the focus is on the difference of elapsed time for the two APIs. First of all some trials have been done and the outcome is showed in the figure 41. With the exception of the first one, the range of values

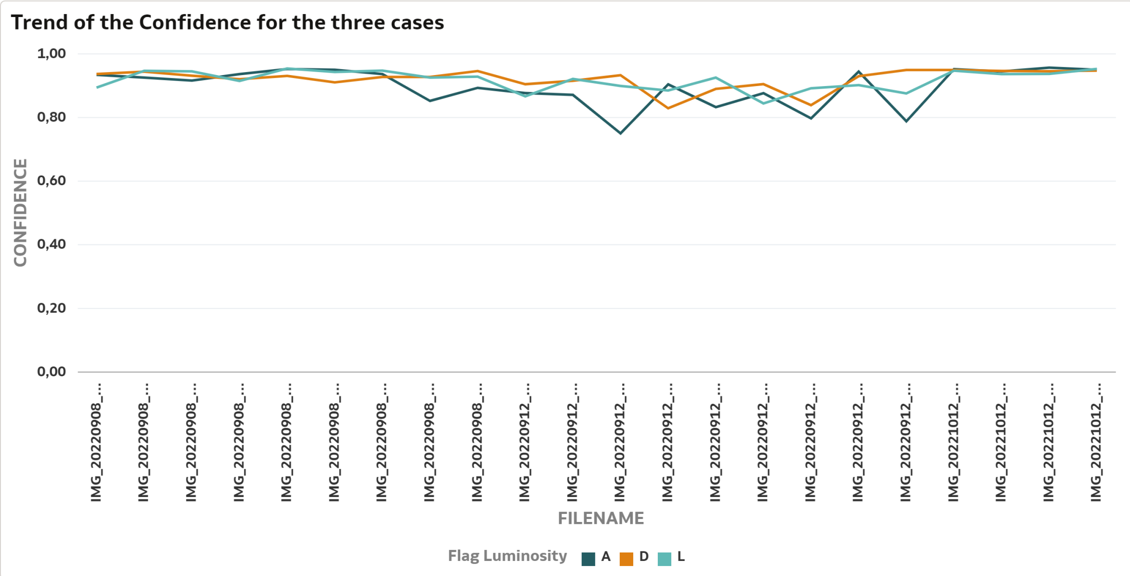


Figure 39: Luminosity analysis: Confidence values comparison

Trend of the confidence for the file analysed for the luminosity. The D label is for the low luminosity values; the L, for the high luminosity values; the A consider confidence values of the same images without any modifications.

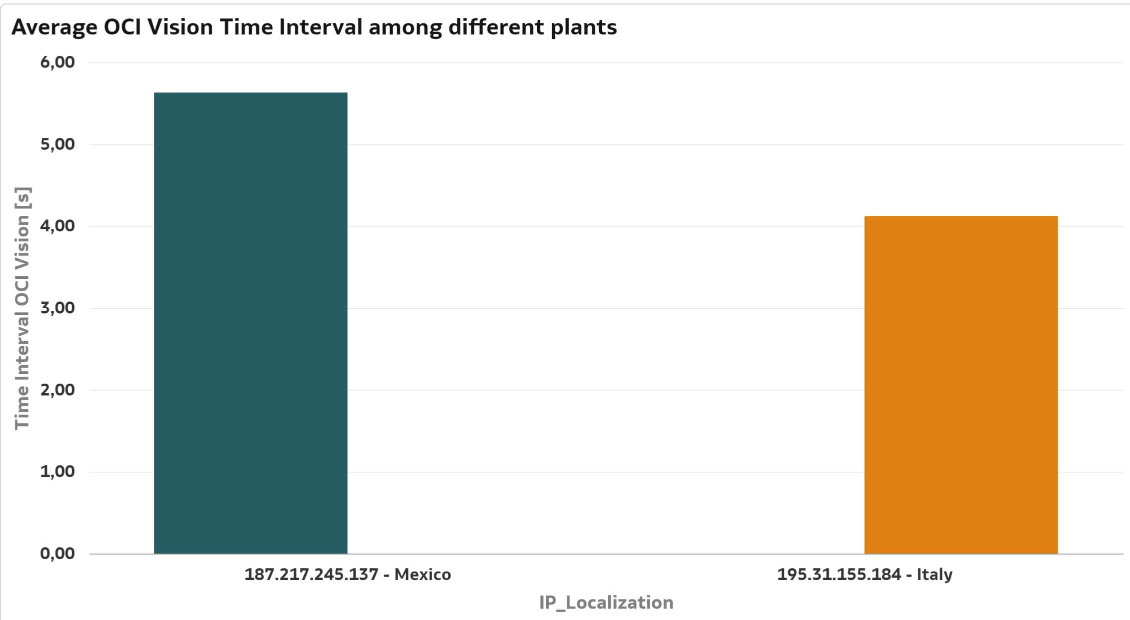


Figure 40: Average values of time intervals of Oracle OCI Vision from different plants

obtained is quite small: the standard deviation over time is $0,53s$, that is much smaller than the one of OCI Vision, which was $2,19s$.

Three trials have been randomly chosen for the OCI Vision API and compared with the three performed with Google Vision API, considering on the x axis each image name. The outcome is reported in the plot of the figure 42. The result shows a particularly different behaviour among the two applications. The average time interval of Google is $1,26s$, the one of OCI $3,77s$. The fact that is common is the standard deviation for each file: even in this case, for the same image the elaboration time is quite constant, since the standard deviation is of $0,38s$, comparable with the one obtained with OCI Vision.

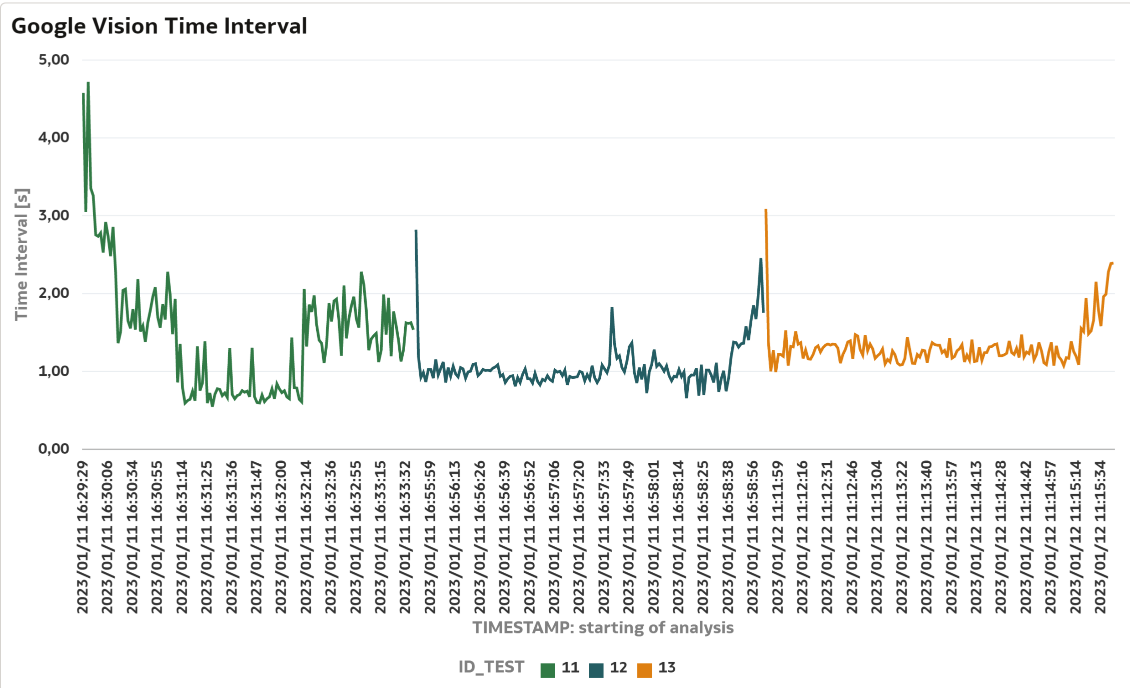


Figure 41: Trend of time intervals of Google Vision

These results could be a starting point for a deeper collaboration with *Oracle*: better performance for the API can be demanded. Moreover, since all the applications used by the company belong to Oracle, choosing OCI Vision is still the best option.

4.2.7 Cropping of labels Analysis

It is possible now to find possible solutions by our side that can improve the results. One strategy that could be adopted is the

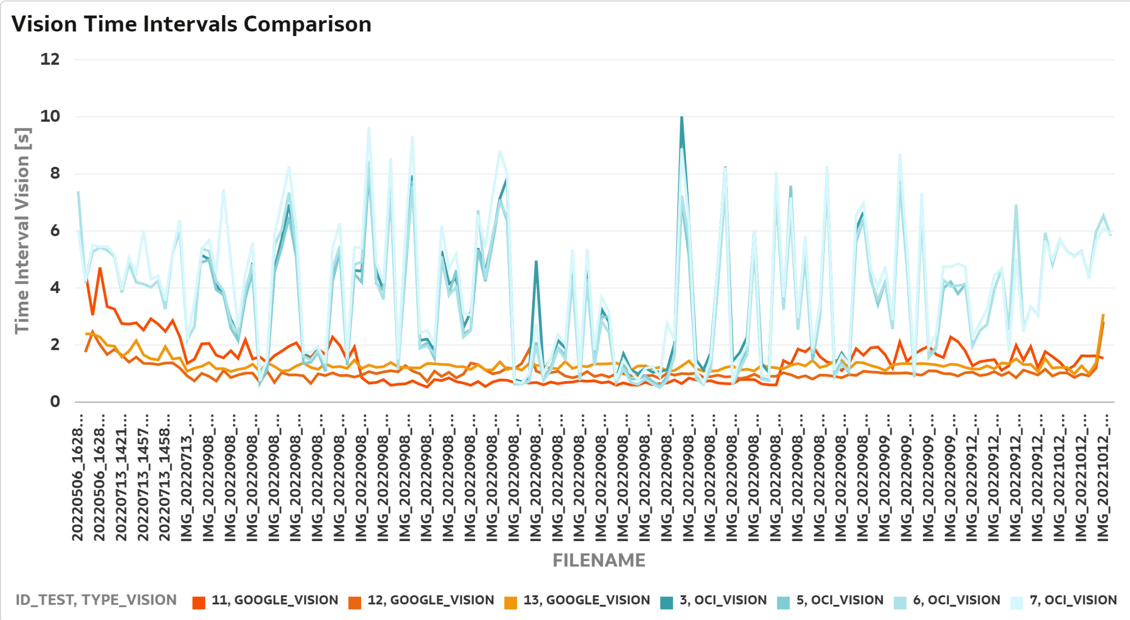


Figure 42: Comparison between the two different type of OCR Visions: OCI Vision and Google Vision

implementation of the cropping (cut) of labels: the labels of each reel image are selected and analysed one by one. At the moment of the performance analyses, the crop is done manually with classical application already installed in the device. Eventually, in the case that this operation will be adopted, the cropping need to be automatized.

In order to perform this analysis, after a manual crop, each label of the image is uploaded, taking trace of the original image from which the label has been extracted. For the resulting confidence of the cropped image it has been taken the average of the confidence obtained for each label; for the OCI Vision time interval, instead, the sum of the intervals for each label. A subset of 99 images has been cropped and then analysed. In the scatter plot of the figure 43, it is present, for each file, the percentage variation of the confidence and time interval.

Let's now start to analyse this outcome. The majority of images fall in the first and second quadrant: this means that this opera-

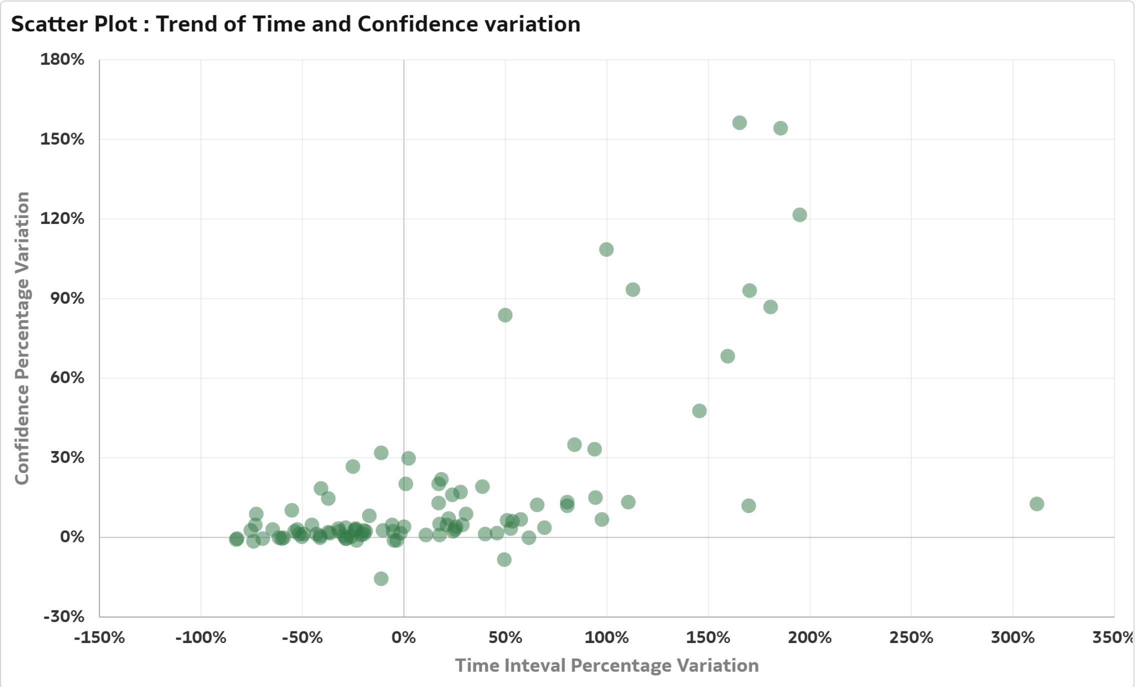


Figure 43: Scatter plot: the time and confidence variation after cropping operation

tion in most cases assures better performance in what concerns the confidence. A great part of the population stays close to the x-axis which means that, if there is not an improvement, there is just a small variation, in positive or negative direction. This observation makes clear that applying the cropping, the confidence is generally positive affected. Considering now the variation of time interval, what is willed is a decreasing of the value, so a negative percentage is desired. Actually, more than half of the images experiences better performances of time interval.

It is worthy at this point to go deep into detail. Firstly, the images with a worsening of time interval are selected: they are 48 out of the 98 of the total subset. In the figure 44 are reported the time intervals, after the cropping, of these selected images and the relative confidence value. The two horizontal line indicate the threshold of $4s$ for the time and $0,96$ for the confidence. Moreover, the file names have been ordered considering an increasing value of confidence variation percentage. What is possible to deduce, by moving with the mouse along the trends, that only the first two of them are negative. This means that only two images experiment of all the data set have a worsening of both measures. For all the others image, a better confidence, even with an high improvement, is obtained. Another aspect to observe, is that the $85,4\%$ the time intervals values are under the threshold of $4s$. This means that, despite the positive time interval percentage variation, the overall time required is still acceptable.

Let's now select all the images that have a worsening in the con-

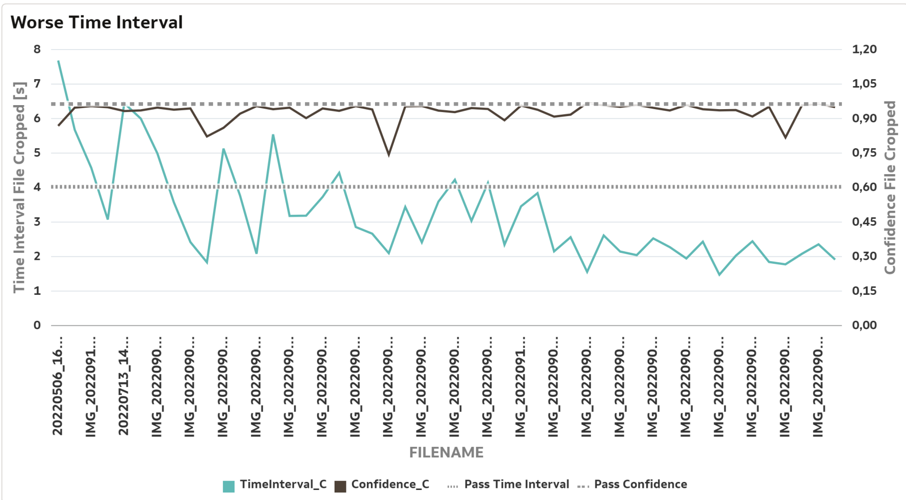


Figure 44: Cropping analysis: worse time interval

Axis x: images that have a worsening of time interval. *Axis y*: trend of time interval and confidence of the selected cropped images

fidence. The plot follows the same rules of the previous one. The number of the selected files is quite low: 15 out of the total subset analysed. Obviously, there are the two images for which there is a total worsening of the performances. With the exception of those, for the rest of images a better time interval is obtained.

To sum up, this operation could provide a general improvement of the performances, making the cropping a good solution to pursue. Nevertheless, just 37 samples out of 99 samples are above the 'Pass' threshold. This means that the cropping is not enough to obtain the desired level of confidence. +

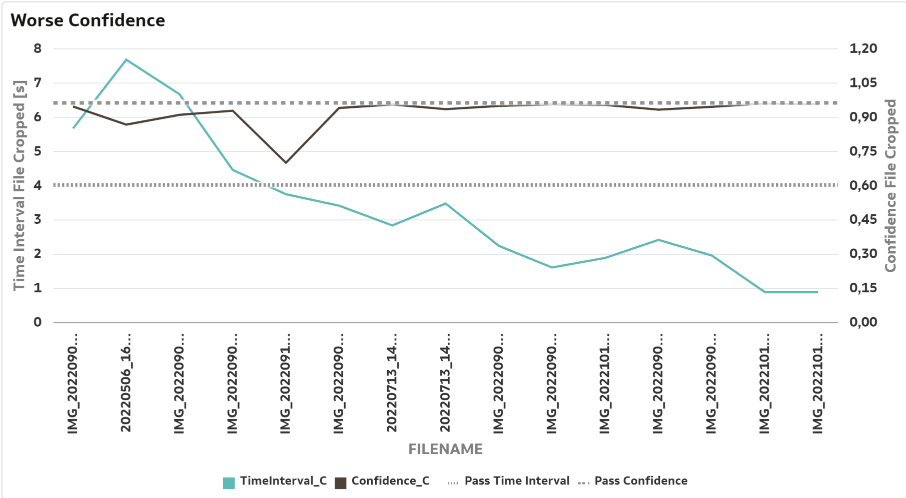


Figure 45: Cropping analysis: confidence

Axis x: images that have a worsening of confidence. *Axis y*: trend of time interval and confidence of the selected cropped images

Other ways to have a better confidence need to be found. It is important to underline, moreover, that the automatic cropping of the labels need to require a small amount of time otherwise the time improvement will not be reached.

4.2.8 Data Science Time Interval analysis

Another aspect to focus the attention on is the elapsed time for the elaboration of the algorithm on Data Science. The final aim of this API is to associate the mandatory information for the Smart Incoming with the text read on the labels and validate them thanks to the comparison with the Company's ERP and other internal databases. The way to compute the time interval is exactly the same of OCI Vision. It is important to underline the fact that, during the period of the conduct of this thesis, the algorithm is still in development: the complexity is therefore not comparable with the one will be used for the final version. Nevertheless, a prior analysis has been carried out. The outcome is the plotted in the figure 46. With exception of anomalies, the computed values are very low, making this part, up the moment of the test, not an issue to deal with. The features of this version consist in finding the quantity and the Bitron Part Number from the text read where only words with confidence higher than 90% and 92%, respectively for quantity and Bitron Part Number, have been chosen.The algorithm selects the numbers multiple of 100 or 1000, since the content of a reel follows this rule: if more than one values are found, a warning message is returned. For the Bitron Part number, since the information is a crucial one, a deeper control is applied. Each numeric string, with length of 8 or 11, is compared with a list of Bitron Part Numbers taken from internal databases: the Levenshtein distance is computed and only if the distance is equal to zero, that means a perfect match, the string is selected as Bitron Part Number.

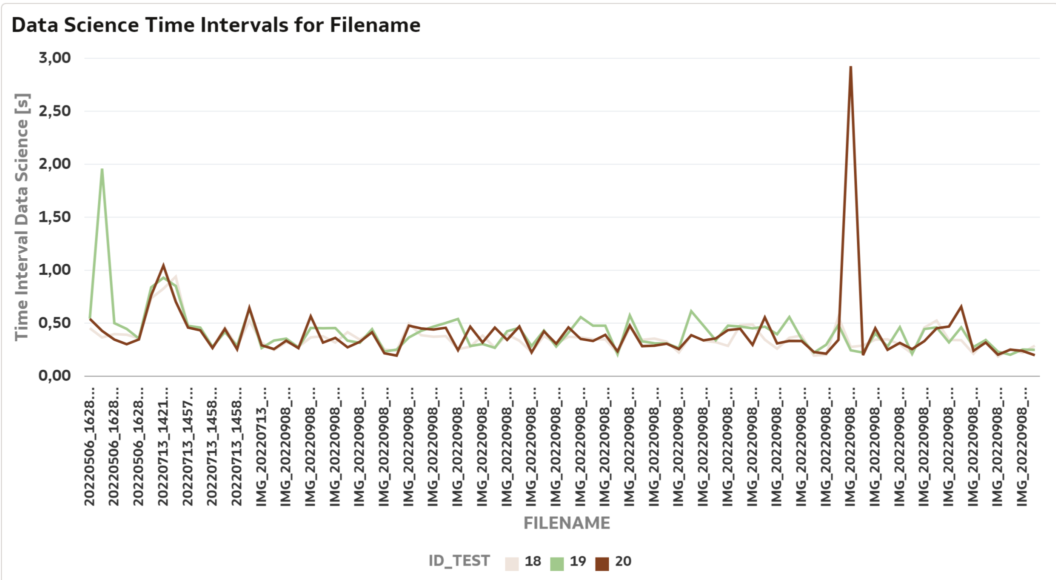


Figure 46: Time Interval of Data Science

4.3 Hardware and Cloud Communication

In this section, it is explained how to take a real-time image and process it. The solution found regards the possibility to access to the embedded webcam of the laptop, take a picture and elaborate it. In the *real* implementation, there will be an external camera, located under the conveyor so that it is fixed the distance between the camera and the labels. The reels can have, indeed, different

heights: in this way, the resulting quality of the image it has been made independent of the size and shape of the reel.
The research done for the **hardware** part have established that the following components are required:

- barcode reader;
- Camera;
- Lens;
- Frame grabber;
- Lighting system;

The main characteristics of the **camera** should be close to: *resolution*: 44.7 MP; *pixel size*: 3.2 μm x 3.2 μm ; *frame rate*:15 fps. For the *lens*, the *focal length* need to be close to 25.0 mm. Regarding the **frame grabber**, an electronic device that capture an analog video signal or a digital video stream, it is used to enhance the performance of the image acquisition since it can already process the image, before sending it to the PC; the *data bandwidth* should be close to 12.5 *Gbps*. In the end, the **lighting system** should guarantee an uniform light, without any reflection on the labels; for this case, a flat dom white light could be helpful.

Going back to the study of the connection of the hardware and the cloud, the user interface showed in the figure 47 allows to take an image in real-time and show it on the grey rectangle, temporarily store and process it according to the actions already presented in the previous sections.
There is a 'Button' component called *Start to record* used to generate an event the execution of an action chain where the function `startRecord()` is called. Here `MediaDevices` interface is exploited since this allows to have access to media inputs, like camera or microphone, in our case just the video is turned on, enabling video track thanks to `MediaDevice.getUserMedia()` method. The

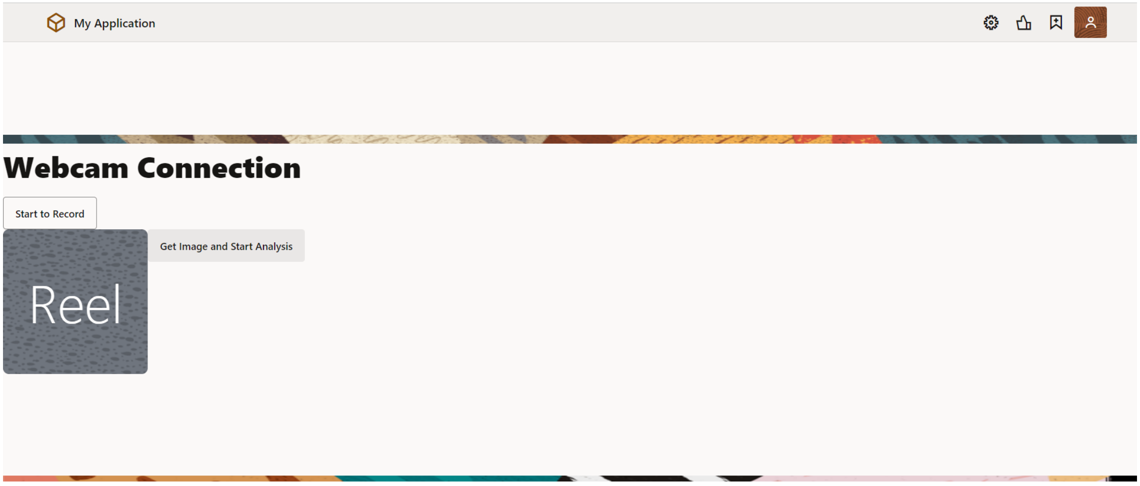


Figure 47: User Interface for hardware/cloud connection

HTML element 'video' is created having as a source right the media stream previously generated. The return value of the function is this HTML element after `video.play()` method, that let begin the media playback, has been called.
Then, the other button pressing generates the action chain *Reel Chain* that is similar to the one seen in the section 4.3 for the User Interface example. In the figure 48 it is possible to observe that the function *getReelimage(video)* is called: the image of the video stream is get and then converted into a data URL, using the method `HTMLCanvasElement.toDataURL()` .
In particular, the `CanvasRenderingContext2D.drawImage()` method of the Canvas 2D API, that provides different ways to draw an image onto the canvas, is used; the one used is the one `drawImage(image, dx, dy, dWidth, dHeight)` where the dimensions and the position of the canvas are specified.
The following operations of the action chain are showed in fig. 48

User Interface Example

A simple user interface has been developed to share the application among operators of different plants that can not have the perception of the back-end development. The aim is to start to validate the software architecture elaborated, trying the application during the

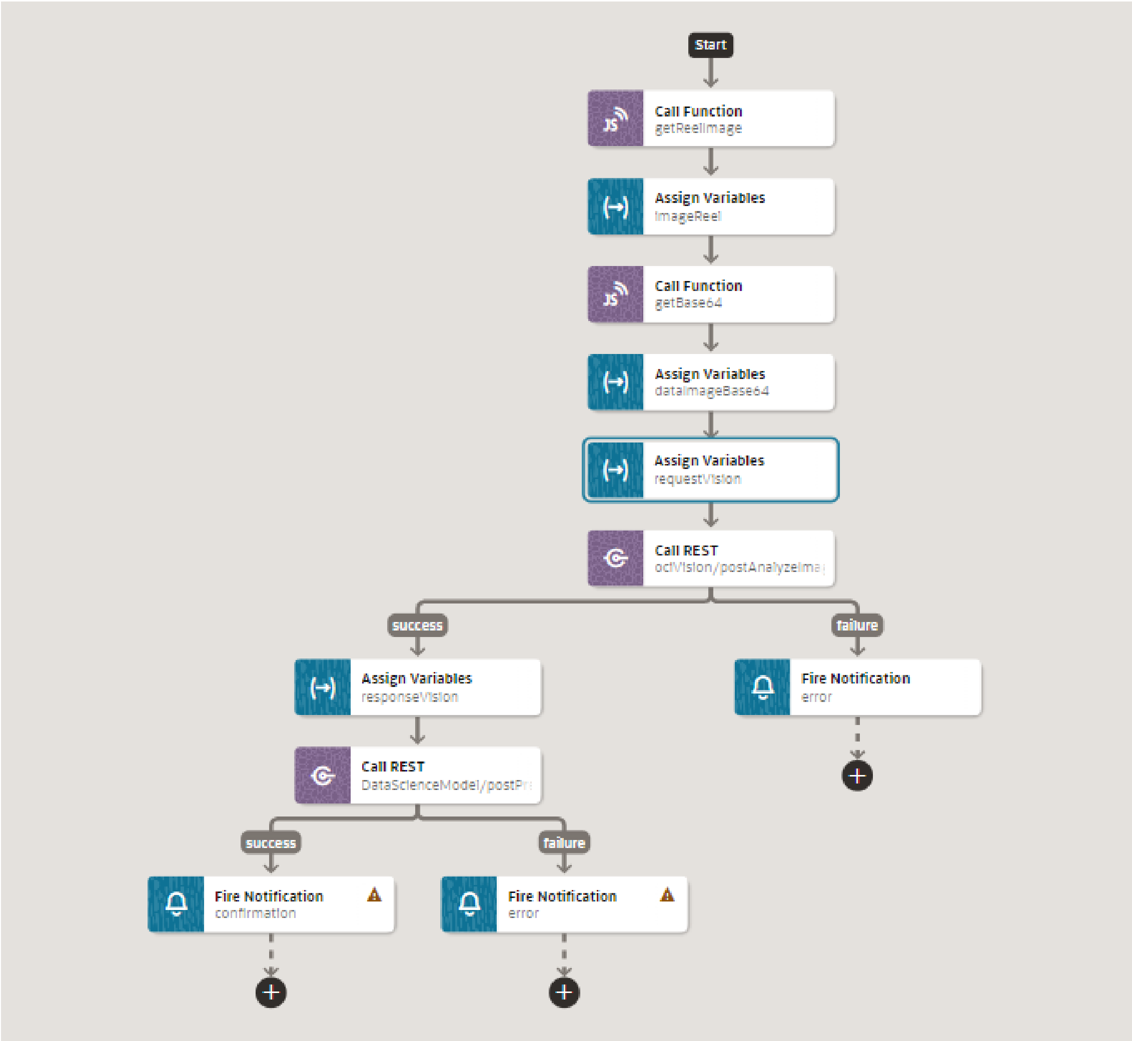


Figure 48: Action Chain executed for the real-time image

current incoming process and observing the resulting of the reading. The application can be used with a smartphone, since the pick Reel component can automatically have access to the camera of a smartphone. In this way, even if the quality of the images is not high, new trials can be easily done. The interface shows, indeed, the results of the Response of OCI Vision (properly filtered) and two key values: the Bitron Part Number and Quantity, found thanks to the algorithm developed on Data Science.

The action chains of this page are slightly different: there is no need to use a loop and some components are added. This preliminary

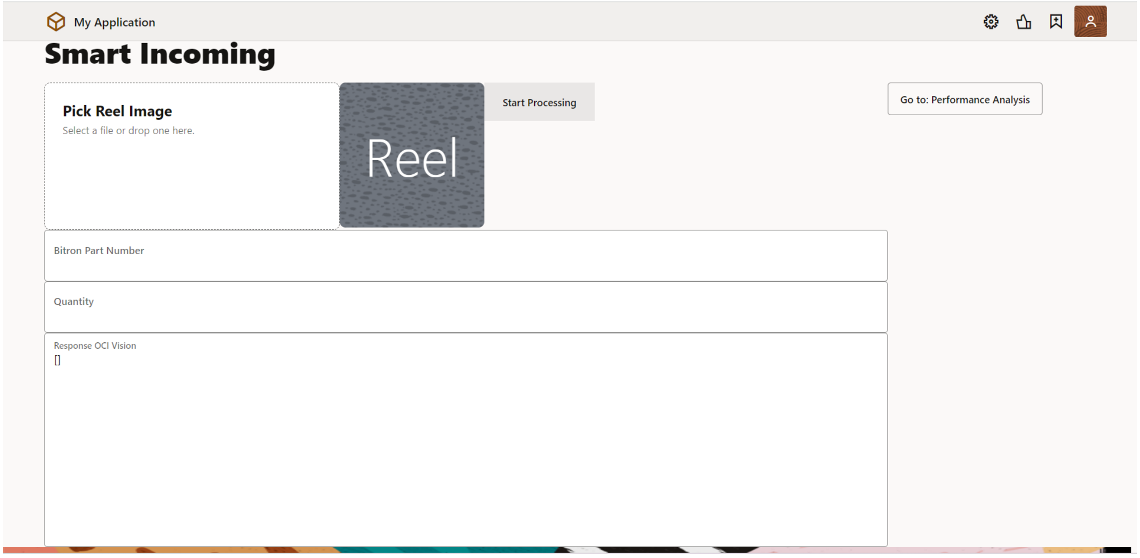


Figure 49: User Interface for the operator

version does not store the results of the algorithm neither. The most important action chain is the one showed in the figure 51. Obviously, in the near future, additional features must be provided to the application to properly deal with all the requirements for the Smart Incoming process.

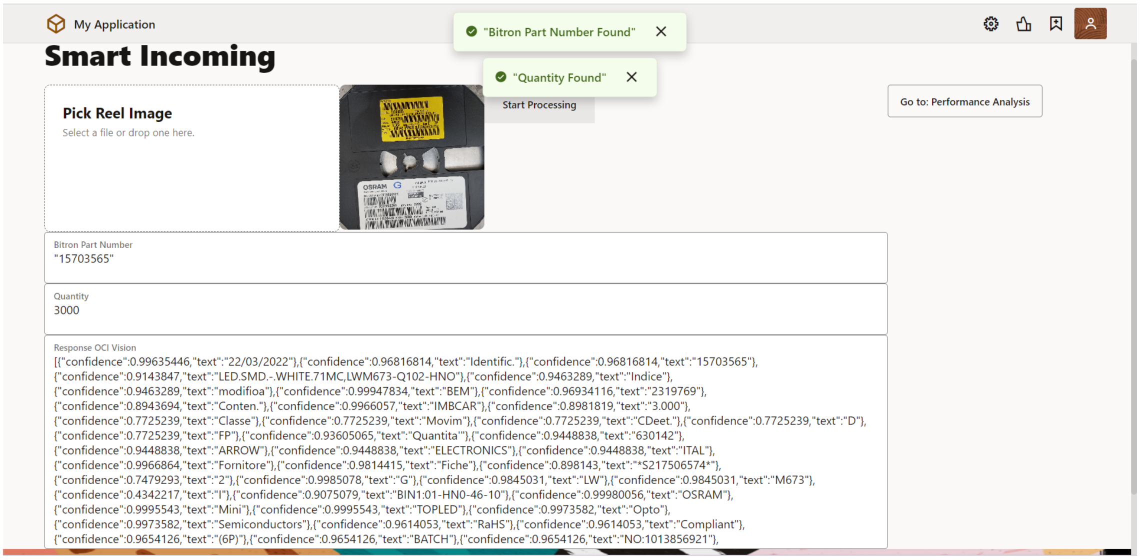


Figure 50: User Interface for the operator after the elaboration

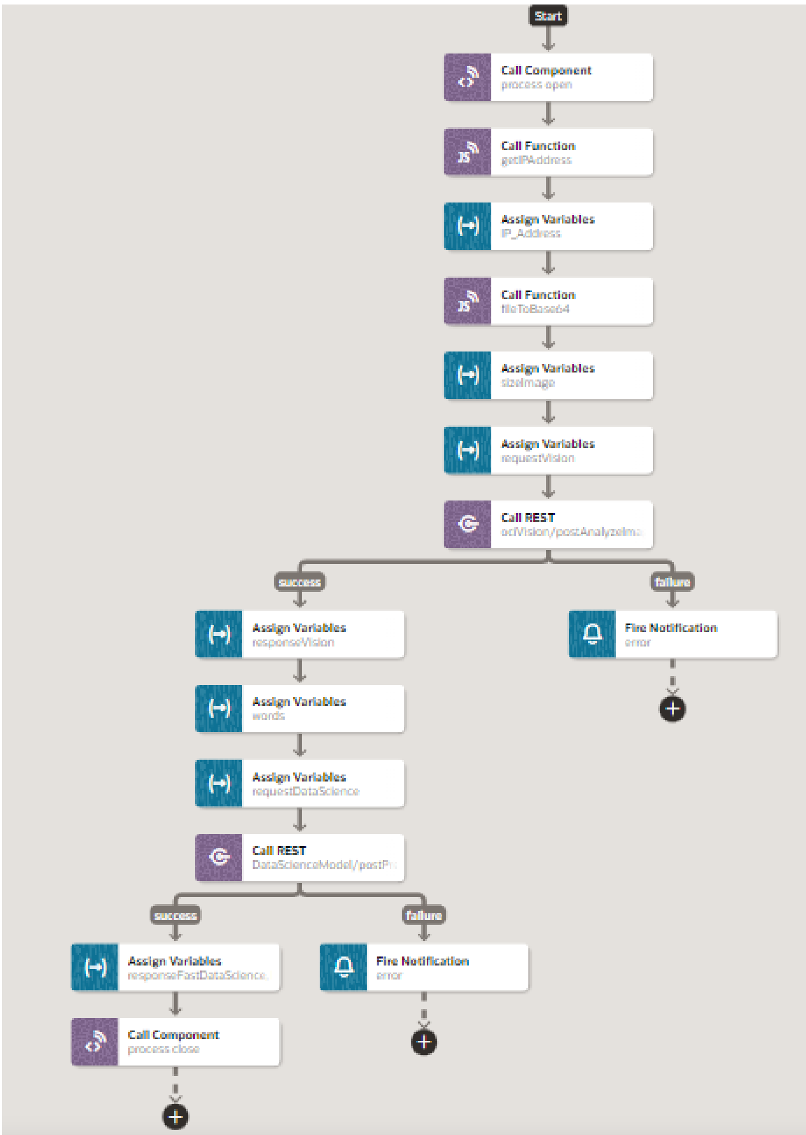


Figure 51: Action chain for the processing the image taken through UI

5 Lighting Products

In this chapter, the topic of lighting products, already presented in the section 3.1.1, is deeply analysed. For seek of completeness, the choice to study the manufacturing line for this kind of products derives to the need of highlighting the importance of integration of the process along the supply chain. Indeed, the improvement of the incoming process, seen in the previous chapter, can guarantee a better traceability for the components and a better management of the assembly part during the manufacturing process.
This kind of products consists in lighting devices mounted both in the front, rear or sides of the external part of a car. The most important components of these products are the LEDs, mainly white, yellow, red and orange. The content of this chapter is therefore studying the adequacy of the current production lines for lighting products and point out the main issues in the assembly and testing part with the aim to find a standardized configuration. Moreover, Lighting products represent a strategic importance for the Bitron company because of their the recent market growth: for the next years the ordered plan is 5 times more than previous year. For this reason the standardization among different plants has arisen, to cope with the variability of the products.

5.1 Adequacy of Assembly line

The assembly line seen in the section 2.2.3 has been thought in the past years, mainly for the products most required at that time. Since the lighting products are becoming more and more important in the production plan of the company, a proper study on the adequacy of the present lines need to be performed.
First of all, a quick explanation of the main features of this kind of product could be helpful. In general, the PCB are composed by a small amount of component, mainly LEDs, and they usually have odd shapes. Up to now, each plant has installed its own line according to their need, and a standardization has not be found yet.

In fact, the operations to carry out on each PCB are not only given by the mounting of the SMD components, but also of other types, like heat sinker for the anterior panels. Moreover, in-circuit-test, functional test, packaging managing are often done off-line, making the handling part a critical issue to take into account, from a quality, temporal and economic point of view.
Since the current lines, dedicated to the lighting, are not enough, it is important to understand if the standardized line could be exploited also for the manufacturing of lighting products. In order to see the critical point, specific lines of final products have been selected. They are the ones that do not require other production step after the pick and place.
The first object to analyse is the Pick-and-Place, shown in the figure 52. As it is possible to observe, this machine is characterised by an high modularity. Each module is distinguishable by the head size and number of components mountable in an hour. In general, the lines have at least six different modules to cope with the need of the present production. The aim is therefore to understand if this configuration can be good for lighting.
The adequacy of the peak and place can be found in the fact that the cycle time of this specific machine should be comparable with the rest of the line. In fact, due to the screen printing and the reflow oven, there are some time constrains to take into account and this let the cycle time to be at least $20s$. In order to observe the adequacy of the present lines, an analysis of theoretical processing time for the PCB in the pp has been performed, by elaborating the data of company databases related just to those products,as already presented, that do not require additional manufacturing steps.
The total number of component mountable for each line is known a priori. Then, the amount of time spent on each panel is computed by simply dividing:

$$Panel\_hour = \frac{component\_hour}{number\_of\_components}.$$

The number of component per panel is computed by the machine for each product. The cycle time is then the opposite of the value

Figure 52: Example of Pick and Place

found, then converted into seconds. The cycle times have been grouped and the number of products that fall in each group, distinguished by the production line where they are manufactured, computed and plotted in the figure below. The analysis takes into account the fact that each product can be done in different lines. That means that for each product, more than one cycle time can be present. Nevertheless, these results are way far from being realistic. Indeed, the time spent inside the peak and place should take into account the time for reading the data matrix (often a qr-code on the PCB that contains all its information for the traceability) and the fiducials (reference point to compute the coordinates inside the panel). For this reason, a corrective factor of $4s$ has been added, in addiction to a corrective factor for the speed of the head, where the performance considered is of 60%. The result is obviously a shift on the right for the distribution (fig 55). As it is clear to see,

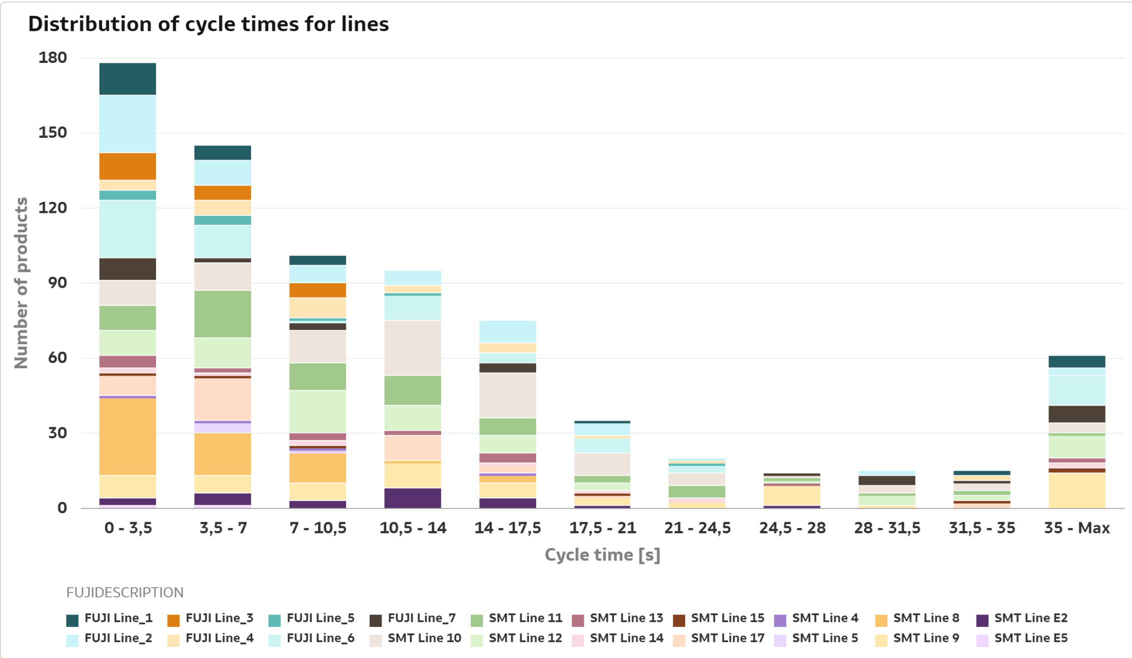


Figure 53: Adequacy of SMT lines for lighting products

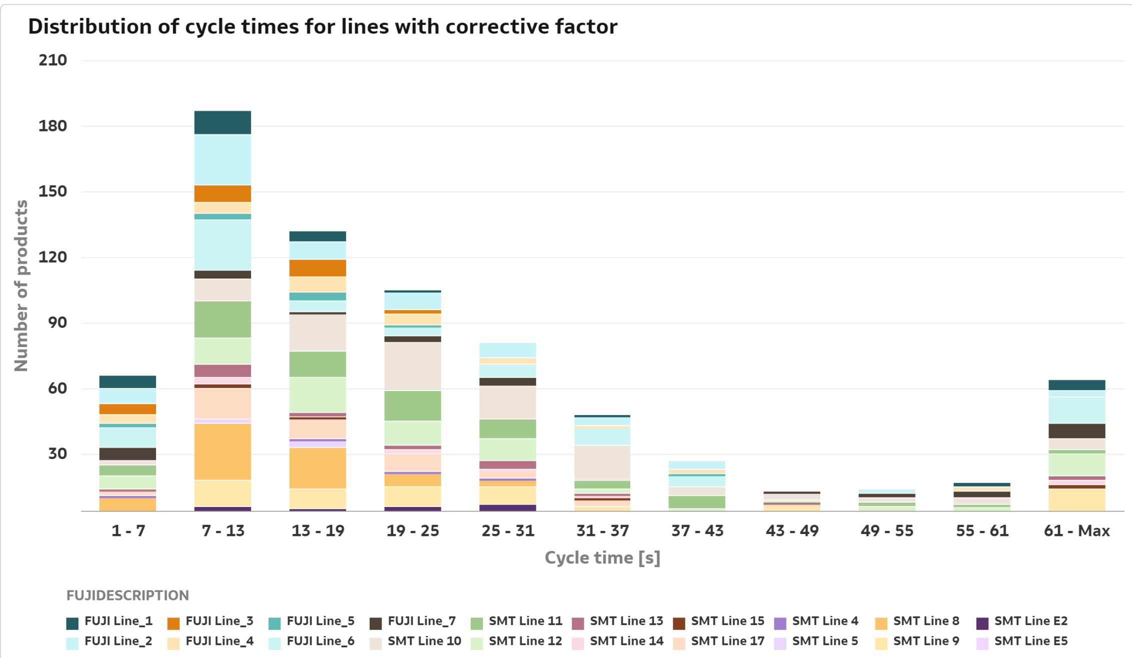


Figure 54: Adequacy of SMT lines for lighting products with corrective factor

the speed of the machine is quite high for this kind of product: as already said, the number of components mounted on these PCBs is generally low. Even considering those corrective factors, the 55, 3%

of the associations product-line experience an over-estimation of the line since the theoretical cycle time computed is less $20s$. This value is referred to the silkscreen printing, located at the begining of the manufacturing process and this is the one that dictates the cycle time since its speed can not be modified and does not depend on the number of components: the solder paste is deposited on all the panel. Having a pick-and-place faster than this value results in a waste of resources since the performance of the silkscreen can not be faster. However, the current standardized SMT line have been build considering to work with very high capacity, where the pick-and-place has been developed being able to follow the silkscreen performance. It is the deducible that the number of modules are over estimated, letting a waste of money firstly, since many modules inside the line are actually not exploited since useless.
An estimation of the working hours in a month to spend on the assembly of this kind of products can be carried on. Basing on the average monthly consumption of each product, the total hours are computed. The consumption is referred to the product, however, in each panel more than one figure (single PCB) can be worked at a time. The number of figures for each panel is registered in the databases as panelization and exploited for the following computation:

$$Tot\_hours = \frac{veragemonthlyconsumption}{panelizzation} * \frac{cycletime}{3600}.$$

The plot below shows the resulting hours for each product and lines SMT, by grouping together the cycletimes considering the corrective factor, too.

Manufacturing of Lighting Products: cycle times from the manufacturing process

The manufacturing of a subset of the products previously analysed has already started. This facts allows to have a comparison between the theoretical and the computed cycle times. In particular, the computed cycle time derives from the *PPH*, pieces per hour

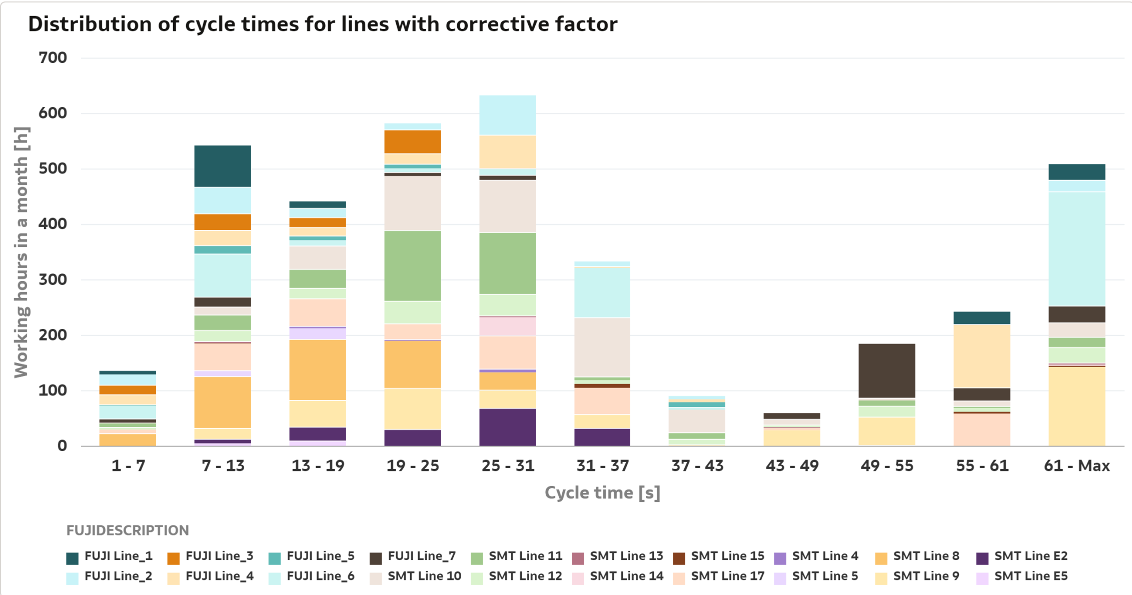


Figure 55: Adequacy, considering the working hours in a month, of SMT lines for lighting products with corrective factor

that means the number of products entering the SMT line in one hour, already present in the company databases, by exploiting the formula

$$cycle\_time = \frac{3600}{pieces\_per\_hour}.$$

The result is therefore the cycle time intended as the elapsed time among the entry of two different panels.
In the plot of the figure 56, the variation of the cycle times related for each line is reported. It is possible to affirm that an average positive variation of the 39% is obtained. In general, the lines mount a greater number of modules than required by this kind of products. Indeed, inserting the pick-and-place in the line, where the bottleneck is at the level of the silkscreen printing, leads to an increment of the average cycle time seen.

Changing the point of view, for each product (identified by the internal code) for which the *PPH* is present, the percentage variation from the value obtained during the adequacy analysis is computed and shown in the plot of figure 57. The outcome is expected, indeed, the $67,7\%$ of the products reports a positive variation of the

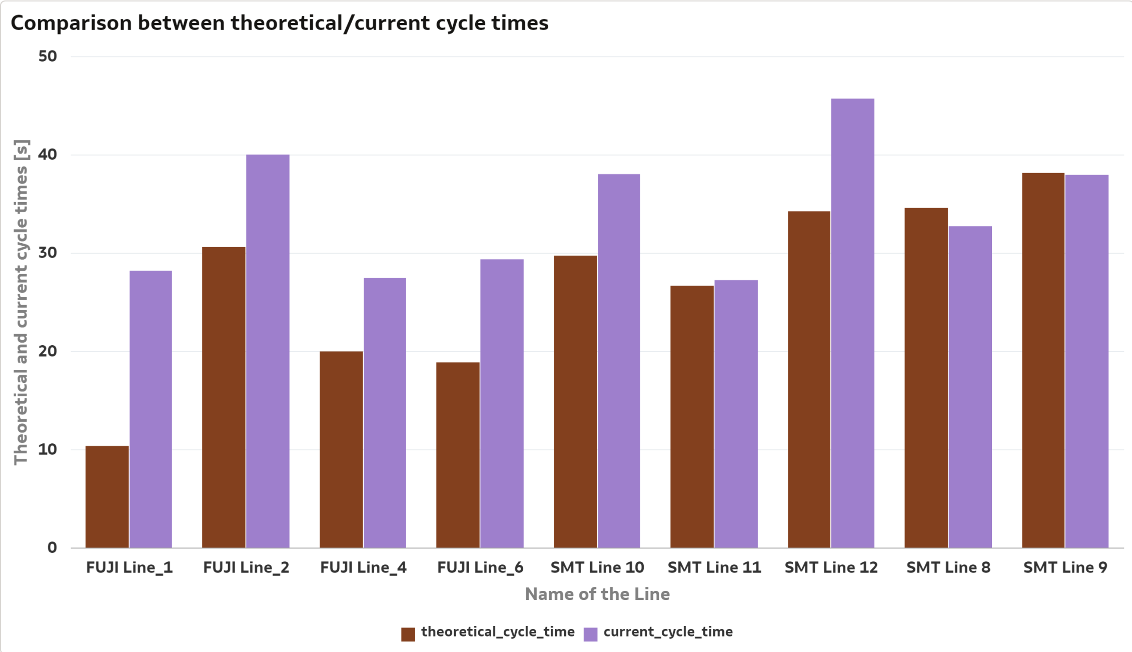


Figure 56: Comparison between theoretical cycle time and current cycle time on different Lines

cycle time, meaning an increase of the measure, even though corrective factor have been considered. Another aspect that leads to this increasing derives from the fact that, in the real implementation, not all the modules are exploited, since useless, therefore, the nominal speed is not the sum of all the modules, but only of the ones really used.

The result is in line with what was expected, in fact, the present SMT line is overestimate, regarding the pick-and-place performances. This leads to an high economical loss. Therefore a dedicated lighting line could have a fewer number of modules for the pick-and-place, allowing a lower investment. However it needs to take into account that the modules characteristics depend on the component's dimension. It should be assured to met the different dimension requirements and, at the same time, minimize the number of modules in order to avoid an overestimation of the line.

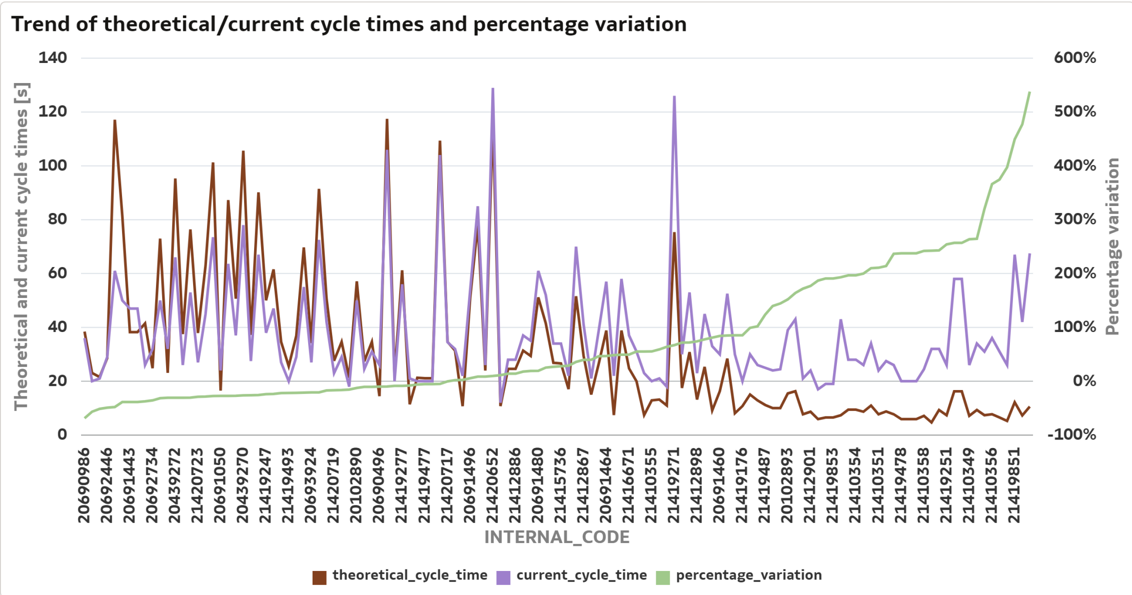


Figure 57: Trend of theoretical cycle time and current cycle time on the left y axes and the percentage variation on the right y axes

5.2 End-of-line Testing phase

The testing phase is a very critical step during the lighting production. It is essential to test the boards and meet customer requirements. Usually, for this kind of products, after the reflow oven, the AOI is exploited to inspect the quality of the board. Just after that, the panels go to the *router* that cut each figure. Up to now, this step is the last one in-line, in particular the ICT and functional tests are made off-line. The decision to put the tests after the router derives from the fact that the router is the most critical part from a mechanical point of view and this can damage the PCB. Therefore to perform the tests in this position is a good choice in order to detect eventual damages. However, this organization leads to increased handling for the operator, generating new sources of defects.

The first test (ICT) consists in verifying the electrical features, checking for shorts, opens, resistance, capacitance, and other basic quantities which will show whether the assembly was correctly fabricated. Then, each LED is tested checking different features explained in the appendix A.1 and A.2.

The instrument used so far is the LED Analyser of FEASA (17). The testing part has a variable *duration*, at least more than $40s$, according to the number of components of the product, especially the number of LEDs since they are tested one by one, and this is one reason that lead the decision to put test out of line. Moreover, if the number of LEDs are more than 20, more analyzers are required: a *daisy chain* method is adopted to communicate more LED spectrometers via a single computer port. This structure adds a time delay of the order of ms, depending on the number of them, to take into account in the overall computation of the testing time. The LED measurements require a very high precision and accuracy, especially for the binning, since the limits that discriminate one bin to the other can be close and the determination of the belonging bin can not be easy. This kind of instrument, moreover, requires periodical calibration, at least once a year and every time a new kind of product start to be tested. Even this fact, means a waste of time and money. Another specific issue that need to overcome is the requirement of a customized fixture for each product, where the analyser are fixed and it is not possible to reuse for different products. This let the economic investment to be very high. This fact also is related to the footprint of the fixture: there is a physical limit for the maximum number of testable LED, because a limited number of Feasa can be mounted. Another problem is the proximity of the LEDs: because of the lens, required to maximize the light in the fiber, a minimum distance of $3,5mm$ must be respected, letting impossibile the test for closer LEDs.
The company is starting to investigate for other suppliers that can assure the same features with a different machine and less expensive solutions.

Figure 58: Feasa LED Analyser

New solutions to apply for LED tester: SPEA example

In this last part of the chapter, a brief comparison of the new tester taken into account and the FEASA in carried out. The discussion does not consider the evaluation of the economical investment.
First of all, the technologies exploited to test LEDs are different: the FEASA uses *optical fiber* connected to the sensors, the T100L, the new tester, uses a *flying scanner* technology to obtain data from the DUT. Since the two tester are based on completely different technologies, the comparison is not straightforward.
Anyway some comparison can be done. The problem of the fixture footprint is overcome since no fiber and sensors are required, making faster also the definition of the test program. As a result, the cost for each fixture decreases a lot. Moreover, this machine does not require periodical calibration, unlike the Feasa.

The two tester have values of **accuracy** [16] and **repeatibility**[17] comparable, except for the chromaticity that has an higher accuracy on the T100L. Moreover, the last one, is able to test a wider range of wavelength, $400-1000nm$, unlike the Feasa where just $450-650nm$. Another key aspect to consider to verify and compare is the test time variation reported in the table 5. In general, the variable involved to the test time are different: the Feasa test time increases with the number of LEDs, the T100L test time depends on the area of the DUT to analyse.

	Feasa	**T100L**
Read-back time	5 ms	No fiber required
Capture time	[2-650] ms	[7-85] m
Number of LEDs in parallel	40 LEDs/s with 2 Feasa (capture time of 200 ms)	240 LEDs/s per Camera (capture Time of 85 ms) (ref. to LED with a diameter of 3 mm + frame of 2 mm)
Scan speed	No scan present	Max 200 mm/s

Table 5: Comparison of time performances among the two LED tester

Nevertheless, the number of LEDs that can be tested with the T100L can be as high as much the resolution of the camera can allow to discriminate among two different points, that means up to 130 μm of distance. This overcome the problem of the minimum distance among LEDs required by the Feasa. It follows that, the higher the number of LEDs, the higher will be the number of LEDs testable in parallel, since the scanning time does not depend on it. It is exactly in this case that the test time performance of the scanning technique become better than the Feasa: this one, has a test time that depends on the number of LEDs to test, since, even though the measurement of 20 LEDs happens in parallel, the values are read sequentially. At the same time, this characteristic is

[16] The accuracy of a measurement system refers to the closeness of a measured value to a standard or known value

[17] Repeatability is a measure of the ability of the method to generate similar results for multiple preparations of the same sample

a weak point: in the case of a low number of LEDs, the scanning time could be higher then the time required by the Feasa. Indeed, the scan speed can not be higher than $200mm/s$, and all the PCB should be scanned anyway.
As *future works*, it could be interesting to continue a more detailed comparison analysis by evaluating test times of different kind of products on both of the tester, willing to understand the minimum number of LEDs on the PCB and dimension of it for which the scanning technique can be preferred. Different kind of products in terms of LEDs density, dimension, position of LEDs should be tested on both, evaluating at the same time economical and technical aspect. Another aspect to consider is the adaptability of it in a standardized SMT line. In general, the scanning technique, not depending on the number of LEDs, can assure a less variable test time among similar products. An interesting estimation could be the computation of the average test time for different lighting products on the T100L. If the time spent is around the takt time of the line, generally dictated by the silkscreen printing and it is about $20s$, the test does not become the bottleneck, not increasing the overall cycle time, allowing therefore the insertion in-line of the tester. Moreover, considering the Company situation, having more and more new products to manufacture, this test machine gives the chance to invest less on the numerous fixtures. However, the initial investment is much higher than the current solution.

Before affirming any kind of conclusion, more numerical data are required: a more in depth awareness of the features of the products to test should be know.

6 Conclusions and Future Works

From what described in the previous chapters, the improvements obtained exploiting Industry 4.0 are several and tangibles. From the possibility to decrease the distance with the customers, assuring a more efficient horizontal integration, to the ability of easily monitoring the production phase, thanks to the proper elaboration of the huge amount of data generated. Moreover, high level of automation assures better quality results, reducing handling and human errors, but also high level of adaptability, indispensable to cope with the increasing customization of the products. It is always possible to improve the performances of a Company by following the criteria widely explained in the first chapter.

Proceeding in the work of thesis, the LED component has been followed from the Incoming in the Warehouse up to the end-of-line testing phase. The aim is to obtain a knowledge of the different processes along the supply chain that involve this kind of components, highlighting the importance of improving the end-to-end integration in order to obtain a better quality of the final product.
Indeed, the discussion starts with a deep focus on the Incoming process observation. In addiction to the critical issues mainly correlated to this type of component, other weakness parts of the Incoming have been pointed out. The solution found by the company to reach a general improvement of the process is reported. It consists in an automatic storing of the information present on the labels of the reels. An image of the component that arrive in the Warehouse is taken and, exploiting OCR technology to extrapolate the text of the image, the mandatory information needed to assure a proper traceability are identified and stored in a dedicated database. It is a full-cloud based architecture. Obviously, key aspects like big data generation, digitalization, cloud structure are really in agreement with the main features of Industry 4.0, explained at the beginning. The main improvements that this architecture can reach consist in

a stronger traceability system, storage of data with higher quality and reliability, standardization of the process since it can applied on any kind of labels, despite the characteristic of them determined by the supplier.

The specific work of this thesis concerned the development of the software architecture that reproduces the main tasks of the future incoming infrastructure, in order to obtain performance analysis. In particular, the data about the time of elaboration of the images and the goodness of the text read have been deeply studied. The aim of this part has been not only understanding the variable involved in the elaboration time, like the amount of text present on the reel, but also proposing different improvements, like the selection of the labels of the image and performing the elaboration of them one by one to obtain a better quality of the reading or a reduction of the elaboration time using Google Vision as software that exploits the OCR technology, instead of Oracle Vision.

To sum up, the new process can guarantee an higher level of the quality of the final product since it assures a stronger traceability system and a generation of a dedicated database that improves the performance also of other process along the supply chain. In particular the production process. Indeed, this solution allows a leaner managements of the LEDs in production, making possible the reduction of set up time for the machines in the *lighting products* manufacturing.

At this point, the focus of the supply chain has therefore moved towards the production. In particular, the assembling and testing phase issues related to the *lighting products* have been studied, with having as objective the application of the goals of Industry 4.0, as, for example the reaching of a standardized line to cope with different customer needs thanks to an higher adaptability and, at the same time, to have a faster return of the investment. . The

first thing seen is the adaptability of the actual lines, where an overestimation of them has been observed: the performance of the pick-and-place, the assembling machine in the line, with the current characteristic is way higher than required for this kind of products. A solution consists in reducing the number of modules that constitute the machine, allowing lower investments for the company.
The last part of the thesis work focus the attention on the end-of-line testing. Indeed, proceeding along the supply chain, before the shipment, the products need to be tested. Since the interest is always on the lighting product, the main important test consists on LED checking. The issues related to this part have been explained, pointed out in particular the problems related to the use of the current tester. A comparison with a new proposed tester has been proposed. The aim of this part it has been looking for a solution that could assures high quality tests with lower investments.

Summarizing the results obtained, it is possible to affirm that focusing on the entire life cycle of a product along the supply chain, modifying the different processes involved with the application of automation and digitalization concepts, can lead to general improvements of the processes of a company, in terms of efficiency, productivity and quality.

6.1 Future Works

Several future works can be detected from the different topics proposed in this thesis. As regards the work specifically developed during the thesis, it is possible to observe various open works. First of all, the User Interface presented can be considered as a starting point for the future real implementation, where the integration with the ERP and other web services must be developed. With respect to the analysis performed, the specific hardware, not present during the period spent on the work of thesis, can allow to carry out more accurate analysis, moreover from all the different plants of the Company. For the second part of the thesis, related to the production process, different consideration can be done. In general, this part can be considered as a starting point for future, more in-depth, analyses on how the line can be modified to obtain a standardized one. For example, considerations about defects detection and reduction of human handling can be done. Moreover, further analyses are required to proper evaluate the new LED tester presented in order to have a more detailed comparison of the performance of the two. In particular, a study on the possibility to put in-line the tester can be carried out.

A Appendix

A.1 Binning of LEDs

The Binning of LEDs derives from the natural variation of the emission properties of LEDs due to the manufacturing process: it depends on the variance in the processing and placement of the die within the LED packaging. Each semiconductor chip has, indeed, slightly different emission properties, they depend on temperature differently, and there is some latitude difference in placement of the die within the LED packaging (16). In general, it is an issue related to mass production of LEDs. Each LED manufacturer then sort the LEDs so that, in each bin, the LEDs properties variation is minimized: in this way it is possible to maintain a tighter control of the possible output variations. Therefore, smaller bin sizes maintain a tighter control of color variation and are consequently more desirable. Each bin can characterized by specific values of *dominant wavelength*, *chromaticity coordinates*, *forward voltage*, *luminosity flux*, *color temperature*. In order to ensure that LEDs have the same light temperature, they are sorted according to the ANSI (American National Standards Institute) standard [18]. It defines chromatic aberrations using the MacAdam ellipses, shown in the figure 59 : regions on a chromaticity diagram that contains all colors which are indistinguishable, to the average human eye, from the color at the center of the ellipse. The ANSI standard, indeed, recommends that the color value has to be located in an ellipse.

This characteristic becomes more important dealing with white LEDs, since color temperature and brightness can vary a lot.

Knowing the LED bin, can allow to avoid an undesirable effect where close LEDs have slightly different color by choosing LEDs belonging to the same group of bin; the luminous intensity can be the same even if bins are different since it is possible to proper

[18] ANSI is the main organization supporting the development of technology standards in the United States. ANSI works with industry groups, and it is the U.S. member of the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC)

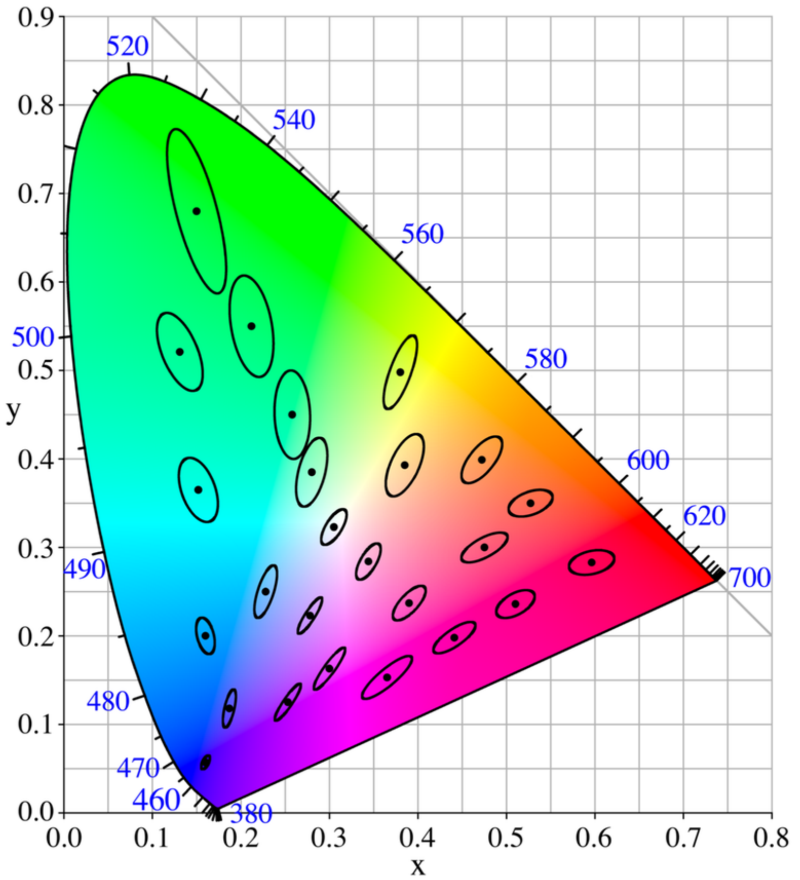


Figure 59: Chromaticity diagram with MacAdam ellipses to indicate the different bin: in each ellipses the colors are indistinguishable for the average humane eye from the center color of the ellipse

design the current flowing on the LEDs.

A.2 LEDs Measurements

Peak and Dominant Wavelength

The Peak Wavelength is the wavelength where the spectrum reaches its highest intensity i.e the maximum power as emitted by a LED. The dominant wavelength of a colour is defined on the 1931 CIE Chromaticity diagram. For monochromatic LEDs it is in general required values of dominant wavelength expressed in nanometer,for white LEDs, instead, the chromaticity diagram is used.

Color and Saturation

Colours can represented by a 360° degree circular Colour wheel. The three Primary RGB values can also be represented as a single value called **Hue**. Hue is a measured location on a Colour wheel and is expressed in degrees.

A pure Colour will be represented on the Colour wheel as a point

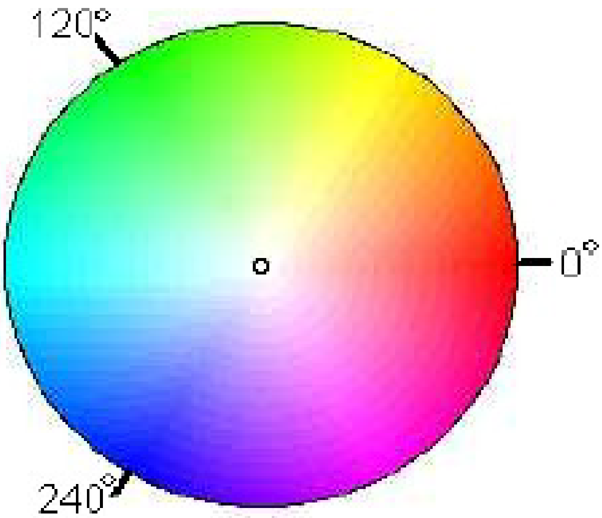


Figure 60: Hue (Color) Wheel (18)

near the outer edge. White will be represented by a point near the center of the wheel. The degree of whiteness in a LED will affect its position on the wheel – the greater the amount of white the closer it will be to the center. The degree of whiteness emitted by the LED is represented by the term **Saturation**. A saturation value of 0% represents pure White. A Saturation value of 100% represents a pure Colour such as Red, Blue, Green, etc.

Luminous Intensity and Luminous Flux

Intensity is a measure of the amount of light being emitted by the LED. The *luminous intensity* , in particular, is a measure of wavelength-weighted power emitted by a LED in a defined direction per solid angle (meaning how bright the beam in a specific direction is). The SI unit of luminous intensity is the candela (cd), a SI base unit (17).

The lumen (lm) is the unit of the total *luminous flux* emitted by a LED. This is the total amount of visible light emitted by the LED in all directions. One lumen is defined as the luminous flux of light produced by a light source that emits one candela of luminous intensity over a solid angle of one steradian. The luminous flux is characterized by the response of the human eye to the different wavelengths of visible light. Indeed, it a measure of the perceived power of light. Therefore, it is not the same as radiant flux (Power) which is a measure of the total light power emitted by the LED regardless of the human eye response (17).

White LEDs: Correlated Colour Temperature CCT

The CIE 1931 color spaces, the chromaticity diagram, is mainly exploited to refer to white LEDs. This diagram, the CIE XYZ or CIE 1931, is a standard reference which has been used as the basis for defining also most other color spaces. This maps human color perception based on the two CIE parameters x and y. For example, white LEDs have approximate co-ordinates of 0.33, 0.33. This varies depending on the fact that they could have blue tint (Cool White) or a Red tint (Warm White). The coordination of a white LED is then not fixed, but changes according to the color temperature. Looking at fig61,a warm color LED will have a color temperature in the region of 2800K while cool white LED will have a color temperature in the region of 6800K.

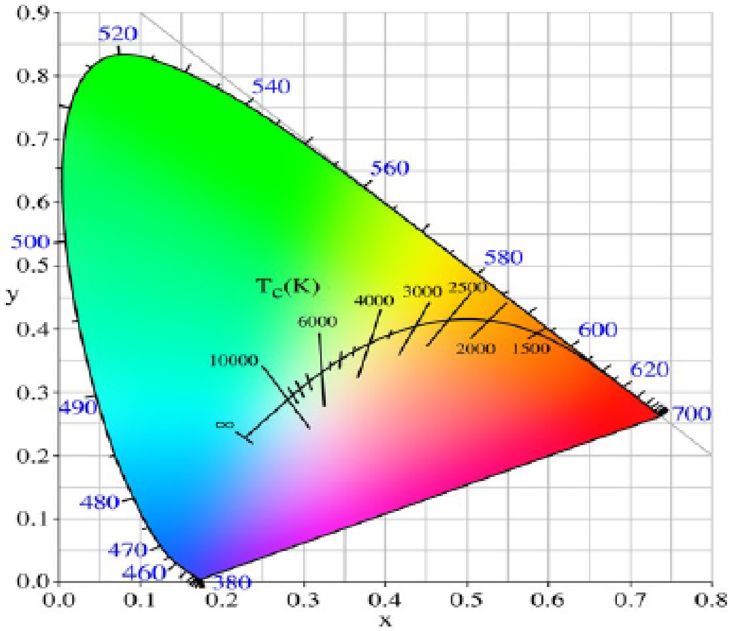


Figure 61: CCT plotted on CIE 1931 Chromaticity Co-Ordinates (17)

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