POLITECNICO DI TORINO

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Master of Science in Engineering and Management

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Continuous improvement through Digital Factory in TE Connectivity, opportunities to create value.

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Acronyms

B2B= Business to Business

BSC= Balance Score Card

DF= Digital Factory

DFD= Data Flow Diagram

DQIP= Digital Quality Inspection Plan

DQSPC= Digital Quality Statistical Process Control

ERP= Enterprise Resource Planning

IOT= Internet of Things

MES= Manufacturing Execution System

PCDA= Plan, Check, Do, Act

SPC= Statistical Process Control

TEOA= Tyco Electronic Operation Advantage

TWX= Thing Worx

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Chapter 1: Introduction

Emerging the new technologies in the field of digital in recent years, has led industries to benefit from the advantages of industry 4.0. The manufacturing environments are putting the new digital concepts in practice through applying internet of things and bigdata in shop floor and in this way, they are expecting to achieve more production's efficiency and productivity.

TE connectivity is an international electronical company with one business unit located in Collegno Italy. TE Connectivity Italy which works as one of the biggest producers of electronical pieces in Italy is recently introducing digitalization in its manufacturing departments. The digitalization in this manufacturing has been defined as a business plan including the digitalization of basic operations, quality, track and trace, tool management, order set up and management and finally predictive analysis. For each of these functions, the company has defined its own capabilities and drivers to be measured after implementing the digitalization.

Among different work processes in production line, in last year, the process of quality control has been the point of concentration in this company to be digitalized. For this, two main capabilities including digital quality inspection plan and statistical process control have been introduced. Digitalization of quality control process through applying continues improvement approach and by implementing different types of industry 4.0 applications is in progress in TE connectivity to achieve the long-term objectives of company.

The main activities which have been done in this research and documented including providing the machines with HYDRA application, digitalization of inspection plans and benefiting from internet of things like camera, gage and projector have been led to monitor the production process through a digital statistical process control. In addition, the connection between digital statistical process control charts and Agnostic Andon, has been done in order to provide the shop floor people including operators, shift leaders and supervisors with the possibility to be aware of the process conditions in a real time. In this way, the responsible people would have this opportunity to do the proper preventive actions in order to solve the issues arose in production line.

The scope of this research consists of implementing digital quality control process in assembly department on 3 machines and for Multifitting MK II product category. All works related to this investigation have been done during winter and spring of 2020 and the data related to the results has been gathered and studied in summer 2020.

As a result of implementing digital quality control process in production line, the rate of scrap in three months has decreased by 1.2%. The costs of inspection and prevention which have been measured based on time, have been diminished by 41% and 30% respectively. The continues improvement analysis predicts that by digitalization of all departments and all products' family, the company can expect more improvements in the key performance indicators defined in business plan.

Chapter 2: Introduction of Company

TE Connectivity is a technology company that designs and produces a variety range of connectivity and sensor products for different types of industries such as consumer electronics, automotive, aerospace, defense, medical, oil and gas, energy and data communication systems.

TE Connectivity is a part of Tyco International Ltd. which is a multinational corporation with registered office in Switzerland and operating headquarters in Princeton, New Jersey (USA). Founded in 1960 by Arthur J. Rosenburg, Tyco Inc. was conceived as an investment company in two main market areas, semiconductors, and materials research. In 2016, it merges with Johnson Controls.

In table 2.1 the general information about the company, has been inserted.

Main Information	
Headquarters	Schaffhausen, Switzerland
Revenue	13.4 billion USD (2019)
CEO	Terrence Curtin (Mar 9, 2017–)
Formerly	Tyco Electronics Ltd
Stock price	TEL (NYSE) $97.94

Table 2.1- Company main information

2.1. Products and Services

TE Connectivity's product portfolio is focused on connectors and sensors that are made to withstand harsh environments.[1] The products of the company have been categorized by the brand in 50 families and based on functionality in 15 (TE Connectivity, 2020).

The list of the products' families based on the functionalities have been shown in table 2.2[2].

Family	No of types	Description	Sample
Antennas	12	The broad range of antenna types include standard antennas and custom antennas for use in a variety of automotive, commercial transportation, rail and consumer device applications.	
Fiber Optics	407	Whether it's a component, system, or a network, TE can help you deliver more bandwidth with the fiber optics solutions and products.	
Cable Assemblies	5091	Our selection of cable assemblies ranges from simple jumpers to power and high-speed data cables to complex harnesses. They are used in a wide variety of applications and industries to interconnect components, sub-systems, and equipment.	
Connectors	228k	A connector is a coupling device that joins electrical terminations to create an electrical circuit. Connectors enable contact between wires, cables, printed circuit boards, and electronic components.	
Application Tooling	33438	There are 33438 types of applications from applicators to portable crimp tools.	

[1] https://www.te.com/usa-en/home.html

2 All the data related to the products have been gathered from TE connectivity official website.

Family	No of types	Description	Sample
Harnesses	10314	It offers a broad line of wire management products such as heat-shrinkable tubing and other wire protection products designed to help withstand tough environments.	
Heat Shrink Tubing	2435	It is a solid alternative to taping, molding or potting. When heated, it conforms to the size and shape of the substrate beneath, enabling quick and easy installation. Its high expansion ratio makes it possible to repair most damaged cable jackets without removing connectors	
Wiring Identification & Labeling	2683	TE offers complete wiring identification and labels for a wide range of industries and applications.	
EMI Filters	1662	Every electrical or electronic device has connections that are a potential source for electromagnetic interference (EMI). Changing international standards obligate designers to constantly review and evaluate their filtering needs.	
Passive Components	40186	From miniature SMD components to huge bespoke products, it offers a large range of Passive Components for use across many applications and most industries.	

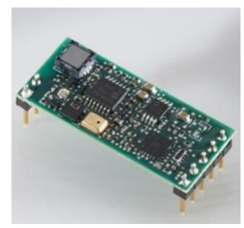
Family	No of types	Description	Sample
Relays, Contactors & Switches	15952	TE switching devices can be used anywhere — in production lines, robotics, lifts, control panels, cash machines, motion control systems, lighting, building systems, solar, HVAC, cars, trucks, buses, off-road vehicles and an array of safety-critical applications.	
Power System	23497	It offers a range of reliable and easy-to-install products for the electrical power industry, equipment manufacturers, and rail transport systems.	
Sensors	3482	A sensor is a device used to measure a property, such as pressure, position, temperature, or acceleration, and respond with feedback. TE Connectivity is a global technology leader, providing sensors and connectivity essential in today's increasingly connected world.	
Terminals & Splices	14864	From basic ring and spade terminals and FASTON terminals to crimp and solder splices, the terminals and splices are available in a wide array of wire types and sizes.	
Wire and Cable Products	16036	Wire and cable products are engineered to link electronic equipment, providing reliable and accurate communication and power management in numerous applications	

Table 2.2- The list of Products

2.2. Business Segments

The company operates in three primary segments:

- **Communication Solutions**

TE Connectivity's communications solutions segment supplies electronic components for home appliances, including products for washers, dryers, refrigerators, air conditioners, dishwashers, cooking appliances, water heaters, and microwaves.

- **Transportation Solutions**

The transportation segment supplies the products for four industries: Automotive, Industrial and Commercial Transportation, Application Tooling, and Sensor Solutions. The automotive industry uses the products of TE connectivity for body and motor, driver information, and safety and security systems. In addition, TE produces a range of products for highway vehicles and transportation, including buses, construction and agriculture.

- **Industrial Solutions**

The most important industrial units in this segment include Industrial, Medical, Aerospace, Defense and Marine, and Energy. In manufacturing automation and process control systems, the products of TE are used for instance in industrial controls, robotics, human machine interface, industrial communication, and power distribution. For the sector of smart building, TE connectivity produces intelligent products which are used to connect lighting, elevators, escalators, and security. The high-speed trains, locomotives and metros use of Its rail products.

In medical industry, the products of TE are used in the fields of diagnostic, imaging and therapeutic.

In addition, the aerospace industry uses the products of TE Connectivity in components of aircraft from designed to aftermarket products. TE also produces for defense segment. The main products in this part include electronic interconnects for military aviation marine, and ground vehicles including electronic warfare and space systems.

Its oil and gas products include cables and electronics which are used for subsea environments in the offshore oil and gas and civil marine industries and in shipboard, subsea, and sonar applications. Also, TE's products are used in the electrical power industry. In this segment, TE produces the solutions for the electrical power generation, transmission and distribution too.

TE connectivity revenue breackdown by business segment shown in Fig 2.1.

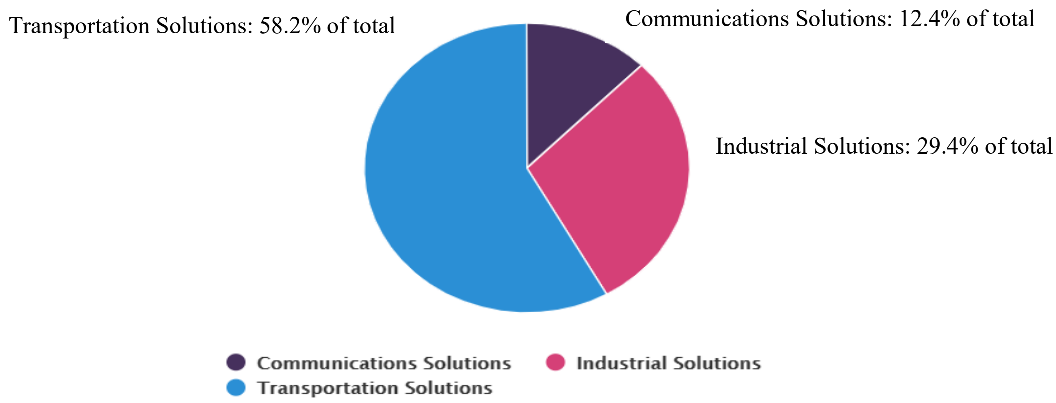


Fig 2.1- TE Connectivity revenue breakdown by business segment

2.3.Geographical Locations

Its geographical operations are spreads across Asia, Europe, the Middle East, Africa, and North and South America.[1] It has 31 office locations across 15 countries and serves customers in 140 countries. The percent of revenue which is generated by the geographical locations is shown in figure 2.2.

[1] https://craft.co/te-connectivity

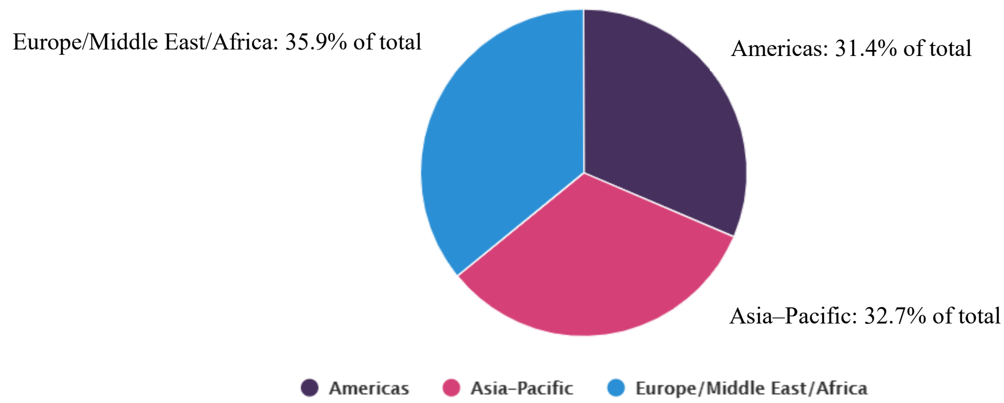


Fig 2.2- TE Connectivity revenue breakdown by Geographical Locations

2.4.Human Resources

TE Connectivity has a global workforce of 78,000 employees.[1] From this number of employees 10% include engineers. TE Connectivity's key executives include Terrence Curtin and 28 others who are mainly from USA.

2.5.Financial

TE Connectivity market cap is $32.3 billion, and annual revenue was $13.45 billion in FY 2019.

2.6.The main Competitors

The industries in which TE connectivity operates are highly competitive, and it competes with thousands of companies that range from large multinational corporations to local manufacturers. Competition is generally based on breadth of product offering, product innovation, price, quality, delivery, and service (csimarket,2019).

The name of some important competitors has been listed here:[2]

- **Transportation Solutions**: This segment competes primarily against Yazaki, Delphi, Sumitomo, Sensata, Continental AG, Molex, and Amphenol.

[1] https://www.te.com/usa-en/home.html

[2] https://csimarket.com/stocks/compet_glance.php?code=TEL#:~:text=Transportation%20Connectivity%20Segment%20Market%20Share,within%20this%20segment%20to%208.7%20%25.

- **Industrial Solutions:** This segment competes primarily against Amphenol, Esterline, Molex, Phoenix Contact, Hubbell, and 3M.
- **Consumer Solutions:** This segment's major competitors include Molex, JST Connectors, Japan Aviation Electronics, Amphenol, and Foxconn Technology Group.

2.7.TE CONNECTIVITY ITALIA DISTRIBUTION SRL

TE CONNECTIVITY ITALIA DISTRIBUTION SRL is in Collegno, Torino, Italy and has 146 employees and generates $156.54 million in sales (USD). There are 308 companies in the TE CONNECTIVITY ITALIA DISTRIBUTION SRL corporate family.

In figure 3, the manufacturing locations of TE around the world is shown.

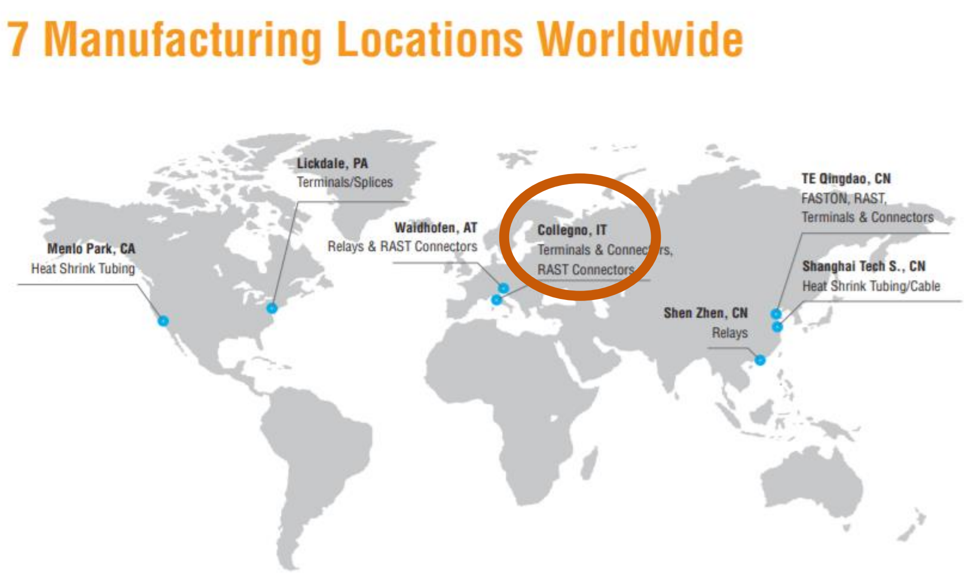


Fig 2.3- TE connectivity manufacturing locations

TE connectivity in Collegno works in communication solutions which essentially applies in Household appliances. The main function of this firm is to design and produce the electrical and electronic interconnection systems by stamping, plating surface treatments, thermoplastic molding and assembly. Therefore, the main production departments of this factory include Stamping, Plating, Molding and Assembly. The functions of sale and distribution of the products are performed by this company too.

2.7.1. Products

The main category of production in Collegno consists of the RAST connectors which are used in appliance sector. RAST connector is a type of wire to board connectors. This type of connector connects a wire to a printed circuit board (PCB), enabling connectivity between circuits. See Figure 2.4.

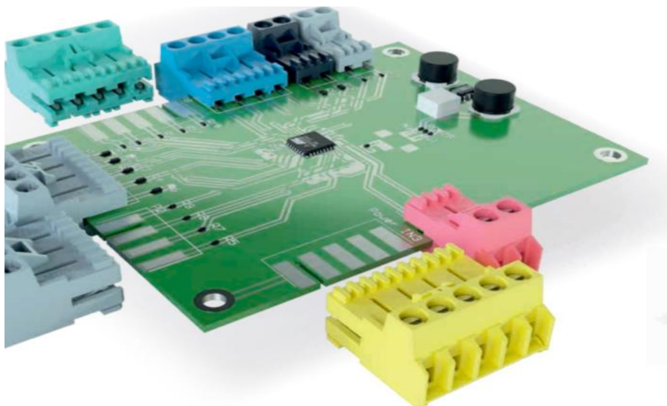


Fig 2.4- RAST connector system

The main lines of production in the category of RAST connector which are produced and distributed in Collegno are:

- **AMP Multifiting Mark II:** Advanced in-line mating technology for the components and contacts of PC boards are incorporated in the direct and indirect versions of these connector systems. See Figure 2.5.

Fig 2.5- AMP Multifiting Mark II

- **AMP DUOPLUG Power**: The AMP DUOPLUG power connector is an economical IDC connector system for safe and fast production of electrical connections. See Fig 2.6.

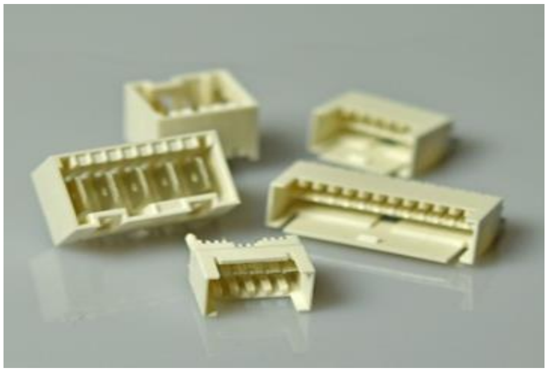


Fig 2.6- AMP DUOPLUG Power Connector

- **AMP DUOPLUG 2.5 Power**: AMP DUOPLUG 2.5 connector system for wire-to-board applications. See Fig 2.7.

Fig 2.7-AMP DUOPLUG 2.5 Power Connector

- **AMP MONO-SHAPE**: The AMP MONO-SHAPE product range, combined with the performances and properties offered by the termination system, allow to manufacture extremely complicated harness structures while still maintaining high production levels. See Fig 2.8.

Fig 2.8- AMP MONO-SHAPE

2.7.2. Production material flow

In order to produce a connector, the raw material of the product, which is generally plastic, enters the molding department. The plastic for the molding operation is in the form of powder and depending the type of product, the type of plastic will be different. Different types of automatic machines in molding department are working in 3 shifts to produce the base of a connector which is named Housing.

At the same time, in the stamping department, another semi product is producing. The metal which should be used as a connector in final product is stamping in a form that would be suitable for transforming the circuit. Therefore, as an input the wheel of Copper or Aluminum or Tin will enter in stamping department, then stamped and finally will be exited as an output.

After Finishing this operation, the two semifinal products will be delivered to the assembly department in order to be assembled and in this way the final product will be ready to sell. In figure 2.9 the flow of material in different parts of production line has been shown.

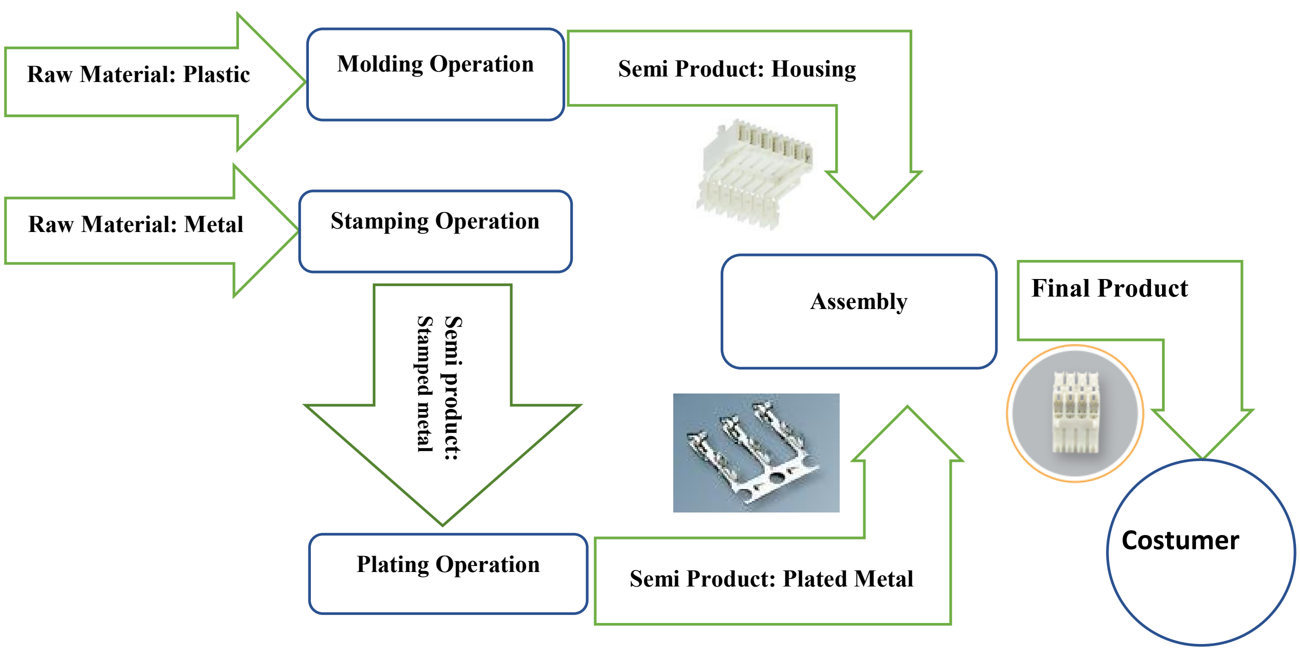


Fig 2.9- The production material flow

There is also the plating department which is responsible of plating the stamped metal. This plated metal is also a final product for TE connectivity, as there are some costumers for it.

2.7.3. Plant Management

The whole plant is managed by the plant manager who is responsible of monitoring the performance of all operational line and support staffs. The main departments which are working under the authority of plant management are manufacturing management, production departments, quality control and continues improvement departments.

- **Manufacturing Management**

Manufacturing departments are managed by the manufacturing manager. It means that all the supervisors should report to the manager of manufacturing who works directly with the Plant Manager. This role is also responsible of managing the value stream in manufacturing environment.

All the activities which are done across the factory are planned, monitored and evaluated by the personnel of the material planning department. The main objective of this department is to ensure that all the operations which are related to the production are done based on the plan.

- **Quality Control**

Quality control is responsible of defining all the specifications of a product. In this department all the standards, procedures and algorithm which are needed to control the specifications of a product are defined. Besides, it is the contact point of customer where all the complaints, claims and requirements of clients are gathered, analyzed and distributed across the company. Quality control is also responsible of modifying the characteristics of a product if it is necessary.

- **Production Departments**

There are 4 production departments including Molding, Stamping, Plating and Assembly. Each manufacturing department is supervised by a supervisor who is responsible of planning and managing the workforces' activities. There are three shifts of working and for each working shift there is a shift leader who is in charge of the personals and the activities are done during a shift. Each machine or in other case each two or three machines will be operated under the responsibility of an operator.

There is a role for setup man. With the start of a new order, the setup man will start to control the state of the machine and will provide it with the proper tools. See figure 2.10.

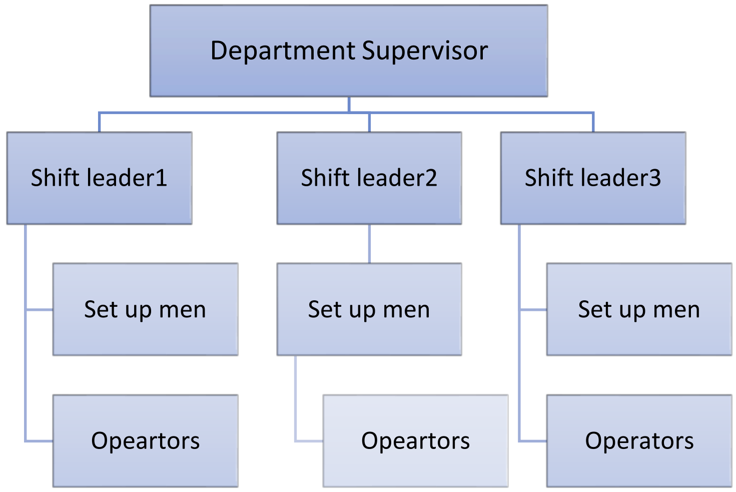


Fig 2.10- Manufacturing Organizational chart

The warehouse is responsible of providing the raw material, stocking the semifinal products and final products. The inventory of the products will be managed through warehouse operations.

- **Continues improvement Analysis:**

In order to monitor the activities which are done by the operators in production line, the head of this department who is a Six Sigma professional based on TEOA (Tyco electronic operation advantage) standard, control the inspection done by the operators, analysis the data which is extracted daily and provide a rich report in order to do the corrective actions. The main tool with which all the analysis will be done is mainly focused on SPC chart. Therefore, the main characters of the products with their specifications which can be visual or dimensional will be monitored on real time.

Root cause analysis is the way continues improvement analysis will determine the root cause of a problem, incident, or quality concern. After diagnosing the main causes of the problem, the corrective actions will be done by the managers and the operators who have been involved in the process.

Chapter 3: Problem Statement

The digitalization process of a factory needs allocating time and resources. Moreover, Digital technologies make major changes in how companies operate from technical point of view to cultural aspects. Therefore, identifying the driving forces of a company for investing in digitalization and putting so much effort into the transformation process would be very important.

In this chapter, it will be answered to two main questions:

- What is the main problem that drives TE connectivity to implement digital factory?
- What are the objectives of TE connectivity to implement digital factory?

3.1. What was the main problem that drove TE connectivity to implement DF?

TE connectivity is working in B2B[1] market. It means that the products of TE which are mainly the connectors will be used in another electronical products. In the sector of appliances, according to Jeff Hummel, RAST product manager at Tyco Electronics, RAST connectors can already be found in washer, driers and most refrigerators in recent years. See table 3.1.

Type of appliance	Number of RAST Connectors per appliance
Dishwashers	40
Dryers	30
Refrigerators	15
Freezers	15
Washers	28
Total	On average 25.6

Table 3.1- The number of RAST connector per appliance

[1] Business to Business

With the emergence of new technologies in the field of connections, the need of electrical companies to more qualified products have increased. New appliances with the capability of IOT will be monitored through smartphone even without presenting at home. Soon, we can expect to see a big growth of such intelligent products. As more and more functionalities are added to appliance products, there is an increase in the number of connectors interlinking these modular functions to the main control unit (Degenhardt et al., 2012)[1]. Therefore, it is obvious that the main challenge for any connector manufacturer is to deliver maximum technical performance in the smallest possible package.

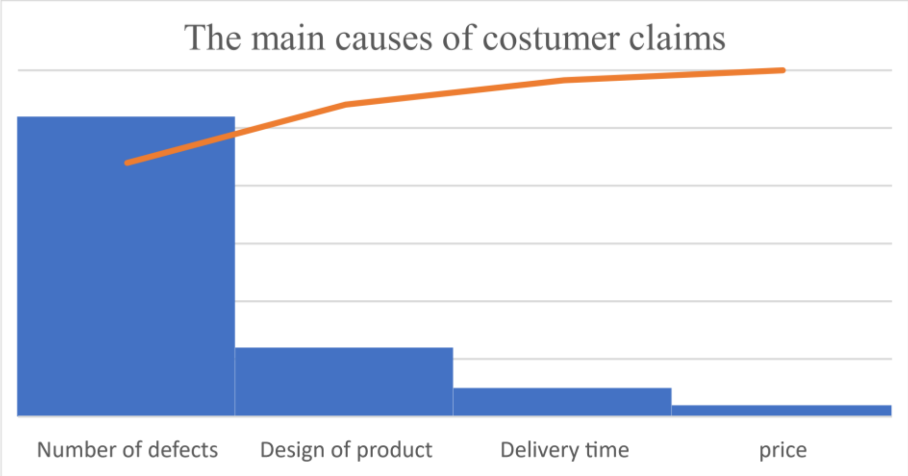
According to the project manager of DF implementation in TE connectivity, there were two main drivers in the market which were the initial points of starting this project: Customer Satisfaction and Market Competition.

3.1.1. Customer Satisfaction

Continues improvement department who is the main responsible of this project, has always been concerned about the indicators which can improve the level of customer satisfaction. It is said that a business that implements good quality controls in its processes is in a better position to provide products that fully meet their client's requirements. This improves customer satisfaction and the potential for the business to retain and maintain the customers over long periods.

The result of the last year's customer satisfaction survey shows that the majority part of the costumer's reclaims has been rooted in product defects. The other elements included price, delivery time and design of product involved a small percent. See graph 3.1.

[1] Michael Degenhardt, born in 1961 is a Development Engineer at Stocko-Contact GmbH & Co.KG, Wuppertal, Germany.



Graph 3.1- Pareto chart of the main causes of costumer claims

In order to analyze the defection which was the most important factor of costumer's dissatisfaction and to improve the situation, after the cause and effect analysis, the organization decided to concentrate on three elements of success model.[1]

1- Process
2- Technology
3- People

Fig 3.1- Organizational success model

[1] Leavitt's Diamond is a model that is one of the critical success factors models. It is used in change management. It was designed by Harold J. Leavitt in 1973. The key success factors according to him include: Structure, Managerial tasks, People, Technology.

After holding several brain storming meetings which have been held to identify the main reasons of defections and cause and effect analysis, the continues improvement department decided to focus on the interconnection point of these three elements. See Figure 3.1.

The analysis group believed that if they could concentrate on the methodology of quality control that is already applied in production line, it would be easier to find a way to improve the level of defections. Among the several methodologies that have been utilized in production environment in order to decrease the number of defects in shop floor, in TE connectivity the method of Six Sigma is used historically. Therefore, the basic element of Six Sigma which is the statistical quality control was considered as a start point.

Therefore, considering the costumer reclaims led the company to search about how to improve the quality of products and decreasing the number of scraps in production line and being aware of the importance of controlling the process by monitoring the SPC charts led to focusing on the issues of the quality process control.

- **Quality Statistical Process Control**

It is obvious that for a product in a size of connector, the accuracy in the measurements is one of the most significant elements affecting on the satisfaction of customer. That part of specification of the products which are related to the quality of products drove the continues improvement department to find a method in which the products specifications controlled in production line effectively.

Therefore, for years, statistical process control which is a method of measuring and controlling quality by monitoring the manufacturing process has been performed in production line. The procedure was in this way, that the data collected from production line was entered into MINITAB[1] software, then it was analyzed by the quality analyst and finally the reports were produced by them to start the corrective actions.

[1] Minitab is a statistics package developed at the Pennsylvania State University by researchers Barbara F. Ryan, Thomas A. Ryan, Jr., and Brian L. Joiner in 1972. It began as a light version of OMNITAB 80, a statistical analysis program by NIST. Statistical analysis software such as Minitab automates calculations and the creation of graphs, allowing the user to focus more on the analysis of data and the interpretation of results. It is compatible with other Minitab, LLC software.

However, the main problem was the situation of SPC in production line in sense of performing the inspections and inserting the data. As, the key principle of six sigma is measurement, it means that if you measure the wrong things, you will get the wrong results. The most important problems related to the procedure of doing inspection in production line have been listed below:

A. Missing the data

In the company, the first step of SPC that is collecting the data, was performed on paper which could cause a series of problems. The main problem arose from inserting the data manually was that sometimes, the handwriting of personals which could be different, were not readable and in the case of not accessing to the operator, inevitably this wrong data was inserted in Minitab.

Using paper in production line, where the operators most of the time are working with the machines, tools, materials, and instruments, will increase the risk of destroying the paper, and its content. Probably, there were sometimes that another person took mistakenly the filled paper, and it would have been disappeared unintendedly. During performing the procedure of collecting the data from the operation site by paper and transforming this data to software, could also appear some faults and therefore, the accurate data could miss in this way.

After inserting the dimensional and visual aspects of the product in a form which had been designed by quality department, the data was transformed in Minitab Software, and was analyzed by continues improvement analyst in order to make the proper managerial report. Based on this report the quality manager could decide about the capability of process and improving the features which needed to be improved.

The process of transforming the data in excel, could cause the issue of missing data too. Besides the human resource’s error that could cause some problems, the version of software or the amount of data which must have loaded could have made some interruptions in the process of statistical quality control too.

B. Cost of quality

The main elements of performing this type of inspections, included paper and the software installed on the computer. Filling the inspection plans by the operators in the form of paper could produce a type of the inspection cost. As far as the paper is concerned, the amount of money which should have invested in this part in order to provide the papers for quality department were remarkable. Another issue related to the amount of papers which should have consumed in shop floor, was the creation of the environmental waste. The time that should have been spent on this type of inspection could certainly generate extra cost for company.

C. The process of decision-making

The main important output of doing SPC would be the fast reaction of the quality personals in the case of facing with a problem. While, the process of inspections was done by paper, it is needed to spend a lot of time to transfer the data into software and to be processed by the quality expert. It would be obvious that the process of decision-making would not be performed in REAL TIME.[1] The concept that has a significant role in decision-making is time and in this case, all the actions which are done in order to improve the quality of a product would be done by delays and as a result, the improvement actions were not done at a proper time.

Accessing near real time to operational data considers as another capability that the mangers can benefit from it. In the case of facing a problem with machine or material, the proactive action will not be done unless the personals have the access to the online status report.

D. Lack of proactive action

Historically, after generating the SPC chart and analyzing the root of the problems, the correction actions were initiated to do. It included a range of activities from changing the oil of machine to turning it off. These actions which do not convey a great amount of direct cost could certainly an indirect cost. Sometimes changing one piece of machine could have resulted into turning the

[1] Relating to a system in which input data is processed within milliseconds so that it is available virtually immediately as feedback to the process from which it is coming, e.g. in a missile guidance system.

machine off and certainly this action could stop the machine from producing based on the production calendar. In this case, the downtime of machine can be considered as an issue.

Another issue related to the stopping machine was that the actions related to fix the problem would be done repeatedly without analyzing the root cause of them. Therefore, it could have happened for several times without doing any preventive action.

In this step, the company, decided to implement a method with which could monitor the state of the process and respond proactively besides of doing correction actions.

E. The measurement tools and equipment

It was not just the manual process of doing SPC that produced the problems, but there was another important factor which was related to the inspection's parameters. Traditionally the main characters of a product which had been inserted in the design drawing file were transformed to the paper carts in order to be monitored by the different roles in shop floor to do the inspections. In the drawing file, in addition to the measurements of characteristic, the tool and equipment needed for this action had been inserted. The problem was that in some cases, the proper tools for a certain character, were not available. In this case, the operator was not able to measure the specifications in a right way, and inevitably inserted a wrong value in the inspection form. As a result, the SPC chart sometimes were not trustable because of being generated by incorrect and insecure data.

In summary, identifying the problems related to the process of controlling the quality in production line, drove TE connectivity to implement the digital factory.

3.1.2. Market Competition

TE connectivity in Collegno which has been a pioneer in producing RAST connectors, has been aware of this fact that the competitive market of RAST connectors is expanding increasingly and the requirements of costumers are changing continuously in the new modern era. In the market of RAST connectors which price is not an important item (the price of each connector is approximately 0.5 euro) the factor which can diversify the producers from others, would be the quality of products.

In addition, the value of data is another factor that today can make a company diversified from other competitors.

- **Value of data**

The manufacturing process has historically generated enormous volumes of data. The data of various products, machines, operators which in future will be able to help the shop floor to prevent from facing a problem. This type of data related to the production line, in the past has been ignored by TE connectivity. In addition, today the importance of big data[1],and the value generated by it are being considered by the industries. TE connectivity is also aware of this fact that converting the data generated from the production line into information, would not only be beneficiary to predict the future trend but also responds to the market effectively as far as the quality of products is concerned.

In sum up, increasing the level of customer satisfaction and responding to market have been always the main strategies that TE connectivity in recent years have focused on. As a result of the action plan that each year will be programmed by the planning office in TE connectivity, improving the quality of products and decreasing the level of scrap rate, have been pointed as the main targets in recent years. As a result of this fact that the main important factor affecting the level of customer satisfaction is the quality of connector, the revision in the method of how the quality is evaluated in TE connectivity is considered.

[1] It generically indicates a collection of information data so extensive in terms of volume, speed and variety that require specific analytical technologies and methods for the extraction of value or knowledge.

3.2. What are the objectives of TE connectivity to implement DF?

Having a methodology in order to identify the objectives of TE connectivity to implement the project of Digital Factory is a necessary. Therefore, the researcher in this part, after consulting with the supervisor, decided to apply the Balance Score Card Model as a framework. The BSC suggests that we examine an organization from four different perspectives to help develop objectives, measures, targets, and initiatives relative to those views (Kaplan & Norton, 1992).

- Customer/Stakeholder: views organizational performance from the perspective of the customer or key stakeholders the organization is designed to serve
- Financial: views an organization's financial performance and the use of financial resources
- Internal Process: views the quality and efficiency of an organization's performance related to the product, services, or other key business processes
- Organizational learning and growth: views human capital, infrastructure, technology, culture and other aspects of internal performances.

Based on Balance score card model which is used in organizations to help develop objectives and measurement, the main initiatives which have been played as driving forces for TE Connectivity in this project have been shown in table 3.2.

Perspective	***Objectives***	***KPI***
Customer-related measures	Decreasing the level of costumer claims	The number of reclaimed products
		The number of scraps
Financial measures	Decreasing the cost of quality	Costs of deficiencies before the delivery to a client
		Costs of deficiencies after the delivery to a client
		Prevention Costs
		Inspection cost
Process measures	Production Efficiency	OEE (Overall Equipment Effectiveness)
	Increasing the speed of delivery	Delivery time
	Increasing the quality of product	FMEA output
Learning and innovation measures	Digital knowledge of Personals	The number of personals working with Digital

Table 3.2- The objectives of TE to implement DF

3.2.1. Costumer related measures:

Increasing the level of satisfaction among the clients is one of the main objectives of implementing this project. After implementing the DF, TE connectivity expects to be witness of decreasing in the number of costumers claims which are related to the defection of a product.

3.2.2. Financial measures

Eliminating defects before production begins reduces the costs of quality and can help companies increase profits.

- **Cost of quality:** This cost which is a mean to quantify the total cost of quality-related efforts and deficiencies arises as a result of 4 factors (Armand V. Feigenbaum, 1956).

- Internal Failure Costs: represent all the costs of deficiencies before the delivery to a client
- External Failure Costs: represent all the costs of deficiencies after the delivery to a client
- Appraisal Costs: represent all the costs to determine the conformance/inspection costs
- Prevention Costs: represent all the costs incurred to keep failure and appraisal costs to a minimum

TE Connectivity as a result of doing this project expect to have a decrease in this cost. From the strategic point of view, it could be expected to see 5% improvements in it after implementing DF in TE connectivity.

3.2.3. Process measures

In sense of process measures, TE connectivity is following increasing the efficiency of production, speed of delivery and quality the products.

- **Production efficiency**

TE connectivity is historically a producer of the electronics pieces and in this sector of market there are other competitors. In the market, in order to have a great advantage over the others the productivity and proficiency are two main factors. Increasing these two elements will not be gained unless the organization improves control of manufacturing workflows and the movement of everything from raw materials to work-in-progress and finished goods.

Since, Scrap rate gives companies insight into the ratio of products deemed scrap in a production run, helping identify an inefficient process, decreasing the number of scraps would be one of the most important indexes which can indicate the level of production efficiency. What Six Sigma philosophy aims at eliminating defects and waste is following in parallel through implementing this project.

- **Increasing the speed of delivery**

TE connectivity is a supplier of many producers in Appliances sector. It is working on providing technology which allows customers to go to market much earlier with their products, and of course maintain them more competitively when they are out there.

- **Increasing the quality of product**

One of the important outputs of this project, would be increasing the quality of a product which is a multidimensional concept.

3.2.4. Learning and innovation measures

As a result of implementing DF, it is foreseen that the level of knowledge in shop floor will increase. Due to this fact that the digitalization will influence on AS-IS processes and will provide some innovations in the way of doing the activities, the personals will need to improve their knowledge about the new processes and how they must do their tasks.

- **Digital knowledge of Personals**

The inspections activities which were done previously just by paper and pen, should be done through new methodology which is completely digital. In this case, it expects that the personals will become familiar with the world of digital.

More the human resources of shop floor know about the information technology, more they will be able to manage their tasks in an effective manner.

Chapter 4: The solution

This chapter has been dedicated to the solution which should be taken into action in order to solve the problem which has been discussed in the previous chapter.

It has been divided to three main parts. In the first part, the concept of Digital Factory will be presented precisely and the situation of quality control in the world of digitalization will be clarified. The second part will be dedicated to the approach and, the methodology of this company in order to implement the digital quality inspection plan. Finally, the activities which are carrying out in the company will be presented in the last part.

4.1. Literature review

4.1.1. Industrial Revolutions

The Industrial Revolution refers to the last years of 18^{th} century when the rural societies with the approach to the agriculture and production of handcraft goods converted to the industrialized ones. The majority part of production which historically belonged to the handcraft goods was replaced by the machines and mechanical instruments in factories. At that time the mass production initiated to be introduced thanks to the new methods and techniques in textiles and other industries (Robert C. Allen, 2007). The industrial revolution has been categorized into 4 classes of industrialization which have been evolved during different period of history.

Industry 1.0: In the 18^{th} century, the use of steam power was introduced in order to assist the workers in production environment. The First Industrial Revolution which began to change the structure of society, led to the replacement of traditional manufacturing process by mechanization. At this time, the industries started to grow thanks to the water and steam power. As a result of this development, the form of businesses started to change from producing for own and the families to the organizations with owners and managers. In this way, the specializations in doing the activities in factories started to become important in the field of functionality.

Industry 2.0: In the 19th and the first years of 20th century, by discovery of electricity, the Second Industrial Revolution was introduced. It was the time of using the railways which had a significant impact on the way of transportation. In this era, the need of people for goods had increased and as a result of this fact the mass production and standardization changed the lifestyle of the societies. More managers and entrepreneurs introduced in order to make innovations and productions to respond the needs of societies.

It is said that this time was the time of growing the two classes among people: the wealthy class who initially were the managers or the owners of factories and the middle class which includes the workers in factories and organizations.

Industry 3.0: In the last years of 20th century, with the emergence of computers the Third Industrial Revolution began to introduce the information technology to the societies. The invention of a variety range of electrical tools and instruments made the societies ready to be witness of new modern era. One of the most important inventions of this period was the introduction of the internet which changed the way of connections basically. The manufacturing benefited from different aspects of technology at this time.

Industry 4.0: Now, we are in the time of Four Industrial Revolution when the flow of information among different parts of organization is being facilitated through IOT and cloud-based processes. The use of robots and artificial intelligence in the context of production is increasing and more influencing the production environment. The big data which is the amount of data stored in manufacturing and organizations considers as a competency for the companies and the way of introducing the goods and services has been affected by digitalization.

In the figure 4.1, the revolutions of the industry have been shown clearly.

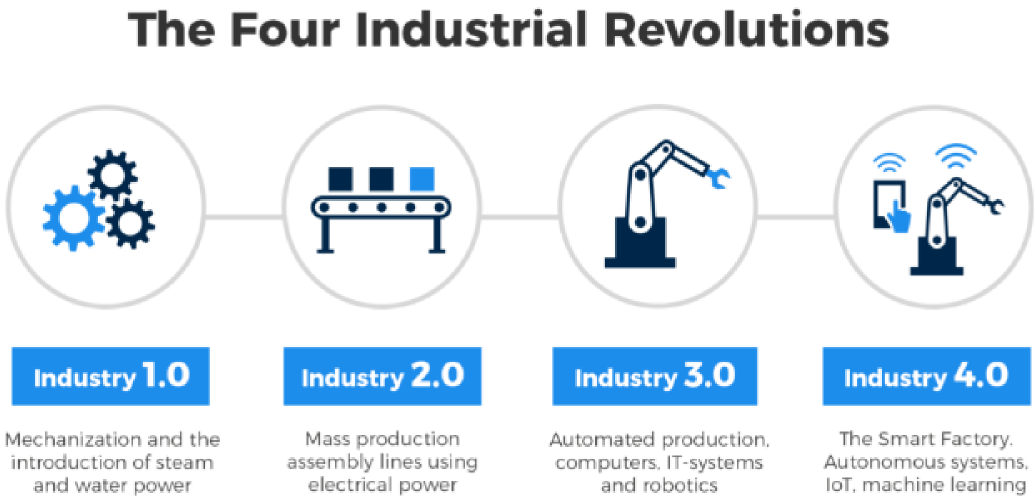


Fig 4.1- The four industrial revolutions

4.1.1.1. The Fourth Industrial Revolution

Klaus Schwab the executive chairman of the World Economic Forum was the first who introduced the Fourth Industrial Revolution. In October 2016, the theme of the world economic forum annual meeting was "Mastering the Fourth Industrial Revolution". This was also the subject and the title of Schwab's 2016 book.[1] In this book, he has explained about the combination of hardware, software, and biology and emphasized on the technology advances in communication and connectivity. Also Schwab sees this era as the time for emerging new technologies in the fields of robotics, artificial intelligence[2], nanotechnology[3], quantum computing[4], biotechnology[5],

[1] Schwab, Klaus (2016). The Fourth Industrial Revolution. New York: Crown Publishing Group (published 2017). ISBN 9781524758875. Retrieved 29 June 2017. Digital technologies [...] are not new, but in a break with the third industrial revolution, they are becoming more sophisticated and integrated and are, as a result, transforming societies and the global economy.

[2] Artificial intelligence (AI) is wide-ranging branch of computer science concerned with building smart machines capable of performing tasks that typically require human intelligence.

[3] Nanotechnology is science, engineering, and technology conducted at the nanoscale, which is about 1 to 100 nanometers.

[4] A Quantum Computer is a processor whose function is based on the laws of quantum mechanics.

[5] Biotechnology is the use of biology to solve problems and make useful products.

the internet of things[1], the industrial internet of things[2], 3D printing and fifth-generation wireless technologies (5G) .[3]

Industry 4.0 covers a verity range of technologies that can make a huge progression in the value chain. Through this way, it will be possible to decrease manufacturing lead times, improve the quality of the overall organizational performance and the final product (Kamble et al., 2018).

It would be possible that through combined structures of data the capacity to locate any product and/or equipment would be simplified (Telukdarie et al., 2018). The operating efficiency in the production line is required through real time control of equipment, energy and quality. This is the value of the combined structures of data which the organization can benefit in the mode of possible profits by reducing the total cost of production (Meissner et al., 2017).

New advances in technology can be considered as the main drivers for change in organizational and individual levels (Köffer, 2015). The trend of advances in technology has potentially affected on the conditions of people in the shop floor and the way that and organization manages the production environment. Because of the possibility of providing the workers with suitable information in any time and in any place, the shop floor may be more productive in their daily works (Daeuble et al., 2015; Mavrikios et al., 2013). In this way, shop floor will be equipped with the proper information in the case of facing the problems related to the production environment and can decide as fast as possible since their knowledge and skill have increased too. (Appelbaum, 2013; Ullrich, 2016).

As a result of the advantages of new technologies, the companies will be able to increase in productivity, utilization of assets, and better decision-making (Bradley, 2015).

- **IOT**: IoT technologies which connect the devices automatically will provide the companies with the ability to collect and process the data generated from shop floor and it will

[1] The acronym IoT refers to any system of physical devices that receive and transfer data over wireless networks, requiring no manual intervention.
[2] The Industrial Internet of Things (IIoT) refers to interconnected sensors, instruments, and other devices networked together with computers' industrial applications, including manufacturing and energy management.
[3] Fifth-generation wireless (5G) is the latest iteration of cellular technology, engineered to greatly increase the speed and responsiveness of wireless networks.

probably lead to deep analysis of manufacturing processes. It is stated (Bradley, 2015) that the advantages of IOT technologies include:

- ✓ reduced time,
- ✓ increased quality and less waste
- ✓ greater visibility of the manufacturing floor

- **Big Data:** The amount of data generated by the different part of a company, different machines and tools and different sources are so enormous that the old applications are not able to process and monitor it. The concept of big data here has been introduced to manage all the data across the factory and provide the different level of an organization with the benefits produced by analyzing this data.

As Mike Moore (2020) stated, the Fourth Industrial Revolution (or Industry 4.0) is the combination of traditional manufacturing and the latest smart technology. This concept initially concentrates on the application of large-scale machine to machine communication (M2M)[1] and IOT to provide increased automation, improved communication and self-monitoring. Today, more believes that by using smart machines that can analyze and diagnose issues, we will not need the intervention of human anymore.

In summary, the fourth industrial revolution is the trend of data exchange and automation in the technologies and processes of manufacturing that include cyber-physical systems (CPS)[2], the internet of things (IoT), industrial internet of things (IIOT), cloud computing[3], cognitive computing and artificial intelligence (Heiner Lasi et al., 2014).

---

[1] Machine to machine (M2M) is direct communication between devices using any communications channel, including wired and wireless.

[2] Cyber-Physical Systems (CPS) are integrations of computation, networking, and physical processes. Embedded computers and networks monitor and control the physical processes, with feedback loops where physical processes affect computations and vice versa.

[3] The Cloud Computing is a computer technology that leverages the internet to distribute software and hardware resources remotely. The Cloud Computing service is offered by special companies defined as Cloud Providers, which deal with the allocation of resources and, upon request, also with the complete management of the service.

4.1.1.2. Digital Factory/Smart Factory

The digital factory is the factory in which all the manufacturing processes will be done in an automatic way. In this factory all the machines can connect with each other through machine to machine applications. Through IOT, it is possible to transfer the data related to the machines and instruments to the computers and by using cloud-base data base, it would be possible to store data related to production, process and human resources. As Kagermann et al. (2013) stated Smart factories constitute a key feature of Industry 4.0.

Monitoring all the functions of production system by constructing a digital factory can make the decisions decentralized. In this way, the process of decision making does not depend on the hierarchical level of individuals. Humans in this concept will communicate and corporate with each other and with digital things in value chain (Mario Hermann et al., 2015). In digital factory sharing the information from suppliers to the customers and across the factory will be facilitated by the flow of information.

Big data which is the main part of value generating in digital factory plays an important role in the world of competition and by utilizing from the enormous data across the factory, it will be possible not only to decrease the cost of production but also to create more benefit.

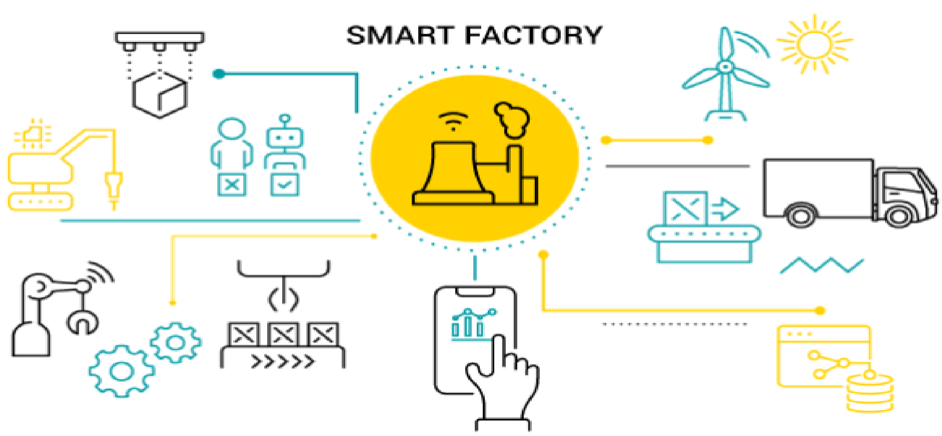


Fig 4.2- Smart Factory

It can be said that the combination of all these concepts from the machines, sensors, connectors, things and data in the production environment has been led to emerge a new factory which named Digital/smart factory. See figure 4.2.

4.1.1.3. Quality Control in the Context of Industry 4.0

The formal definition of quality defined by ISO 9001 is: "Degree in which a set of inherent characteristics satisfies the requirements".[1]

In other words, when the value of a product is met by the final costumer it means that quality has been achieved. In order to be sure about the quality of a product, all the elements which are engaged in the production including machines, equipment and system should fulfill the requirements of a quality. The quality will not be acquired just in laboratories but in the physical environment of manufacturing.

Also, it is not just a tool for monitoring the activities. The quality should be considered as a mechanism to predict the issues that in the future the organization might face. With this approach, in the case of facing a problem in the production line, quality can prevent it from occurring again and can solve it rapidly. In the context of digital factory, quality control plays an important role, as it is one sector which encounters with a big amount of data every day. The inspections start from the first stage of supply chain where the control of raw material is matter. In the process of production, controlling the process by the quality control instruments produces an enormous amount of data which can be stored on cloud. The statistical analysis which is done based on this data can be distributed among the stockholders in order to make decision properly.

Interactive dashboard with the main important graphs and analysis which is done based on the data collected from the factory can generate a value for the company in the sense of marketing and attracting clients too. This dashboard also will be able to send alerts of a specific anomaly to the workers and in this way can prevent from occurring another time.

[1] Standardization, I.O.: for: ISO 9001:2015, Fifth Edition: Quality management systems—Requirements. Multiple, Distributed through American National Standards Institute (2015)

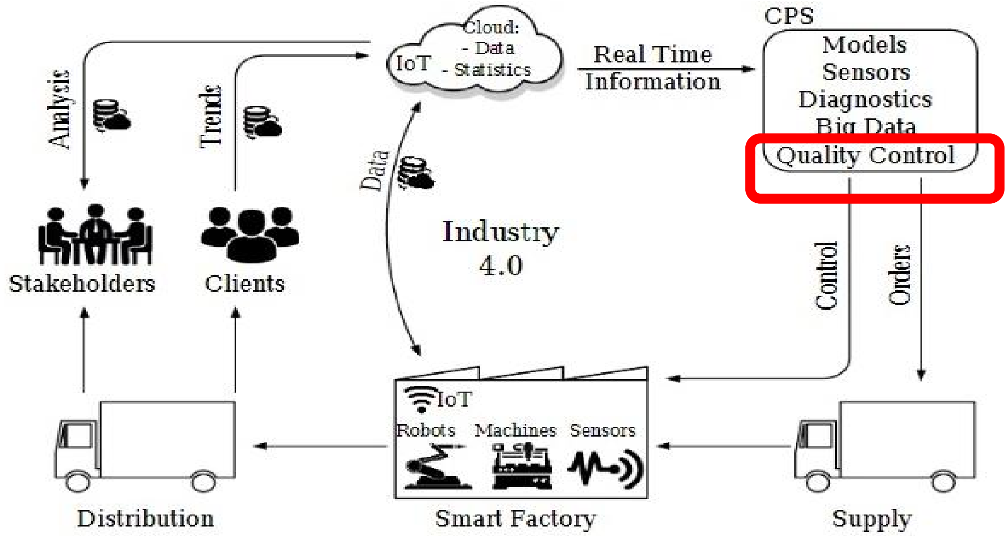


Fig 4.3- Illustrating the main elements of Industry 4.0

As it can be seen in figure 4.3, the relationship between the quality control and digitalization has been illustrated clearly.

4.2. Methodology

Before explaining about the activities carrying on in order to implement Digital Quality Control in TE connectivity, it is very important to consider the approach of this company and the methodology which has been considered in order to be digital in statistical quality control process. Here and first, it should be clarified that implementing digital factory is not a project but a business plan. It has been considered as a plan in align with the strategy of company.

The approach of the company for digitalization has been the continues improvement method which is ongoing improvement of products, services or processes through incremental and breakthrough improvements. The continues improvement department believes that by digitalization the process of quality control in the production line, the company will be witness of improving in the performance gradually. Therefore, the PDCA[1] method has been considered as a tool to develop this plan. See figure 4.4.

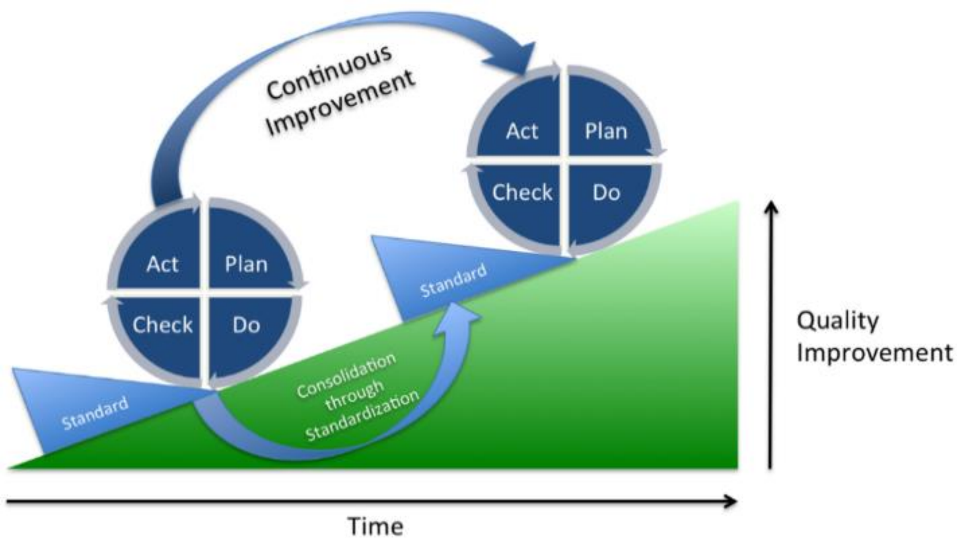


Fig 4.4- Representation of the continuous quality improvement associated with the application of the PDCA cycle

[1] The Deming cycle or PDCA PLAN- Do- Check- Act is a method of management iterative four-step used for the control and continuous improvement of processes and products . It is also known as the Shewhart cycle, (or PDSA cycle, English acronym PLAN- Do- Study- Act,). Another version of this cycle is called, OPDCA, where the "O" has the meaning of both "observation" and "grasping the current condition."

By considering the PDCA cycle in each stage of digitalization, in the first stage, the problem considered based on the cause and effect and the data related to the production line. After planning, the phase of doing the activities triggered and based on the feedback, the corrective action started. The most significant property of this methodology is that this cycle will be done incremental[1]. It means that each phase of the road map could start when the previous phase is in the phase of implementation.

4.3. Business Plan

Here, the most important factor affecting in business plan will be indicated. As said, the first step in planning is to have a clear road map to achieve.

There are two main factors that based on them the continues improvement department with the collaboration of the supervisors of all production departments and the quality manager, decided to present its roadmap for digitalization.

1- The priority of products: It is calculated based on the data relating to the volume of productions, sale and the importance of the clients. In summary, the products which have been selected to be involved in digitalization are those group which have main impacts on value chain at company.
2- The priority of manufacturing department: Based on considering the value chain, the department which is the final stage of supply chain has been chosen.

Therefore, considering these two elements, the Assembly department among the other department and the Multifititting MK II among other product family have been chosen.

After selecting the department and the product, among several machines in assembly department, 3 main machines have been selected as the pioneers in digitalization.

[1] Incremental Model is a process of software development where requirements are broken down into multiple standalone modules of software development cycle. Incremental development is done in steps from analysis design, implementation, testing/verification, maintenance.

Therefore, the 6 level of digitalization has been identified as:

1- Connecting the machines to the quality terminal
2- Preparing the Digital Quality Inspection Plan (DQIP) for each part number of a product
3- Linking the DQIP to Digital Quality Statistical Process Control (DQSPC)
4- Using of digital measurement instruments in production line
5- Implementing ANDON application for managing the violations in production line
6- Preparing Digital Fast Response Board (DFRF)

As mentioned in the business plan part, these levels have been done in a way of incremental.

4.4. Technical aspects

The main idea is that the inspection points generated by digital quality inspection plan, should be done by the shop floor through the system manually or by utilizing the digital instrument like gage, caliper or projector depending on the product's feature. After collecting the data by Hydra System which is the manufacturing main system, this data will be transferred to another system named TWX[1]. The main function of this system would be the presentation of inspections data in the form of SPC chart. Here, the most significant output would be the generation of alerts in case of the production process is out of control.

The alerts generated by TWX, will be transmitted automatically into another system named ANDON. The main function of this application is to send the notifications in the form of E-mail or telephone messages to the specific person. It is obvious that the notification which is arrived at the shop floor persons who are responsible of fixing the issues, should be considered as an input for problem solving process.

The problem-solving process which would be done through fast response board, can be counted as one of the main outcomes of this project. Through this process, the managers will be able to prevent from facing an issue for another time.

Therefore, the main applications which are involving include:

1- MES (Hydra)
2- DM.TEC
3- TWX
4- Agnostic Andon

The DFD[2] of this system illustrated below in the figure 4.5.

[1] ThingWorx Manufacturing Apps are a set of role-based starter apps built on PTC's industry leading IoT platform.
[2] A data-flow diagram is a way of representing a flow of data through a process or a system (usually an information system). The DFD also provides information about the outputs and inputs of each entity and the process itself.

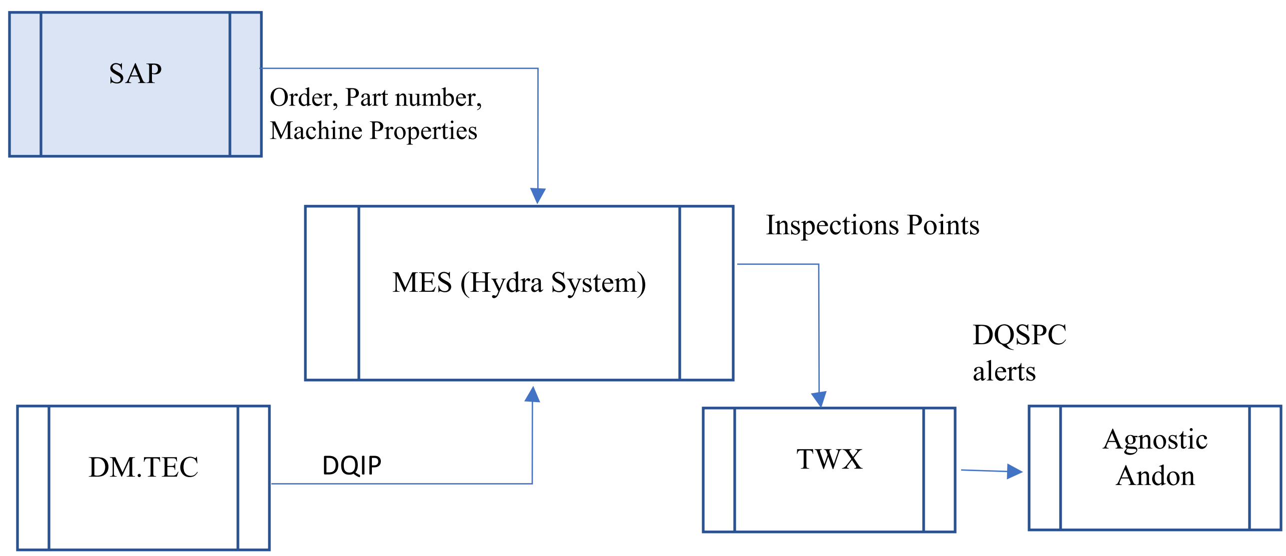


Fig 4.5- Data Flow Diagram

As it can be seen in the picture 4.5, the data related to each production order will be requested by the MES system. As in the SAP_ERP system the material planning department has allocated also the machine to the order, here in the MES the order which is running on each machine is traceable. The data related to the inspection plan of each product, will sent to the MES from DM TEC by another service. All the inspection points gathering from the shop floors will be taken by another application which is named TWX to make the SPC charts. All the data related to the alerts will be saved in the database of Agnostic Andon in order to be notified through Email.

The Big Picture of DQIP project at 01.07.2020

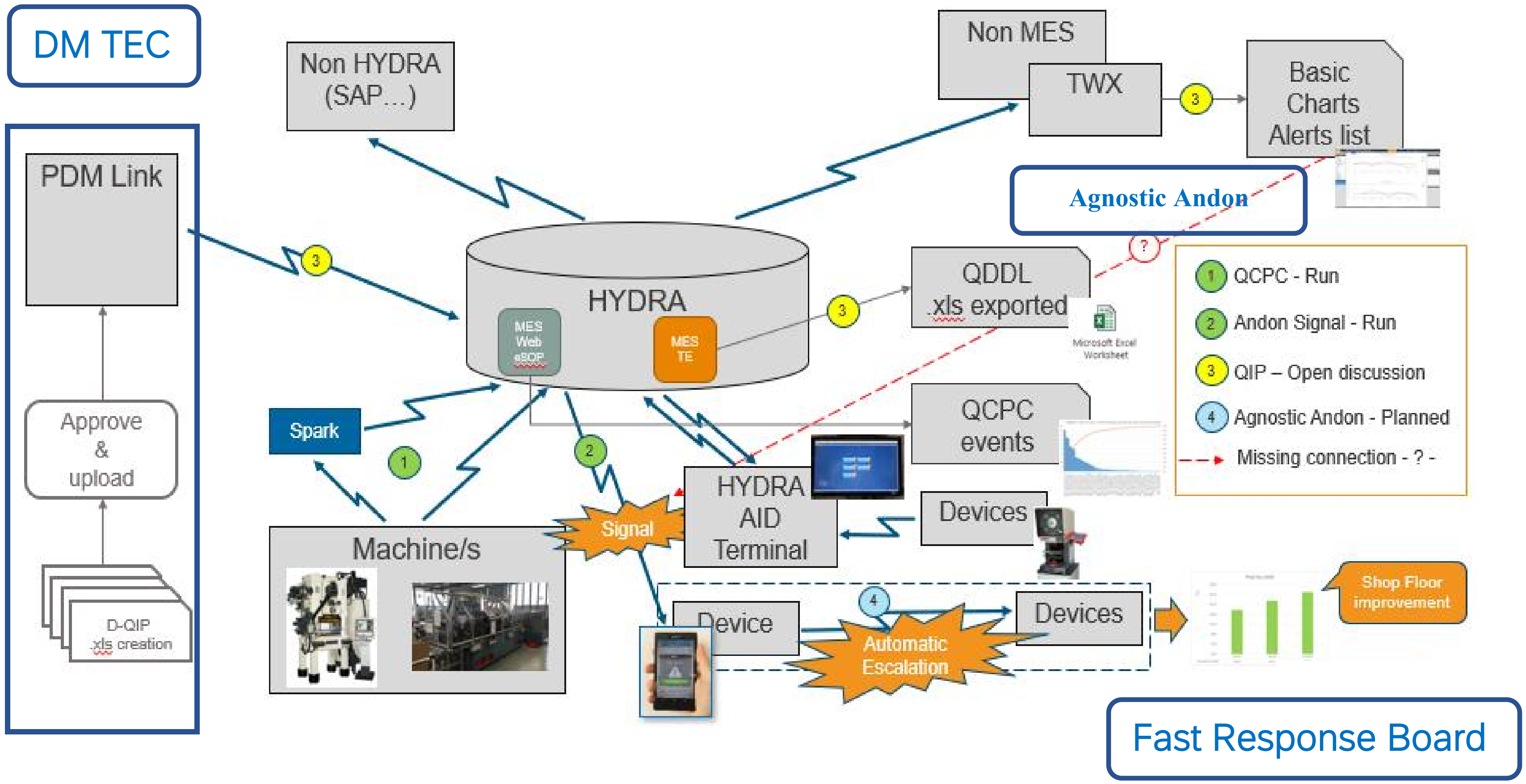


Fig 4.6-The Big Picture of DQIP project

4.4.1. DQIP: Digital Quality Inspection Plan

An inspection is an activity such as measuring, examining, testing or gauging one or more characteristics of a product and comparing the results with specified requirements in order to establish whether conformity is achieved for each characteristic. [1]

This activity includes a series of checking the products from raw materials, semi-finished products and final products. Generally, the final goods before shipping to the clients should be controlled based on the checklists which contain all the main aspects of a product.

The main specifications of a product in TE connectivity are two types. Visual and Dimensional. All the data related to these two aspects of a product should be gathered through quality inspection plan which has been traditionally done though paper.

In order to do the inspection in a digital way, it has been developed the DQIP which is an Excel file that includes all the main characteristic of a product with all inspection's requirements.

See figure 4.7.

The main components of DQIP including:

- The Part Number: Each product includes several part numbers which are different in one or more characteristics.
- The Process Area: Which can be selected through Assembly, Stamping, Plating, Molding.
- Inspection Type: Which can be two types. "Measure" or "Verify".
- The Type of Inspector: Which can be selected from a range of choices. It is obvious that it depends on the process area and the family of product. It includes Line Inspector, Set up man or operator.
- The Interval Type: The inspection can be done anytime from start of order, start of shift or even in hour.
- Frequency: Here the frequency means the time interval between two inspection.
- Sample Type: It can be selected as part, set, strip and ... depending on the type of product.
- Sample Quantity: It is the number of samples in each interval types should be selected by the inspector.
-

[1] This definition comes from the ISO 2859 standard, which is derived from MIL-STD 105 E.

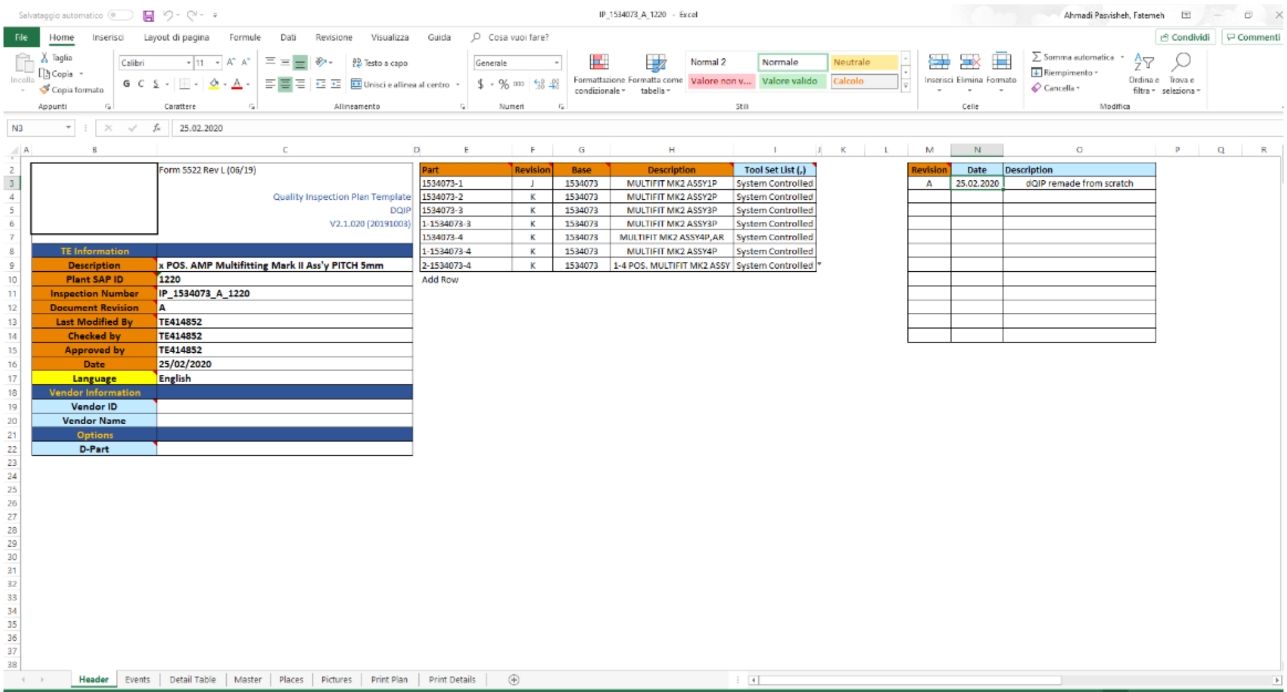


Fig 4.7- Digital Quality Inspection Plan

All the information related to the features of a part number, measures, and the equipment needed for doing the measurements should be inserted into this file. These characteristics imported from the file of quality inspection which has been attached to the file of a product's drawing. In some cases, the meeting with quality department and supervisor of production department is also needed to decide about the most important features that should be considered as inspection point in this file. This file is the main inspection plan for each part number that should be filled precisely. Because all the inspection points which are shown in the terminal of quality in the shop floor came from this file. The completed file should be uploaded in Windchile[1] PDM link.

After uploading this file in PDM link and making a relation between this file and the part numbers through Windchile DM.TEC system, all the features of the products with the specific type of inspection will appear on the MES system which has been installed in each terminal in each production department.

[1] PTC Windchill is a Product Lifecycle Management (PLM) software product that is offered by PTC. Windchill is currently being used by over 1.1 million users worldwide.

4.4.2. MES: Manufacturing Execution System

The main part of digital factory is done through the application of manufacturing execution system. Manufacturing Execution System (MES) is the central part and data hub in a manufacturing environment, connecting ERP and shop floor through horizontal and vertical integration. As a perfect example of modern and Industry 4.0 orientated MES, HYDRA is described, basically modular structured with plenty of standard functions, covering all production areas and departments in a factory, such as machine connectivity, production management, production logistics, quality management, resource management, energy management, and HR (MPDV, 2020). See figure 4.8.

Fig 4.8- Manufacturing Execution System HYDRA

Collecting vast real-time production data is just the very first step, where many MES systems linger about. More important is to analyze and utilize mass production data, turning Big Data into Smart Data. MES Hydra offers various analysis tools and reports for the sake of efficiency and transparency (Kletti and Deisenroth, 2018).

4.4.3. Machines

To manage all the activities related to production it is necessary that all the machines would have been identified in MES. So, the first step of digitalization would be the connection between the MES and the operational machines in shop floor. In order to reach to this goal, all the production machines with their properties including the name, the process area, the capacity and working time have been identified in MES and they have been physically connected to the production server through cable and wire.

In the figure 4.9, one of the machines from assembly department has been illustrated.

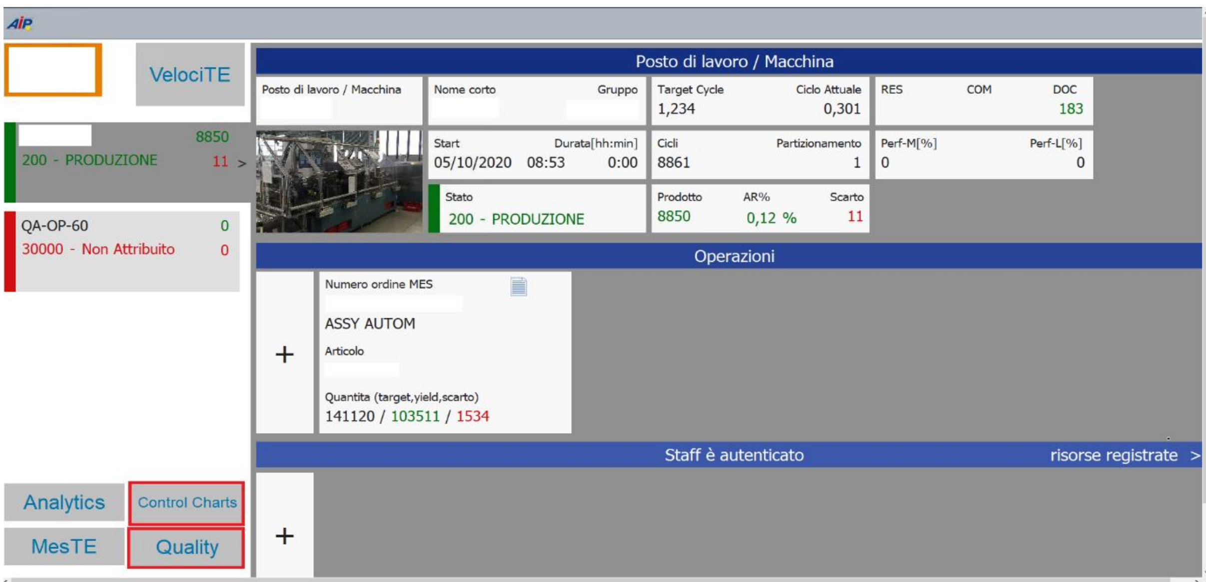


Fig 4.9-The machine linked to quality station

As you can see all the properties of the machine can be modified and there is this ability to change the state of the machine according to Kanban algorithm by the operators. In this way all the states that the machine is encountered during the production process will be registered automatically. See figure 4.10. Through this method, it is possible to get access to the report of machine's downtime. This report which is named QCPC can be the basis of more analysis on the machines. The analysis which will be done on this data can certainly generate a great value for the company.

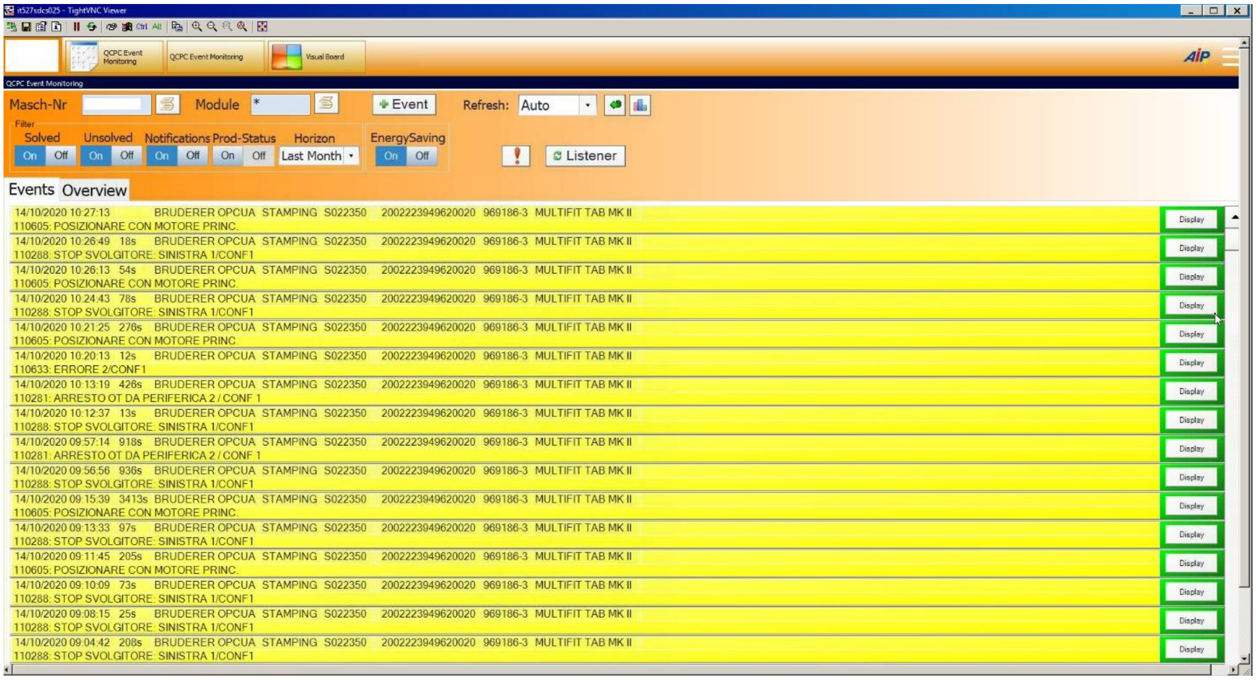


Fig 4.10- The list of events related to machine's states

AIP is the interface with which the shop floor people will have access to the machines and the states of it. In order to have the quality inspection points on the monitor of each machine in shop floor, it is needed to connect each production machine to the quality operation which has been identified in MES. The main activity which should be done, is to identify the quality terminal in MES and connecting one or more machines to this terminal.

The DQIP package, has been precedingly installed on the server of MES. So, we will have the inspection points which have been identified in DQIP on the quality terminal connected to the production machine. In this way, the operators in shop floor would be able to work with quality station after measurement and insert the data related to the specific product.

4.4.5. The terminal of quality

In the figure 4.11 as it is shown, the personals including line inspectors, set up men and operators will have access to insert the data of inspections. In this way, the inspections of each character will be done online. All the papers in manufacturing line in each department will be removed step by step.

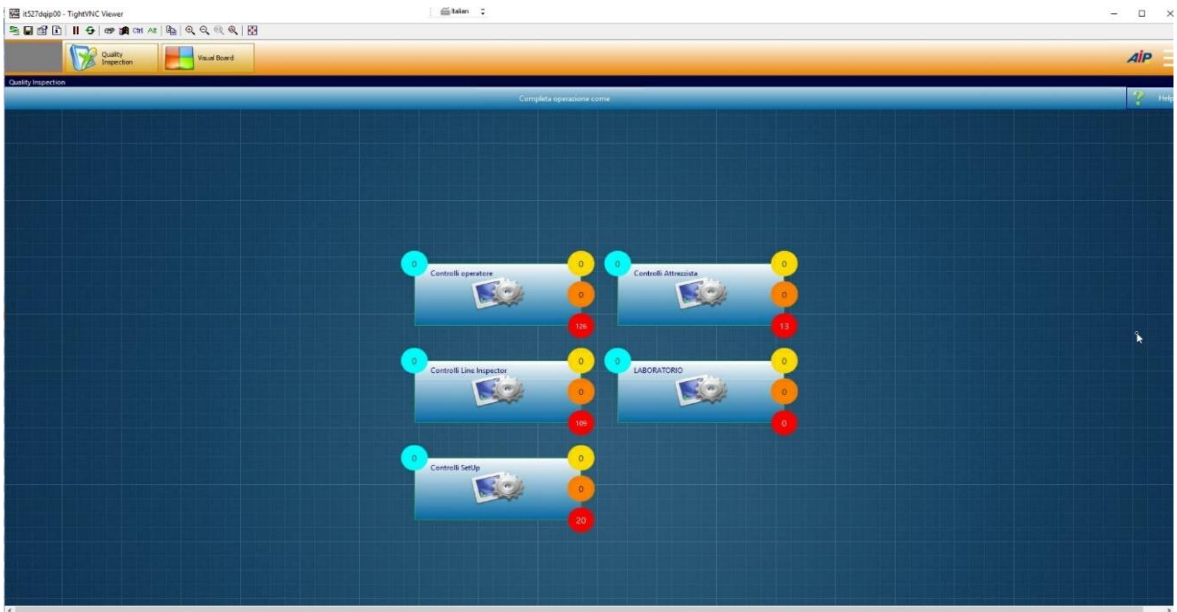


Fig 4.11- Quality Terminal

The main feature of this page is that the state of inspection points is shown with the different colors. There is also the possibility to see the numbers of inspection points in each state.

1- Red: when all the inspection points of one product are open.

2- Orange: when some parts of inspection points have been inserted

3- Yellow: when all the inspection points are closed.

In the figure 4.12, you can see these states clearly.

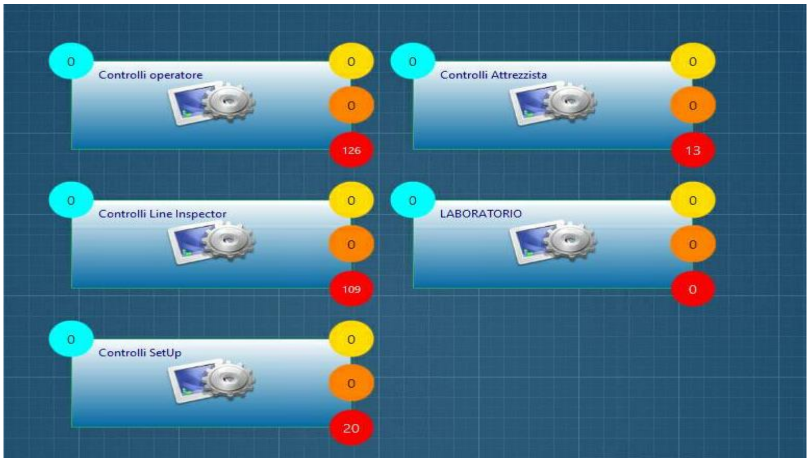


Fig 4.12- Quality inspection interval on the quality terminal

By clicking on the type of interval, all the machines which have been already linked to this specific interval types will be appeared on the screen. The inspector has the access to the machine just by selecting the machine. In this step all the features which have been already inserted into DQIP will be shown. See figure 4.13.

The inspectors have this possibility to insert the measurement of a character in case of being a dimensional feature.

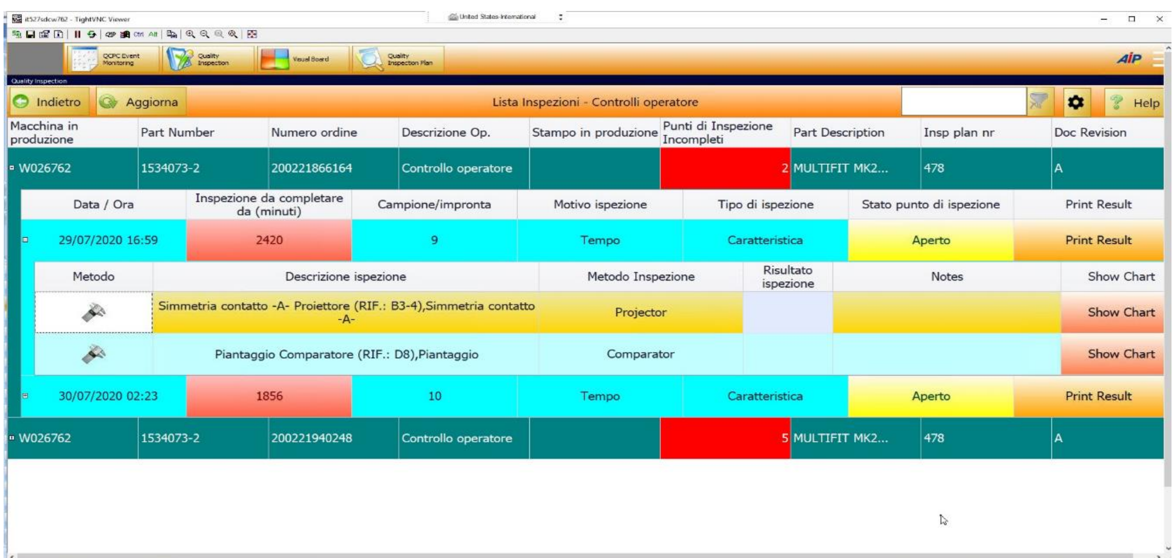


Fig 4.13- Quality inspection points in quality terminal

As you can see in the figure 4.14, the LSL and USL of the character have been shown. If the inspector inserts a number which is out of this range the system will show that with the red color.

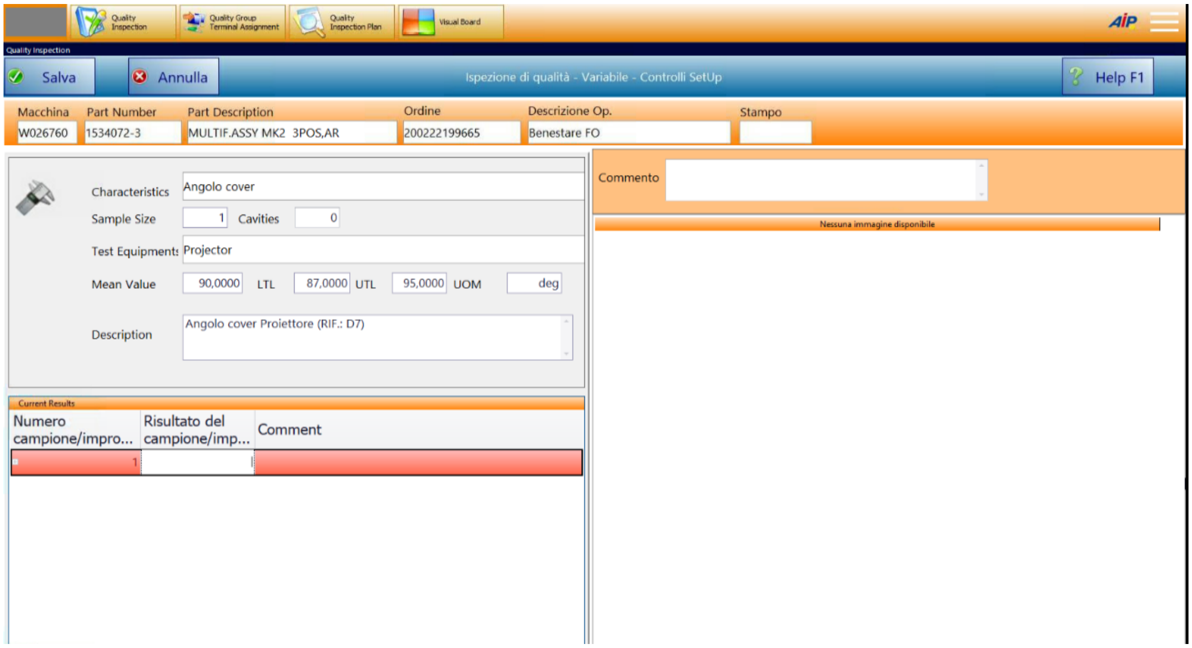


Fig 4.14- Dimensional point in quality terminal

In the case of having a visual character, the inspector should insert Ok or NOK to clarify the state of the feature. See figure 4.15.

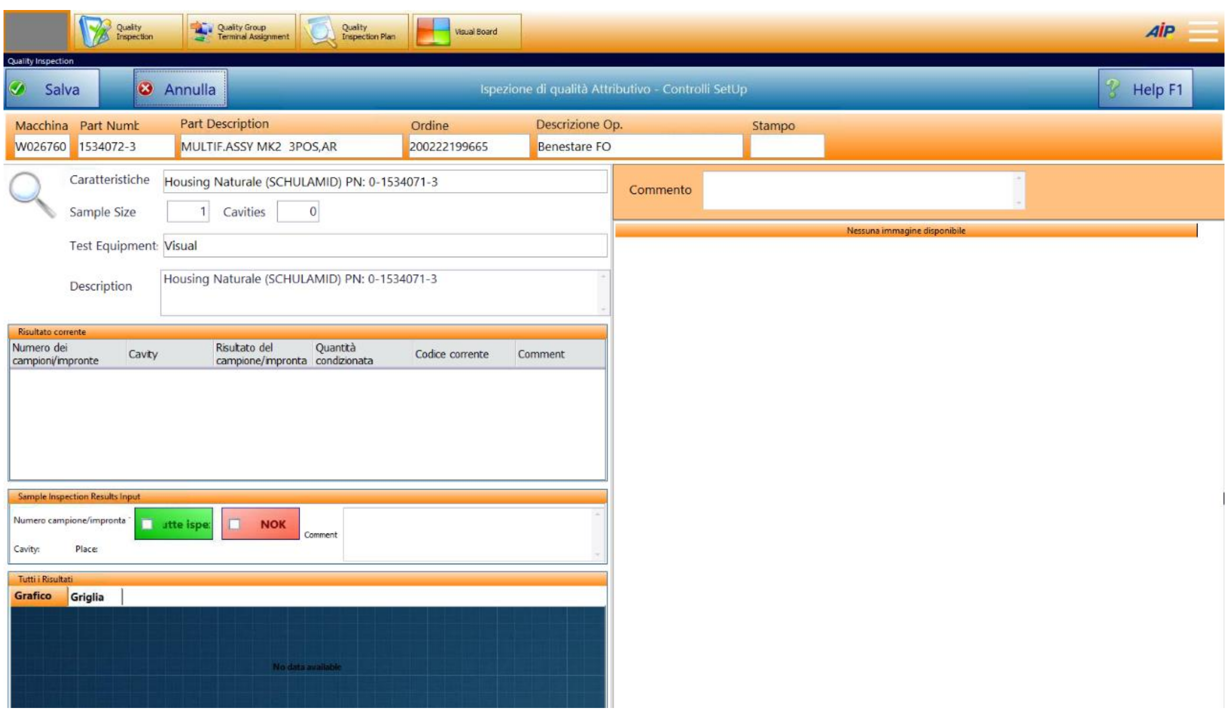


Fig 4.15- Visual inspection point in quality terminal

4.4.4. Internet of Things

Since, one of the advantages of digitalization is to utilize the digital measurement instrument, here the inspector can use the gage, caliper or comparator which are able to connect with the computer through Bluetooth or Internet. In this case, the inspectors will have this possibility to benefit from the digital instrument instead of inserting the data manually in the system.

Internet of things in manufacturing can be defined as a future where every day physical objects in the shop floor, people and systems (things) are connected by the Internet to build services critical to the manufacturing. Smart factory is a way towards a factory-of-things, which is very much aligned with IoT (Shariatzadeh et al., 2016).

One of the most important aspects of digitalization is to utilize of the metrological instrument which are connected through the internet into computer. In this way, the inspectors do not need to insert the data manually. In figure 4.16 you can see two digital measuring tools. In the left side, there is a projector which has been equipped with a connector to connect directly to the system and in the right side there is a height gage with the ability to be digitalized.

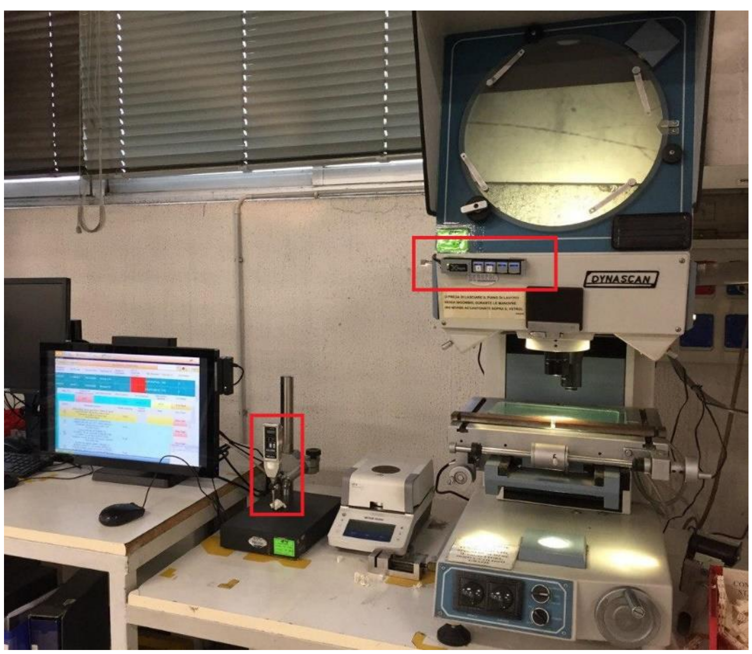


Fig 4.16- Measuring tools equipped with IOT

Another technique which is being applied in shop floor includes gathering the data related to the specifications of a product by tele camera’s capturing. In this way the cameras which have installed into each production machine will be able to capture the dimensions of a product and send this data directly to Thing Worx which is responsible of generating the QSPC charts.
In the figure 4.17, it can be seen a camera which is capturing the dimensions of a product which is being produced in production line. Some main specifications of products will be captured by tele camera and the measures will send to TWX in order to generate SPC.

Fig 4.17- Capturing the data by tele camera

Through this method, the near Real-Time monitoring of quality process would be achievable.

4.4.5. DQSPC: Digital Quality Statistical Process Control

Whether the data inserted by the inspector manually in the system or transferred by the bluetooth of measurement instrument into computer, the result of gathering the data in this mode, will be the SPC chart which are the output of TWX application. Through TWX application, it is possible to see the points which have been inserted in shop floor in the form of SPC diagram. This graph will be shown in the terminal of quality too.

Here, there is this possibility to filter the orders which are running in production line. Two main charts which are shown are Run Chart and I-MR Chart.

In the figure 4.18, the Run chart related to the running order has been shown.

Fig 4.18- Run-chart by TWX

In addition to Run chart, there is the I-MR chart with the possibility of generating alerts in the case of being out of control. The list of Alert Tracker will show all the alerts generating in real time. In the figure 4.19 it can be seen the points which are in red. These points specifically are out of control (3 of them are bigger than UCL and one of them is lower than LCL). Obviously for all these points we should expect that the alerts be generated.

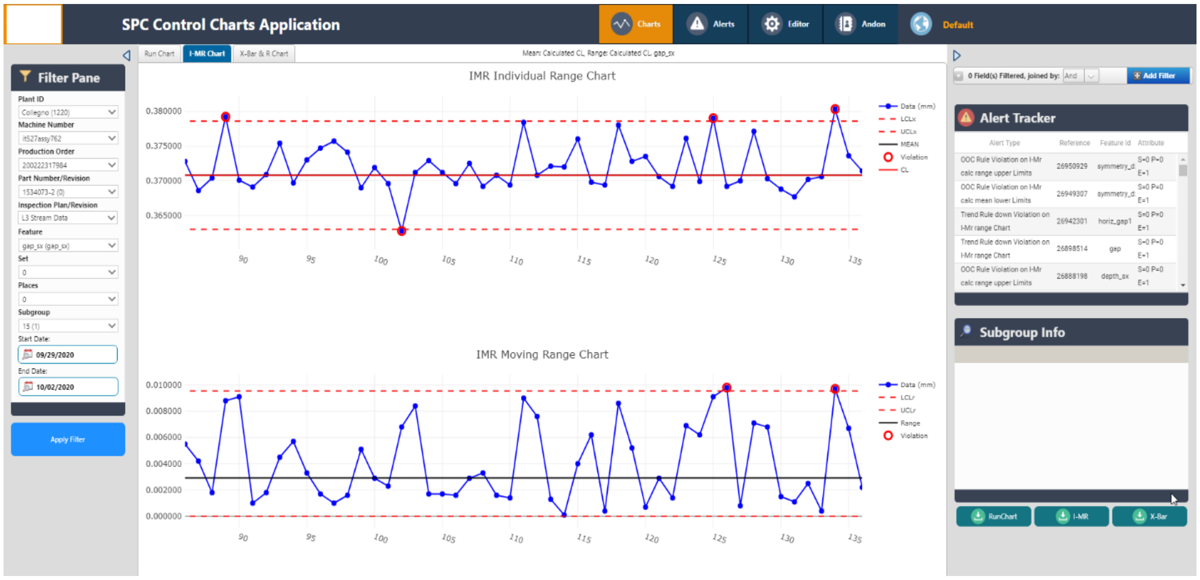


Fig 4.19- I-MR-chart by TWX

The alerts generated by TWX will be automatically imported to the Agnostic Andon.

4.4.6. Agnostic Andon

Andon is a Japanese term used in the manufacturing field to refer to a system to inform operators who deal with management, maintenance and more of the presence of a quality or process problem (Liker, 2004).

"Andon" is defined as a type of alarm used on production machinery when applying the Kaizen methodology. Often it refers to a tower composed of lights of different colors (each of which refers to a status of the machinery) that signal any anomalies. The Andon billboard is one of the main components of the quality control system according to the concept of autonomy that was initially explored by Toyota as part of the Toyota Production System and is now part of the lean production approach . It gives the operator the ability to stop production when a defect is found and ask for assistance immediately. In figure 4.20, an alert which has been received by operator is shown.

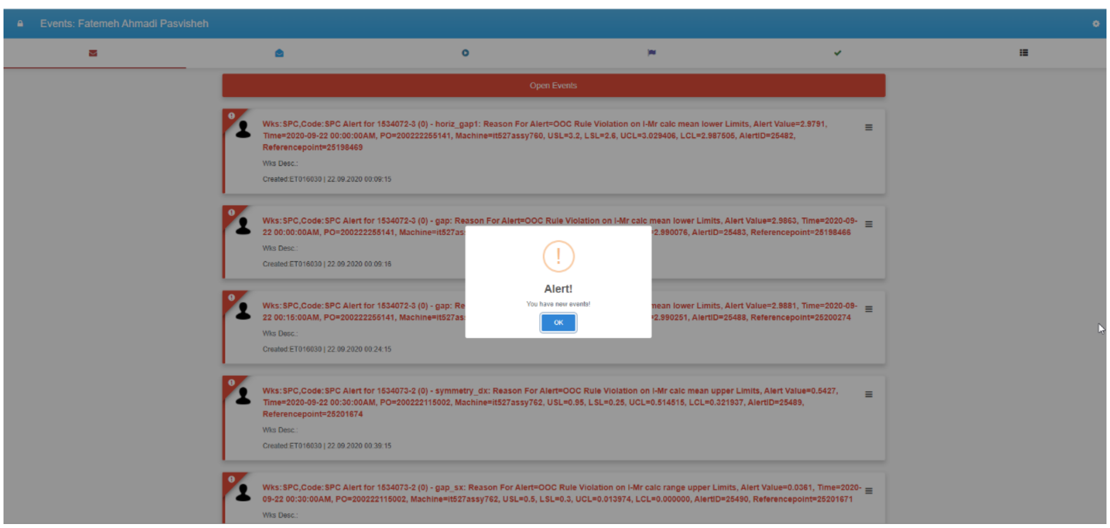


Fig 4.20- Generating alerts and receiving on phone

One of the most important features of digitalization would be the implementation of Andon Agnostic application. In this way, all the alerts related to a product which have been generated by QSPC will notify the shop floor in the form of an Email. In figure 4.21 a list of email generated by Andon application has been illustrated.

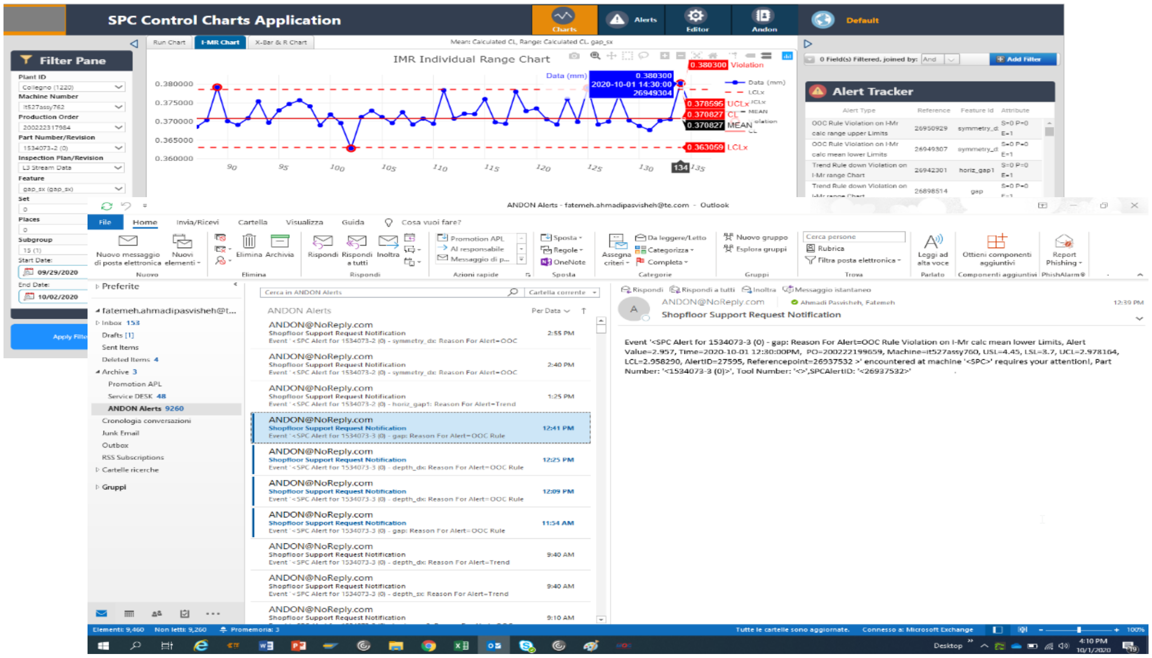


Fig 4.21- The Email related to the specific alert

It is also possible for the operators to do escalation to the next level in the case of facing with a problem that they are not able to solve it. In this case, the second level who is more expert in this field will be engaged. See figure 4.22.

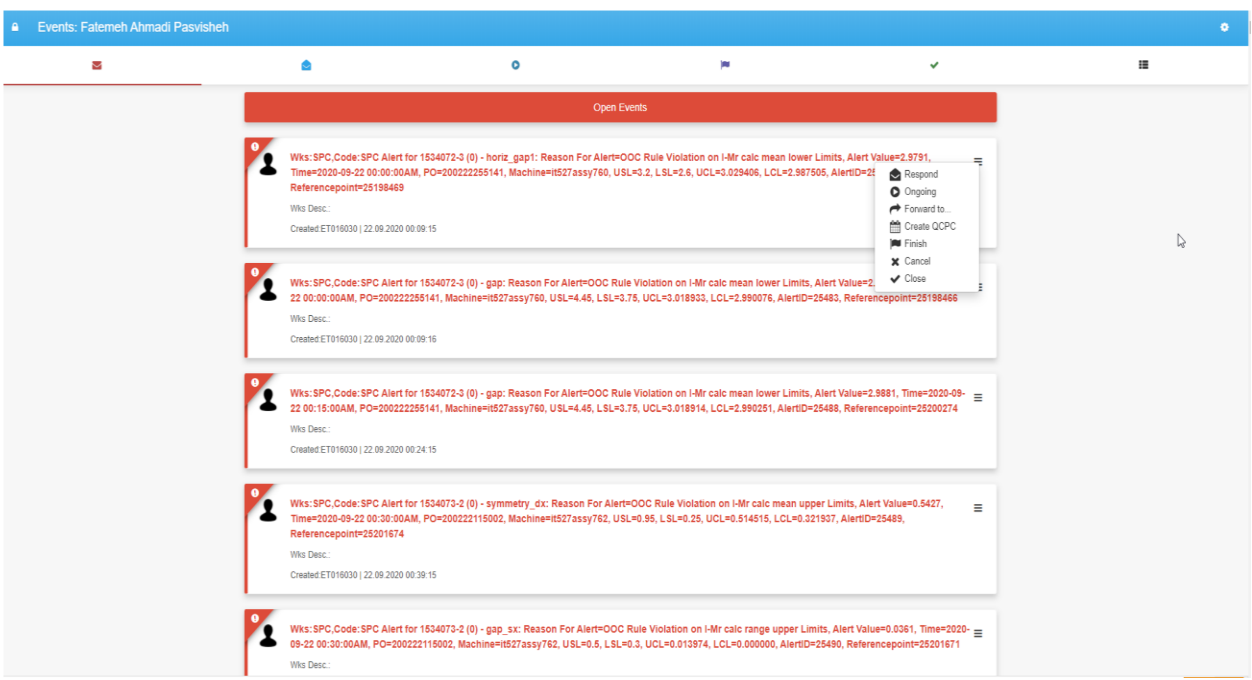


Fig 4.22- The escalation of alerts

4.4.7. Digital Fast Response Board

As it can be seen in the figure 4.23, the main parts of FRB would be the problems which have been raised from production line, the cause of those problems and the immediate actions that should be carried out in order to solve the problems immediately. It is also very important to consider the Deming cycle here, as this will prevent us to face with the repeated problem for another time.

The teams managing the process can overview the information, conduct data mining into the testing data, quickly conduct root cause analysis, and significantly improve quality and Yield. Quality Line's technologies make it possible to run a quicker and accurate root cause analysis that will:

- Anomaly detection of quality and yield problems.
- Prediction of failure rate.
- Smart collections between stages of production for quick problem prevention.
- Monitor vendors and subcontractor's quality of products.
- Monitor qualification of shop floor operators.
- Reduce faulty products return rate from customers.

In Appendix 4, the form of FRB which is traditionally used in company has been inserted.

4.5. Activities

The process of digitalization in a company includes a series of a functions which should be carried out by the team of digital factory. By performing the activities which are defined by the leader of the team, each part of the main puzzle of digital factory will be completed in a period of a time. Here the main activities carried out by DF team have been explained precisely.

- Preparing DQIP, by digital factory implementation team: For each part number the DQIP should have been prepared in order to upload in system.
- Connecting the machines to the quality terminal: In order to be shown the inspections point on the machine, it is necessary to make connection between the machines and quality operations.
- Installing touch screen monitor in production line: This activity has been done in order to make the working with computer easier for shop floor people.
- Training the shop floor: One of the main tasks of implementing this system has been the task of training the shop floor including line inspectors, set up men and the operators who are responsible of doing the inspection and working with digital instruments
- Testing the systems before implementing in production site: Before each releasement, the systems including AIP, TWX and Andon should have been tested by DF team. In this way, the DF team would have been sure that in the shop floor, they will not face with the problem related to the system.
- Gemba walk: One of the main daily tasks would be Gemba walk which is the action of going to observe the actual process. By doing Gemba walk the DF team could understand the issues of people, system and process when they were working with this system.
- FMEA[1] meeting with the supervisors: During implementing the system, in the phase of preparing the DQIP, sometimes it was needed to have a meeting with the product managers, designers, quality engineers and production manager in order to decide about one feature which is needed to improve. Therefore, one of the outputs of this project has been the improvement in the quality of a product by developing FMEA.

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[1] Failure Mode and Effect Analysis is a methodology used to analyze the mode of failure or defect of a process, product or system , analyze the causes and assess which are the effects on the entire system / plant. Generally (but not necessarily) the analysis is performed in advance and is therefore based on theoretical and not experimental considerations.

- Preparing performance report: It is very important to be aware of the performance of people who are working with new system. Therefore, each week, the managerial report has been prepared by DF team to evaluate the state of system in shop floor. In this way, all the personals who are involved in this project would be able to follow the progressive of the project and the level of collaborations in the organization.

Chapter 5: Conclusion

As a summary, it should be stated that the process of digitalization in the company is a long-term plan that has been started with quality control process. The objectives of the company certainly will achieve completely after implementing all parts of digitalization and in a long term. However, each part of this project, has generated a certain benefit in a short term that can lead to create value for the company ultimately.

As illustrated in figure 5.1, the process of digitalization in quality control started with implementing DQIP. After implementing DQIP, all the data will be stored in a cloud- data base in order to generate the DQSPC in TWX application. The alerts which are generated for the violations, will be sent to the responsible of each machine through Agnostic Andon application. See figure 5.1.

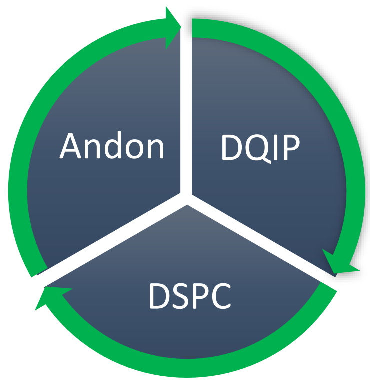


Fig 5.1- Digitalization cycle in quality control

5.1. The achievements

Through all the KPIs which have been indicated as the measurements of objectives after digitalization, the main indicators of implementing DQSPC have been the number of scraps and the cost of quality. Before implementing DQIP, in assembly department 5.6 hours in a day were needed just to fill the papers of inspections by shop floor. After implementing DQIP, it has decreased to 3.3 hours. It means that just by changing the method of inspection from paperwork to paperless, the company has been able to save 41% of time. The inspectors in this way, will have more time to allocate on controlling the quality of the products instead of just filling the forms of inspections.

By monitoring the production process through DQSPC, the operator who is responsible of machine, will have access to monitor the process through DQSPC shown in each monitor of terminal. In this way, the shop floor people will get access to the state of production process and before the machine stops, they can perform some preventive actions. Therefore, the rate of scraps will decrease. In the comparison with the previous year the number of scraps after implementing digital SPC has decreased by 1,2% and it is anticipated that after implementing DQSPC in all the departments and for all the products, the company would save a great amount of money in this field.

One of the most important features of this project has been the connection of ANDON and DQSPC. Before implementing Agnostic Andon, which has been done by the contribution of the candidate, the company has benefited of ANDON just to show the state of machine (on/off). In This way, when the machine stopped, the operator of the machine received a notification and after that, the step of investigation about machine started.

However, after implementing Agnostic Andon, all the violations related to a product with the reason of them and all the states of machine will be sent to the operator in Real Time. In this way, the time allocated for decision making will decrease. The time allocated to response to a problem in the process of problem solving has diminished by 30% in 3 months respect to the previous year. So, in this case it can be said that the prevention cost has decreased too.

One of the main objectives of this project which has been the improvement in machine downtime and changeover should be considered. At the time of doing this research these indexes have not been measured. However, it is obvious that they will improve in a long term.

The other qualitative benefits of digitalization which will ultimately result into the customer satisfaction in a long term include:

- Improving the design of the products through modifying the specifications of them
- Increasing the contributions of people in shop floor to do the quality control inspections
- Increasing the digital knowledge of people in shop floor
- Storing the big data and generating the business intelligence reports
- Improving the state of metrological tools

5.2. The Challenges

Although, the process of digitalization gives the company this opportunity to improve the efficiency and effectiveness of production, there might be some challenges and obstacles which impede the project to be performed effectively. Some of the main challenges of digitalization in TE Connectivity have been mentioned here.

- ✓ Agility of organization: The company is an international type with different layers of hierarchy. As a result of this fact, sometimes adding just one small feature to the system needs to be proved by different persons. Therefore, the process of decision making takes more time in comparison with the local companies with less organizational level.
- ✓ The resistance of operators: Traditionally they have worked with pen and paper and working with new instruments which needs more attention and knowledge about IT have created resistance in production departments.
- ✓ Culture of being digital: Most personals in the shop floor are middle ages who are not sensitive about the importance of digitalization. Therefore, their motivation to work with the system is low.

5.3. Future activities in the company

There are some activities which are suggested to be done in the near future in the company including:

- ✓ Digitalization of fast response board: It is suggested that the FRB system be designed. With this system all the supervisors will have this possibility to work easily with a system to manage the problems raised in production line. After implementing DFBR, it is predicted that the preventive cost will decrease as the cost of problem solving will diminish.
- ✓ Dedicating more full-time resources to the project: In order to improve the progress of digitalization it is suggested to dedicate more fulltime IT personals.
- ✓ Allocating some shop floor workers as Key-users: Since, the knowledge and motivation to work with digitalized tools are different among personals, it would be better to allocate some personals with high degree of IT skills as the key users. They can also train other people in

production line. In this way, not only the speed of digitalization will be improved but the shop floor's sense of collaboration will be enriched as well.

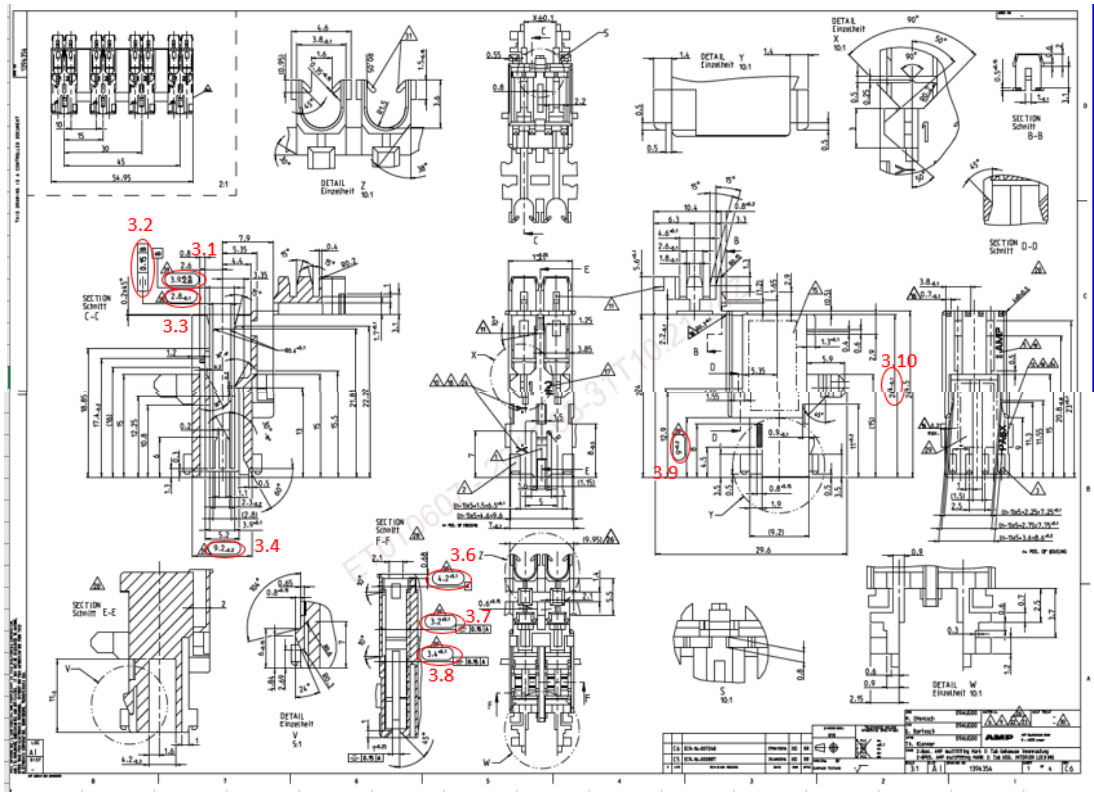
5.4. Future researches

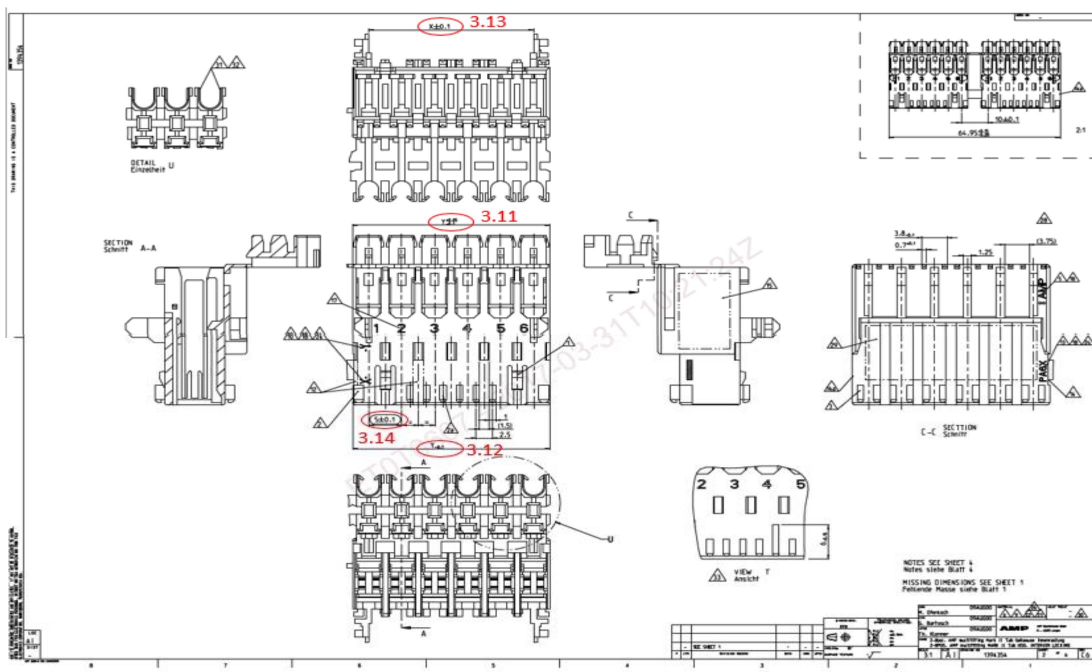
For the future researches, it is suggested that the researchers who are interested in the field of digitalization to work on other aspects of digitalization. In particular, the part of managerial reports that the data can be stored and analyzed to help the different level of organization in the process of decision making. In this field, the importance of Big data and the role of Power BI which can produce a great value for the company can be considered.

The DQCPC which is being implemented in the company in order to increase the efficiency of production and decrease the downtime can be considered as another research subject too.

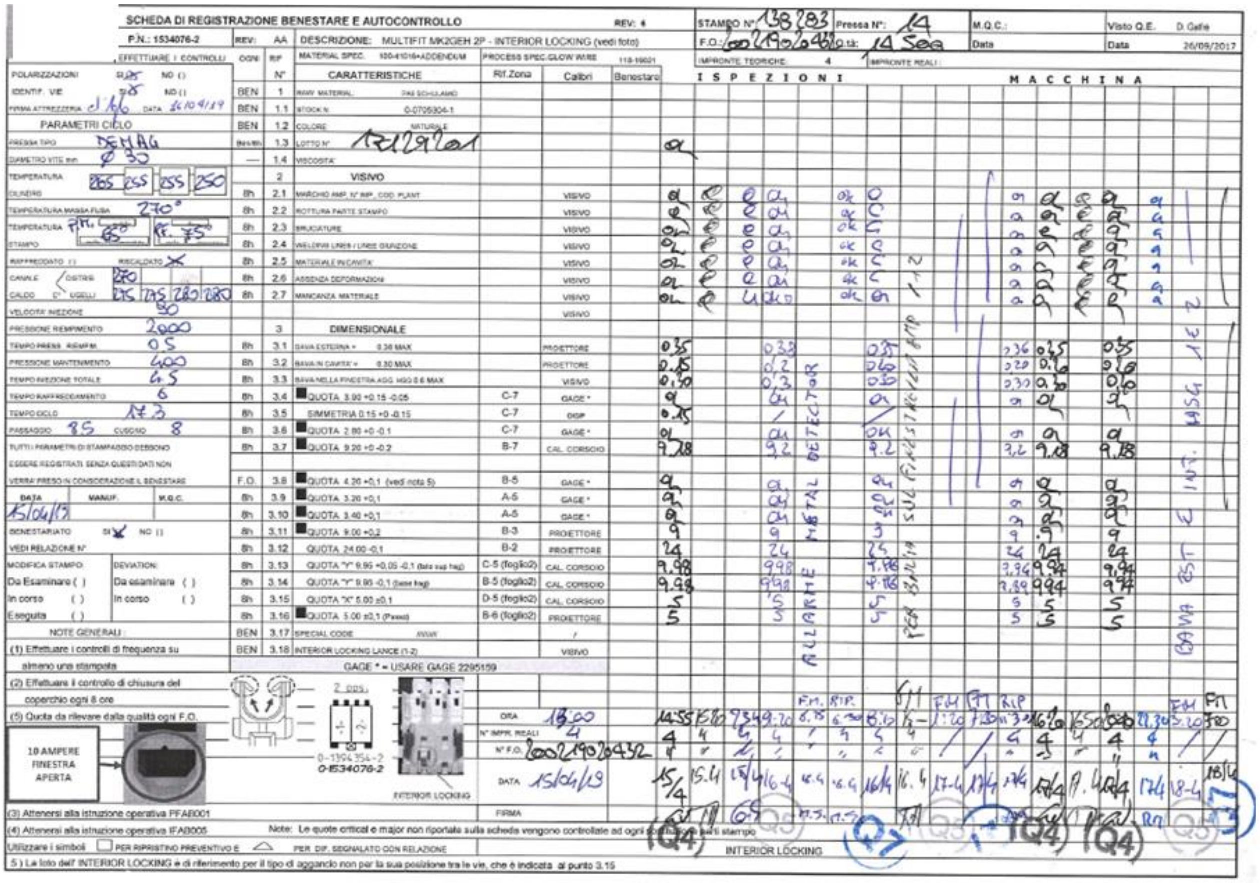
IOT and the role of it in production environment in the company can be another field which needs to be concentrated and be improved.

Appendix 1- The design of a product with the main characters





Appendix 2- The inspection form related to a product done by shop floor manually



SCHEDA DI REGISTRAZIONE BENESTARE E AUTOCONTROLLO — REV: 4

P.N.: 1534076-2 — REV: AA — DESCRIZIONE: MULTIFIT MK2GEH 2P - INTERIOR LOCKING (vedi foto)

MATERIAL SPEC: 100-41016+ADDENDUM — PROCESS SPEC.GLOW WIRE: 118-19021

STAMPO N°: 138783 — Pressa N°: 14 — F.O.: 002190 — IMPRONTE TEORICHE: 4 — IMPRONTE REALI — M.Q.C. — Data — Visto Q.E.: D. Gallè — Data: 26/09/2017

POLARIZZAZIONI	SI X NO ( )
IDENTIF. VIE	SI X NO ( )
FIRMA ATTREZZERIA	DATA 16/04/19
PARAMETRI CICLO	
PRESSA TIPO	DEMAG
DIAMETRO VITE mm	Ø 30
TEMPERATURA CILINDRO	265 255 255 250
TEMPERATURA MASSA FUSA	270°
TEMPERATURA STAMPO	FM. 65° / FF. 75°
RAFFREDDATO ( )	RISCALDATO X
CANALE CALDO	DISTRIB. 270 / N° UGELLI 275 275 280 280
VELOCITA' INIEZIONE	30
PRESSIONE RIEMPIMENTO	2000
TEMPO PRESS. RIEMPIM.	0.5
PRESSIONE MANTENIMENTO	400
TEMPO INIEZIONE TOTALE	6.5
TEMPO RAFFREDDAMENTO	6
TEMPO CICLO	17.3
PASSAGGIO	85 CUSCINO 8

TUTTI I PARAMETRI DI STAMPAGGIO DEBBONO ESSERE REGISTRATI. SENZA QUESTI DATI NON VERRA' PRESO IN CONSIDERAZIONE IL BENESTARE

DATA	MANUF.	M.Q.C.
15/04/19		

BENESTARIATO SI X NO ( ) — VEDI RELAZIONE N°

MODIFICA STAMPO	DEVIATION
Da Esaminare ( )	Da esaminare ( )
In corso ( )	In corso ( )
Eseguita ( )	

OGNI	RIF N°	CARATTERISTICHE	Rif.Zona	Calibri	Benestare
BEN	1	RAW MATERIAL: PA6 SCHULAMID			
BEN	1.1	STOCK N: 0-0705904-1			
BEN	1.2	COLORE: NATURALE			
[illegible]	1.3	LOTTO N°: 1212921			
—	1.4	VISCOSITA'			
	2	VISIVO			
8h	2.1	MARCHIO AMP, N° IMP., COD. PLANT		VISIVO	
8h	2.2	ROTTURA PARTE STAMPO		VISIVO	
8h	2.3	BRUCIATURE		VISIVO	
8h	2.4	WELDING LINES / LINEE GIUNZIONE		VISIVO	
8h	2.5	MATERIALE IN CAVITA'		VISIVO	
8h	2.6	ASSENZA DEFORMAZIONI		VISIVO	
8h	2.7	MANCANZA MATERIALE		VISIVO	
				VISIVO	
	3	DIMENSIONALE			
8h	3.1	BAVA ESTERNA = 0.30 MAX		PROIETTORE	
8h	3.2	BAVA IN CAVITA' = 0.30 MAX		PROIETTORE	
8h	3.3	BAVA NELLA FINESTRA AGG. [illegible] MAX		VISIVO	
8h	3.4	QUOTA 3.90 +0.15 -0.05	C-7	GAGE *	
8h	3.5	SIMMETRIA 0.15 +0 -0.15	C-7	DISP	
8h	3.6	QUOTA 2.80 +0 -0.1	C-7	GAGE *	
8h	3.7	QUOTA 9.20 +0 -0.2	B-7	CAL. CORSOIO	
F.O.	3.8	QUOTA 4.20 +0,1 (vedi nota 5)	B-5	GAGE *	
8h	3.9	QUOTA 3.20 +0,1	A-5	GAGE *	
8h	3.10	QUOTA 3.40 +0,1	A-5	GAGE *	
8h	3.11	QUOTA 9.00 +0,2	B-3	PROIETTORE	
8h	3.12	QUOTA 24.00 -0,1	B-2	PROIETTORE	
8h	3.13	QUOTA "Y" 9.96 +0,05 -0,1 (lato sup hag)	C-5 (foglio2)	CAL. CORSOIO	
8h	3.14	QUOTA "Y" 9.96 -0,1 (base hag)	B-5 (foglio2)	CAL. CORSOIO	
8h	3.15	QUOTA "X" 5.00 ±0,1	D-5 (foglio2)	CAL. CORSOIO	
8h	3.16	QUOTA 5.00 ±0,1 (Passo)	B-6 (foglio2)	PROIETTORE	
BEN	3.17	SPECIAL CODE [illegible]		/	
BEN	3.18	INTERIOR LOCKING LANCE (1-2)		VISIVO	

GAGE * = USARE GAGE 2295159

NOTE GENERALI:

(1) Effettuare i controlli di frequenza su almeno una stampata

(2) Effettuare il controllo di chiusura del coperchio ogni 8 ore

(5) Quota da rilevare dalla qualità ogni F.O.

10 AMPERE FINESTRA APERTA — 2 pos. — 0-1394354-2 — 0-1534076-2 — INTERIOR LOCKING

ORA: 13:00 — N° IMPR. REALI: 4 — N° F.O.: 100219020432 — DATA: 15/04/19 — FIRMA

(3) Attenersi alla istruzione operativa PFAB001

(4) Attenersi alla istruzione operativa IFAB005

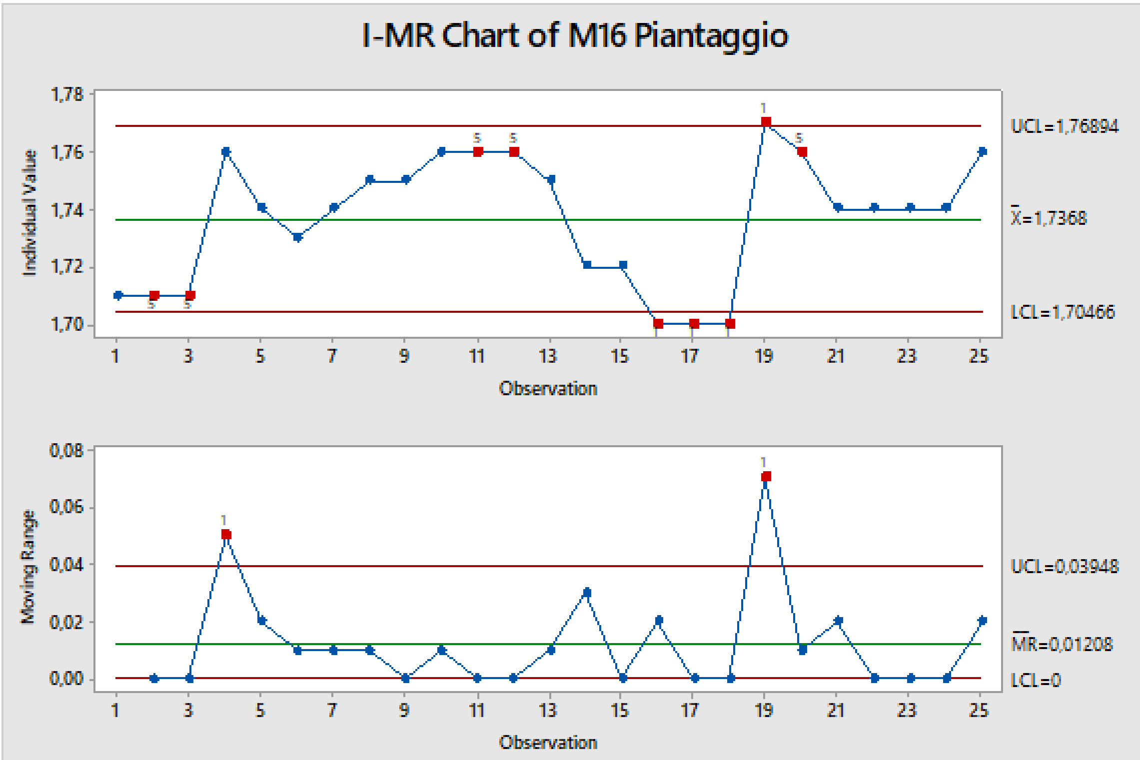
Note: Le quote critical e major non riportate sulla scheda vengono controllate ad ogni [illegible] stampo

Utilizzare i simboli ☐ PER RIPRISTINO PREVENTIVO E △ PER DIF. SEGNALATO CON RELAZIONE

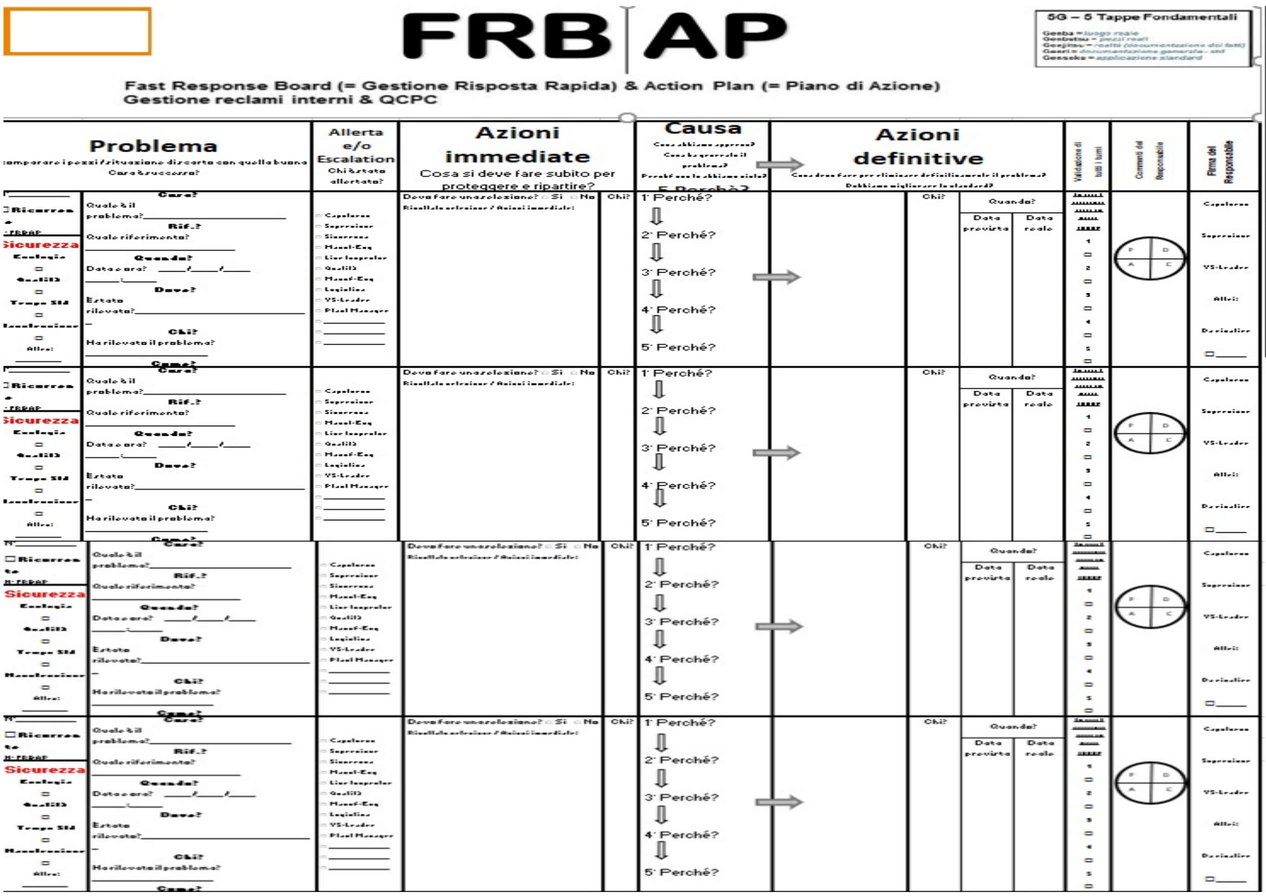
INTERIOR LOCKING

5) La foto dell' INTERIOR LOCKING è di riferimento per il tipo di aggancio non per la sua posizione tra le vie, che è indicata al punto 3.15

Appendix 3- The export of Minitab software



Appendix 4- Fast Response Board



FRB | AP

5G – 5 Tappe Fondamentali

Fast Response Board (= Gestione Risposta Rapida) & Action Plan (= Piano di Azione)
Gestione reclami interni & QCPC

Problema	Allerta e/o Escalation	Azioni immediate	Causa	Azioni definitive	Validazione di tutti i turni	Commenti del Responsabile	Firma del Responsabile
Quale è il problema? Rif.? Quale riferimento? Quando? Data e ora? Dove? E stato rilevato? Chi? Ha rilevato il problema? Come?	Capoturno, Supervisor, Sicurezza, Manut-Eng, Lean Leader, Qualità, Logistica, VS-Leader, Plant Manager	Deve fare una selezione? Sì No. Chi?	1° Perché? 2° Perché? 3° Perché? 4° Perché? 5° Perché?	Chi? Quando? Data prevista, Data reale	1, 2, 3, 4, 5	P D A C	Capoturno, Supervisor, VS-Leader, Altri:
Quale è il problema? Rif.? Quale riferimento? Quando? Data e ora? Dove? E stato rilevato? Chi? Ha rilevato il problema? Come?	Capoturno, Supervisor, Sicurezza, Manut-Eng, Lean Leader, Qualità, Logistica, VS-Leader, Plant Manager	Deve fare una selezione? Sì No. Chi?	1° Perché? 2° Perché? 3° Perché? 4° Perché? 5° Perché?	Chi? Quando? Data prevista, Data reale	1, 2, 3, 4, 5	P D A C	Capoturno, Supervisor, VS-Leader, Altri:
Quale è il problema? Rif.? Quale riferimento? Quando? Data e ora? Dove? E stato rilevato? Chi? Ha rilevato il problema? Come?	Capoturno, Supervisor, Sicurezza, Manut-Eng, Lean Leader, Qualità, Logistica, VS-Leader, Plant Manager	Deve fare una selezione? Sì No. Chi?	1° Perché? 2° Perché? 3° Perché? 4° Perché? 5° Perché?	Chi? Quando? Data prevista, Data reale	1, 2, 3, 4, 5	P D A C	Capoturno, Supervisor, VS-Leader, Altri:
Quale è il problema? Rif.? Quale riferimento? Quando? Data e ora? Dove? E stato rilevato? Chi? Ha rilevato il problema? Come?	Capoturno, Supervisor, Sicurezza, Manut-Eng, Lean Leader, Qualità, Logistica, VS-Leader, Plant Manager	Deve fare una selezione? Sì No. Chi?	1° Perché? 2° Perché? 3° Perché? 4° Perché? 5° Perché?	Chi? Quando? Data prevista, Data reale	1, 2, 3, 4, 5	P D A C	Capoturno, Supervisor, VS-Leader, Altri:

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2- Daeuble, G., Oezcan, D., Niemoeller, C., Fellmann, M., Nuettgens, M. and Thomas, O. (2015). Information needs of the mobile technical customer service – a case study in the field of machinery and plant engineering. Proceedings of the 48th Hawaii International Conference on System Science (HICSS).

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