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The World Class Manufacturing Methodology,

Theoretical Model and Practical Application in Ariston Thermo Group

Design of the Automated Machine for the Cartoning of the Water Heaters,
Implemented by the Early Equipment Management Pillar

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Table of contents

Introduction ... 3
Ariston Thermo Group ... 4
The Genga Plant ... 5
History & Location ... 5
The Products ... 6
The Production System ... 6
The Automations ... 7
The Implementation of WCM ... 8
The WCM Methodology ... 9
Evolution of the WCM ... 10
The WCM Structure ... 12
The Tools of WCM ... 14
The Auditing System ... 15
Ariston Thermo Group and the WCM ... 16
The EEM Pillar ... 17
Goals & Expected Results ... 17
The D.R.E.A.M. Approach ... 18
Life Cycle Cost (LCC) ... 19
Cost of Modifications ... 20
New Product Launch ... 21
The 7 Steps of EEM Pillar ... 22
Step 1: Planning ... 23
Step 2: General Concept ... 25
Step 3: Detail Design ... 28
Step 4: Construction ... 32
Step 5: Installation ... 36
Step 6: Production Tests ... 38
Step 7: Start Up ... 39
The Carton Insertion Automation ... 42
Choice of the Project ... 42
Step 1: Project Inputs and Planning ... 43
The Final Lines in Genga ... 43
Flow Chart ... 47
Cardboard is "alive" ... 48
Project Inputs ... 49

KPI Definition 51
Gantt & Schedule 54
Step 1 checklist 55
Step 2: Definition of General Specifications 56
Benchmarking 56
3D computer vision using structured light 59
Adoption of vacuum pumps 61
Suction cups clogging 63
Use of multiple suction cups in parallel 64
Use of capacitive sensors 65
Modification of software hierarchy 67
RobotStudio 68
Industry 4.0 compliance 69
Carton specification 71
Ariston specification 72
Project technical specification 73
Supplier selection 74
Checklist step 2 80
Step 3: Detail design 81
Equipment Failure Mode and Effect Analysis 81
Detail design 82
Step 4: Construction 119
Production tests 122
Acceptance testing 124
List of modifications 126
Step 4 checklist 127
Step 5: Installation 128
Step 5 checklist 130
Step 6: Production tests 131
Step 6 checklist 132
Step 7: Start-up 133
Project Review 135
Final Conclusions 140
Bibliography 142

Introduction

The following dissertation regards a case study for the practical implementation of the World Class Manufacturing (WCM) methodology to an industrialization project at the Ariston Thermo Group plant in Genga. The WCM methodology is a set of procedures, tools and instruments aimed at the achievement of lean manufacturing and Ariston has adopted it in 2010 with the purpose of improving the quality and the efficiency of its industrial activities and the goal of becoming an excellence in the world of manufacturing.

After a brief introduction about Ariston Thermo Group and the plant in Genga, a theoretical overview of the WCM methodology will be given. Focus will then be brought on the Early Equipment Management Pillar, the division of the plant that is in charge of carrying out the industrialization activities. An extended explanation of the responsibilities of the pillar will be given, as well as a detailed explanation of the tools and instruments that are adopted to ease the projects of installations of equipment in the plant.

The core of the dissertation will focus on a practical case study of the activities of te EEM Pillar: the installation of two robotized automatic platforms for the packaging operations performed on the electric water heaters assembles along the final lines of the plant. The plant in Genga is one of the oldest factories in the Ariston Thermo Group, and because of this it brings a series of infrastructural, layout and logistic constraints to every new installation of machinery. At the same time, the challenges faced by ATG in the worldwide market, demand a constant improvement and increase of the efficiency of the plant, and these two competing factors require the industrialization of the plant to be faced with harder more complex projects every year. The WCM methodology offers a robust guide during the development of such projects, ensuring that the new equipment has been carefully designed and reviewed so as to respect the highest effieciency standards of the plant, to solve any previous technological issue identified at plant or company level, and to guarantee an on schedule installation and a quick production start-up.

Ariston Thermo Group

The history of the Ariston Thermo Group begins in 1930, when the Merloni Industries are born out of the entrepreneurial burst of Aristide Merloni who founds a small plant for the production of weight scales in the city of Albacine, in the Ancona province of the Marche region, in Italy. The company grows and in the 50s begins to diversificate its production by entering in the market area of the thermic comfort. The Ariston brand was born in the 60s, the brand is both a reference to the name of the founder Aristide and to the greek work with the meaning of "the best". The brandization takes place initially inside the Merloni group and has the goal of best identify in the eyes of the consumer the range of thermic comfort products with the highest efficiency and performances.

Halfway through the 80s, the Merloni Termosanitari (which is the division of the company that produces products for the thermal comfort and includes the Ariston brand) separates from the Merloni group and acquires the Rheem Radi company, which has been operating in the manufacturing of electric water heaters for about 70 years and is an appreciated brand among the consumers. The growth of the group continued throughout the years with a series of acquisitions: Simat was acquired in 1988, Chaffoteaux & Maury and Elco in 2001. These groups represented the top manufacturers of boilers and heating systems in the European market and allowed Merloni Termosanitari to become the leading group in the sector.

In 2009, the name of the company is changed to Ariston Thermo Group. Today, with a yearly revenue of 1.43 billions of Euros, ATG is the world leader in the manufacturing of water heaters, boilers, burners and relative components.

ARISTON THERMO GROUP

The Genga Plant

History & Location

The Genga productive site was built by Ariston Thermo Group during the early sixties, and opened for production in 1966, having recently celebrated its first 50 years of operativity. The 75’000 square meters of the plant (17’000 of which dedicated to production and 18’000 of which dedicated to finished products stockage) are found in the heart of Italy, in the outback of the Marche region, just 10Km from Fabriano, the headquarters of Ariston. The location of the site is rather unusual, as the plant is inside an area that was later declared a protected regional park, the “Parco Regionale della Gola della Rossa” famous for the “Grotte di Frasassi”, the largest cave system in Europe which is located just 1Km away from the production site.

Although beautiful, the geographical location brings with it a set of environmental problematics. The plant in Genga has a rather unfortunate history of dealing with natural events, having been targeted over the years by accidents: hit by the earthquake of 1997, flooded in 2003 and damaged by heavy snowfalls in 2012 it still stands strong today as one of the most important productive sites for Ariston Thermo Group.

Today it employs around 300 people to produce 1,5 milion water heating systems every year.

The Products

The Genga plant is focused on the production of electric water heating systems (sometimes improperly called "boilers") with a litrage that ranges from 50 to 100 litres for the primary production. Secondary departments are specialized in the production of larger systems and in the gas water heating systems (a production line that was imported in Genga when the plant of Rovereto was shut down).

The range of products count over 300 different water heating systems, most of which share the same production lines and differ significatively in only the capacity, the orientation (either vertical or horizontal), the type of resistance used and in the aesthetics of the bottom cap and of the external casing.

The most commonly found structure for the water heaters is that of a metallic boiler composed by a top and a bottom cap that are shared among all the products and a central shell ring that varies in length depending on the required capacity. The boiler is enamelled internally and enclosed in a white-varnished shell. Polyurethane (PU) foam is used both to lock the boiler with respect to the encasing and to guarantee thermal insulation for higher performances. The heating process is provided by an electrical resistance longitudinally across the boiler and controlled externally by the user via either buttons and knobs or through an electronic display interface found on a plastic cap on the bottom.

The Production System

The plant in Genga is one of the few ones in the Ariston Thermo Group that deals with the entire realization of the product: starting from metal sheets and ending up with the packaged finished product ready for the market. Despite the high specialization of the production (as already explained the product range is wide, but most of them share the same processes) the plant layout is not organized as a typical flow shop or as a perfectly integrated assembly line. This is due to the fact that the plant is relatively old and its output rate has increased enormously over time, therefore new productive departments have been implemented over time pandering the spaces available and sometimes enlarging the structure. Most products follow a predefined path through the various departments through a set of conveyor chains passing above the machinery: in its lifetime inside the plant a product crosses the plant multiple times back and forth as the layout of the departments is not optimized for productivity, but a result of the gradual evolution of the system through time.

The vast majority of the products shares the same order of processing, here follows a brief explanation of what operations are performed by each department:

- Shearing and press-forming. The core boiler is composed of a top and bottom cap which are generally identical for all the range of products which are press-formed and then embossed.
- Welding. Here the central shell ring is formed via calendering and then longitudinal welding, the diameter of the cylinder is generally constant among the range of products and only its length varies according to the required capacity. The shell is then MIG welded to the top and bottom caps.
- Enameling. The internal walls of the boiler are sandblasted and enameled with powdered that is later vitrified in dedicated furnaces.
- Pre-assembly. The external casing is formed via a calendered central cylinder bordered to a top and a bottom cap. The boiler is fixed in the enclosing structure via the mounting bracket.
- Varnishing. Here the external shell is varnished using electrostatic powder. Polyurethane is then injected in the interspace between the boiler and its encasing both to block relative motion of the parts and improve the thermal insulation of the system.
- Final assembly and packaging. The two final lines are used to assemble the remaining components which in this case can vary widely depending on the product. The finished product is then packaged and sent to the stock through conveyor rollers.

The Automations

The plant in Genga is a highly automated one. This is the result of multiple aspects that come into play. On one side is the fact that the infrastructure of the plant is relatively old and there is no possibility of significatively modifying the layout of the departments and of the production lines in a way that is economically sustainable for the company. Part of the automations is therefore required to substitute the human in places where an operator cannot work safely nor efficiently. On the other hand is an economical parameter: the cost of labor in Italy is comparatively high with respect of that of other countries in the rest of Europe and of the world. Ariston has in recent years fought this cost by bringing part of the production in other countries, often closer to the market (e.g. China, Vietnam, Bahrain, South Africa). But Ariston has also a strong willingness to maintain as much of the production as possible in Italy, where 40% of the income of the company is produced (this is significative in light of the fact that 89% of the profit comes from foreign markets). Automations are therefore required to maintain the transformation costs at a competitive price while working in Italy.

Every year new automations are implemented in the site, but as time passes the level of complexity of such automations increases drastically (the easier installations are often done first). It results that welding process, PU injection, movimentation of products (loading and unloading from the conveyor chain), bracket mounting, flange insertion and screwing and many other operations are performed by robotic applications.

The Implementation of WCM

The implementation of the WCM methodology started from early 2011. The first years have been devolved to the learning of the use of the most basic tools and instruments, to the selection of model areas for each pillar and to the restoring of the basic conditions of the departments and machines.

After 6 years of work the plant has now reached a total of 49 points, placing it very close to the awarding of the broze level. Despite this, many challenges still have to be faced, as the old infrastructure and layout imposes serious constraints on the development of the Safety Logistics, and Worplace Organization Pillars.

The WCM Methodology

The World Class Manufacturing is a methodological approach that was developed starting from the early 2000s so as to provide a rigorous set of tools and techniques to face the everyday problematics of the production systems. This focused effort on the improvement of the manufacturing system has become, especially in the most recent years, a necessary requirement for the companies that aim at being competitive in the global market. Similar methodologies were initially proposed and introduced starting from the second postwar in the Japanese automotive industry, most notably in Toyota, where the first of such methodologies, TPS (Toyota Production System), was developed. The TPS is at the very base of the concept of lean manufacturing, i.e. the notion that in order to be competitive on the market, a company needs increase its production while reducing its consumption of resources. The core of the success of the Toyota system, that brought the relatively small company to worldwide success, was not in the implementation of large scale investments to increase the productivity by adopting the newest technologies, but lies more in the reorganization of the workplace activities so as to get more value out of the human operator activities. Methodologies similar to the TPS have emerged and evolved during the years, but their focus was mostly in the management and control of targeted projects: examples of this are the TPM (Total Productive Maintenance) which focuses its attention on the maximization of the efficiency of the individual plants and installations, or the TQM (Total Quality Management) which instead aims at managing and improving the quality of the finished product.

The WCM is a new approach with the ambitious goal of integrating all of the above methodologies in a global and standardized set of tools that draws the best of the other methods such as lean manufacturing, TPM, TQP, and so on. The core objective at the hearth of the WCM methodology is that of achieving constant improvement of the productive system, a concept normally referred to as Kaizen which means improvement in Japanese. Despite its origins founding deep roots on the manufacturing revolution that took place in the early 50s in Japan, the WCM distances itself from it in the tentative of getting closer and more palatable to the much different occidental culture of industrial production. Another core component of the WCM methodology is the application of the logic of Just In Time (JIT) production, i.e. the concept that a leaner manufacturing can be achieved by producing only what is actually consumed by the market: this can avoid the accumulation of finished products in the warehouses. The WCM has been also developed as an integrated methodology, with shared logics and concepts that can be implemented among the various business units of a company so as to improve the total productive performance. The TPS ideals are therefore extended and integrated to all of the different departments of the manufacturing of a company. This concept of integrating different functions of the production is of paramount importance as often, different divisions of the company might find themselves in competition with each other: the WCM tries instead to create a shared vision so that the reaching of the objectives can be achieved via a sinergy of all the divisions.

The WCM tools and techniques are based on a series of stronghold points that find their roots in the Japanese methodologies of the past century:

- Focus on constant improvement of the production system
- Involvement of all the people (from the managers to the operators) as the key to achieve the constant improvement
- Safety has to be always the primary concern, and the reaching of zero accidents is the goal
- The methodology are not oriented at improving individual projects, but rather they aim at revolutionizing the approach to work
- The solution to problems has to be found by attacking their root cause and not by mitigating its consequences
- Waste (Muda in japanese) is not tolerable, both in terms of the discard of defective products and in terms of the use or misuse of the time of the operators
- Achieving of zero accidents, zero quality defects and zero finished product stockage and zero breakdowns of the machinery
- Identification and highlighting of the errors with the purpose of creating error proof processes
- Adoption of preventive and predictive techniques of maintenance to avoid production losses due to breakdowns caused by lack of maintenance

These are just a few examples of all the important core concepts of WCM.

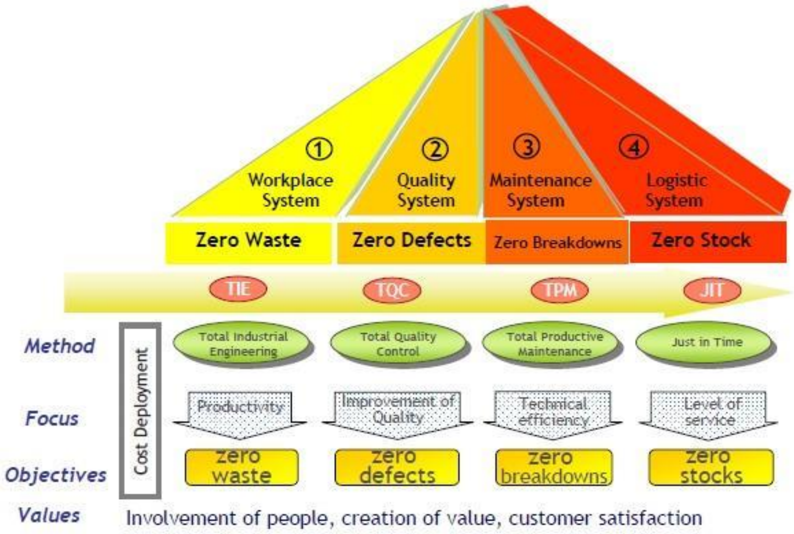
Evolution of the WCM

Since its initial ideation by Schonberger, the WCM has incorporated through time more and more techniques associated to the various manufacturing technologies. Most of such technologies were not directly developed by Schonberger, but rather they were already present in other manufacturing systems. The main achievement of WCM was in the unification of so many different concepts and ideas, that were often associated with conflicting aspects of production, under a unique methodology. As time passes, a growing number of instruments is now associated with the WCM methodology.

1980	1986	1989	1991	1996
JIT/Kanban	JIT/Kanban	JIT/Kanban	JIT/Kanban	JIT/Kanban
TQM	TQM	TQM	TQM	TQM
TPM	TPM	TPM	TPM	TPM
TQM	TQM	TQM	TQM	TQM
Cellular Manufacturing	Cellular Manufacturing	Cellular Manufacturing	Cellular Manufacturing	Cellular Manufacturing
MRPII	MRP II	MRP II	MRP II	MRP II
	CIM	CIM	CIM	CIM
	Empowerment	Empowerment	Empowerment	Empowerment
	Kaizen	Kaizen	Kaizen	Kaizen
		Technology Managment	Technology Managment	Technology Managment
		System Managment	System Managment	System Managment
		Training	Training	Training
		Total Material Flow	Total Material Flow	Total Material Flow
		Desing Management	Desing Management	Desing Management
		Manufacturing Strategy	Manufacturing Strategy	Manufacturing Strategy
		Perform Measures	Perform Measures	Perform Measures
			Benchmarking	Benchmarking
			Structure & Culture	Structure & Culture
			Innovation Strategy	Innovation Strategy
			Corporate Strategy	Corporate Strategy
			Group Technology	Group Technology
			Batch Size Reduction	Batch Size Reduction
			Non Financial Measures	Non Financial Measures
				Simultaneous Engineering
				BPR
				Vendor Quality
				Supplier Partneship

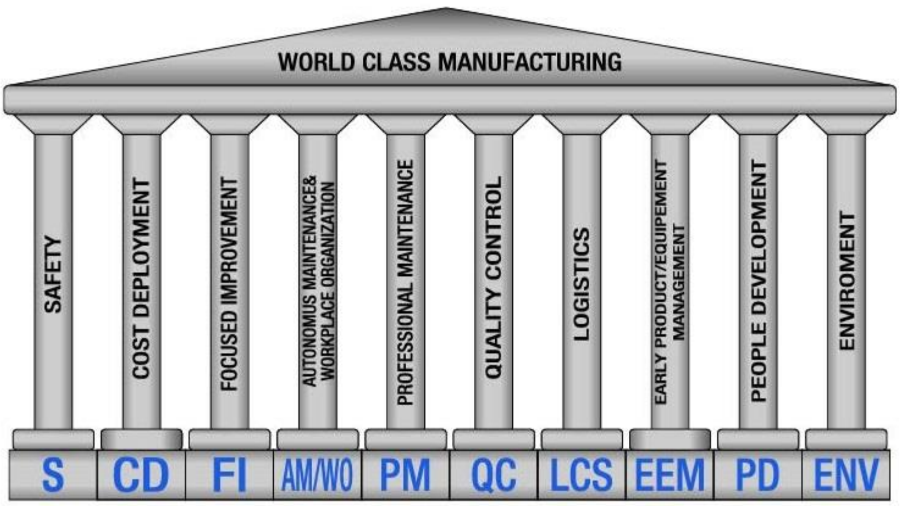
A milestone in the history of WCM was the intervention of Professor Hajime Yamashina from the Japanese University of Kyoto that collected many of the Japanese manufacturing techniques and tools and adapted them to the Occidental culture. In 2005 FIAT, which is now know as FCA, is the first large manufacturing company to implement WCM under the guidance of Sergio Marchionne.

The crucial difference between WCM and any other methodology lies in the different approach to cost reduction. The traditional techniques of industrial accounting are not able to predict the relationship between each activity and the cost reduction it can bring. The WCM, instead, approaches the problematic with a methodology known as Cost Deployment, according to which it is possible to determine a specific prioritization of interventions to achieve a cost reduction. The cost reduction is possible because wastes and losses are put in relation with their root cause: this allows to intervene "surgically" at the origin of the losses by, for instance, implementing an improved technical solution. This allows to clarify the relationship between the application of continuous improvement and the achievable results in terms of costs and benefits. The criterions used to choose which interventions have to be prioritized are those that bring the highest benefits: reduction of the number of accidents, reduction of the defective units produced, reduction of the stock levels, reduction of the number of faults and breakdowns...



The WCM Structure

The desire of WCM for being a unifying methodology that can be applied to all the different areas and divisions of the productive system without creating conflict or competition among them is perfectly represented by the way in which it is structured. The WCM approach subdivides the various functions of the productive system in pillars: 10 pillars are managerial and 10 pillars are technical. The pillars are the structural elements of the so called "WCM Temple". Each pillar contributes equally to the overall solidity and strength of the temple, and this symbolizes the fact that the different areas and functions of the productive system have to be developed simultaneously and in parallel to guarantee a strong foundation. Each pillar represents therefore a specific area or division of the productive system, and each pillar contribute to the goal of continuous improvement with a set of tools and techniques specifically developed for its area of interest.



The goal of the 10 managerial pillars is that of involving the management of the plant and of the company in the implementation of the methodology, and in the adoption and diffusion of the standards and best practices developed. The 10 managerial pillars are:

- Management commitment
- Clarity of objectives (Key Performance Indexes)
- Route map towards WCM
- Allocation of highly qualified people to model areas
- Commitment of the organization
- Competence of the organization towards improvement
- Time & budget
- Level of detail
- Level of expansion
- Motivation of operators

The technical pillars are instead devoted to the continuous improvement of specific areas of the practical production. Their goals and activities are listed below:

- Safety (SAF): continuous improvement of the safety of people in the plant, with the goal of reducing the number of accidents, spreading the culture of prevention, and improvement of the ergonomics of the workplaces
- Cost Deployment (CD): analyzes costs and losses to identify systematically their sources and root causes (both in the productive and in the logistic systems), directs the efforts of the other pillars toward the projects that bring the highest economical advantages and examines the potential benefits of all the developed projects
- Focused Improvement (FI): defines the priorities of intervention based on the causes of losses identified by the Cost Deployment, aims at eliminating the inefficiencies in the plant by drastically reducing the causes of waste, promotes the development of the competences specific to problem solving
- Autonomous Activities (AA) whose goal is to achieve the continuous improvement of the equipment and of the workstations, which is composed of the two sub-pillars of Autonomous Maintenance (AM) that aims at improving the efficiency of the machinery by adopting maintenance strategies that revolve around the activities of the operators and not of specialized personnel, and of Workplace Organization (WO) which focuses its attention on improving the workplace safety by increasing the ergonomics of each station and on reducing the economic losses due to the unbalancing of the activities in the stations, especially for what concerns the NVAA (Non Value Added Actions) performed by the operators

- Professional Maintenance (PM): aims at constantly improved the efficiency and the performances of the equipment and machinery installed in the plant by applying advanced techniques of failure analysis focused on the identification of the root cause, and facilitates the cooperation between operators and manutentors towards the goal of reaching zero breakdowns of the equipment
- Quality Control (QC): constantly works toward improving the quality of the product to satisfy the requirements of the market by ensuring the absence of defects in the products, and by improving the training of the operators
- Early Equipment Management (EEM) and Early Product Management (EPM): optimizes the delivery time and costs of the new installations and the characteristics of the new products respectively, by planning and respecting the schedule of the new installations, ensuring the reduction of start-up times for the new machinery and by reducing the Life Cycle Cost (LCC) of the equipment
- People Development (PD): aims at the continuous improvement of the professional competences of operators and employees by creating a structured system of training and formation
- Environment (ENV): focuses on the reduction of the environmental impact and on the avoidance of energetic wastes, ensures the compliance to the environmental laws and promotes the culture of energy saving and waste avoidance.

The Tools of WCM

One of the most important aspects of the WCM methodology is in the involvement of people. All the functions of the plant are required to promote and to participate in the projects and in the activites: the managers, the pillar leaders, the pillar teams, the line managers, the maintainers, and the operators. Constant improvement can be achieved only when everyone is focused towards reaching the goal of making a change inside the plant, no matter how small it is.

A set of tools is taught to every member and worker of the plant so as to create the basis for continuous improvement:

- Development of priorities: the best way of improving the efficiency of the plant is in the ability not only to solve problems, but also to classify problems according to the degree to which they affect the production. Priority assignment is a core aspect of the WCM approach, as it is for example shown by the fact that the Focused Improvement Pillars directs the working efforts toward the largest causes of monteray losses that have been identified by the Cost Deployment Pillar
- Systematic clarification of the objectives: reaching a particular goal or result is possible only if the people working to achieve it have a clear understanding of its importance and on the intermediate steps that have to be taken to reach it

- Use of sketches: drawing a schematic representation of a problem is often the best way to communicate in a technical environment, so the WCM methodology encourages the use of sketches to represent and explain problems
- 5W+1H: What? When? Where? Who? Which? How? These six questions are at the base of the solution of every issue. Too often, when trying to solve a problem, someone has already an idea of what the cause and consequent solution could be, but because of this preconception he forgets to actually examined with an incrased depth the true origin of the issue, and he is not able to determine the root cause, i.e. the criticality thatn has to be resolved
- Root cause identification and 4M analysis. Again, to solve a problem it is necessary to delve into its depth until finding the root cause that originates it, otherwise any other solution can result to be just a temporary fix that cannot bring improvements in the long run. The 4M analysis is another tool that works in the direction of determining the root cause: the possible causes of an issue are classified according to the cathegory in which they belong, so either of Man, Machine, Method or Material. Then, one by one, the possible causes are examined and eliminated until the problem is solved
- Problem description is another key point in the development of the skills required to achieve constant improvement. When a problem is identified, it has to be clearly explained to everyone: the more details and specifics are given, the easier can be for someone working on it to determine the cause and the solutions
- Avoidance of human error. Human error is a common source of issues in the manufacturing environment, it would be foolish to expect everyone to work always perfectly in any given moment of the shift. However, certain countermeasures can be implemented with the purpose of reducing the number of errors: standard procedures can be set and taught to people, operators can be trained to better understand the manufacturing processes, or it can sometimes be possible to create error proof workstations via the implementation of specific technical solutions that make human error impossible during the execution of the activity

The Auditing System

The WCM Association provides an auditing system to certify the level of success that each plant has reached in its attempt to improve its productive system. The audits are periodical checks that take place twice every year: an external auditor visits the plant and verifies the work done by the employees to implement the WCM methodology.

At the end of each audit, a score between 0 and 5 points is assigned to each of the 20 pillars, thus giving a final score to the plant that ranges between 0 and 100. The score certifies the results achieved by the plant and is also used as an incentive to keep improving, and creating a healthy competition between the different plants of a company. Each point is assigned by respecting particular criteria that are relative to the area of attention of the pillar.

Ariston Thermo Group and the WCM

The Ariston Thermo Group started adopting the WCM methodology in 2010 with the purpose of increasing its competitivity on the market by reaching the excellence level for what concern manufacturing and production systems. 13 plants are currently involved in the project. The plant in Genga has recently reached 49 points on the auditing score system, and aims at reaching the bronze medal soon.

The EEM Pillar

The Early Equipment Management Pillar deals, as its name implies, with every aspect of the design and installation of new machinery and automations in an industrial plant. The WCM methodology provides a wide range of tools aimed at reaching a vertical start-up of the operations through a thorough step-by-step analysis of each phase of the project. From the early phase of pure planning to the latest stages of production trials, every decision is weighted so as to ensure an installation in time with respect to schedule and a quick start-up.

Goals & Expected Results

The start-up time is defined as the time interval between the end of the production trials for a certain installation and the attainment of the full production capacity. It is generally desirable to achieve a vertical start-up, i.e. to reduce as much as possible the amount of time during which the newly installed machinery remains unused or operates below its ideal capacity which is what normally happens during the early stages of production. It is easy to identify some of the reasons why a slow start-up generates losses:

- Not fully operational machinery produces at a slower rate with respect to the desired one, and often this problem is amplified by the fact that it can result in a bottleneck to the operation of downstream installations and a consequent reduction of the overall output of the plant. This represent a loss due to lost production.
- Whenever the installed equipment is unused, even if for a short amount of time, it represents a capital investment that is not generating value and therefore a loss due to capital locking-up. The same applies, for instance, to operators employed to work on the machine.

But while the minimization of the start-up time is an important aspect of each project, the EEM Pillar also needs to take in consideration the complete life-cycle of every installation. Increasing the lifespan of the machines and reducing the life cycle cost (LCC) are two parameters that often go hand in hand: a reliable systems tends to function properly over a longer period of time and this effectively reduces the costs due to maintenance or due to stoppages. Reliability and robustness of a system are a function of a variety of parameters that need to be analyzed independently at each stage of the project. One simply can think of how cost and time-effective could be an installation in which maintenance cycles and procedures are predetermined so as to avoid loss of production due to the failure of critical components. Similarly, a machine has to be easy to set-up, to start-up and to inspect thus reducing considerably the amount of time spent on (respectively) operating the machine and diagnosing problems. It is therefore evident how a careful design that starting from the early phases takes in consideration all of the above aspects is more likely to produce an efficient final result.

Needless to remind that the WCM methodology always puts safety and quality as its highest priorities, and all of the newly acquired equipment always has to comply with the highest safety standards while outputting products of high quality.

The D.R.E.A.M. Approach

As already seen, the WCM methodology often reinforces the strongest and most important concepts for each pillar using acronyms. In the case of the EEM Pillar, the acronym that the designer needs to keep in mind is DREAM:

- Development: the equipment that a factory decides to acquire and employ requires an often considerable investment in terms of time and money. Such investment needs to be carefully pondered so as to insure that it will bring some advantage to the production system. The reasons behind the decision of installing new machines may vary, but the most common reasons are those of increasing the quality standards of the products and/or of increasing its cost competitiveness. All the while, new equipment can replace older instrumentation thus increasing the safety of the operators and the operability conditions. Cost competitiveness improvement can arise again from various sources, but in general it is achieved by reducing the transformation cost of the operation by reducing manpower employment.
- Reliability: the longer the lifespan of a machine, the higher the payback it guarantees since the initial investment is spread over a longer period. The utilization of risk assessment and evaluation tools such as FMEAs (Failure Mode and Effect Analysis) is therefore crucial during the detail design of a project as they allow to predict and anticipate future problems which could arise.
- Economy: it would be ideal for a plant to always acquire the most advanced equipment, with the highest efficiency and standards of operation, but at the same time it would be extremely costly. The investment on new installations need always to be adequate to the need of the company. Every investment must pay for itself over a payback period that is aligned to the economical availability of the plant. The only exception to this is, again, represented by the particular situation in which installations are required to improve the safety of the operators, by removing unbearable risks. In any case, the EEM Pillar must work on selecting the equipment that is most cost effective, both in terms of initial and running costs. Often, choosing the cheapest solution to a given problem results in higher running costs over the years and therefore a preventive analysis needs to be performed.
- Availability: the new installations have to be able to meet the business requirements. Often new machines are installed in a plant with the goal of increasing the productivity or the quality and such goals have to be met.

- Maintainability: strictly linked to the concepts of reliability and economy is the idea of maintainability. When the machinery is designed with the goal of make it easier to operate, access, clean, inspect, check and maintain a longer lifetime of the installation is likely. All the same, the time an operator requires to perform the actions just mentioned is greatly reduced, and this improves the cost effectiveness of the workforce.

Life Cycle Cost (LCC)

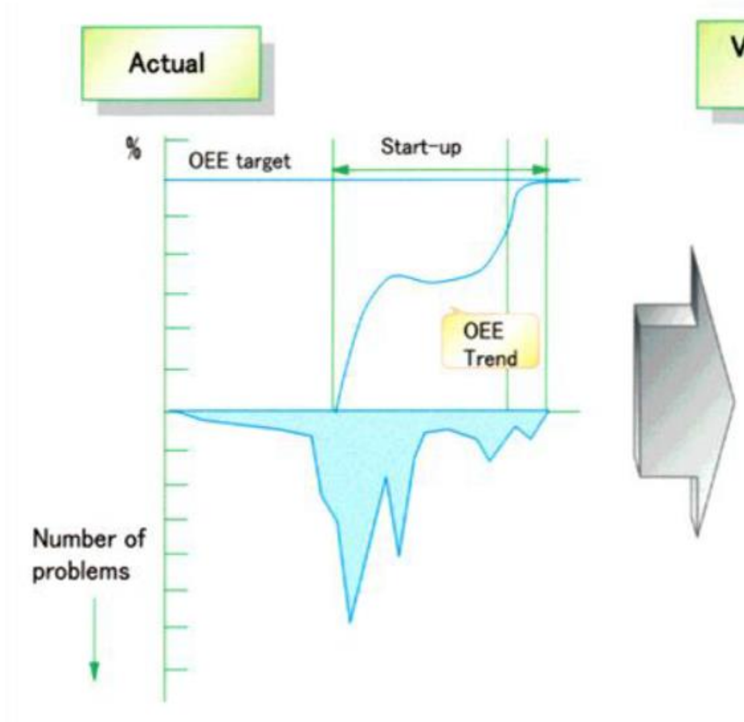
It has already been stated earlier how the reduction of the life cycle cost of every new installations is one of the highest priorities for the EEM Pillar. But which ones are all the costs that need to be taken into consideration while computing such a parameter?

- Initial costs (IC): here are listed all of the costs that occur during the design and installation of a new machine. The price of the commission is the first important number that comes to mind, but it's far from representing the total of the ICs. A careful design must include the cost of the people involved in the project and the cost of lost production that can happen during the phase of installation (especially when replacing older equipment) or during the early phase of production (where the machine might be underperforming while undergoing proper set-up and calibration).
- Operating costs (OC): once the installation becomes fully operational and until it is dismissed it incurs in a series of operating costs which are of course lower with respect of the ICs, but only in the short period. Their significance has to be evaluated in the long run. Such costs are the cost of the manpower required to operate the equipment, the cost of the energy necessary to run it and of the consumable material it may need (lubricant for instance). In the manpower cost one needs not only to consider the number of operators and the amount of time they work on the machine, but also the time required to inspect, clean and maintain the installation. At the same time, it could be evident since the early stages of design if a solution might require more maintenance than another.
- Disposal costs (DC): the cost of dismissing some machinery has also to be taken into account. Disposal costs may vary considerably from application to application and might have a different weight depending on the company needs in a certain moment. On one side is the impact on the infrastructure of the plant that a certain installation has, on the other there might be a company need to keep the production flexible over time (a machine could be displaced to another production plant or there might be a need to modify it so as to be able to process a wider range of products). A typical example of this is the use of robotic anthropomorphic arms that gives more flexibility at dismission as opposed to cartesian automations which have lower chances of being recycled.

The minimization of the overall cost of the installation is the goal for the EEM Pilar, as this directly implies reaching the maximum profitability of the plant and a shorter payback time. All of the above parameter have to be carefully weighted: often a cheaper machine can bring higher running or disposal costs and the more expensive solution might be more indicated.

Cost of Modifications

One of the main reasons why problems emerge in the late stages of the implementation of a new project is the lack of a rigorous methodology during the earlier stages. Minor design flaws (often simple distractions) during the early design of a machine, can result in processing difficulties that appear only at later stages (installation or start-up), at which point any further modification will require some investment and a delay in the scheduled start of production. Most installations are commissioned to specialized external companies that provide the know-how in creating and deploying a technical solution for the requirements of the plant. On the dark side, an external company has almost always a lack of knowledge of the details of the production system of its customer. As a result, any miscommunication of the plant needs to the machinery supplier may lead up to design mistakes that can be detected and corrected only in later stages of work. It is easy to see how this has a negative impact on the project: the later a problem is discovered, the harder and the more expensive it will be to correct it. For example, problems can become evident during the construction and initial testing of a machine, which would lead to a setback to the detailed design stage causing a delay of the project and an increase of the costs due to remanufacturing of the modified components. Another scenario could be the one in which mistakes are found during the installation of the machine: errors in the definition of the machine layout or in overseeing its influence on the plant infrastructure represent a huge problem as the expenses due for modifications at such a late stage of the project become huge. This discourse doesn't just apply to design mistakes: any idea or suggestion on how to improve the performance of the installation is most welcome during the early design, where it could me more easily implemented without requiring huge modifications to the project or even the remanufacturing of components.



The best time for modifications in the design is therefore in the early stages, where everything is still debatable and in definition. As the project progresses towards detail design, construction and then installation the cost of further modifications keep rising, often making further changes uneconomical. At the same time, once a certain concept and layout of the machine is defined, the possibility of improving the performances of such design decreases over time: every suggestion that comes in during construction or installation will inevitably bring delays and an increase in costs, both of which might not be bearable at such moment.

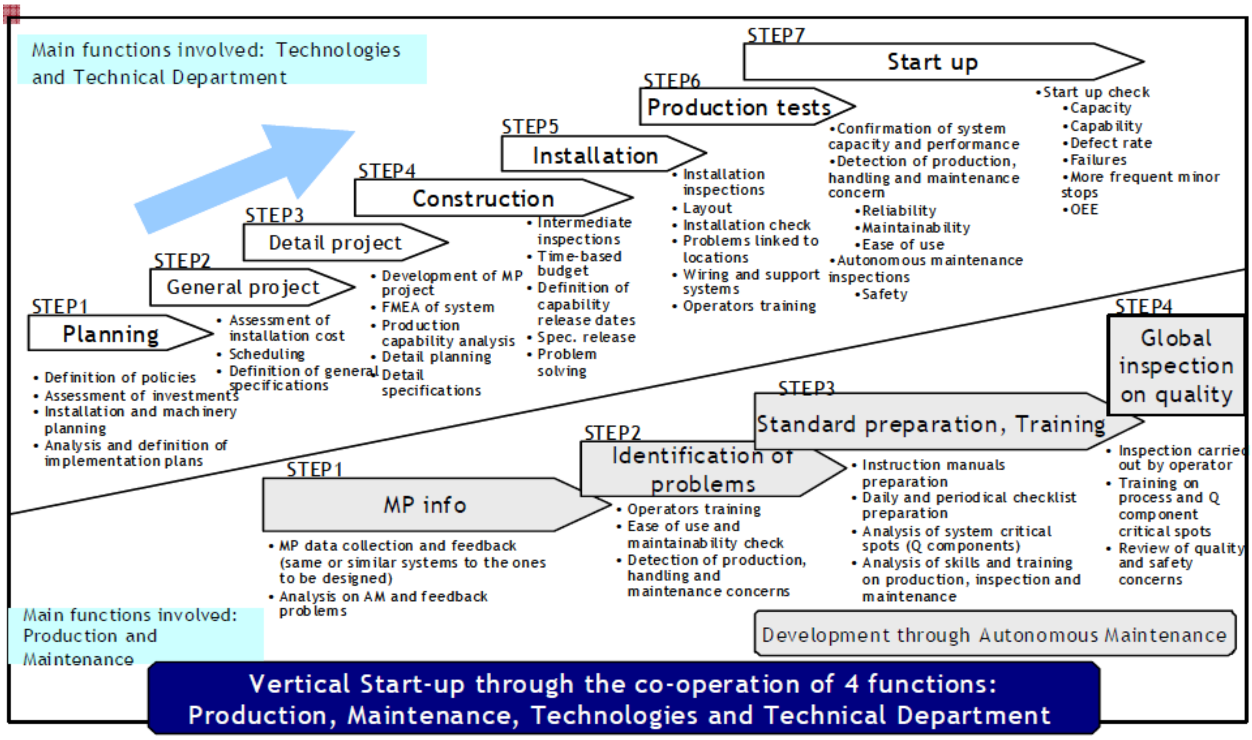
New Product Launch

A particular scenario in which the EEM Pillar plays a fundamental role is that of a new product launch, a situation that involves all the departments of a company: the marketing, the management, the product development, the manufacturing and so on. The development of a new product requires a carefully coordinated effort of the company to satisfy the ideal time to market. The industrialization department, and so the EEM Pillar, needs to make sure the plant is ready on time for the start of the new production, which in most cases requires some adaptations of the owned machinery or the installation of new equipment required to obtain certain characteristics in the final product. Delivering the required manufacturing system is certainly the highest priority of the EEM Pillar during the launch of a new product, but it's not the only one. The industrialization can always give important feedbacks during the product development about the type of processes that need to be adopted and the materials that can be employed. Product development does not follow a one way direction from the marketing and management to the manufacturing and through the technical department, but it's a process in which the flow of information is bidirectional. The EEM Pillar can always provide useful feedback on how to design a new product so as to make it easier to manufacture with the existing machinery available in the plant.

The 7 Steps of EEM Pillar

The WCM methodology is structured so that it can be implemented step by step by each department of the plant, with a gradually growing level of difficulty. This can be easily seen for most pillars such as AM (Autonomous Maintenance), PM (Professional Maintenance) and WO (Workplace Organization) where the initial steps always require a clean up of the work environment, a restore of the basic conditions and a reorganization of the basic activities that allow to maintain and then gradually improve such conditions over time.

The story is different for the EEM Pillar, as the 7 steps procedure proposed by the WCM approach has to be followed through entirely for each new project. Each of the steps regards one of the core phases of the equipment project, starting from pure planning until reaching the production start-up. For each step, a set of instruments and procedures is proposed so as to support through the design of the equipment, in particular the EEM Pillar is responsible for creating and updating verification checklists for each step. Despite being a relatively simple and inexpensive tool, checklists can be tremendously effective when reviewed at the end of each step to evaluate whether best practices and the highest standards have been respected during the activities at that stage of the design. Every step of the project has its own set of checklist items that represent a collection of ideas and suggestions for improvement from virtually anyone that is even remotely involved in the work. New items are appended to the lists in each new project, since every new installation is expected to reinforce the knowledge of the pillar. New information does not only come from new ideas, but also from the recognition of previous mistakes: checklists ensure that even the smallest mistake done in the past is not repeated in future projects.



Step 1: Planning

The successful realization of a project requires spending a certain amount of time on a preliminary analysis of its various aspects. What is the intended goal? What are the benefits the company expects from a successful project? What is the budget and the investment plan? What problems can emerge at later stages of the project? These are the basic question around which the planning stage revolves around.

The company always has a set of long and short-term objectives for the plant to reach. Such objectives are generally the increase of one or more parameters such as product quality, plant safety, product output rate or reduction of the transformation cost: every new proposed project must be consistent to such vision. Multiple ideas can be on the table at any moment and determining which project to prioritize is not always trivial because of the many, often conflicting, factors that compete. Once a project has been selected among others, its objectives and expected results have to be clearly stated so as to establish the first requirements.

The planning step enters its core phase with the determination of the project inputs. The task the equipment is required to perform has to be analyzed and broken down to the simplest individual operations. A flow chart can therefore be drawn to represent the basic principle of operation that is expected from the machine. Often the way in which the task is performed and the order of each operation is imposed by the process, but in some other cases modifications or improvements are possible and have to be evaluated: this is especially important when the project revolves around the replacement or the revamping of older machinery.

Other project inputs come usually from the other Pillars of the plant. As explained in the introductory segment about WCM, every Pillar is responsible for the collection, sampling and analysis of valuable data. Such tables and matrices can be helpful in making sure the new installation tackles with as many problems as possible. Just as a few examples:ù

- The EWO database from the PM Pillar and the data collected by the FI Pillar on micro-stoppages can provide valuable information on which technical solutions can be adopted to avoid common problems (if the solution to a problem is known, there is no reason for a new project not to try to tackle it),
- The QC Pillar's matrices can point out all the quality defects that emerge from the process or from its individual operations, so that a study can be made to assess if there is margin for improvement,
- The ENV Pillar can give feedback on the energetic inefficiencies of the plant that a new installation can help reduce.

But the statement of objectives and required inputs, per se, is of little use without instruments to actually measure the final results. Key Performance Indicators (KPI) are values used to measure the successful reaching of the goals that have been set. Some KPI can monitor the overall result, while some other can be established so as to verify whether certain parameters are in a given target. Each Pillar uses a set of particular KPIs useful for monitoring its results, in the case of the EEM Pillar, the most prominent KPIs adopted are:

- OEE (Overall Equipment Effectiveness) is a very strong parameter that comes from the aggregate of three independent measurements: availability, performance and quality. The availability is the percentage of time the equipment is actually working with respect to the total amount of time it is expected to be working. It therefore gives an indication on the robustness of the machinery to failure and stoppages, but can also provide insights on the amount of time necessary for the initial set-up and other routine operations such as calibration and so on. The performance is the production speed of the installation with respect to its nominal production speed, and takes into account temporary decreases in the installation production rate. The quality measurement represents which percentage of the total output products have been produced with the required quality. Generally the quality index used is the First Pass Yield (FPY), that is the ratio of correctly processed units being outputted to the total number of inputted units. The OEE is obtaining via multiplication of such three parameters.
- Production Capacity, i.e. the production rate the equipment is supposed to satisfy which generally depends on market request of the product. In other cases, a particularly high production capacity might be required if the machine is intended to be working for a lower number of hours.

- Start-up time was already described above. When used as a KPI an interval of time between installation and full-rate production is given as an objective.

The economical aspect of the project has to be taken into account. A investment plan, with a certain assigned budget has to be provided so as to guide any further decision about the design features.

Last, but not least, deadlines for each macro-stage of the project have to be defined. This is crucial for many different reasons. The company might be expected to launch a new product within a certain time schedule and therefore have a tight requirement to begin production before a given date. On the other side, interventions on the plant will usually have an effect on production: in most scenarios, the incoming equipment is going to replace older machinery or is going to be installed on a production line that already hosts other operations. When this is the case, the best time to proceed with a new installation is during a production stop (which usually can occur during summer in August or around Christmas time) and this implies that every design step has to be timed so that the machine is ready to be deployed in during such stops. A delay of even just a few days on such windows might require the whole installation process to shift by months. A project map, usually a Gantt chart, has then to be laid out to impose some macro-deadlines for the principal milestones.

As anticipated, the WCM methodology requires completing each step with a review of the work done and an analysis of the advancements made. Here follows an example of the checklist items that have to be verified before advancing to step 2:

- Are all of the project inputs available? (product characteristics, production volumes, scheduled time, budget)
- Are the efficiency objectives of the project been identified and clearly defined? (OEE, start-up time, cycle time)
- Have the quality objectives of the project been defined?
- Has the level of required autonomy of the application been defined?
- Have the safety risks related to a malfunctioning of the automation been identified preventively?
- Has an initial, rough layout been identified and defined?
- Has the plant been involved in the activities?
- Has the project development team been created?

As of 2018, the plant in Genga has 181 elements in its step 1 checklist. New items can be added to the checklist as possibilities for methodology improvement are detected.

Step 2: General Concept

In the second step, the layout and concept of the equipment to be installed is defined from a general point of view. Here the overall specifications and characteristics of the machine are identified and written on the technical specification document provided to the equipment supplier. The most important aspect to take in consideration during step 2 is that of achieving a strong front loading. Front loading means trying to define as many required characteristics as possible at the beginning of the project: the goal is of course always that of trying to minimize the number of modifications that will be required at later stages. Every time a particular technical characteristic is oversighted, its later addition to the specifications of the project will inevitably cause some delay or increase in costs: this can be due to the fact that either modifications to the existing blueprint of the project have to been evaluated or that the supplier of the equipment will charge the cost of late modifications to its initial economical offer.

Front loading is therefore a crucial activity for the plant and a lot of effort has to be spent on the determination of the characteristics of the desired machinery. This is no work for a single person, nor for the EEM Pillar alone, but the coordination of as many people as possible can bring far better results. A good starting point for the EEM Pillar is performing an internal benchmarking in which an a analysis of the equipment already present inside the plant can give hints on how to improve the design of the incoming installation. It is often the case that the plant already owns machines that are performing all or part of the operations that the new project is required to perform (e.g when the project aims at an increase of production rate or at replacing older equipment). In such instance the work of writing a technical specification is simplified, since there is already at leasts a basic knowledge of the principles of operation, of the performances and of the most commonly found problems of the equipment. But this is not always the case, a new machine may perform a totally different set of tasks requiring a larger effort in the individuation of the desired characteristics and of the performance objectives. In companies producing on more than one plant, the benchmarking activity needs also to be made externally by an analysis of the technical know-how of other plants. An important aspect of the benchmarking is the review of the MP-Infos of each plant. MP-Infos are the second fundamental tool of the EEM Pillar together with the use of checklists: here follows a brief digression required to explain what they are and why they are so important in the definition of the specifications.

MP-Info

A Maintenance Prevention Information (often referred to as MP-Info or MPI) is a document providing valuable information on how to reduce maintenance interventions on certain equipment. Whenever a solution to a recurring problem is found, it is optimal to record it as a best practice standard in an MP-Info, so that the information on how to solve a certain problematic (it does not matter how small) is handed down in the plant. In every WCM company the MP-Infos are shared among the plants so that common problems can be solved by everyone. It is easy to imagine that solutions to major problems are often recorded and shared by most companies throughout their plants, but the MP-Infos are a tool that allow even the smallest technical solutions to be shared. MP-Infos can regard both process and product, meaning that the product development department can tap into them to improve product design. The continuous improvement, even through small changes, is a core element of the WCM mentality and the standardization of solutions can simplify a lot the task. For the sake of example, a typical MP-Info database can contain anything, from advanced technical details on how to correctly position a certain class of sensors to improve their performance to trivial solutions that can simplify keeping the equipment clean such as lexan screens to avoid critical zones being excessively exposed to dust or processing waste.

The MP-Info collection represents therefore a source of valuable information for the EEM Pillar as it basically contains a huge amount of detailed technical information on how to avoid a certain problem will come up over time, and as stated over and over, the more problems are solved at the beginning of the project, the lower their impact will be in the future.

After this preliminary work of analysis of previous knowledge, meetings are organized with the participation of members of all the other Pillars. Such meetings are used as an additional brainstorming tool to define a preliminary concept and layout of the machine and to understand how the choice of different solutions can impact the final result and the rest of the plant.

An analysis of possible suppliers has then to be performed. The plant has usually already a history of collaborating with certain suppliers and can therefore analyse which of them might be most suitable to design and build the desired equipment. Ideally, the technical solutions proposed by each supplier that is consulted have to be aligned as the EEM Pillar has defined the concept and layout of the machine and its technical characteristics. In practice this can be hard to achieve in situations in which the level of complexity of the project is igh. In the current state of the industrialization world, many of the new installations are extremely automated and as the equipment design becomes more and more complex, the examination of different technical solutions often requires considering different supplier with different technical proposals because of their different technological specializations. The automatization of a certain process or operation can be achieved in multiple ways, each one of which usually has a set of suppliers that is most indicated for it. The choice between the usage of an anthropomorphic robotic arm or a cartesian robot is a common example as some suppliers are more competent in using one of the two solutions. But even when a first “skimming” is done, one can identify further details such as the use of a vision system and its level of complexity or the possibility of implementing a collaborative robot that further help in the search of the best supplier for the work. Multiple suppliers have to be consulted for a price quotation of the project so that a comparison between different economical offers is available.

The choice on which supplier to order from is a purely economical one, but it does not come from the sole comparison of the quotations on the paper: a much wider range of parameters has to be taken into account. First of all it is necessary to verify that the offers are aligned with what established in the initial budget plan, usually the management of the company will proceed with the investment only if a certain maximum payback period is guaranteed. Second, in the final decision it becomes fundamental the calculation and comparison of the LCC of each of the proposed solutions. Initial, operational and disposal costs of each of the alternatives needs to be evaluated and only this parameter allows to correctly identify the best offer.

A risk analysis is also suggested: a preventive analysis of which problems can arise at various stages of the project and of how likely they will manifest can bring some interesting insights in understanding whether a particular technical solution, or a particular supplier, can generate problems at later stages and additional costs and delays with them.

The second step concludes with the choice of the definitive concept for the machine and of the supplier that will design and manufacture the equipment. Before proceeding to the third step, the checklist of the second step is analyzed, reviewed and, if needed, updated. Here are some example of the items that can be found in the checklist of step 2:

- Have the problematics and criticalities of any similar installation in the plant been identified and documented so as to request focused improvements for the new project?
- Has the possibility of implementing predictive maintenance systems in the insallation been evaluated?
- Has any simple solution been taken in consideration with the aim of improving the reliability and the maintainability of the equipment?
- Has the possibility for the equipment to automatically perform functions of self-cleaning, control, diagnostics or lubrication been evaluated?
- Has the environmental impact of the project been evaluated?
- Are there any problematics related to the connection of the new equipment with the upstream and downstream processes?
- Is it necessary to modify the processing tolerances for the new equipment?

Currently, the plant in Genga has 578 elements in its step 2 checklist.

Step 3: Detail Design

Once the supplier has been selected, the order is sent, together with the official technical specifications document. The correct compilation of the technical specifications is crucial as the supplier will use it as a reference during the design phase: from this point on, any modification the plant will request the supplier will almost always imply an increase of the costs and some delays. Writing the technical specification requires then again to delve into the MP-Info database, this time in search for MP-Infos with all the standards adopted by the plant. A common problem in the design of the equipment for a plant is that details which have not been clearly specified in the order lead the supplier to an excessive liberty in decision making on such details. Assuming that the developer will always come up with the best solution to any problem does not represent a robust methodology, so the EEM Pillar has to try to anticipate as many issues as possible.

While during step 2 the definition of a general concept of a machine drew lines on the general characteristics expected from the machine such as:

- Required quality standard
- Required production rate
- Cycle time
- Position in the plant
- Layout and maximum dimensions
- ...

now, in step 3, the requests have to be much more detailed and common specifications can be as the following:

- Equipment standardization: use of components coming from certain producers only so as to reduce the obsolescence risk, reduce the number of parts stocked in the maintenance storage of the plant and limit the requirements for additional training. A common request could be that of using PLCs, motion controllers, electronic parts, manipulators, vision systems, vacuum and pneumatics components from certain suppliers only.
- Application of standardized labels to functionally identify the role of each component so as to simplify the inspection, check and maintenance of the equipment.
- Use of lexan panels to protect from dust and other contaminants zones which are critical or that cannot be easily reached during normal cleaning. The same can hold true for zones in which pressure gauges or other measurement instruments are found so that the functioning of the machine can be checked rapidly.

Despite the supplier now has all of the required technical informations and specifications to develop and design the solution by itself, the EEM Pillar should collaborate and intervene when required to guarantee that the project runs smoothly and without problems. Regular meetings with the supplier can be organized to keep in check the status of advancement of the project while discussing advanced features of the machinery as it becomes more and more defined over time. Again, meetings and brainstorming sessions can be organized to discuss the details of the project. Important suggestions can come from other Pillars or even from the operators that will operate that equipment (or that maybe have worked with similar equipment in the past). The most important verifications at this point of the design will revolve around 6 core points:

- Safety is always a priority. Any new installation has to be compliant to the latest laws and standards. As the design progresses it becomes evident which situation can represent a safety concern
- Quality of the outputted product is a function of even the smallest characteristics of the plant. During step 3 it is possible to tamper with the details of the installation so as to ensure the required standards of quality

- Maintainability is another important aspect to consider: the higher is the amount of time a maintainer needs to spend on the machine, the higher the LCC operating costs. A common example of how in the detail design is possible to improve the maintainability is in the placement of critical components in a machine (the ones that, when fail will inevitably cause breakdown). The most critical components should always be readily accessible and be able to be replaced quickly.
- Visual Management improvement has some features in common with the improvement of the maintainability, but as seen from the perspective of who actually works on the machine. The operator should be able to rapidly assess the status of the machine, substitute consumable components, lubricate the machine and so on.
- Reliability of the machine is again a critical aspect of the reduction of its overall LCC. Components need to be properly sized [...]
- Set-up is the action of preparing the machinery to be operated. On Monday at 6:00 the machine is usually turned-off and cold, the amount of time the operator needs to turn it on, calibrate it, verify its functioning and in general prepare it for production will be subtracted from the available production time. Thus, simplifying the setup of the machine will positively affect it's OEE.

Step 3 is usually the step in which most decisions have to be taken. Some decisions will be big and largely affect the functioning of the equipment, some will be small and only regard sizing and other detail technical characteristics of components. Some decisions will be responsibility of the supplier, others will require the collaboration of the plant. The elevated number of details that have to be specified will inevitably cause the risk of mistakes to increase. But step 3 is also the last step the machinery will spend on the blueprint, as construction comes next, so here is when it is most crucial to find and solve the latest problems. During construction the supplier will inevitably start the production and assembly of the required components and any successive modification will require remanufacturing some of the parts and modifying the assembly on the go thus bringing delays and increase of costs. Also, it is worth nothing that after step 3, some modifications might not even be feasible anymore as they would affect excessively the existing layout of the installation.

As many technical aspects have to be fully determined, and as problems of various severity arise almost inevitably during the design, step 3 is an especially important moment for the generation on new MP-Infos. One should not imagine MP-Infos as documents that are only compiled when improvements are brought on older equipment present in the plant. The very definition of MP-Info regards whatever upgrade or refinement can be contrived, successfully implemented on machinery and finally standardize as a solution for similar problematics on equipment that shares similar features. The detail design during a new project is therefore an extremely prolific time to individuate solutions that can be standardized and recorded to be applied in other machinery or in other plants. This is of course a consequence of the fact that multiple people coming from different departments and companies collaborate to identify solutions and best practices for the ongoing project.

So even if the solution comes up while the machinery for which it is realized is still on the blueprint, it is optimal to record it on a MP-Info for future reference. The usefulness of this can proved by imagining that, for the sake of example, another plant of the same company might want at a later time, install similar machinery in the factory: the consultation of the MP-Info will almost certainly give precious insights regarding which direction to pursue while saving the precious time that would probably be spent on discussing again the same problem with different people and a different supplier. This activity comes full circle with the one discussed in step 2, where the EEM Pillar is required to analyze the database of the MP-Infos in order to benchmark for solutions already standardized at company level.

It has already been highlighted the fact that step 3 is the first step in which modifications to the design start coming at a price. Even while the machinery is still on paper, late changes can require the supplier to go back and revisit many features and components that were already defined. When unforeseen problems come up, it might even be necessary to review the general concept of functioning and the separate economic quotation of additional systems. An example of this could be the case in which in an initial stage of the project only the use of sensor for the correct position identification of a component are expected, while it later comes up that this can achieved with the required precision only using a more sophisticated vision system. It becomes therefore important at this point to redact another document: the list of all the modifications apported. The EEM Pillar should not purely list all the changes that have been introduced as the project progresses, but each modification needs to be analyzed in terms of the benefits it brings in face of the costs it involves.

A delivery schedule can then be detailed. Initially, when the order is received, the EEM Pillar together with the supplier establishes roughly the final deadline. As the project grows in detail, the original Gantt chart needs to be updated with the foregone times in which the blueprint design will be completed, the beginning of the construction, of testing, acceptance testing and installation of the machinery. This provides the EEM Pillar with an useful tool to organize all of the subsequent activities of the plant.

Finally, as for every step, a checklist has to be reviewed so as to verify that care has been taken with respect to every technical spec of the design. The step 3 checklist tends to be the most cumbersome and challenging to complete. The elevated number of items that have to be analyzed comes from the low level of the technical aspects under analysis: while for most steps the checklist items regard a verification that the correct methodology has been implemented, in step 3, technological and engineering considerations comes into play. Even the most trivial and basic aspects of engineering design need to be carefully evaluated, here follows an example of the typical items one can find in the step 3 checklist:

- Are there any weak points in the design of the automation?
- Does the installation method satisfies the precision criteria?
- Are the rotating parts of the equipment designed to be always in equilibrium?
- Has the possibility of using a centralized lubrication system been considered?

- Are eventual losses of fluid easily accessible and removable?
- Does the project consumes more power than initially expected?
- Has any eventual chemical compound to be used during operation been specified?
- Has inflammability of any of the areas been identified?
- Is the equipment able to stop safely in case of fault or stoppage?
- Is it required for the operators to wear any kind of DPI?
- Has it been designed a system for the identification of any defective product?
- Has it been designed a system to automatically expel from the production line any defective product?

The step 3 checklist is generally the one with the most items in it, as any individual part or component in the machinery can be subject to it, for this reason, the plant in Genga has 1780 items in its step 3 checklist.

Step 4: Construction

As the design of the equipment gets closer to its completion, the production of the required components and their assembling starts in the construction phase. Whenever the the joint cooperation of plant and supplier is successful during the 3 initial stages, no modifications should be required to the original design starting from step 4 and proceeding onwards. If the methodology described above and the respective tools are applied correctly, the probability of a late-found error appearing is low. The earlier mistakes and problems are detected, the easier it is to correct them cheaply, quickly and with solutions that are not influencing in an excessively negative way the rest of the design. Alas, when any problem is spotted during step 4, or later, some of the ongoing activities need to be halted while the designers, and the EEM Pillar are busy finding a solution. It is worth remembering that a problem emerging while some of the components are already being produced, will require some of them to be redesigned and consequently remanufactured with a waste of time and materials. The higher the quality of the design and of the simulation of the process during step 3, the lower will be the chance of problems emerging during the construction.

The plant, in particular the EEM Pillar, is responsible of supervising the status of progress of the construction via some intermediate inspections at the supplier site. The supplier should provide a schedule of the production, assembling and testing of the equipment so that it will be easier to organize proper checks. During the manufacturing of the components, the plant has to verify that the produced parts respect the nominal specifications and the standards of quality required. Later, as the assembling begins, it will be possible to verify whether the dimensions of the layout are aligned with the initial indications on space availability on the plant site. Also, at this point it is possible to control that sub-stations of the installation are robust and working as needed. Finally, when the whole machine has been completed, small-scale production tests can begin. This is a critical moment: for the first time it is possible to see the equipment actually performing the required operations on the product.

While in an initial moment, the verification of the operativity of each individual substation is performed to guarantee that is conform to the performances foreseen during the design, in a later time the whole system will operate simultaneously. The higher the complexity of the machine, the higher the number of variables at play and the harder it might be to understand how the interaction of different subassemblies can affect the efficiency of the whole. The preliminary tests are usually carried on at a much lower production rate with respect to the nominal one, in order to certify that the process produces the expected results in terms of quality. As tests continue over time, they will reach the nominal speed required by the plant. During such production tests for the machinery, the EEM Pillar and of other employees of the plant is fundamental: the supplier does not possess a profound knowledge of the product and of the process required to produce it, so the people working in the plants should collaborate as much as possible in helping the supplier to achieve the correct level of quality. it is worth pointing out that many companies will require the built equipment to work smoothly on all the range of products it is currently producing. Therefore testing has to be executed for all such product variants.

The construction of the machinery is an extremely good moment to introduce some additional features aimed at lowering the LCC cost of the project, focusing in particular on the operating costs. One of the tools the WCM methodology proposes to reach this goal is the use of a machine ledger.

Machine Ledger

The machined ledger is an instrument developed to simplify the Professional Maintenance (PM) of the installation by allowing to easily keep under control the maintenance of the equipment. In this document, the machine is divided in functional groups. Every component is then classified according to its criticality in guaranteeing the operativity of the machine (one of the goals of the PM Pillar is that of achieving zero failure breakdowns on the machines) and specific informations are given about its maintenance.

For every component in every functional group, the following informations are provided:

- Drawing of the functional group to which it belongs and indication of its position
- Functional description
- Amount of such components present in the group
- CILR description (more on this briefly)
- SMP description (more on this briefly)
- Maintenance policy for the component, i.e. the type of activity that is performed in order to maintain the functionality of the machine. The components can be maintained (or replaced) as their breakdown occurs, or according to a certain

variable: time based for the substitution after a certain number of hours the component has worked or condition based depending on a set of variables that are present on the machine in a certain moment (vibrations, mechanical noises...)
- Description of the activities that have to be periodically performed and their frequency
- Whether the component can be maintained while the machine is working or if turning it off is required

The EEM Pillar is responsible for guiding the machine supplier in the drafting of this important document (an activity that has to be expected by the specifications in the order). The machine ledger is then translated into a large calendar that is usually posted on a board close to the installation. The professional maintainer will use it as a tool for scheduling and performing correctly the required activities.

CILR

CILR (Cleaning, Inspection, Lubrication & Refastening) are periodical activities performed by the operators on the equipment as a form of autonomous maintenance, and therefore the creation of calendars for this activities is a responsibility of the AM Pillar. As explained above, the Machine Ledger identifies the path that has to be followed in order to maintain the base conditions of the machinery and therefore guarantee its operativity and efficiency over time. Many fundamental activities are performed by the professional maintenance, but many others can be complete by the operators that usually operate the machine. In the latter case, the actions that have to be done are not extremely complex and therefore do not necessarily require the intervention of professional technicians, but a worker can perform then with little training.

The CILR activities are:

- Cleaning: one of the key points of the work done by many Pillars is the keeping of basic conditions through cleaning and tidying up the workstations and the machinery. Often cleaning is the step 0, the initial one, for the Pillar activities. Starting from step 1 it is then required to organize the work so that the original conditions can be sustained over time. Typical cleaning activities regard putting in order the tools and then proceeding to remove dust, dirt and scraps from the working environment.
- Inspection is the observation of the work equipment in search for clues on the conditions of the machinery. During these operations it is possible to verify the correct setup and calibration of the machine, check that the most critical components are working correctly and that noise and vibrations are within normal ranges.

- Lubrication and Refastening of some components in the machinery can be often done by operators with a little training without the intervention of the professional manutentors. An important step in the cooperation between the PM and AM Pillars is in the transferring of some of the PM activities to the AM: in this way the easiest task for the professional maintainers can be teached to the operators. This improves the efficiency of the maintenance in the plant as the best technicians are not “wasting” time on trivial tasks.

SMP

A Standard Maintenance Procedure (abbreviated as SMP) is a document that contains a set of instructions that a technician has to follow in order to ensure the correct maintenance of the equipment. A set of such documents is usually collected in the machine ledger, so that any skilled maintainer that needs to operate on the machine is able to do so without requiring previous knowledge of the installation or training about the activities.

The standardization of the procedures has two main purposes. The first is the necessity of guaranteeing that maintenance is executed always in observance of the highest safety and quality standards, even for the most trivial tasks. Two different mauntentors can perform the same activity, e.g. lubrication of a bearing, in two different ways: they can use different types and amounts of lubricants, they can take longer or shorter amount of times for completion and they can be more or less precise in the operation. Consequently, it is evident how the highest quality of the result can be achieved only by imposing a step by step procedure that ensure that no detail is neglected. The second consideration is, as is the case for CILR routines, a maximization of the efficiency: standard procedures can be faster than an unorganized set of activities performed in a non-specific order.

Another core aspect of the standardization of such little details, lays in the fact that they help creating automated mechanisms in the professional maintenance. Taking care constantly of the low level technical aspects of the equipment is the key in making sure that the larger operating groups of the machine can run smoothly and safely over time thus reducing the LCC of the installation. Simultaneously, any later problem that might arise on the machine will be easier to identify as the correct following of SMPs (and of the maintenance calendar, of course) will already filter out any smaller inconvenience (where it is worth pointing out again that even the failing of a small trivial part can disrupt the correct functionality of the machine, causing a breakdown due to failure).

Once the technical specifications of the machinery have been thoroughly controlled and the on-site tests prove that the equipment has achieved the initially set goals in term of performance and efficiency, the EEM Pillar and the plant manager can proceed with supervising the official acceptance testing. If the equipment succeeds in the testing, the supplier can prepare its consignment to the plant, which proceeds in step 5.

It is again fundamental to note every change implemented on the project at this stage in the modifications list. Some modifications can be quick fixes such as simple changes in the software that improve the cycle time of the machine, but in other cases it might be that modifications on some parts or assemblies are required to obtain a significative improvement or (in the worst case scenario) to actually reach the initially prefixed objectives. In the latter case, each change inevitably introduces a delay and a cost which might not even be able to balance the benefits it introduces if it is a kind of tempering aimed at reaching the initial goals.

Lastly, step 4 checklist is used to verify that best practices have been followed, here follows an example of typical step 4 checklist items:

- Has the encumbrance of any actuated motion been verified to fit the layout?
- Has the lifetime of any tool been evaluated and specified?
- Has the cost of any consumable tool been defined?
- Is the consumption of refrigerant fluids aligned with what expected during detail design?
- Are the efficiency parameters aligned with those required by the technical specification?
- Is the illumination in the work areas adequate?
- Have all the components specified in the technical specification been adopted?
- Are pushbuttons for the safe reset of the automation from outside the layout been predisposed?

1132 items are currently found in the step 3 checklist of the plant in Genga.

Step 5: Installation

The official acceptance of the equipment provided by the supplier marks an extremely important milestone in the project: the plant (supported by the EEM Pillar) confirms that the machine is conform to the specifications initially indicated and the supplier can proceed with the installation. Pointless to say that from this point on the supplier will probably be reluctant to make further changes on the equipment without charging an additional fee. Hopefully for the plant, all of the modifications that can bring a significative improvement of the machine have been detected and applied at earlier steps. During the installation there's always still the possibility to identify some margin for improvement, but at this point the benefits will be relatively small and costs really high creating negative conditions for modifications.

Installation has to be carefully scheduled with a Gantt as a careful calibration of the plant and supplier activities is required. The supplier has to disassemble the machinery, prepare it for expedition and ship it to the plant. On the other side the plant has to arrange a set of conditions that allow the smooth installation of the equipment:

- The plant has to make sure that workers are available to unload the trucks with the equipment and store all the parts safely waiting for installation.
- When the installation regards the substitution of another machine, the older equipment needs to be properly disassembled and dismissed.
- The infrastructure of the plant might need some modifications to host the incoming installation (connection to electricity, air or water supplies, digging of holes, building of support structures...)
- Careful planification needs to ensure that the installation activities have as little impact as possible on the production of the plant. Many different countermeasures can be adopted depending on the case. Sometimes the new machinery will be installed on a new area of the plant and then require no stop of the production, other times the machine needs to be implemented on a line, thus requiring a stoppage of such line. Commonly installations can be scheduled during production stops (August or Christmas) where the impact on plant efficiency is contained.
- The plant will require work permit for the supplier employees that will be operative on field.
- The support of the PM might be required, therefore the workshifts of the maintainers can be adjusted consequently.
- Predisposition of data connectivity to other machinery or to a plant management software (e.g. via ethernet)

it is easy to see that any miscommunication with the supplier can create problems that, even when small and easily fixable, cause delays on the installation.

A later stage of the installation is the training of the people that will deal with the machine during its lifetime. Operators usually need to be able to understand how to properly turn-on, turn-off, calibrate and set up the machinery for each kind of incoming product to be processed and CILR activities need to be introduced. Mechanical maintainers are required to identify all the mechanisms and the parts they are composed of, their principle of operations and the way they interact. Electrical maintainers on the other side will need to examine electrical schemes of the installation and to understand the structure of PLC or robotics programming used for the application.

Eventually, the list of modifications has to be uploaded with recent changes. The general goal of the EEM Pillar is always that of front loading so as to avoid any significative mistakes that require a corrective intervention at a late stage of the project, therefore ideally there should be no late-found errors at step 5.

Here follows an example of usual items for step 5 checklist:

- Is the disassembly of every component developed so as to avoid damage during the maintenance?
- Are the components that require maintenance easily reachable?
- Is the correct working range of pressure gauges indicated on the display?

- Is the zone for the accumulation of wastes coherent with what is indicated in the layout?
- Is the documentation compliant to the requests of the plant?
- Is the workforce required to keep the equipment in the production aligned with what specified at earlier stages?
- Has a set of spare parts for the initial cycle been provided?

The plant in Genga has a set of 664 items in its step 5 checklist.

Step 6: Production Tests

Step 6 consists in a series of tests aimed at verifying that the installed equipment is compliant to all of the plant requirements. In contracts with the suppliers, the machinery might be required to pass also all such tests other than the acceptance testing in the supplier workshop.

- Safety is analyzed first as always: emergency and safety systems such as relays, barriers, fail-safe-ing of the software are actuated to verify their operativity under all circumstances
- General functionality of the machine is analyzed to ensure every functional part is working regularly and as expected
- AM and PM pillar should check that standards for the maintainability of the installation are respected and that the machine ledger has been properly redacted together with CILR cycles and SMP
- The machine is set up and enabled to work on the new environment, for instance it might be necessary to fix working points of the automations. In general it will be possible to examine what are the required operational parameters
- Start-up and first working cycles are performed and carefully analyzed to check the overall functionality of the stations
- Quality of the outputted product is controlled making sure it stays within the standards defined by the specification and checking that the machine does not introduce new defects
- Automatic cycles of the machine are then run. In this case the focus is on the overall synchronism of the operations and on the interaction with the other machines in the line
- Manual cycles can be run to verify that operators or maintainers can perform single cycles manually when, for instance, they need to verify the correct operation of the machine
- Specific procedures for the set-up, reset and exclusion of the installation can be viewed and checked.

If all of the above preliminary tests have been passed successfully (which should almost always be the case since all such conditions were already verified during the construction step) the machine can proceed with some production tests during which the equipment produces at a gradually increasing rate. The very first tests can be run when the production is stopped, but as the goal to be achieved is that of vertical start up, then the machine has to be able to be quickly deployed on the running production line. A first more clear idea about cycle times, production rates and other performance indicators can be obtained and scheduling of the following activities can be fixed accordingly (avoiding for instance to put the machinery in full opeartivity when it is not safe to do so because of the large number of microstoppages required to fine tune all the parts).

At this stage it is crucial to be able to identify problems which are related to the production system. During extensive production testing many problems that were invisible during the construction can become evident and require a quick solution. An example might be the fact that during testing at the supplier plant are usually performed in small batches, as the constructor does not provide of the working space, of the material and of the infrastructure required to produce for longer runs. Especially in the case of large products, the supplier might need to test the machinery with a small number of parts per run. This means that problems regarding the logistics or in general all the aspects of production that cannot be easily simulated in earlier steps can arise. Foreseeing such complications is of paramount importance for the EEM Pillar, particularly in light of the fact that simulation and reproduction of the critical situations cannot be done easily.

The list of modifications is updated accordingly (ideally it is not updated) and step 6 checklists are controlled:

- Has a number of products to process been defined?
- Has the report of quality acceptance been drafted?
- Is the cycle time of the equipment compliant to the technical specifications?
- Is the first pass yield compliant with the requirements of the plant?
- Has there been any significative interruption of the test activities?
- Has a general test for the safety of the installation been performed?
- Is the illumination of the areas adequate to guarantee the safety of the operators?
- Are the areas that need to be accessible to the manutentors properly illuminated^
- Has the DPI effectiveness been tested?
- Have the operators and the manutentors properly trained to use the equipment?

A total of 223 items is present in the step 6 checklist in the plant at Genga.

Step 7: Start Up

Finally, after installation, verification and testing, the machine can be put in production. The lower the amount of time the machine passes in the testing phase, the better for the plant.

This is usually true also for the start up phase as at this point any problem related to the new equipment that emerges causes inevitably cascading problems in the rest of the production. Stoppages or production slowdowns can create bottlenecks impacting the efficiency of other machines connected on the line and of other adjacent departments with a consequent loss of money and of production for the plant.

Production scheduling has to be fixed accordingly, to balance the necessities of machine testing and plant productivity. If the methodology has been followed carefully though step 1 to 6, then most of the testing has already been done and the machine should be able to guarantee performances high enough to keep pace with the rest of the production line.

At step 7 it is possible to verify the real performance indicators of the machine, as for the first time the whole system is in action. OEE is computed via an analysis of both the actual cycle times and of the stoppages caused by the equipment. Quality and safety performances can be analyzed over a wider span of time (a particular defect, for instance can arise only with certain conditions that were not simulated during tests or after a certain amount of time has passed).

AM and PM activities are implemented according to the specific calendars created for maintenance and CILR cycles and the keeping of base conditions is verified over time.

Project Review

As the equipment is deployed in the plant, it comes the time for the EEM Pillar to make a balance of the project. The results can be observed in terms of how successfully the expected key performance indexes have been attained. The achievement of the initially set KPIs is the minimum acceptable result, surpassing the initial expectations is of course ideal provided that the set goals remain challenging enough for the plant.

In case the KPIs have not been reached, it is necessary for the Pillar to understand what caused such failures. Sometimes the problem can be evident, as in the case of a conspicuous delay in one of the steps or the late found of a design error that needed to be correct with a waste of time and money. In other situations, the missed results can be a byproduct of a multitude of smaller factors that contributed. The WCM tools are helpful in determining at which point the methodology was not implemented correctly or where it can be strengthened in its application. The list of required modifications for the equipment at various steps highlights where the most significative design problems emerged and can be used as a starting point to verify whether the reviews performed at the end of each step are scrupulous enough. The step checklist items are updated consequently.

Every new project builds new knowledge for the EEM Pillar with the huge amount of information it brings. The gained experience has to be exploited for future projects, where a smarter planning can be deployed. Every new step can then be approached in a different, more mature, manner. One of the main benefits of the WCM methodology is that it strengthens the mechanisms that increase the level of knowledge of the plant and develops a steeper learning curve: every new project is entered with the mindset of doing better than in the previous one. This mentality growth has to be verified by comparing all the projects deployed by the EEM Pillar through time. A graph of the modifications required by the installation over time can be plotted: on the horizontal axis steps 1 through 7 can be found, while the vertical axis counts how many changes have been necessary at each step. On the same plot one can superimpose a second vertical axis showing the how the cost of the project increased over time so that it is possible to verify which are the steps that brought the most expensive changes: the more the changes and the more their significance, the larger the difference between the lines of the forecasted and the expected costs.

The Carton Insertion Automation

The following chapter will be used to show a case study for the application of the World Class Manufacturing methodology regarding the activities of the Early Equipment Management Pillar and will illustrate the step by step project of an automation installed at the Ariston Thermo Group plant of Genga (AN), in Italy. The WCM methodology is just a tool that cannot provide very useful per se, but needs to be correctly implemented by real people in real scenarios which offer differ vastly from each other. The following case study represents therefore a single scenario for the application of the EEM Pillar methodology of the many available, but it will nonetheless provide many insights to a deeper understanding of the WCM.

A premise will be given regarding some background information of the plant in Genga and the particular circumstances that brought the necessity of implementing the new automation. After the premise, the development of the project will be illustrated by following the step by step approach proposed by the WMC methodology that was explained above.

Choice of the Project

Among the new projects scheduled for 2017, the Genga plant had to pick a process to make it automatic. The choice of which path to follow was not obvious as each automation project brings with it a number of different challenge that the EEM Pillar needs to confront with. The main ideas for new applications regarder:

- Automatization of the packaging, and in particular of the carton insertion i.e. the placement of the product inside a box
- Automatization of the electric testing, a procedure needed to ensure the correct operativity and the safety for the user of each product
- Automatization of the welding testing. Every boiler, after welding, is immersed in a water tank and pressurized with air so that any imperfection in the welding (holes or cracks) can be identified via the inspection of air bubbles coming out of the boiler.

After a preliminary analysis (more on which later), carton insertion has been approved as the project for 2017, while electric testing was moved to 2018 (and as of March 2018 it is in step 3, detailed design, with installation planned for August). The carton insertion was evaluated as an easier project, which brought more advantages to the plant as it also involved the restructuring of the logistic apparatus that brings the boxes on the final assembly line.

Step 1: Project Inputs and Planning

As one can easily imagine, whenever a plant decides to embark in a new high complexity project that will likely require significative investments both in terms of money and time, there have to be good reasons to do so. In some situations, the plant might require to install an automation in order to remove a person from a dangerous location or activity, while in other scenarios the plant may want to improve its efficiency. In the case of the carton insertion robot for the plant in Genga, the latter was the case. Increase in the efficiency can be achieved in different ways:

- One can think of substituting older equipment with some new machinery able to guarantee a higher Overall Equipment Efficiency (OEE) thus maximizing the usage of available work time and reducing the amount of stoppages and micro-stoppages on the machine. It is worth pointing out that this is particularly important in the situations in which the installed equipment is along a production line. Any stop of the machine would inevitably cause the whole line to stop, thus creating a loss for missed production and, most importantly, generating loss due to the inactivity of the operators that work on the line
- A second possibility is that of reducing the transformation cost of the operation which can be done for instance by reducing the used material, reduce the scraps wasted by the machine, improve the quality of the outputted product by reducing the number of scrapped or reworked parts or increasing the production rate. Unfortunately, as in the case of the Ariston plant in Genga many of such conditions are already highly optimized, it might be necessary to implement an automation that replaces the work of a person. The cost of labor in Italy is significative and it is often easier to create an efficiency by letting an automation do the work.

The reduction of the transformation costs was the primary parameter analyzed in the evaluation of the possibility to improve the efficiency of the packaging.

The Final Lines in Genga

Originally, at the beginning of the project, the packaging of the finished product was performed along the final production lines. The final lines in Genga are 3:

- Final line 1 & 2 are the main lines used for assembling as they account for most of the production, they are pretty much identical in their layout with only some small differences. Each final line is supplied by a conveyor chain that comes from respectively the varnishing departments 1 and 2. The conveyor chains travel overhead and descend on ground level where an operator tucks the product in a cartene bag and then proceeds to fit the polystyrene pad that constitutes the bottom of the packaging. The water heaters are then unhooked from the chain by, respectively, a robotic arm on Line 1 and a simpler automation of Line 2. From this point on, the product runs on a conveyor chain whose speed is usually kept at 4m/min (a bit lower for some product varieties that require a higher number of operations). A variable number of operators proceed with the final assembling operations that usually consist in the insertion of the thermometer, sticking of the identification label, installation of the electronic controller, wiring, electric testing, closing of the cartene bag and placement of the top plastic cover. Two operators then complete the packaging: the first one inserts the carton and the last one lays down instruction and warranty papers and finally puts the top polystyrene pads. Every such operation has a takt time of 12 seconds, which defines most of the cycle times for processing around the plant. The box keeps running on rollers where it gets closed and sent to the warehouse.

- Final line 3 runs parallel to the other lines, but is dedicated to different types of product. On line 1 and 2 one can find all of the electrical water heating systems with capacity ranging from 50 to 100 litres, while on line 3 run gas water heaters and products with capacity up to 200 litres. The higher volume and complexity of the products, combined with the contained market request, allows the line to produce at a much lower rate. Nonetheless, the operations to be performed are similar to the ones described before.

Because of the lower production rate on the third final line, only the first two have been taken in consideration for the automation process. Also, the third line outputs a range of product that varies greatly in shape, volume and type of operations that have to be performed on it, while products on the other lines are much more similar. It would not create any advantage, at the moment, to automatize also the third line packaging.

The Workplace Organization (WO) Pillar has used the final assembly lines (1 and 2) as its model area, thus working hard on improving the work efficiency. One of the most important objectives for the WO Pillar is that of enhancing the working conditions of the operators. This has been achieved, among various other implementations, by an ergonomic analysis of the various workplaces aimed at ensuring that every worker operates in a “golden zone” where motions are reduced everything is placed so as to avoid excessive physical fatigue (for example by suspending the used tools on the ceiling of the line with a jolly). The activities performed on each station are balanced among the operators and, most importantly, an analysis of the value of each activity has been analyzed.

Such analysis allow to understand how effectively the time of each operator is employed. A key goal for the WO Pillar is the reduction of the so called Non-Value-Added Actions (NVAA), i.e. all the operations that to not contribute directly to the creation of value in the finished product, for instance looking, walking, reaching for a needed tool, the time spent in identifying the correct position of a point, manipulations of a component such as rotating it, and on and so forth.

This is a first crucial point in the identification of where an automation can come into play for the reduction of transformation costs in the plant. In the carton insertion process, the percentage of time spent by the operator for NVAA is really high, thus much of his time is wasted and this represents a loss for the company. During the 12 seconds of its working cycle, the operator has just the right amount of time to pick up a carton, open it, orient it in the right direction and then proceed to insert it from the top of the water heater, while the product keeps running along the conveyor. He has no time to do nothing else. Across the years, the efforts of the WO Pillar allowed the operation to be greatly simplified. One just needs to visualize the operation of inserting a carton on a moving component at a high that varies by the capacity, but that is in the worst case scenario given by the sum of the height of the conveyor plus that of a 100L water heater to understand that is not an easily optimizable operation. Nonetheless, the cartons are arriving via an AGV and automatically placed aside the operator with the most convenient orientation, and the worker has been put in condition to work in his golden zone, thus reducing the amount of non-ergonomic movements. Alas, the volume of the box is cumbersome, especially in the case of the 100L capacity and as the pure insertion of the carton only requires 4-5 seconds, picking up the box, open it and orient it covers the remaining time available in the 12 seconds cycle. Here the percentage of NVAA is therefore above 50% representing a significative inefficiency that, given the level of optimization of all the other variables, can be corrected only with an automation of the process.

The final lines work on two shifts. The morning shifts works 7 hours and 10 minutes from 6am to 2pm (including two 10 minutes breaks and a longer lunch break), while the evening shift starts at 2pm and finishes 8 hours later at 10pm only during periods of heavy production. It sometimes, instead, happens that production can be stopped a bit earlier at 8pm. As the supply for both the lines come from different departments (pre-assembly 1 and varnishing 1 for line 1 and pre-assembly 2 and varnishing 2 for line 2) it is sometimes required to improve the production rate to work "line on line" during the longer breaks, which means that during the half hour lunch break of line 1, the operator of line 2 are displaced on line 1 to keep the production flowing. A total of four operators are therefore working on the insertion of the box (one operator per each line on each shift). It is worthwhile highlighting that there is no single operator working on the packaging station for the whole shift, but rather all the operators along the line work cyclically on the different stations so as to avoid the repetitivity of doing the same identical operation every 12 seconds for 8 hours.

The plant has a budget that can be spent in various way to improve the performances. Except for the case in which a new installation is severely required to drastically reduce risks and dangers for the operators, thus increasing the safety of the workplace, it is necessary to prove that any new machine is able to provide a significative profit over time. Whenever the plant in Genga intends to install new equipment an Investment Request (IR) document has to be redacted to prove the gains and advantages brought by the intervention. The standard policy used to decide on this profitability is in the definition of a maximum payback period of 3 years since the start-up. So a rough estimate of the available budget can be computed as the goals for the new equipment are defined.

Here come into play the industrialization (both at company and plant level) and therefore the EEM Pillar with the definition of clear goals given all the assumptions made above:

- Increase the productivity of the plant as measured in terms of the ratio of pieces produced per number of people employed to produce them, therefore reducing the transformation cost of the product. It is evident how the cost of an operator is about constant over time, while an automation to substitute him has a very high initial cost, but gives lower expenses while operative
- Elimination of an operation that is inherently uncomfortable for a human operator. Despite the WO Pillar efforts to allow the operator to work in his golden zone, the manipulation of the cumbersome boxes is nonetheless unhandy and wearing over time
- Elimination of NVAA performed by the workers, as much useful time is wasted on picking the carton, opening it and orienting, while only 40% of the available cycle time is actually employed to insert the carton, adding value to the product
- Quality improvements. An automation can increase the repeatability of the cartoning process, ensuring that the box is never inserted the wrong way (later an accurate analysis of the carton will be shown) and avoiding a carton to be inserted on the wrong product (something that can happen during production changes). An automation will also have a vision system that can better discriminate eventual defects in the carton and discard it consequently, even if carton defects are not one of the priorities of the Quality Control (QC) Pillar

In order to estimate the potential budget it is then possible to compute the savings coming from the dismissal of 2 operators over the maximum payback period for the installation, that is defined at 3 years. The plant in Genga employs both fixed term and temporary workers, the latter are the ones that can be replaced by the automation for obvious reasons. The cost of 1 hour of work for the company is 29€, giving a daily cost of 232€ per person. This is computed over the days of work per year which are usually 220, times the 3 years of the payback period and finally doubled up to account for the double shift.

$$\left(\frac{29€}{hour}\right) * \left(\frac{8h}{shift}\right) * \left(\frac{2shift}{day}\right) * \left(\frac{220days}{year}\right) * 3year * 2 = 612'480€$$

On top of this, the industrialization needs to consider:

- The potential running cost of the equipment, this can be done by comparison with similar machinery

- An additional 10% of the cost of the equipment for the spare parts bought in advance
- Cost for the training of maintainer, again this parameter is set using [...]
- Cost for the eventual missed production and for the losses due to stoppages that will inevitably happen during the production tests and the start-up of the machine. As said earlier, the cartoning is not the last process of the packaging and the automation will be placed along the existing conveyor, where every stop will imply that the work time of 2 to 12 people (depending on the complexity of the final assembly) can be wasted. For this particular application, the EEM Pillar has expected 2 weeks of start-up time has a goal (more on this later)

What results is a potential budget of about 500'000€ that has to be compared with the offers from the suppliers. It is important to highlight the fact that the clear definition of the concept and functioning of the automation will be fully defined only in step 2, therefore all of the above calculations are a first rough estimation of the economical feasibility of the project and will be repeated with greater detail as the solution becomes more and more defined.

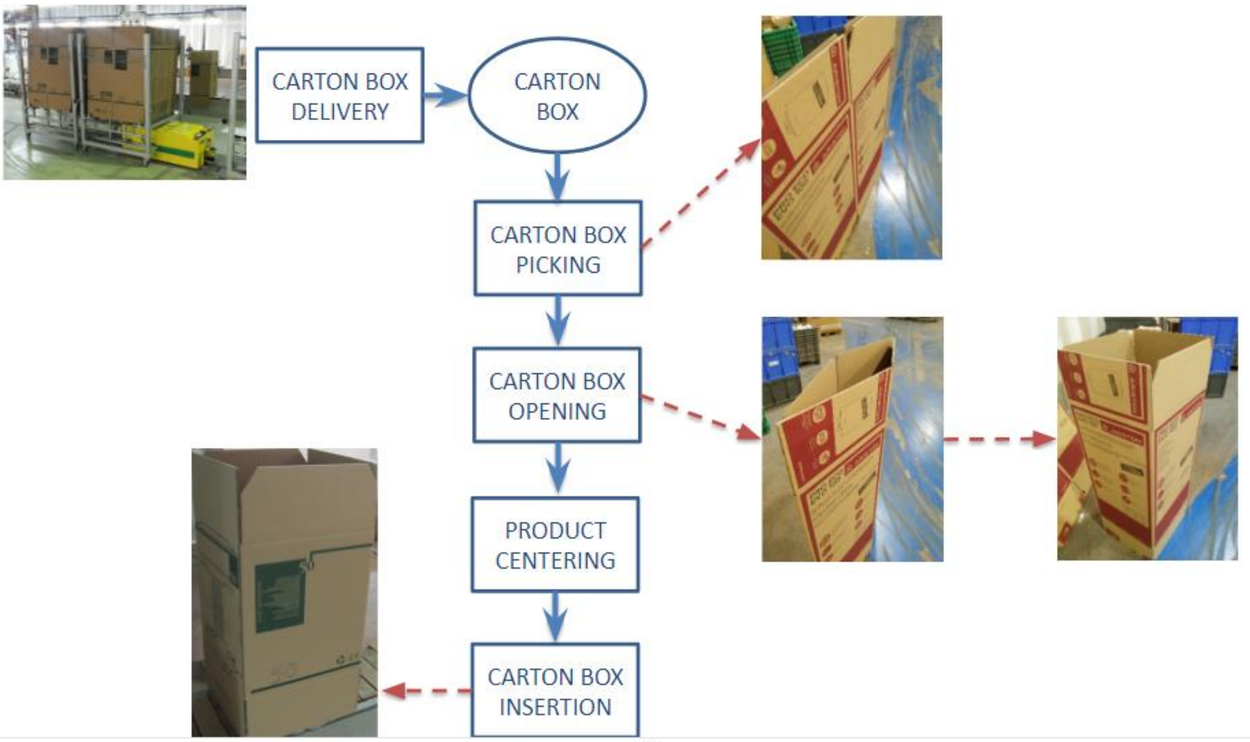
Flow Chart

Building a flow chart of the operation that the machine has to perform is a first important step in understanding what will be required from the design. Breaking up the larger operation in all its sub-actions can give insights on what each subsystem of the equipment will have to perform. In the case of the carton box opening, the flow chart is pretty straightforward, as the order of the operations cannot be modified:

1. Picking up of the carton: the cardboard box arrives at the station in packs of 60 pieces piled-up and needs to be separated from the others to be manipulated
2. Opening: the cartons arrive at the station flattened which is of course the only smart way in which they can be easily stored and displaced. The opening the carton requires to pull to separate the two sides so that the internal opening can fit the product
3. Product centering: the water heaters arrive at the station leaning on the conveyor shutter on their polystyrene pads. The pads are often not perfectly aligned with the longitudinal direction of the conveyor which is something the operator can easily compensate for. An automation needs an higher level of repeatability of operation to be able to efficiently insert the carton, or better, it is generally more economical (when possible) and faster in terms of cycle time to provide a solution that guarantees the positioning of the part to be processed rather than making the whole automation compensate for it. An additional concern come from the observation that the orientation of the product in its polystyrene pad is not constant for all the products. This can cause the mounting brackets of the water heater to emerge out of the longitudinal plane of the pad, therefore causing troubles during the insertion as the bracket can scratch the cardboard surface. This is again something the operator

can compensate for by manipulating the box in its descent, but it is an action with an extremely low repeatability for a machine, so a way to center the product inside the pad is necessary

4. Carton insertion: the value-added part of the operation and another key moment. Some kind of manipulator is expected to descend on the water heater while keeping the box open and perfectly squared and perpendicular to it. Again, the operator is able to invite the carton gently by making some little adjustments left and right so as to smooth the operation, while this can prove difficult for an automation



Cardboard is “alive”

One of the major issues with having an automation that needs to manipulate a box is that cardboard is “alive”, with the meaning that paper components show an extremely low repeatability in their behavior. It follows that it is not straightforward to predict how a cardboard box behaves while is being picked up and opened. As underlined earlier, robots and other automations do not generally work well in situations where repeatability of the parts they need to manipulate is low. This is one of the major problems that has been presented to the supplier in the specifications.

Additionally, a larger number of parameters come into play. The plant in Genga uses boxes coming from three different suppliers, each of which uses slightly different processes thus producing different results. Some boxes are more rigid and others are softer, also the force required to fold the front and lateral flaps can vary accordingly. Some cartons are in the standard “havana” color, while others are painted white and this influences the way the box behaves if exposed to humidity: just as an example, the presence of moisture in the air can cause the pile of boxes to be more or less convex in the central section. The way in which the cartons are stored also has some side effects. The supplier is requested to send the flattened boxes in lots of 60. Each of such lots is stored in the warehouse piled to other lots: it turns out that the boxes on the bottom of the pile have to withstand a much greater weight over time and sometimes tend to stuck a little together.

Just as a note before the following section, it was evident at this point that the only way to pick up and manipulate the cardboard without damaging it was that of using multiple suction cups connected to a vacuum pump, but the detailed of the manipulation will be discussed in step 2.

Project Inputs

Along with the basic information the new automation needs to perform and with the goals that the installation aspire to achieve some other inputs can prove useful. Any technical decision that is made for new equipment needs to take in considerations all the necessities of the plant, in particular the record of safety problems, quality defects and problems related to the maintenance. These inputs are required to make sure the new equipment will not undergo the same problematics that the plant is already aware of in other machines or departments and at the same time they will try to anticipate possible emerging issues related to the new way the process is done. Here follows a list of the additional inputs that the EEM pillar examined for the project:

- Safety: safety is always the primary concern for the WCM approach. Fortunately, the carton insertion operation is not dangerous and the operator is already working in his golden zone, so for this project safety was not a major concern. Also, the Genga plant is highly automatized with many robots already employed in various departments. No safety concerns are in search for a solution: safety fences and robust fail-safe lock-out procedures are already the standard.
- Quality - Scraps & Reworks: if quality is always the main WCM concern, quality is the second. In this case, again, no defects in the product are due to the packaging operation. A low number of boxes is defected and slightly decreases the robustness of the packaging if inserted. An automation has therefore to be able to identify defects in the cardboard so as to avoid the problem.

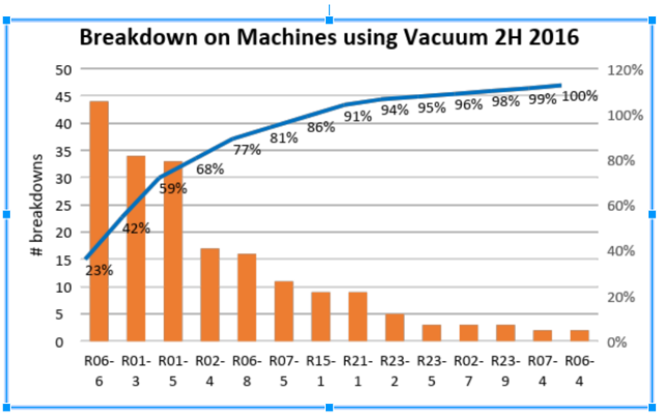
ARISTON THERMO GROUP

QA Matrix Stabilimento di Genga (2° semestre 2016)

Famiglia	Elettrico			Gas		
Modello	50 lt	80 lt	100 lt	50 lt	80 lt	100 lt
Pz prodotti totali		1306993			42436	
Pz controllati al CS		9185			1007	
Pz in garanzia						
Periodo di riferimento	Giugno 2016 - Dicembre 2016					

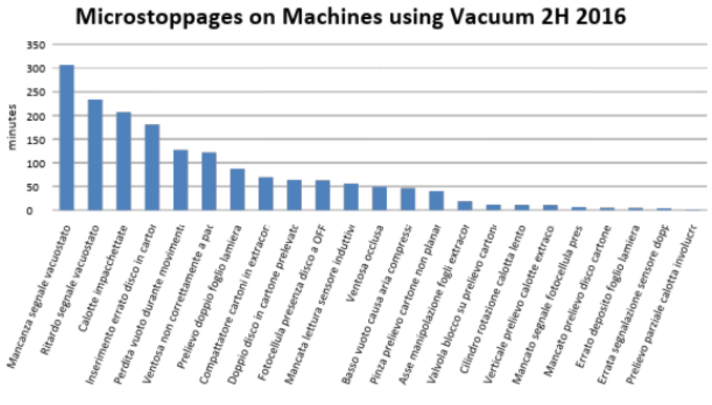
Scarto/ Ripasso	Numero difetto	Famiglia	Modello	Descrizione difetto	Pz difettosi nel periodo di riferimento (Help A) Reparto-icoming	Processo	Statistico	Mercato	Totale	Frequenza % (Help A) %	Frequenza (A) R=1:10	Costo Materiale (Help B) €	Costo Materiale (B) R = 1:10	Tempo Manodopera (Help C) min	Costo Manodopera (Help C) €	Costo Manodopera (C) R = 1:10	Gravità (Help D) A0= 10; A1= 5; B=1	Gravità (D) R = 1:10	Rilevazione (Ri) Reparto 1	Processo 3	Statistico 7	Mercato 9	A*(B+C)*(Σ Ri)*D	Priorità percentuale
ripasso	166	elettrico	80 lt	verniciatura "screpolata" su manicotti	0	0	0	60	60	0.0046%	1.00	0	0.00	1	0.3863	1.00	A0	10	0	0	0	1	90	1.69%
scarto	70	elettrico	80 lt	ammaccati invern	89	0	0	0	89	0.0068%	1.00	6.26	10.00	10	3.8633	7.00	A1	5	1	0	0	0	85	1.60%
ripasso	1	elettrico	80 lt	perdita circ. inf. sald1	4884	0	0	0	4884	0.3737%	2.00	2	4.00	4	1.5453	4.00	A1	5	1	0	0	0	80	1.50%
scarto	58	elettrico	80 lt	scarti sald 2	258	0	0	0	258	0.0197%	1.00	3.38	7.00	8.27	3.195	7.00	A1	5	1	0	0	0	70	1.32%
ripasso	168	elettrico	80 lt	perdita di poliuretano da valvola saso	0	3254	0	0	3254	0.2490%	2.00	0	0.00	2	0.7727	2.00	A1	5	0	1	0	0	60	1.13%
ripasso	16	gas	80 lt	macchie grasso gas	0	639	0	0	639	0.0489%	1.00	0.31	2.00	2.84	1.0972	2.00	A1	5	0	1	0	0	60	1.13%
ripasso	75	elettrico	80 lt	perdita di poliuretano da tappo foro scarico vern2	0	9600	0	0	9600	0.7345%	4.00	0	0.00	1	0.3863	1.00	A1	5	0	1	0	0	60	1.13%
ripasso	150	elettrico	80 lt	calotte involucro esterno con bozze	6000	0	0	0	6000	0.4591%	4.00	0.5	2.00	0.5	0.1932	1.00	A1	5	1	0	0	0	60	1.13%
ripasso	122	gas	80 lt	deflettore mancante	0	12	0	0	12	0.0009%	1.00	0	0.00	5	1.9317	4.00	A1	5	0	1	0	0	60	1.13%
ripasso	52	gas	80 lt	ghiere sporche di smalto	0	200	0	0	200	0.0153%	1.00	0	0.00	5	1.9317	4.00	A1	5	0	1	0	0	60	1.13%
ripasso	2	elettrico	80 lt	grumi vernice	821	0	0	0	821	0.0628%	2.00	0.52	2.00	4.35	1.6806	4.00	A1	5	1	0	0	0	60	1.13%
ripasso	12	elettrico	80 lt	Orientamento Imballaggio errato	0	600	0	0	600	0.0459%	1.00	0	0.00	5	1.9317	4.00	A1	5	0	1	0	0	60	1.13%
scarto	37	gas	80 lt	scarto caldaie gas	636	0	0	0	636	0.0487%	1.00	10	10.00	0	0	0.00	A1	5	1	0	0	0	50	0.94%
scarto	48	elettrico	80 lt	scarto cesoia prem 1	11294	0	0	0	11294	0.8641%	4.00	0.52	2.00	0	0	0.00	A1	5	1	0	0	0	40	0.75%
ripasso	128	gas	100 lt	calotte gas con ruggine	2001	0	0	0	2001	0.1531%	2.00	1.22	2.00	1.56	0.6027	2.00	A1	5	1	0	0	0	40	0.75%
scarto	144	elettrico	80 lt	scarto cesoia prem 2	7486	0	0	0	7486	0.5728%	4.00	0.52	2.00	0	0	0.00	A1	5	1	0	0	0	40	0.75%

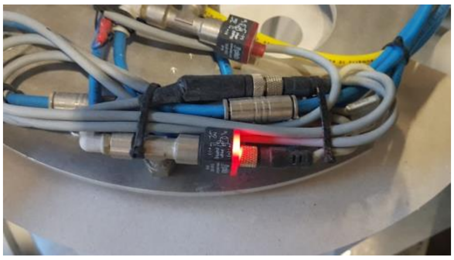
- Breakdowns: the Emergency Work Order (EWO) database of the professional maintenance is examined in search of the most common causes of failure with consequent breakdowns of the machines. Maintenance prevention is of paramount importance as it allows to reduce both the running costs of the installation (thus lowering the overall LCC) and the cost of maintenance deployment. The analysis of the EWO database showed



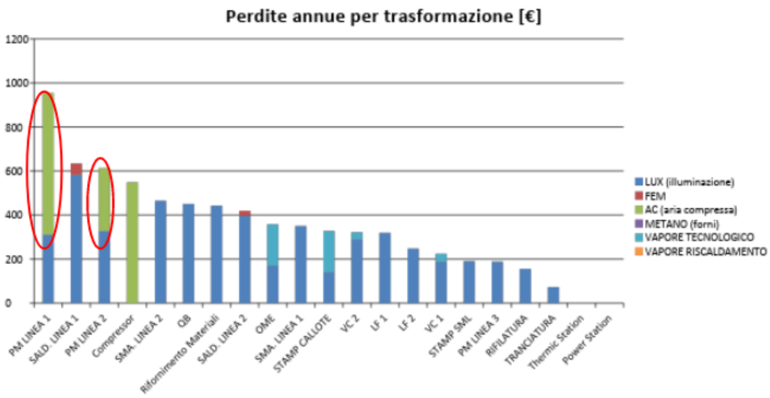
	UoM	
Breakdowns	N° breakdowns/ month	4
MTTR	Minutes	23,7
MTBF	Hours	95,9

- Micro-stoppages: micro-stoppages are defined via a standard policy of the Genga plant as any stop that lasts less than 5 minutes, whereas a stoppage over 5 minutes is considered as a breakdown that requires the intervention of the maintenance. In the machinery employing vacuum pumps and suction cups it often happens that the cups become clogged and stop working properly. An important input for the project is therefore trying to find a way to make sure this will not happen in an application that is highly dependent on such suction cups.





- Energy losses: one of the greatest sources of energy losses along the final lines is in the transformation of energy. All the comppressed air is in fact produced via the usage of electrically powered compressors



KPI Definition

Key Performance Indexes have then been selected for the carton insertion project. Selecting the correct goal is crucial in the constant improvement process promoted by the WCM methodology. Goals have both to be reachable (it's pointless to set impossible targets) and challenging enough. A goal that is "too easy" for the plant is not going to improve significantly the final result of the project and will not probably bring any significative increase of knowledge for the plant.

As every machine is different, it is not always easy to correctly identify the best possible KPIs. Machines offer differ enormously from one another and even similar equipment can require different targets depending on the production situation. Regarding the carton insertion automation, the plant of Genga had no experience of previous similar installations.

Genga employs many automation, but none of these operates in the final packaging therefore a benchmarking for the target has been performed by looking at the most recent installations of automations of similar complexity, at the KPIs that were assigned to them and at the result that have been obtained.

Here follow the final targets that have been set for KPIs:

- OEE 95%: The total effective productive time has to be a minimum of the 95% of the total time available for production. This parameter, as explained earlier, is obtained as the product of 3 sub-parameters that identify key effectiveness values for the machine:
    - Rv = 99.8% is the availability parameter and accounts for the amount of time the machine is not available to work with respect to the period of time it is supposed to be up and operative. This value has been extrapolated by comparison with other automations and the typical amount of time they are down due to a failure or breakdown of some kind. As illustrated earlier, the carton automation will have to work with pieces moving on conveyor belt. This belt for the two final lines starts in the station where the water heater is unhooked from the conveyor chain and ends up directly in the finished products warehouse. Any stoppage along the line causes inevitably the whole line to stop working with consequent losses for missed production and for the inactivity of the workforce. It is therefore evident how the requirement for robustness of the machine is compulsory. Stoppages due to mechanical/electrical failures will require the stoppage of the final assembly line for prolonged time, the temporary exclusion of the cartoning automation, and the deployment of an additional operator to execute the box insertion while the machine is being repaired.
    - Rf = 95.4% is the performance parameter, it indicates the speed at which the equipment works with respect to the nominal speed at which it was designed to work. This parameter has been set slightly lower than the other two for reasons dictated by earlier experience with vision systems in automation. By comparison with robots employed in the bracket screwing operation it has been noted that the automatic recognition of objects using a vision system is not trivial. Many variables come into play: the shape, material and quality (in terms of precision with which it was manufactured) are the main parameters that come into play. Additionally, for 2D vision systems, even the daily variation of natural/artificial light can generate issues. The automation is usually programmed so as to be able to check multiple times for the presence/absence of an object and its correct position and orientation in space. This, jointly with the fact that vision requires data elaboration from the software, often generates slight delays in the operation of the robots. For all

the above reasons and by taking in consideration any other possible cause of slowdown for the operation, the 95.4% value has been selected.

  - Rq = 99.8% is the parameter that contributes to account for quality defects for the machine. The first pass index (percentage of good outputted product with the respect of the total that have entered the machine) for this particular application needs to be very high. Currently the cartoning operation produces a ridiculously low number of defects which are generally due to imperfections in the cardboard, such as a lack of glue that causes the box not to close perfectly. At the same time, at the time the box is lowered, the product is traveling on his polystyrene pad and inside a cartene bag, therefore there is no possibility for the carton to damage in anyway or scratch the product. Ideally then, the cartoning machine must not introduce new defects. This can prove trickier since for an automation the cardboard is not an easy material to work with. Recognition of a defective box is important: the operator can easily discard an unglued carton as the problem is evident in his eyes, so the same needs to be possible for the automation. Also, if the manipulation takes place using some hardware, these materials must not scratch the surface of the water heaters or introduce any kind of source of damage.

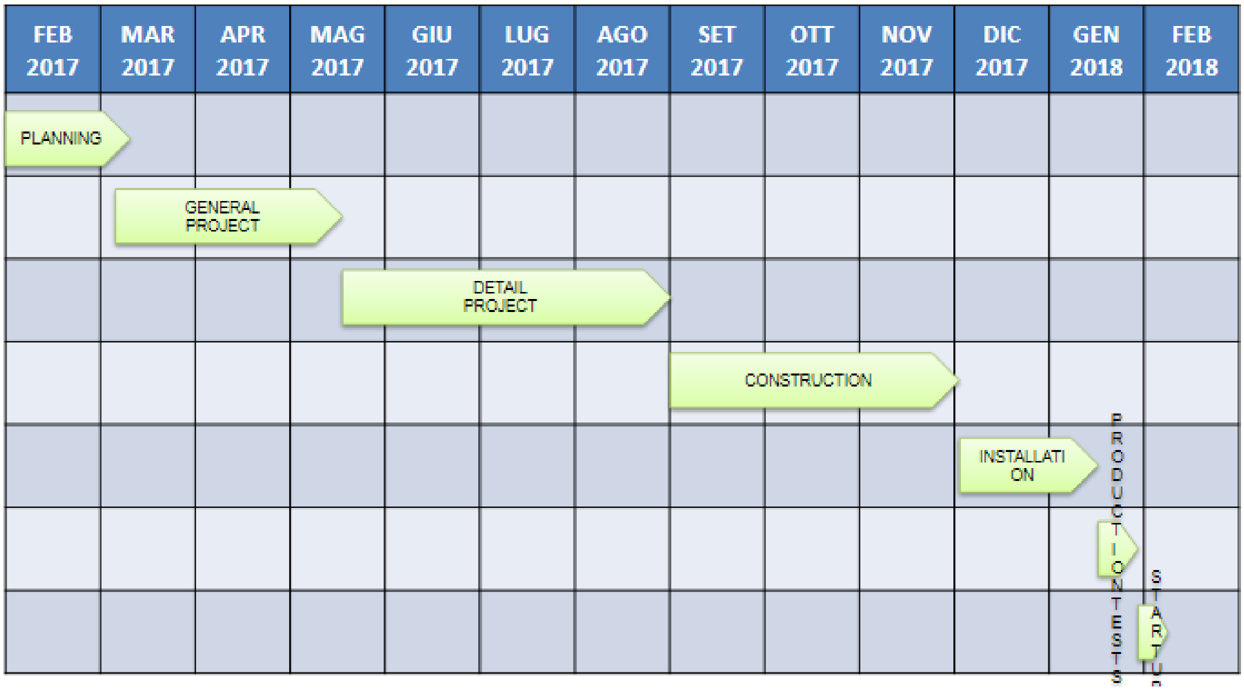
- Production capacity: 300 pieces per hour. This parameter is dictated by the current Takt time of the final assembly lines. The conveyor belt moves with a constant (generally) speed of 4m/s and each operator works with every product for a maximum of 12 seconds. The automation will be required to produce at the maximum rate at which the whole final line can produce, i.e. 12 seconds apiece for 1 hour, giving the required capacity of 300 pieces per hour.
- Start-up time: 2 weeks. This is an extremely important index for the plant and the EEM Pillar for all of the reasons explained in earlier sections. For the cartoning application, the 2-weeks goal is extremely important for two main reasons . The first one, again, is the fact that the machinery is placed in a productive line in which the stations are synchronized and every stoppage of the machine causes the inactivity of the whole line. The second is a reason of available space: the physical insertion of an automation along the final lines is going to reduce considerably the amount of space available at the moment. The space occupied by the operator that performs who performs the cartoning is relatively small, and any kind of machinery installed will inevitably occupy a larger layout. Other than this, one needs to consider the space required for the safety barriers that are found on the border of the machine. The installation has been expected for a long productive stop (more on which later), but production tests and start-up are performed with the plan fully operative, so an operator will serve as a backup for the machine during such period of time. However the space available for the operator is highly reduced and the automatic reception of lots of cartons via AGV will not be available.

The following chart provides a summary of the KPI requirements

KPI		Target	UoM
OEE	Rv	99,8	%
	Rf	95,4	
	Rq	99,8	
PRODUCTION CAPACITY		270	Pcs/h
START UP		2	Weeks
CILR		45	Minutes/Week

Gantt & Schedule

The last step that the EEM Pillar works on before proceeding to step 2 is the planning of the various project phases.



The above scheme is a simplified version of the actual GANTT. It shows how the 7 steps of the project were scheduled to take place during the time. Two things are immediately visible. First, the length of the project spans a year, and this is due to the high level of complexity of the project which is one of the most ambitious ever undertook by the plant: a diluted scheduling ensures therefore against the arising of any problematics at the various stages. Second, it is possible to see how the steps of general design, detail design and construction are set to take most of the time: this ahs to be the desired outcome of the implementation of the WCM methodology as front loading allows to anticipate the criticalities at the early stages of design. All of this is aimed, as shown, at obtaining a quick start-up after the installation.

Step 1 checklist

The end of each step consists in an activity of review and assessment of the work that has been done during the phase. The checking of items in lists allows to verify that procedures have been followed through thoroughly and that no major oversights have taken place.

EARLY EQUIPMENT MANAGEMENT - VERIFICA STEP 1 "PIANIFICAZIONE"

1

DOMANDE TOT.	191
COMPLETATE	160
NON COMPLETATE	0
NON APPLICABILI	31

DATA: 28/01/2016
PROGETTO: Isola robotizzata avvitatura staffa
TEAM: EEM TEAM

HOME

N°	ARGOMENTO	DOMANDE	STATO	COMMENTI
1	GENERAL	SONO DISPONIBILI TUTTI GLI INPUT DEL PROGETTO (CARATTERISTICHE PRODOTTO, VOLUMI, TEMPI, COSTI)?	OK	
2	GENERAL	SONO STATI DEFINITI ED ESPLICITATI GLI OBIETTIVI DI EFFICIENZA DEL PROGETTO (OEE, START-UP TIME,T CICLO...)?	OK	
3	QUALITY	SONO STATI DEFINITI ED ESPLICITATI GLI OBIETTIVI DI QUALITA' DEL PROGETTO?	OK	
4	GENERAL	SONO STATI DEFINITI ED ESPLICITATI I LIVELLI DI AUTOMAZIONE?	OK	
5	SAFETY	SONO STATI PRESI IN CONSIDERAZIONE TUTTI GLI EVENTUALI RISCHI DEL PROGETTO LEGATI AL MALFUNZIONAMENTO DELL' AUTOMAZIONE (SICUREZZA)?	OK	
6	GENERAL	SONO STATI PRESI IN CONSIDERAZIONE ELEMENTI INNOVATIVI (SCANNER CON ILLUMINAZIONE)?	OK	
7	GENERAL	E' STATO DEFINITO UN LAY-OUT DI MASSIMA?	OK	
8	GENERAL	E' STATO COINVOLTO IL PLANT DI RIFERIMENTO (SE PRESENTE)?	OK	
9	GENERAL	E' STATO COMPOSTO IL TEAM DI SVILUPPO?	OK	
10	WO	SE L'IMPIANTO SI FERMA È PREVISTA LA POSSIBILITÀ DI FAR FARE LE OPERAZIONI AGLI OPERATORI COME PRIMA?	OK	

Of the 191 checklist items analyzed during step 1, 160 were successfully completed, while 31 where found to be not applicable to the current project.

Step 2: Definition of General Specifications

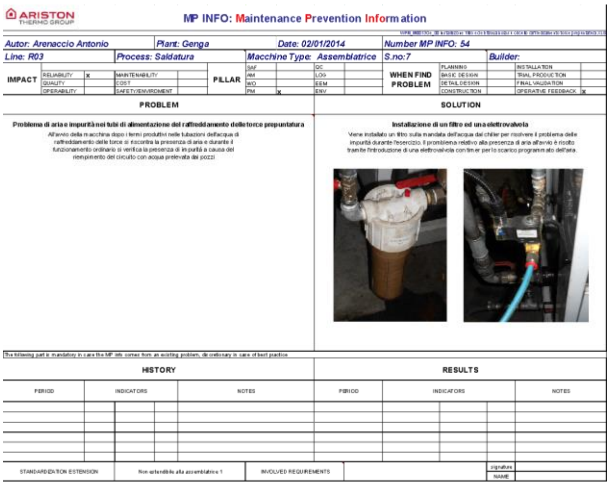
In step 2, the concept of the machine and its layout have to be defined. While step 1 focuses mostly on the definition of general needs for the plant and the consequent target-setting for the new equipment, step 2 aims at obtaining a clear idea of the working principles of the machine that will be then designed in large detail by the supplier during step 3. At this point, the first technical decisions have to be taken, and it is crucial for the plant to take the correct decisions right at the beginning, before writing down all the specifications for the supplier. Any further large modification will require additional costs and eventual delays, thus care must be taken.

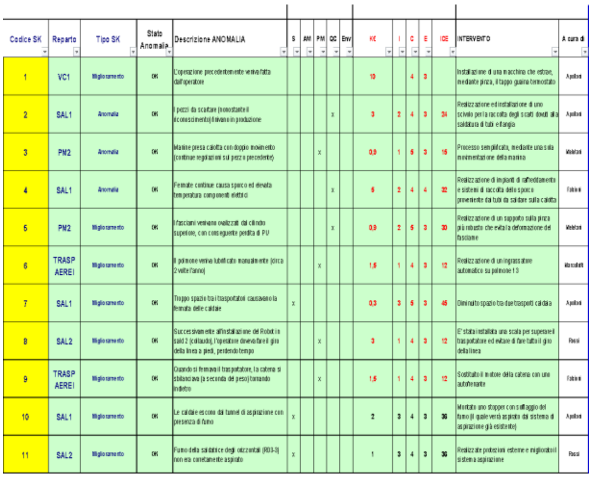
The technical specification for the project is therefore produced at this stage (once the general concept and layout of the machine has been approved) and provided to the supplier. After each supplier presents a price quotation, a choice is made and the project can enter the detail design phase.

Benchmarking

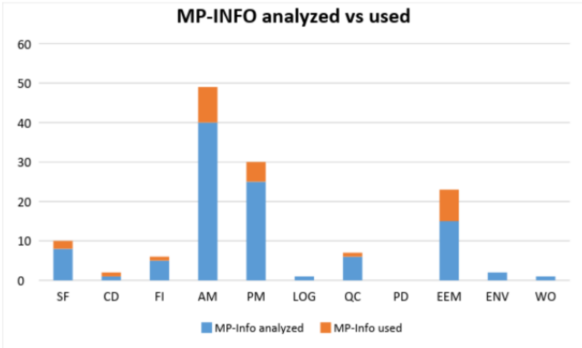
Benchmarking is the activity of searching for best practices to follow in subsequent stages of the project. The WCM methodology suggests to make two separate benchmarkings: one internal at plant level, and one external at company level.

The internal benchmarking is done by looking at technical solutions that are already successfully deployed in the plant. This can be done by taking the MP-Info (Maintenance Prevention Information) database and scanning it in search for solutions replicable in the new application.



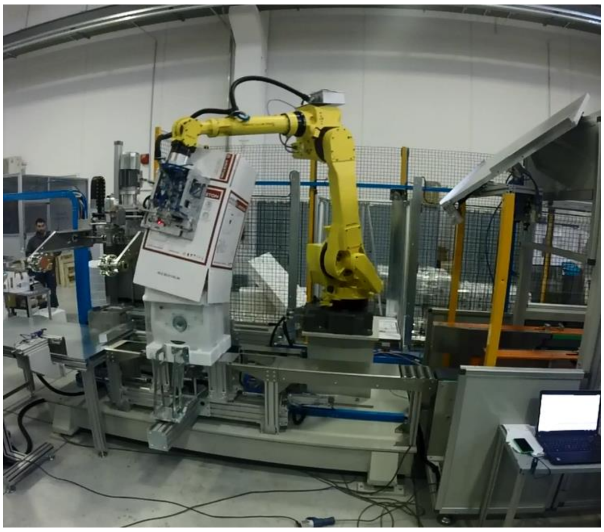


Codice SK	Reparto	Tipo SK	Stato Anomalia	Descrizione ANOMALIA	S	AM	PM	QC	Env	KC	I	C	E	ICE	INTERVENTO	A cura di
1	VC1	Miglioramento	OK	L'operazione precedentemente veniva fatta dall'operatore						10		4	3		Installazione di una macchina che estrae, mediante pinza, il tappo guaina termostato	Apolloni
2	SAL1	Anomalia	OK	I pezzi da scartare (nonostante il riconoscimento) finivano in produzione				x		3	2	4	3	24	Realizzazione ed installazione di uno scivolo per la raccolta degli scarti dovuti alla saldatura di tubi e flangia	Apolloni
3	PM2	Anomalia	OK	Marine presa calotta con doppio movimento (continue regolazioni sul pezzo precedente)			x			0,9	1	5	3	15	Processo semplificato, mediante una sola movimentazione della marina	[illegible]
4	SAL1	Anomalia	OK	Fermate continue causa sporco ed elevata temperatura componenti elettrici				x		6	2	4	4	32	Realizzazione di impianti di raffreddamento e sistemi di raccolta dello sporco proveniente dai tubi da saldare sulla calotta	Fabini
5	PM2	Miglioramento	OK	I fasciami venivano ovalizzati dal cilindro superiore, con conseguente perdita di PU				x		0,9	2	5	3	30	Realizzazione di un supporto sulla pinza più robusto che evita la deformazione del fasciame	[illegible]
6	TRASP AEREI	Miglioramento	OK	Il polmone veniva lubrificato manualmente (circa 2 volte l'anno)			x			1,5	1	4	3	12	Realizzazione di un ingrassatore automatico su polmone 13	Marcelletti
7	SAL1	Miglioramento	OK	Troppo spazio tra i trasportatori causavano la fermata delle caldaie	x					0,3	3	5	3	45	Diminuito spazio tra due trasporti caldaia	Apolloni
8	SAL2	Miglioramento	OK	Successivamente all'installazione del Robot in sald 2 (collaudo), l'operatore doveva fare il giro della linea a piedi, perdendo tempo			x			3	1	4	3	12	E' stata installata una scala per superare il trasportatore ed evitare di fare tutto il giro della linea	Rossi
9	TRASP AEREI	Miglioramento	OK	Quando si fermava il trasportatore, la catena si sbilanciava (a seconda del peso) tornando indietro			x			1,5	1	4	3	12	Sostituito il motore della catena con uno autofrenante	Fabini
10	SAL1	Miglioramento	OK	Le caldaie escono dal tunnel di aspirazione con presenza di fumo	x					2	3	4	3	36	Montato uno stopper con soffiaggio del fumo (il quale verrà aspirato dal sistema di aspirazione già esistente)	Apolloni
11	SAL2	Miglioramento	OK	Fumo della saldatrice degli orizzontali (R03-3) non era correttamente aspirato	x					1	3	4	3	36	Realizzate protezioni esterne e migliorato il sistema aspirazione	Rossi



Out of the 160 MP-Infos checked, a total of 80 was implementable in the current project.

The external benchmarking is done at company level and happens on two distinct levels. The first of step consists in looking for similar applications that are already operating on other plants. The second step, similarly to what is done during the internal benchmarking, requires searching in the updated MP-Info databases of other plants to "copy" the best practices they are already implementing. The Ariston company produces electric water heaters in different plants around the world: despite different plants are usually focused on different variants of the products, the operations that are performed during manufacturing share some common traits. It is therefore not uncommon that a plant experiments on a new type of machine to improve a specific process and that such solution is then replicated to some extent in other facilities. In particular, automatic cartoning applications were already implemented in some other plants [Namur, Osimo] and most notably in Cerreto. The latter plant is found in the city of Cerreto d'Esi, less than 20Km away from Genga and is another historic structure in the Ariston company. In Cerreto water heaters with a lower capacity are produced, most of the production is focused on volumes up to 30 liters. The manufacturing of such water heaters is incredibly similar in processes to that in Genga with the main difference being the external casing made of plastic instead of metal. Along the final line the products move on conveyor rollers towards the finished products warehouse. The packaging is automated by using two Fanuc robots on the two separate final assembly lines. The robot is supplied the cartons on piles and uses a vision system to correctly identify the position and orientation of the top box. It then proceeds to pick up and lift the still closed box using the multiple suction cups on its end effector and deposits it on an diagonally inclined plane at the top of a specific separate structure. The carton lands on the surface and slides downwards both longitudinal and lateral direction reaching the corner of the plane where is position is rigidly defined with respect to the world reference frame. The surface is itself provided with suction cups that are activated at this stage of the process with the purpose of keeping one side of the box stuck on the plane while, simultaneously, the robotic arm reaches a specific position relative to the corner of the plane, leans on the other side of the box and starts pulling it open. As the box reaches its open condition, the end effector catches it from the side by using pneumatically actuated lateral claws. At this point the robotic arm has full control of the open box and proceeds to position it straight above the water heater (which meanwhile has reached a station in which it is blocked in a fixed position with respect to the reference frame of the robot) and lowers to insert the carton. The water heater is finally released from the station and can go on in its route to the warehouse.



The solution used in Cerreto is effective, clever and relatively simple, but despite providing some interesting ideas for a similar implementation at in Genga, a few considerations have to be made:

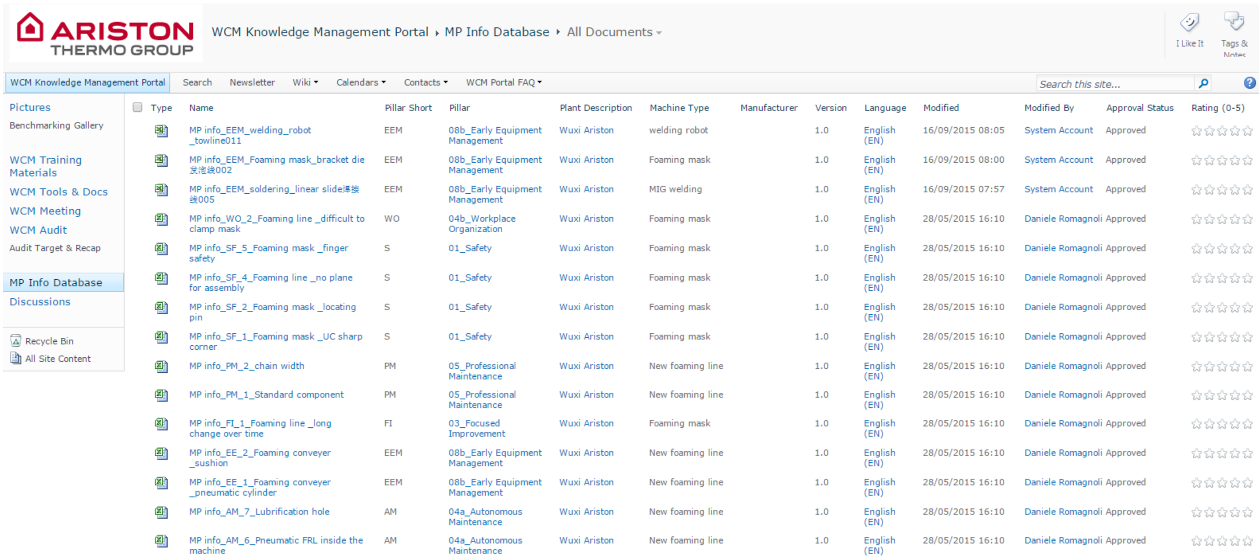
- As stated at the beginning, the products manufactured in Cerreto are much smaller (maximum 30L) than those of Genga (maximum 100L). The carton is larger and heavier and thus its manipulation is harder.
- The TAKT time along the final assembly lines in Cerreto is 20 seconds, much larger than the 12 seconds per cycle that are found in Genga.

These two points combined make it extremely complicated to replicate the Cerreto automation in Genga. Picking up the carton, releasing it on a plane, pulling it open and then grabbing it on the sides while lifting it up again is a series of simple operations that require a specific amount of time to be performed and cannot be accelerated much more than what already happens in Cerreto. This means that only a few of the concepts have been taken in consideration for being implemented in Genga, namely:

- The use of a robotic arm for the picking up and insertion of the carton
- The use of a station in which the water heater is stopped and waits for the insertion in a specific position that is fixed with respect to the robot reference frame so as to guarantee the repeatability of operation

- The use of a 7th axis independent from the robot to help the robot opening the box as this is a critical operation with a really low repeatability and cannot be performed effectively by the robotic arm alone.

The existence of similar installations across the company also implies the presence of a rich database of MP-Infos containing precious information about the complications that this type of machine can bring to the project. Every plant tries to keep a record of the problems and complexities related to the project so as to build some knowledge and a know-how that can prove helpful for future similar applications in other facilities. MP-Infos can contain best practices regarding both high-level project specifications such as suggestions about layout and concept of the machine or lower level design details regarding the durability and operability of single components.



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Name	Pillar Short	Pillar	Plant Description	Machine Type	Manufacturer	Version	Language	Modified	Modified By	Approval Status	Rating (0-5)
MP info_EEM_welding_robot _towline011	EEM	08b_Early Equipment Management	Wuxi Ariston	welding robot		1.0	English (EN)	16/09/2015 08:05	System Account	Approved	
MP info_EEM_Foaming mask_bracket die 发泡线002	EEM	08b_Early Equipment Management	Wuxi Ariston	Foaming mask		1.0	English (EN)	16/09/2015 08:00	System Account	Approved	
MP info_EEM_soldering_linear slide焊接线005	EEM	08b_Early Equipment Management	Wuxi Ariston	MIG welding		1.0	English (EN)	16/09/2015 07:57	System Account	Approved	
MP info_WO_2_Foaming line _difficult to clamp mask	WO	04b_Workplace Organization	Wuxi Ariston	Foaming mask		1.0	English (EN)	28/05/2015 16:10	Daniele Romagnoli	Approved	
MP info_SF_5_Foaming mask _finger safety	S	01_Safety	Wuxi Ariston	Foaming mask		1.0	English (EN)	28/05/2015 16:10	Daniele Romagnoli	Approved	
MP info_SF_4_Foaming line _no plane for assembly	S	01_Safety	Wuxi Ariston	Foaming mask		1.0	English (EN)	28/05/2015 16:10	Daniele Romagnoli	Approved	
MP info_SF_2_Foaming mask _locating pin	S	01_Safety	Wuxi Ariston	Foaming mask		1.0	English (EN)	28/05/2015 16:10	Daniele Romagnoli	Approved	
MP info_SF_1_Foaming mask _UC sharp corner	S	01_Safety	Wuxi Ariston	Foaming mask		1.0	English (EN)	28/05/2015 16:10	Daniele Romagnoli	Approved	
MP info_PM_2_chain width	PM	05_Professional Maintenance	Wuxi Ariston	New foaming line		1.0	English (EN)	28/05/2015 16:10	Daniele Romagnoli	Approved	
MP info_PM_1_Standard component	PM	05_Professional Maintenance	Wuxi Ariston	New foaming line		1.0	English (EN)	28/05/2015 16:10	Daniele Romagnoli	Approved	
MP info_FI_1_Foaming line _long change over time	FI	03_Focused Improvement	Wuxi Ariston	Foaming mask		1.0	English (EN)	28/05/2015 16:10	Daniele Romagnoli	Approved	
MP info_EE_2_Foaming conveyer _sushion	EEM	08b_Early Equipment Management	Wuxi Ariston	New foaming line		1.0	English (EN)	28/05/2015 16:10	Daniele Romagnoli	Approved	
MP info_EE_1_Foaming conveyer _pneumatic cylinder	EEM	08b_Early Equipment Management	Wuxi Ariston	New foaming line		1.0	English (EN)	28/05/2015 16:10	Daniele Romagnoli	Approved	
MP info_AM_7_Lubrification hole	AM	04a_Autonomous Maintenance	Wuxi Ariston	New foaming line		1.0	English (EN)	28/05/2015 16:10	Daniele Romagnoli	Approved	
MP info_AM_6_Pneumatic FRL inside the machine	AM	04a_Autonomous Maintenance	Wuxi Ariston	New foaming line		1.0	English (EN)	28/05/2015 16:10	Daniele Romagnoli	Approved	

In the following pages, an overview of the main technical features that have been specified to the supplier is found. Some of them come from best practices and MP-Infos, other are requirements for this particular project that have been discussed and analyzes in step 2.

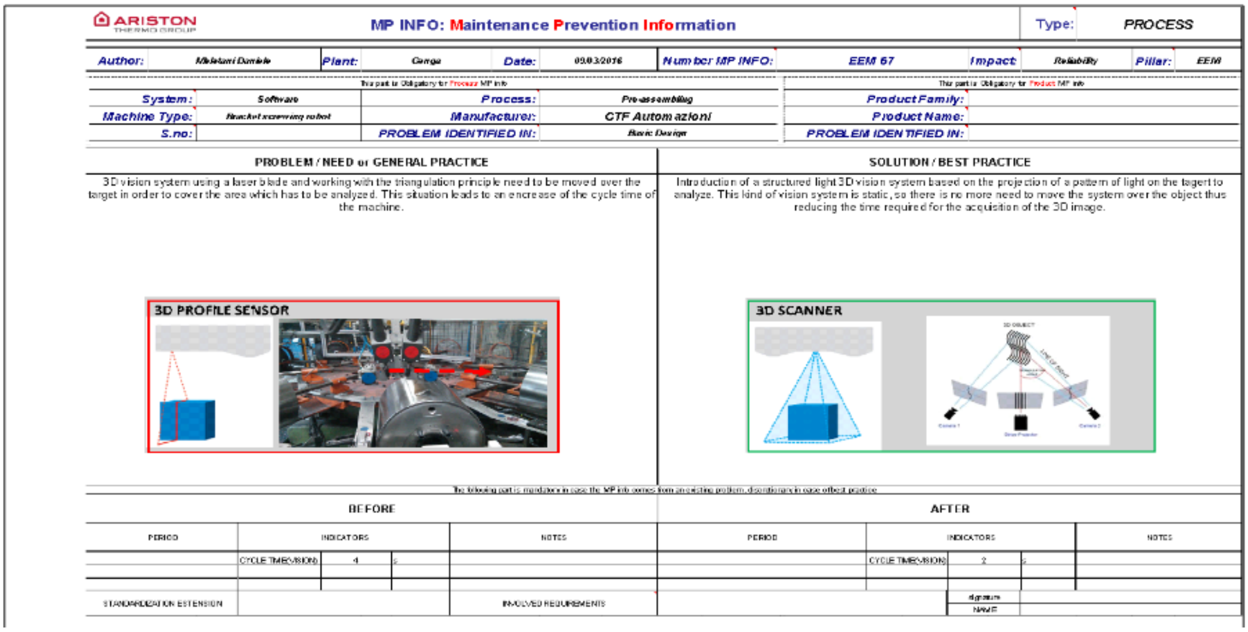
3D computer vision using structured light

Digital vision is always a very delicate and critical point for an automation. Vision systems are often crucial in the correct identification of the position and orientation of the products or of some specific features on it which is a basic requirement of many complex applications in which the machine needs to substitute a human being. Different technological solutions are available on the market, each one has some advantages and some drawbacks: generally, the higher the complexity of the identification process, the higher the price of the equipment and the slower the process. In the plant in Genga, many different vision systems have been adopted in different automations across the years and therefore both the EEM and PM Pillars have some experience on this type of technologies. The use of bi-dimensional light vision systems has been discarded immediately for a number of reasons, the main one being the fact that it is a technology that is extremely dependent on ambient light and on the presence of a certain type of contrast and color in the area that is analyzed: small variations of the ambiental illumination (even the ones due to the alternation of the day and night cycles) can prevent the system to work properly. 2D light vision tends also to be slower than its 3D counterpart. 3D vision on the other hand, does not require a specific lighting of the environment and can work independently from the conditions of contrast and color. It also allows, as its name implies, the recognition of three dimensional features and parts on the products.

The automatic carton insertion is a process that will require the identification of the position the the flattened box so that some kind of manipulator can be able to pick it up and open it in order to guarantee a correct insertion on the product. This identification process might seem relatively easy if one imagines a flat carton leaning on a plane surface: the computer vision is only required to locate two perpendicular edges of the box to find the corner and have therefore a solid reference to know exactly where each portion of the carton is in the space. Problems arise once more details about the process are analyzed. As stated earlier, cardboard is a material with a low finished product quality which is inherently due to its composition, structure, and to the fact that generally it is only produced with the intended aim of serving as packaging. Cardboard boxes suppliers, therefore, are never pushed for tight tolerances on the final dimensions and shape. This is fine for packaging purposes, but might represent a problem if the box has to be manipulated by an automation: large tolerances on the exact position in which the two sides of the carton are superimposed and glued results in a different overall dimension of the flat box that can compromise the correct pick-up from the manipulator, as the corner is not anymore a certain reference with respect to the rest of the carton. Also, the corners of the flat box (which are the easiest point in which the vision system can identify position and orientation) are also the most easily damaged during transportation and storage, as they are exposed.

All the parameters analyzes above, combined with the previous plant experience with other robotic platforms installed in the plant in previous years, resulted in asking to the supplier in the technical specification to adopt a 3D vision systems that uses structured light to identify the carton box correctly. An MP-Info existed on the subject: it was compiled during the design stage of an automated platform in which two Fanuc robotic arms are used in the screwing of the support bracket of the water heater during pre-assembly. An operator inserts the external casing of the product on the boiler that is moving in stations on a rotating board. Once the bracket screwing station has been reached, a 3D vision system scans for the presence and correct position of the screw hole, while the first robotic arm picks up the bracket from a conveyor and then proceeds to reach a position in which a screw feeding system is provided. The screws are initially poured in a vibrating bowl, where they are slowly directed along a chute. At the end of the slide, individual screws are then separated and placed in slots that have a fixed position with respect to the robot reference frame, so that the robot can easily pick them up for insertion. The robot uses two electric screwdrivers to secure the screws on its end effector, verifies the effective presence of them by moving in front of two laser sensors and finally moves on the water heater in the position that was identified by the vision system, lowers on its and proceeds with the screwing of the bracket. The second robot is used to feed the brackets on the conveyor mentioned earlier: the brackets are initially found in caissons where a magnetic manipulator is used to automatically draw and move some of them on a conveyor belt. There, the second robot uses another vision system to identify the random position and orientation of each of the brackets and to move accordingly with the purpose of placing them on the feeding system for the first robot. The platform is one of the most complex that are present in the plant and many problems were found during the detail design of the automation, as the initial hypothesis of using a 3D profile scanner in the identification of the holes proved inaccurate and excessively slow. Even with the introduction of the structured light system, the vision operation has to be performed in masked time with respect to the activities of the anthropomorphic manipulator.

For all the above reasons, the use of a structured light 3D vision system has been prescribed in the technical specifications provided to the suppliers.


ARISTON THERMO GROUP

MP INFO: Maintenance Prevention Information

Type: PROCESS

Author:	Malatesti Daniele	Plant:	Genga	Date:	09.03.2016	Number MP INFO:	EEM 67	Impact:	Reliability	Pillar:	EEM

This part is Obligatory for Process MP info

System:	Software	Process:	Pre-assembling
Machine Type:	Bracket screwing robot	Manufacturer:	CTF Automazioni
S.no:		PROBLEM IDENTIFIED IN:	Basic Design

This part is Obligatory for Product MP info

Product Family:	
Product Name:	
PROBLEM IDENTIFIED IN:	

PROBLEM / NEED or GENERAL PRACTICE	SOLUTION / BEST PRACTICE
3D vision system using a laser blade and working with the triangulation principle need to be moved over the target in order to cover the area which has to be analyzed. This situation leads to an encrease of the cycle time of the machine.	Introduction of a structured light 3D vision system based on the projection of a pattern of light on the tagert to analyze. This kind of vision system is static, so there is no more need to move the system over the object thus reducing the time required for the acquisition of the 3D image.

The following part is mandatory in case the MP info comes from an existing problem, discretionary in case of best practice

BEFORE					AFTER				
PERIOD	INDICATORS			NOTES	PERIOD	INDICATORS			NOTES
	CYCLE TIME(VISION)	4	s			CYCLE TIME(VISION)	2	s	
STANDARDIZATION ESTENSION				INVOLVED REQUIREMENTS		signature / NAME			

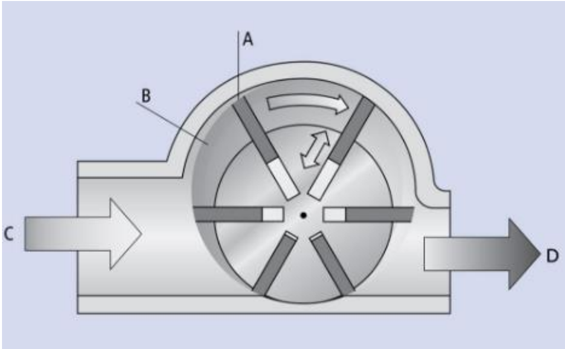
Adoption of vacuum pumps

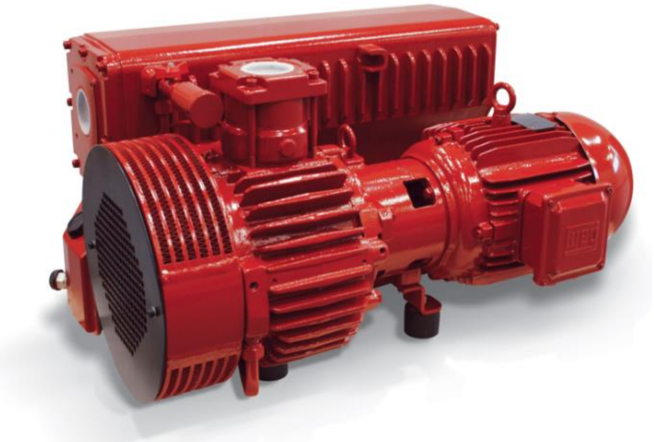
The choice on the best technological solution for the plant for the generation of vacuum is crucial, especially for what concerns the operating costs of the installation: different vacuum generation technologies present different running costs in terms of energy consumption, reliability and maintainability.

Across the plant, many of the machinery that requires vacuum generates it using the Venturi principle. Compressed air is pumped in the ejector and accelerated through the Venturi nozzle, thus increasing the dynamic pressure and simultaneously decreasing the static air pressure. Once the air exits the nozzle it then quickly expands, causing air suction from the vacuum connection. This type of generators cause two main inefficiencies in the plant:

- As shown by the energy losses pareto in step 1, the plant suffers from losses due to energy transformation. The venturi principle vacuum generator requires the input of compressed air, which was initially generated by electrical equipment. The inefficiency of each step sums up and causes a general increase of the energy consumption required by the machine.
- The use of compressed air blown through a Venturi nozzle can cause clogging of the vacuum generators.

A solution to both problems has been identified in the adoption of electric vacuum pumps. Such devices are electrically actuated, therefore they do not need the injection of compressed air, and this means that the overall energy transformation efficiency is improved. An eccentrically mounted impeller uses sliding lamellas to create vanes that vary in dimension during the cycle. The air enters the compressor in a small chamber, which dimension increases along the cycle, so that pressure is reduced up to a partial vacuum.





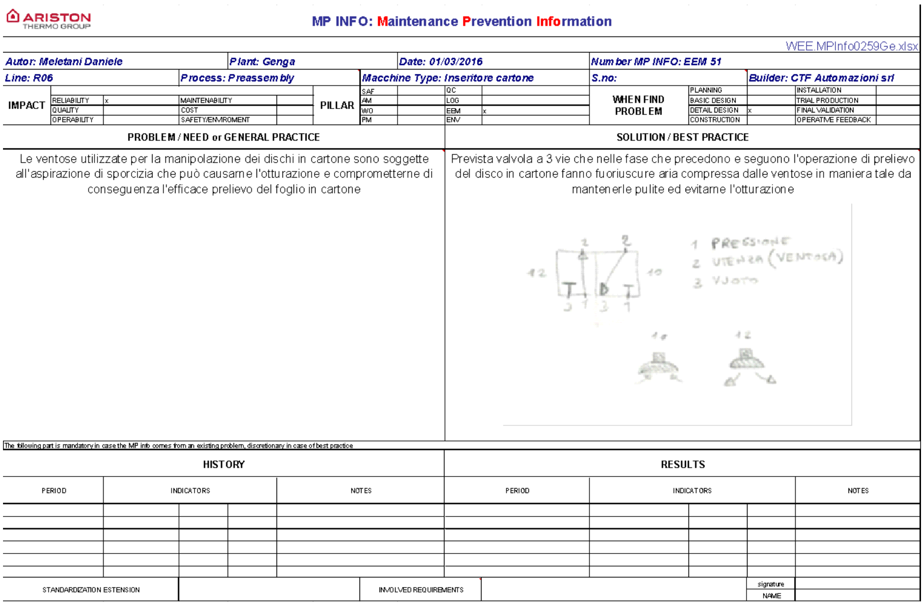
An analysis of the EWO database also allowed to estimate that adopting this technology the plant can avoid around 1.8 hours a month of breakdown stoppages due to vacuum generators clogging.

Suction cups clogging

Other particularly significative specifications regarded the adoption of vacuum as a method for carton drawing and manipulation. Vacuum pumps and suction cups tend to clog easily, causing consequent micro-stoppages and faults in the machinery and therefore producing efficiency. A number of technical solutions has been identified in the Ariston plants over the years, here follow a few sample MP-Infos addressing the issue that have been considered in the project.

Suction cups are the contact point between the robot's end effector and the carton. The vacuum pump produces a negative delta with respect the environmental pressure that causes the soft rubber cups to stick with the cardboard surface of the box. This is a reliable mean for manipulating a material such as carton that can be easily damaged by clamps, claws or other mechanical devices, but it nonetheless presents some drawbacks as well. One of the main problems lies in the fact that the suction due to the vacuum pulls in the cups a lot of dust and other small light parts that can be in the area. This, over time, provokes clogging of the suction cups or of the tubes, the pick-up process is therefore interrupted and the machine will not work properly. To restore the initial condition, a stoppage of the automation is required so that cleaning and maintenance can be performed.

The presence of dust and other particles in the environment is something that is inevitable in a large manufacturing plant, also, cardboard manipulation causes itself the generation of small particles of paper that can be easily picked up in the suction process: the reliability of the automation had to be improved to avoid this type of problem. The solution comes from an older MP-Info of the plant: the manipulation of cardboard discs which are used in the pre-assembly operation to avoid the sticking of the two caps of the inner boiler and the external casing. Such cardboard discs are inserted on the boiler by the use of an automation that relies on suction cups and that, therefore, showed various problems related to dust accumulation and clogging. The solution in that case was the implementation of 3-way valves that allowed blowing compressed air through the suction cups during the phases preceding and following the sucking operation. In this way, any dust that entering the cups during the cycle is immediately expelled before the next cycle begins, thus significantly reducing the risk of clogging.



ARISTON THERMO GROUP

MP INFO: Maintenance Prevention Information

WEE.MPInfo0259Ge.xlsx

Autor: Meletani Daniele	*Plant: Genga*	*Date: 01/03/2016*	*Number MP INFO: EEM 51*	
Line: R06	*Process: Preassembly*	*Macchine Type: Inseritore cartone*	*S.no:*	*Builder: CTF Automazioni srl*

IMPACT	RELIABILITY	x	MAINTENABILITY		PILLAR	SAF		QC		WHEN FIND PROBLEM	PLANNING		INSTALLATION
	QUALITY		COST			AM		LOG			BASIC DESIGN		TRIAL PRODUCTION
	OPERABILITY		SAFETY/ENVIROMENT			WO		EEM	x		DETAIL DESIGN	x	FINAL VALIDATION
						PM		ENV			CONSTRUCTION		OPERATIVE FEEDBACK

PROBLEM / NEED or GENERAL PRACTICE	SOLUTION / BEST PRACTICE
Le ventose utilizzate per la manipolazione dei dischi in cartone sono soggette all'aspirazione di sporcizia che può causarne l'otturazione e comprometterne di conseguenza l'efficace prelievo del foglio in cartone	Prevista valvola a 3 vie che nelle fase che precedono e seguono l'operazione di prelievo del disco in cartone fanno fuoriuscure aria compressa dalle ventose in maniera tale da mantenerle pulite ed evitarne l'otturazione

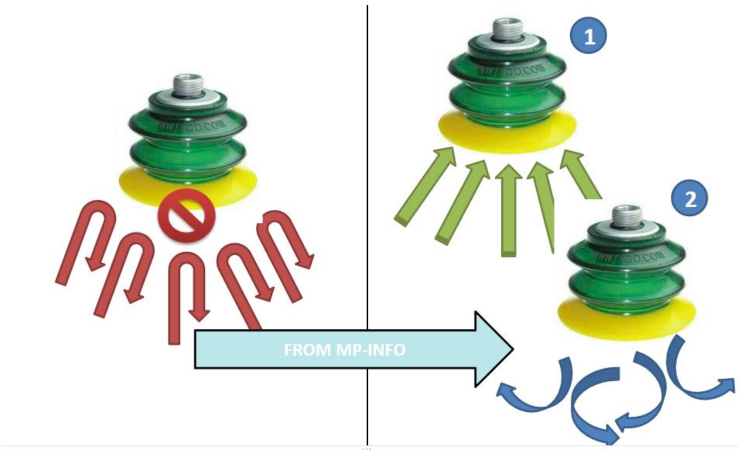
1 PRESSIONE
2 UTENZA (VENTOSA)
3 VUOTO

The following part is mandatory in case the MP info comes from an existing problem, discretionary in case of best practice

HISTORY			RESULTS		
PERIOD	INDICATORS	NOTES	PERIOD	INDICATORS	NOTES

STANDARDIZATION ESTENSION		INVOLVED REQUIREMENTS		signature	
				NAME	

A similar solution has then been prescribed in the technical specification, anticipating the onset of this problematic in the future.



Use of multiple suction cups in parallel

Another solution to the problem described above was found in the plant of Namur, in Belgium. There, another variable was considered as well: suction cups are made in a rubber material that is highly deformable so as to perfectly adapt to the surface of the object that needs to be manipulated and guarantee stucking during the suction phase. As both rubber and cardboard are not rigid, in some scenarios it might happen that the two surfaces do not adhere perfectly to each other during sucking, resulting in the cup not being used effectively.

Redundancy has in this case proved another effective solution: by adopting the same best practice that has been proposed by Namur, the technical specification now prescribes that suction cups are used in a number that exceeds the actual requirements of the automation. If any of the suction cups fails for any reason, the operation can continue smoothly and the issue can be easily resolved during a time in which the machine is not working, thus avoiding production stoppages.

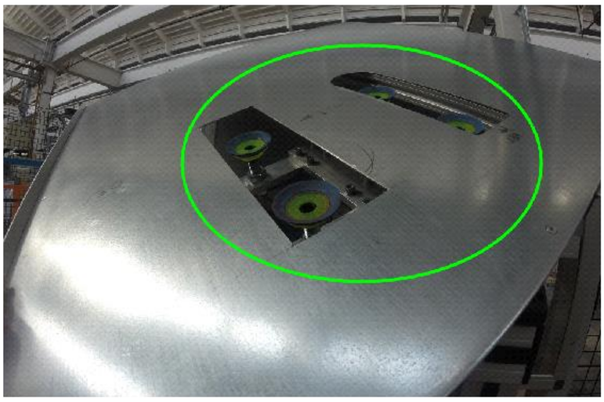
ARISTON THERMO GROUP

MP INFO: Maintenance Prevention Information

Author: Andrea Testa	*Plant: 05*	*Date: 14-12-15*	*Number MP INFO:43*
Line:	*Process:*	*Machine Type:*	*S.no:* / *Manufacturer:*

IMPACT	RELIABILITY		MAINTENABILITY		**PILLAR**	SAF		WO		LOG		**WHEN FIND PROBLEM**	PLANNING		INSTALLATION	
	QUALITY		COST			FI		PM		EEM	x		BASIC DESIGN		TRIAL PRODUCTION	x
	OPERABILITY	x	SAFETY/ENVIROMENT			AM		QC		ENV			DETAIL DESIGN		FINAL VALIDATION	
													CONSTRUCTION		OPERATIVE FEEDBACK	

PROBLEM / NEED or GENERAL PRACTICE	**SOLUTION / BEST PRACTICE**
VACUUM MISSING DURING CARTON BOXES OPENING PROCESS	USE TWO LINES OF SUCTION CUPS FOR OPENING THE CARTON BOXES



The following part is mandatory in case the MP info comes from an existing problem, discretionary in case of best practice

HISTORY					**RESULTS**				
PERIOD	INDICATORS			NOTES	PERIOD	INDICATORS			NOTES
	STOPS	MIN/SHIFT	10			STOPS	MIN/SHIFT	0	

STANDARDIZATION ESTENSION	FINAL LINES	INVOLVED REQUIREMENTS	SUPPLIER	signature	
				NAME	ANDREA TESTA

Use of capacitive sensors

Another issue related to the manipulation of cardboard lies in the correct choice of how to sense it: the automation is required to verify whether the box has been picked up correctly. The choice of the sensing devices is complicated by a number of issues related to the material, in particular:

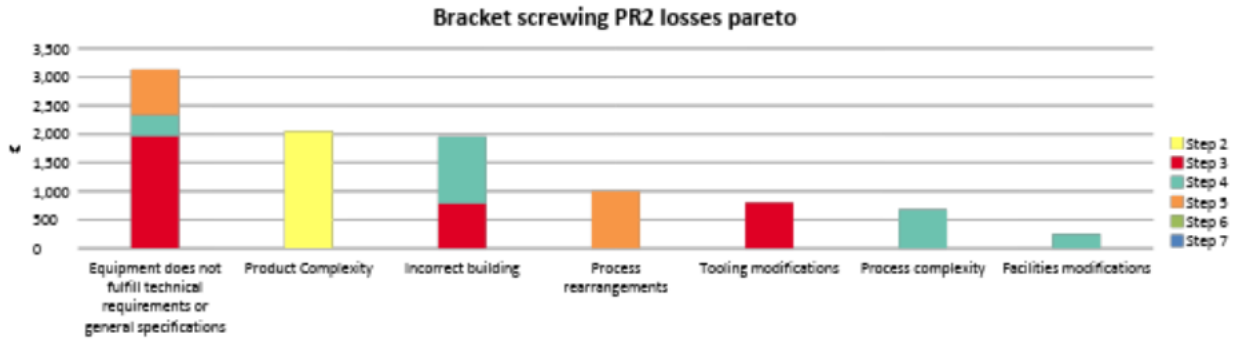
- Inductive sensors are not suitable to sense a cardboard object has it has a very low conductivity

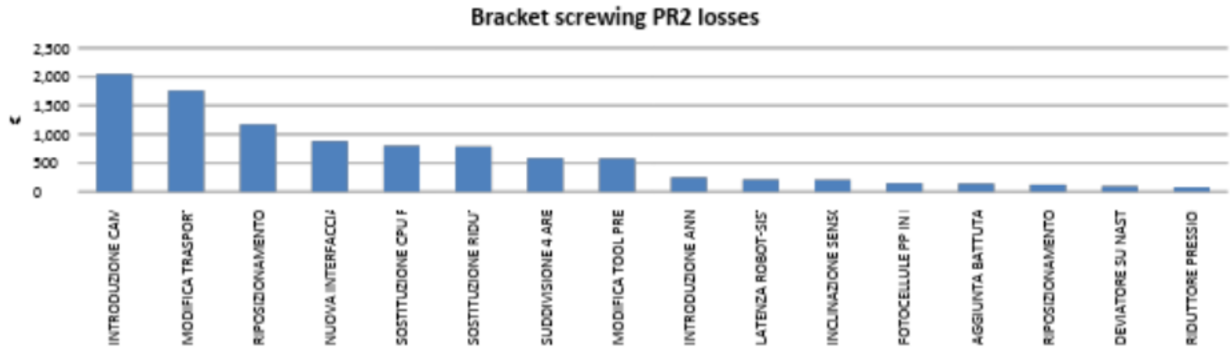
- Vacuum switches require a certain level of vacuum to work properly. Being the box a relatively low item, the amount of vacuum effect required to lift it its relatively low and the switches are therefore not a reliable solution
- Photocell sensors are not able to verify correctly the presence or absence of a flat item, and the box is flat

Again, the proposed solution comes from the automation that manipulates the cardboard discs described earlier. In this case capacitive sensors have been implemented to check whether the disc has been picked up or not: the flattened box functions as a second plate for the capacitor and can be identified correctly.

it is worth pointing out how vacuum switches are used over the plant in many applications and a good know-how about their functioning and main problematics has been built over time. Vacuum switches are often not the most reliable sensing device and it has been estimated that using capacitive sensors for the carton insertion can save around 2.4 minutes of micro-stoppages per work shift which represents a significative saving over time.

The WCM methodology suggests to use previous EEM projects as a reference for improvements on new installations. A review of the previous project, the robotic platform for the screwing of the bracket in the pre-assembly phase, has been performed so as to identify and anticipate any possible criticality in the carton insertion automation. In particular, a pareto indicating the major causes for the losses on the bracket screwing automation has been analyzed. In that case, the major problems that appeared during the design and construction of the machinery were imputed to complexities in the correct development of the robot software, in particular for what concerns the vision system.

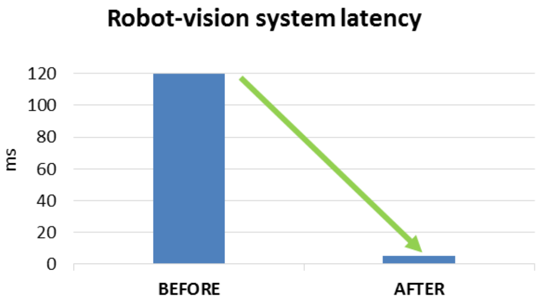


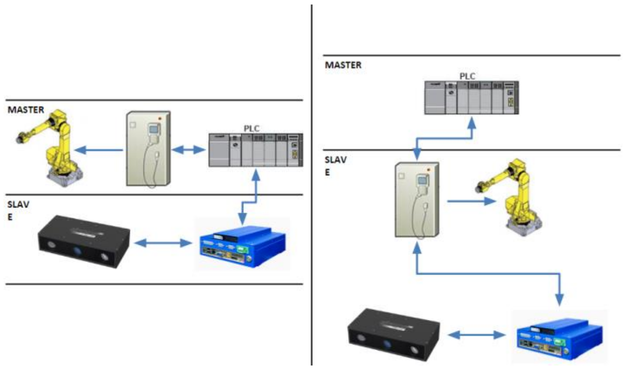


A number of precautions have been explicitated in the technical specification so as to counteract their eventual replication in the new project.

Modification of software hierarchy

It has already been explained how the vision system caused major problems in the bracket screwing platform and the negative impact on the cost deployment of the project is visible in the pareto above, where it is clear how many of the economical losses (and, not shown, delays) in the delivery were imputable to the software structure and management. Losses were mainly caused by an incorrect selection of the proper vision system during the detail design stage, as well as to the general slowness of the process itself, which mainly due to the time required by the software to analyze the scanned image in search of the holes, but that also suffered because of the latency of communication between the various devices. The bracket screwing robot initially sent the images acquired by the vision system through the PLC before they are analyzed and processed by the robot controller. The controller finally establishes the trajectory and path of the anthropomorphic arm and instructs the motion. In this type of software structure, the robot controller and the PLC had the same hierarchical level and each information needs to be processed by each sub-component, thus causing a significant latency in the data transfer, which was estimated at about 120ms. The latency was almost completely eliminated by modifying the software structure so as to have the PLC as the master of the automation and the robot controller as a slave at a lower level in the software hierarchy. The information from the vision system comes from an even lower level, a slave of the robot controller, but in this case does not need to be received by the PLC before being sent to the robot controller.

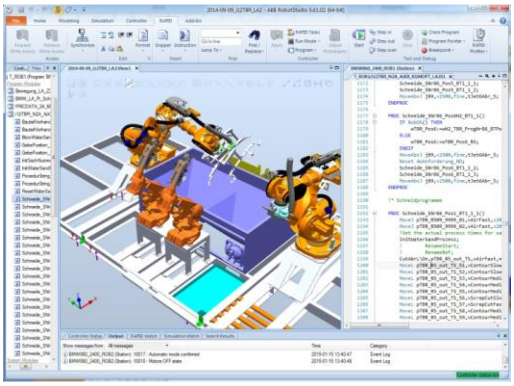


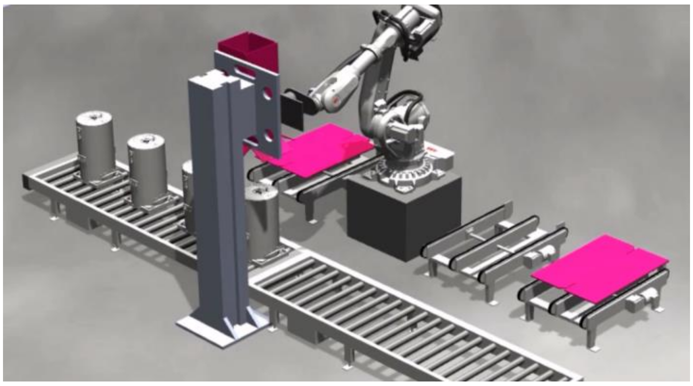


120ms might not seem like a huge gain in terms of time, but in the bigger order of things of requiring a cycle time of 12s is certainly a significative gain. The same kind of logic is proposed to the supplier during the redaction of the technical specification.

RobotStudio

For the first time, the EEM Pillar decided to experiment in the early project stages with a software developed by ABB that allows to simulate the layout and operation of a robotic platform. RobotStudio provides a complete range of tools that can prove useful at different stages of the project. The main purpose for the EEM Pillar at this stage was to identify various possible layouts and concepts for the carton insertion automation and simulate encumbrances of the various apparatuses as well as various solutions for the actual operation. This allowed to make a first estimate of the achievable results in terms of cycle time and operability for different machine concepts.





RobotStudio is a tool that can be useful at every stage of a project. It allows to pick the robotic arm that best suit the requirements of the project, and allows to recreate the environment in which it is going to be deployed. The modeling and simulation tools it contains, allow to create a realistic 3D version of the layout even at early stages: furing step 2 the layout is still not completely defined, but it is however possible to verify the actual encumbrances of the various parts, components or intermediate stations that the automation uses. With this rough layout available, the motion of the robot between the various working points can be tested and verified, and an estimate of the cycle time of the various operations can be computed.

RobotStudio can be also employed at more advanced stages of the project, such as detail design. Also, once the automation has been started up and is active in production, it can be possible to test any desired modification or optimization of the software, so that it is not required to stop the robot during the simulations. The EEM Pillar is currently starting to use this kind of tools during early design, so as to be more capable of understanding the concept and the layout of each platform while preparing the initial documentation for the project. This simplifies any further work, and allows the plant to be more prepared to certain technical solutions once the suppliers are met for the first time.

It is worth noting that the technical final technical specification was a result of the effort of the work of the various pillars as well as of the contribution and technical know-how provided by the initial proposals of the suppliers during the preliminary visits at the plant. Before sending a final technical specification, each machinery supplier is invited to the plant to make an on-site evaluation of the technological solutions that are feasible. Different suppliers have different know-hows and therefore are able to identify possible criticalities in the project as well as provide suggestions on concept and layout features. The EEM Pillar is responsible for collecting also the inputs and suggestions coming from the suppliers before redacting the technical specification.

The final technical specification that has been sent to three different suppliers consisted of two parts: the first one regards some general requirements of the Ariston company, the second one is a series of indication specific to the project and is the part that has been referred so far in the text.

Industry 4.0 compliance

Among the requirements included in the specification, there is a particular provision regarding the compliance of the project to the Italian National Industri 4.0 plan. This plan is a set of economic measures which the Italian government set to help enterprises evolve and catch the opportunities offered by the fourth industrial revolution.

The third industrial revolution brought computers, information technologies, robots and internet in the everyday reality of manufacturing. Now, the fourth revolution introduces the concept of interconnectivity and interoperability between the machines: data produced by machines and collected by sensors are communicated across the plants to other equipment and to people via internet. Such data are collected, elaborated and analyzed in a way that aims at improving the efficiency of the factory and of the production. It is worth pointing out how the revolution is also in the way the data is used to make decisions. Previously people gathered production and machine data to try and create models and predictions on how to improve their efficiency, now instead, computer systems are able to do so by themselves: decision making is decentralized.

Many new 4.0 technologies are now available to the world of manufacturing, but not all the companies are able to afford them: the National Industry 4.0 plan in Italy has been devised with the purpose of helping industries to reconvert to such new technologies and gain competitivity on the world market. Among the other things, the plan offers an "hyper-depreciation" for new material goods, technologies or devices purchased during the period between 2016 and 2018 that abilitate the company to the Industry 4.0 world (this is not the only measure, but is the most significative one for the automatic carton insertion of the plant). The general requirements that allow the access to such economical benefits require the installation to:

- be controlled by a PLC or CNC software
- be interconnected to the factory management software (e.g. SCADA)
- be automatically integrated with the logistic system of the factory, with the feeding or supplying chain or with other machinery found upstream or downstream the process
- have a simple and intuitive man-machine interface
- be compliant with the most recent parameters in terms of safety and hygiene

Also, all of the Industry 4.0 compliant machines need to satisfy at least two of the following characteristics that allow them to be considered as or integrated to cyber-physical systems:

- have systems of remote maintenance, diagnosis or control
- be able to continuously monitor the work conditions and the processing parameters using adequate sensing device, and be able to automatically adapt to correct any drifts in the process
- possess characteristics of integration between the physical machine and the virtual model of its behavior during operation
- integrate smart devices, instrumentation or components aimed at interconnecting, sensorizing or automatically controlling the processes
- include smart systems for the marking and identification of products with the purpose of guaranteeing the traceability of the individual products
- [...]

The list of possible implementation that abilitate Industry 4.0 is long.

The resulting economic advantages are also significative as it becomes possible for the enterprises to deduct from the taxes the 250% of the taxable, thus allowing them to buy new equipment with a great discount. For this reason, Ariston requires all the new installations to be compatible with the prescriptions of the Industry 4.0 plan: this represents a great opportunity to renovate old machinery in the plants.

The list of all the prescriptions adopted for the project in order to make it Industry 4.0 compatible will be detailed later, during the presentation of step 3.

Carton specification

Due to the fact that the process with which the boxes are inserted was going to be changed, meetings have been organized with the carton suppliers to establish guidelines for the future production of carton lots. Being the carton lots an item that does not normally require a particularly high level of precision during the manufacturing, and due to the fact that no major product problematics ever emerged in the past years of work with the suppliers, the technical specifications regarding the lots were poorly defined. The only additional requests brought out by Ariston were the fact that each box has to be composed by exactly 60 items, that an additional cardboard sheet has to be put at the top and at the bottom of each lot to ensure the protection of the boxes during their manipulation with the forklift trucks, and that the lots have to be strapped on the sides so that the lot will not overturn during manipulation.

With the employment of an automation for the cartoning, the technical specifications for the carton lots had to be reviewed and strengthened. Here are a few of the crucial adaptations asked to the suppliers:

- Removal of intermediate straps in the lot. One supplier did not simply put large straps around the entire lot to avoid the overturn of the cartons, but also added additional intermediate smaller straps every 10 boxes. This was not the best case scenario even before the introduction of the automation, as the operators in the picking area were required to cut open and slip off all such straps: a series of non value added actions that consumed the available time for the operator. The introduction of the automatic logistic systems for the automation requires these intermediate straps not to be present at all, in fact, the vision system of the robot will not be predisposed to discriminate the presence of such straps and they can end up causing stoppages or even damage to the automation
- Use of standardized cardboard sheets at the top and bottom of the pile for protection. At this stage of the project it was still not clear whether the robot had to deal with the additional protection sheets present in the lot or not. Since any modification to the product asked to the suppliers is a lengthy process that involves

many divisions inside the Ariston company and due to the fact that the supplier might in those case have to slightly modify its production system, a few months can pass since the draw up of the technical specification and its actual implementation. Because of this, the plant tried to intervene as early as possible and to anticipate any possible crucial theme regarding the cartons, so as to avoid delays at later stages of the project

- Avoidance of intercalary sheets of any kind. Similarly to what explained earlier for intermediate straps, some suppliers also add intermediate sheets of paper every few boxes. This will have to be avoided once the automation will go in production
- Definition of a PPM quality (defective Parts Per Million). Before the introduction of the automation, some of the boxes arrived at the plant without the string of glue that joins its faces: the result is that the box remains open in the middle and cannot be inserted, so the operator proceeds to discard it. This discard operation is not possible (or, at least, not easy to perform) with a robot, therefore any defective box would cause a micro stoppage of the production line, negatively affecting the efficiency of the machinery. By specifying a particular value of PPM quality, the plant is able to better predict how the defective quality of cartons is going to affect the automated production
- 100% dinking of the flaps. As the robot will be responsible to fold the lower flaps open, it is necessary that the dinking process is performed correctly an all of the flaps. If the junction between the flap and the face is not properly processed, the robot would not be able to open it and this would inevitably cause a micro stoppage and a consequent inefficiency of the production line
- Presence of an air gap between the flaps. The process used to join and glue together the two extremities of the flat carton has a tolerance that depends on the extent to which the two extremities are superimposed during the gluing process. If the superimposition of the faces is excessive, the absence of an air gap between the upper and lower flaps creates complications to the operator during the opening of the carton. Whatever represents a small problem for an operator can be a stopping problem for an automation, therefore the tolerance of the process must, in any case, ensure the presence of an air gap between the flaps
- Absence of dust from the surface of the boxes. As the robot will use a vacuum pump connected to suction cups to lift the carton, cleaning and absence of dust or other particles from the top surface of the boxes has to be guaranteed so as to avoid obstruction of the cups. This is a requirement that all the supplier already met, but writing it in specification was important so as to avoid the emergence of the problem in the future.

Ariston specification

The Ariston technical specification is a document drafted at company level and regards a general series of policies that have to be respected while working with ATG. This document is the same for all the plants across the group.

Project technical specification

The project technical specification is another document, which is instead drafted at plant level and regards technical requirements specific to either the plant or the project. Here is a list of the main focus point of the document:

- Requirements of the automation in terms of cycle time, OEE and other KPIs
- Layout requirements: space available, infrastructural constraints…
- Product specifics: models, variants and their dimensions. In this case both the specifics of the water heaters and of the cartons have been indicated (more details about this are found below in the chapter)
- Technical requirements: use or avoidance of certain technologies, or of particular brands of components

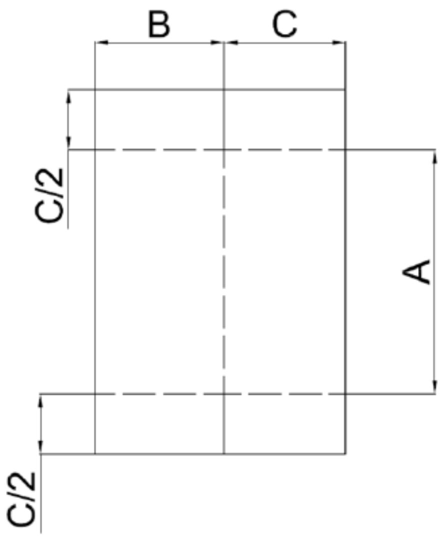
An overall range of 424 models has to be processed through the automation. Some of these models are produced in much larger quantities, while other ones do not reach the thousand produced unities in a given year. Nonetheless, all of such products are assembled along the two final production lines and have therefore the be processed in the automatic carton insertion station. Despite the actual number of variants of product available for production, the differences among them are actually small. The main differences lie in the heights, in the diameters, and in the fact that the product can be either vertical (tubes on the lower side) or horizontal (tubes on the cylinder). Here are the large families that contain every possible combination of the 424 available:

- 50L vertical (diam. 450mm, height 460mm)
- 80L vertical (diam. 450mm, height 665mm)
- 100L vertical (diam. 450mm, height 817mm)
- 50L vertical-EVO (diam. 450mm, height 490mm)
- 80L vertical-EVO (diam. 450mm, height 695mm)
- 100L vertical-EVO (diam. 450mm, height 835mm)
- 50L SEF (diam. 470mm)
- 75L SEF (diam. 470mm)

The dimensions of the polystyrene pad at the bottom the product while it travels along the conveyor are:

- 480x450mm or 470x490mm for products with diameter of 450mm
- 505x505mm for products with diameter of 470mm

Some of the produced models share the same packaging solution, and some of the boxes are "neutral" as they are not branded in any particular way. Because of this reason, the number of available carton models is just 86. The dimension of the boxes are 3: height of the face and length of the face on the two sides (as most of the boxes do not have a square base, but rather a rectangular one). The height of the flaps is a function of the other measures. The scheme belows shows all the available combinations.



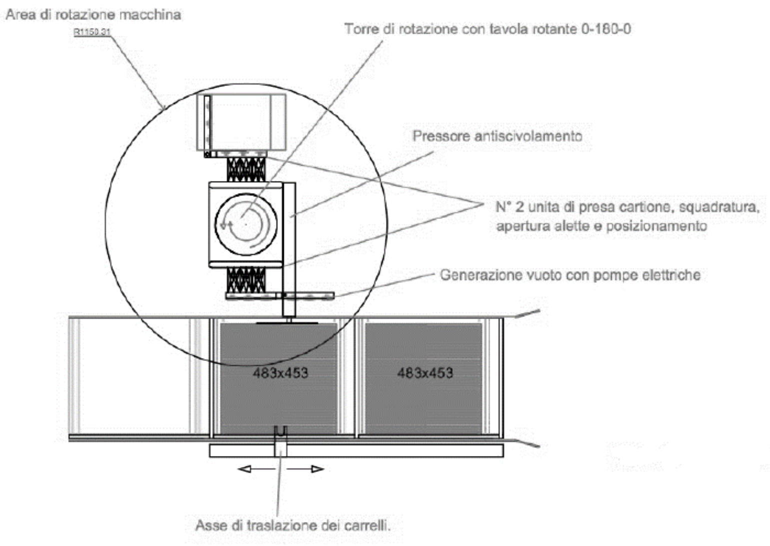
	A	B	C
50 V	555	483	453
50 V FLECK	570	483	453
50 V FE	570	493	473
65 V	677	483	453
80 V	760	483	453
80 V FLECK	775	483	453
80 V FE	775	493	473
100 V	912	483	453
50 V EVO	585	483	453
80 V EVO	790	483	453
100 V EVO	930	483	453
100 V FLECK	930	483	453
100 V FE	928	493	473
SEF 50	635	510	510
SEF 75	825	510	510

Supplier selection

As stated earlier, three suppliers have been contacted for a price quotation about the carton insertion automation.

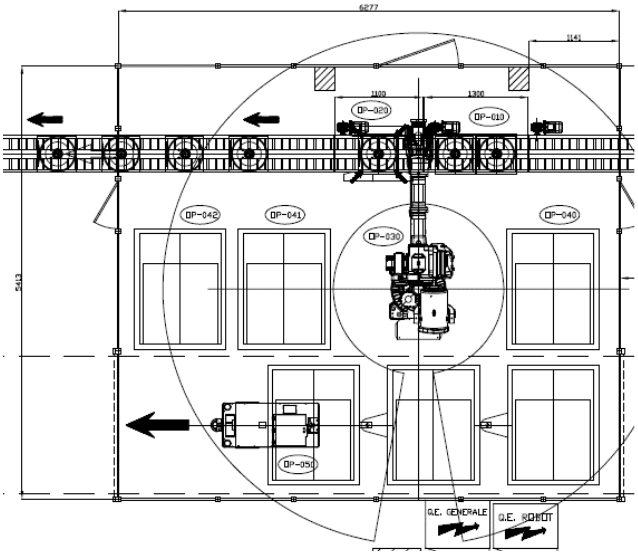
The first supplier is based in the Marche region and has some previous experience of installations in the plant at Genga. The proposed solution is the use of a 2.7m tall tower placed on the external side of the conveyor that presents at its summit an electromechanical rotating board with two separate apparatuses, respectively used for the pick-up and insertion of the box. The board on the top therefore rotates allowing one of the stations to pick up a box and the second one to insert it, each operation requiring an estimate 10s of time, while the remaining two seconds are used for the rotation motion. The drawing and opening of the carton happens therefore in masked time with respect to the insertion. The product needs to be stopped along the conveyor so as to allow the correct insertion of the box. It is worth noting that this supplier is more specialized in automations that to do not require anthropomorphic robots.

The economical request was 393'500€.



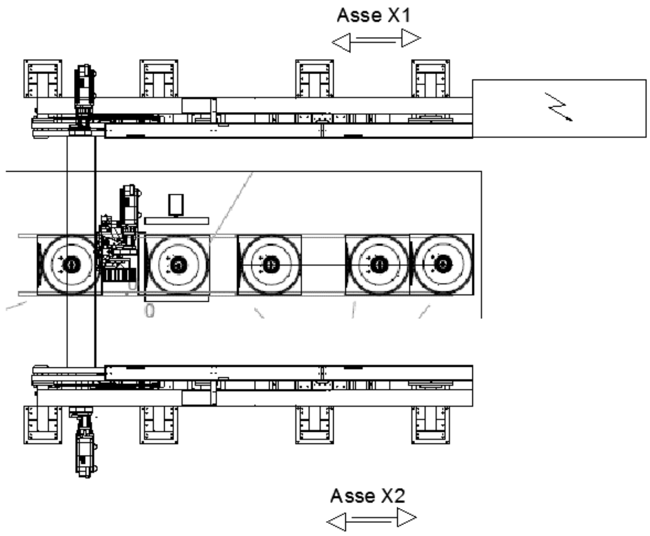
The second supplier is based in northern Italy, in Lombardia and is the furthest away from the plant of the three and has never worked with the Genga plant, despite having worked for other Ariston plants in Europe. Its specialization is in robotic platforms and the proposed solution reflects their main focus. The proposed layout presents a 3m ABB anthropomorphic robotic arm with a carrying capacity of 165Kg that is found on the external side of the production line in between 3 loading bays were the cartons are placed. The robot uses suction cups on its end effector to pick-up the flat box and then proceeds to open it against a 7th axis controlled by the robot that is found on the opposite side of the conveyor, just above the product that is stopped on a specific point of the conveyor. Once the box has been opened, the robot lowers and performs the insertion.

The economical request was 220’000€ per automation, for a total of 440’000€



The third supplier is again from the Marche region and, again has some past experience of working with the plant for previous installations. The proposed concept involves the use of a pantograph automation, placed above the conveyor and across it laterally, that is able to move above it to pick up the carton, open it and insert it on the product.

The economical request was in this case 417’000€

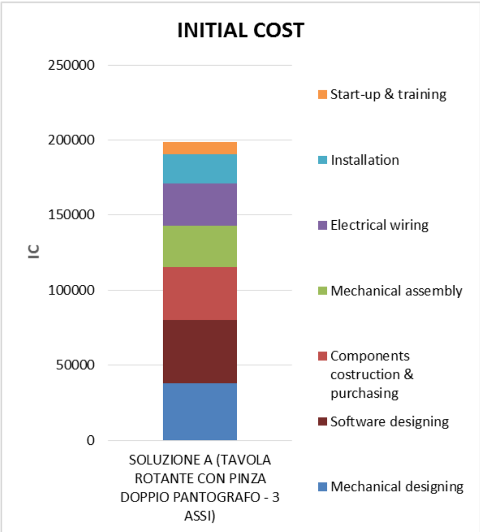


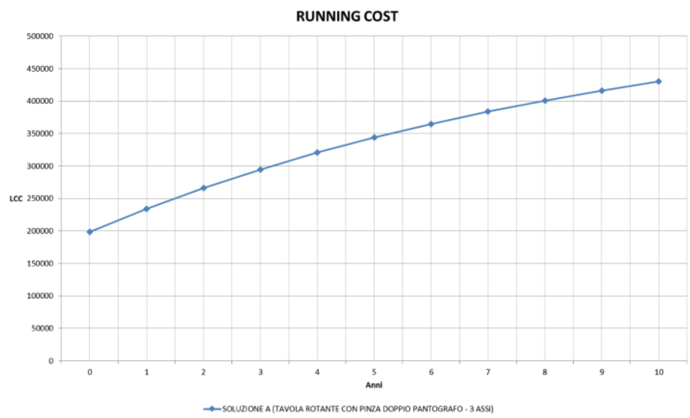
The three proposed technical solutions are, as is evident, very different from one another which results in different life cycle costs. Provided that all the three solutions are feasible and with similar performances, the LCC is the main parameter to analyze in order to make a final choice. The initial investment required for each of the options is summed to its estimated running costs over a period of 10 years and finally the estimated disposal costs of the installation are added.

The evaluation of the running cost for each of the solutions is performed by analyzing a series of paramters related to the energy consumpion, the efficiency of the equipment and the time and cost of maintenance (both in terms of the cost of the operators and that of the spare parts). The obtaiend result is a yearly cost of the automation which is plotted in the initial 10 years of the installation.

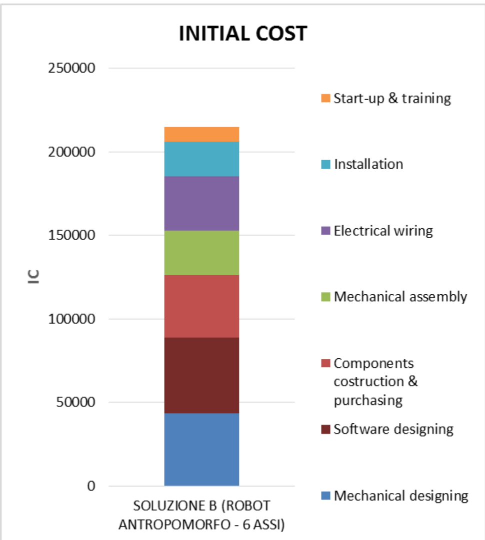
Here follows a series of graphs and charts representing the distribution of the initial investment and the estimated running costs for each of the proposed solutions.

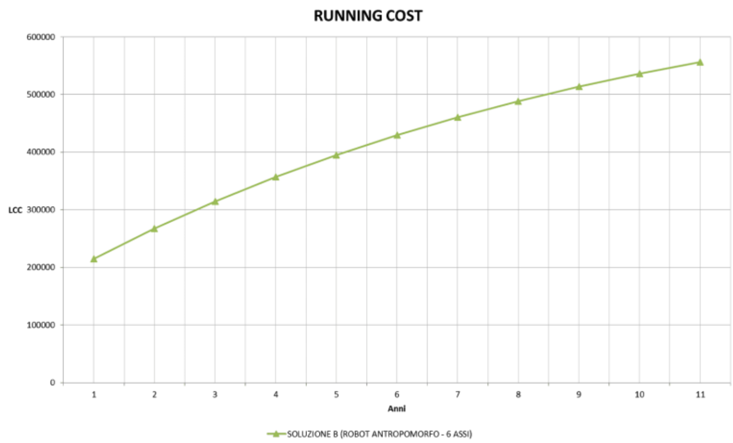
Solution A



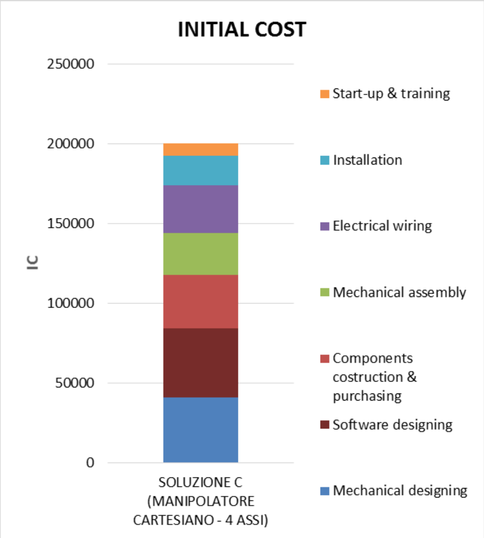


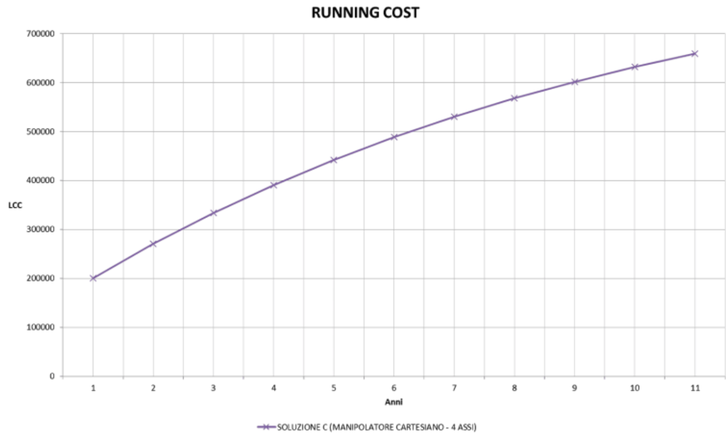
Solution B



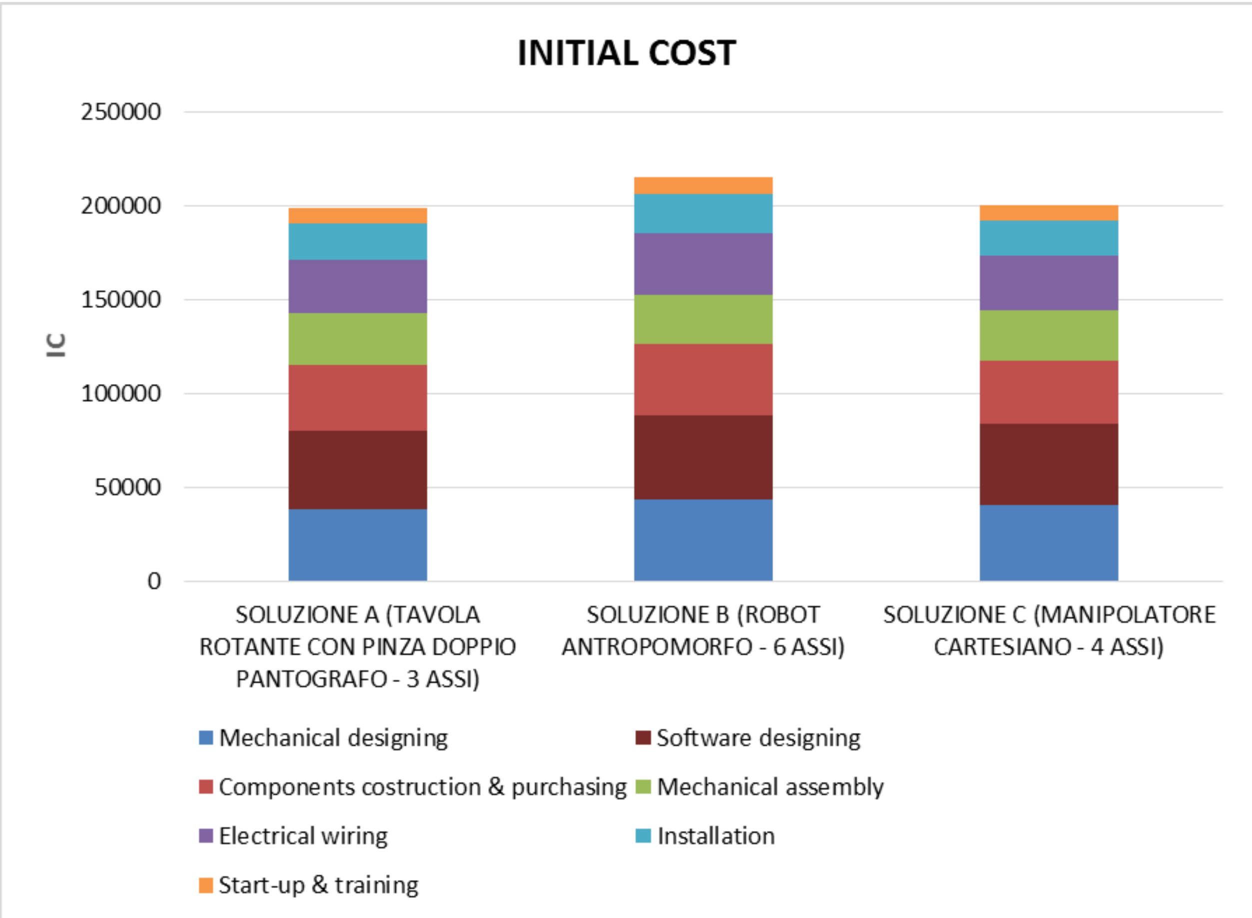


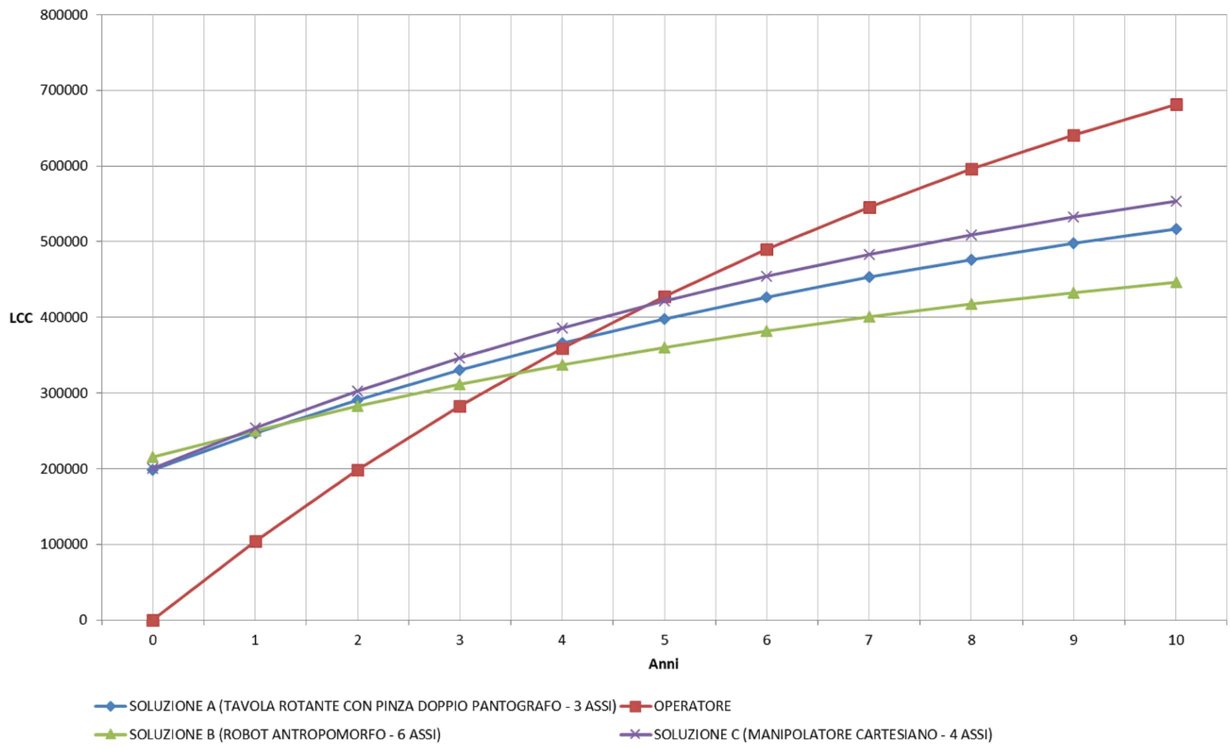
Solution C





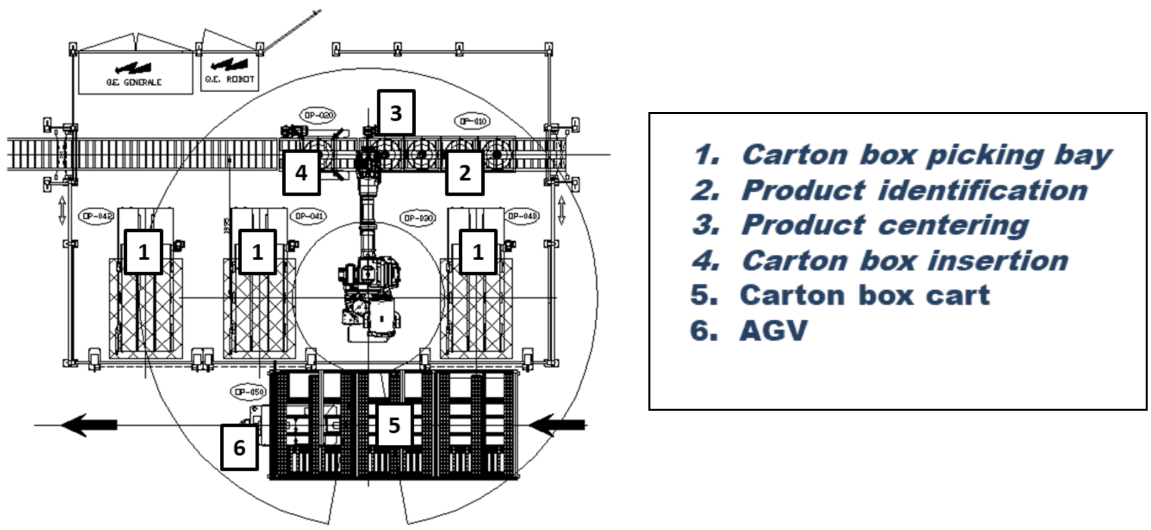
Below, a direct comparison of the three solutions.





The redline shows the current situation, i.e. the labor cost of the operator over the 10 years period. The adoption of an automation is clearly advantageous for the plant.

Despite the higher initial investment required, the solution that adopts the the anthropomorphic robot arm is the one that performs better in the long run in terms of operating costs and therefore the order for the equipment has been sent to the second supplier that proceeded with the detail design of the installation.



Checklist step 2

At the end of step 2, the checklist was controlled. Out of the 578 available items, 532 were correctly verified, 45 were not applicable to the project and only one had to be reviewd as it resulted non ok.

Step 3: Detail design

As the supplier receives the order, the detail design of the machine can start. The WCM methodology expects the EEM Pillar to tightly cooperate with the constructor in this stage as it is a very delicate phase. The supplier is of course responsible for the design and validation of individual components and sub-assemblies, but the plant must supervise such activities so as to guarantee that the guidelines of the technical specification are followed tightly and no problem arise. Whenever doubts on the design or on the layout come up, the EEM Pillar must guarantee support to the supplier so that the best technical solution for the plant is always adopted. The supplier does not possess an extended knowledge about the details of the product and processes that take place in the plant, so there is always some risk of misdesign when communication is not effective.

A very good first step to undertake so as to start an effective collaboration with the supplier is the scheduling of a series of individual and joint meetings where to share ideas, point out problems, identify criticalities and externalize concerns about the project.

Equipment Failure Mode and Effect Analysis

The EFMEA (short for equipment failure mode and effect analysis) is a document redacted during the various meetings described above which enlist all of the possible problems and process complexities that are highlighted by either the plant or the supplier. Trying to foresee the arising of problems is crucial as it allows to avoid having them appear at later stages. Writing down each critical point permits to create a specific action plan with a set of actions and countermeasures to deal with the concern. Also, tracking of the issue becomes possible so that no point has to be left open on the list at the end of the project.

The EFMEA collects a series of information about any identified problem so as to make it possible to easily track it over time, prioritize its resolution, and find an appropriate solution. The module used by the Ariston plants to draft an EFMEA form is composed of a few sections:

- Initially the component, or the function, that can be subject to the failure is indicated
- Then failure is analyzed in terms of its cause and effect, and it is specified the first location in which the problem can be detected during production
- A risk analysis is performed by estimating the likelihood of the failure and the severity of the situation caused by the failure. This allows to index the identified problems by assigning a Risk Priority Number to their resolution
- A responsible is assigned to the point and an initial suggestion for the solution is devised, a prediction on how the RPN can be reduced is performed
- When the final solution is implemented, the form is updated once more with a description of the performed intervention and a calculation of the new RPN

ARISTON THERMO GROUP

E.F.M.E.A. Form

EQUIPMENT FAILURE MODE EFFECTS ANALYSIS

PLANT (concerned)	Genga	PLATFORM Mngr	Borrelli Alessandro	name	-	Date 1° edition
SUPPLIER	Robotech srl	F.M.E.A. Leader	Daniele Meletani	name	-	Date last edition
PRODUCT	Scaldabagni EWH	SYSTEM	Linea finale assemblaggio	SUB SYSTEM	-	COMPONENT
PROCESS	Inserimento imballo	PHASE	Inserimento imballo in cartone	DEPARTMENT	-	EQUIPMENT
Component						
Sub process						

DESCRIPTION (component - phase)	FUNCTION (functionality)	FAILURE: FAILURE MODE	EFFECT	CAUSE	SITUATION & RISK: DETECTION	RPN INDEX: S	O	D	RPN	
PLC	Sovrintendere al funzionamento dell'impianto	Inserimento del codice errato di imballo	Imballi da togliere e sostituire in magazzino prodotto finito	mancato controllo incrociato tra pordotto finito e imballo disponibile	Magazzino prodotto finito	6	5	6	180	In di re pr
Ventose prelievo scatola	Garantire l'aderenza dell'imballo alla pinza del robot	Mancato prelievo del cartone	Arresto del ciclo automatico dell'impianto	Ventose otturate da sporcizia	Bordo impianto	3	6	6	108	In ve im
Portali ingresso - uscita imballi	Permettere l'ingresso e l'uscita dei pacchi di imballi solo in presenza dell'AGV	Caduta saracinesca con rischio cesoiamento	Cesoiamento	Rottura cavi contrappesi portali	Bordo impianto	10	4	2	80	Pr co
		Mano incastrata tra pacco imballi in uscita da carrello e portale	Cesoiamento	Presenza di spazio libero tra carrello e portale	Bordo impianto, lato ingresso imballi	10	2	1	20	Pr l'ir

Among the problems found during this type of analysis, here are some of the most prominent ones.

The automation can mistakenly insert the wrong carton on a given product. The cause is the missing crossed control of product and box, and the effect is that it would be required to manually open the boxes, extract the products and repeat the cartoning with the proper boxes. With a "manual" system for the insertion of the codes of both packaging and water heater in the automation, the risk of this problem presenting itself is extremely high because of the high number of available combinations. Also, the effect is particularly negative as the time wasted to repair the created damage is high. Therefore the RPN of this particular point was determined to be very high. The found solution was in asking the automation to be able to automatically control the incoming product and the code of box it wants to insert, so as to avoid any mistake.

Another identified problem was in the robot missing the pick up of a carton which can be caused by the clogging of the suction cups on its end effector. The result is the necessity to intervene for the maintenance of the suction cups, thus stopping the production. The risk of this situation presenting itself was evaluated as high, and, even if the severity of the result was not as high as that of the example above, the obtained RPN still placed the priority of intervention on the issue among the highest ranks. The adopted solution was in the adoption of alternating sucking and blowing cycles for the cups, so that they can keep themselves clear from dust and other sources of clogging.

Detail design

For the sake of clarity, in the following section, the principle of working of the designed automation will be introduced. A more detailed analysis will be presented whenever a particular sub-system of the machine required a greater attention during the design, whenever any significative modification has been implemented to improve the project and when WCM documentation was produced as a result of this.

General principle of working

The automation is composed by an ABB robot, an anthropomorphic arm, placed on the external side of the production line. On the wrist of the robot, a complex set of tools is present on the same end effector: a 3D vision system, a set of suction cups, and a set of pneumatic actuators that are responsible for the mobility of the cups. During operation, the robot moves above one of the three carton loading bays that are placed around it and performs a 3D scan using structured light so as to identify the correct position and orientation of the flat box with respect to its reference frame. As the carton is identified, the end effector lowers on it and proceeds with the pick up phase, where a set of suction cups actuated by a vacuum pump cause the box to stick to the robot wrist tool. The arm then moves so as to make the opposite side of the flat box face the production line, right in front of the robot. One other side of the conveyor rollers line, a 7th axis is present. This 7th axis is composed by a vertical column and a set of tools that are able to slide up and down such column independently from the robot. The tool of the 7th axis is provided with another set of actuators and suction cups and its main purposes are those of helping the robotic arm in the delicate carton opening phase and then proceed with the insertion of the box on the product by lowering on it.

So while picking up the carton is a responsibility of the robot, and while inserting the box is a responsibility of the 7th axis, the opening process is assigned to both and is the most critical stage of the operation in terms of complexity. The robot moves so that the flat carton is facing the 7th column and slowly approaches it up to a contact point. In this moment, the robot focus its sucking action on a single face of the box, while the opposite face is held in position by the suction cups on the 7th axis. The wrist then moves backwards, describing an arc through a set of points and thus allowing the box to gradually open and reach its squared condition.

When the box is fully open above the product insertion station, the process is not over yet: lowering the carton in this way would inevitably cause the lower flaps of the box to hit either the water heater or the rollers and to rip off the cardboard. What happens instead at this stage is that a set of actuators on the robot, the 7th axis and on another external axis on the opposite side, cooperate to flex all of the lower flaps up to a point in which the cardboard yields and loses rigidity: by doing so it is possible to avoid the flaps elastically going back to their original orientation, aligned with the face of the box. Near the end of the opening stage, two pneumatic cylinders are actuated and cause two lateral plates on the robot wrist to rotate so as to clamp the open box on its front and rear faces (front and rear intended with respect to the direction the water heater moves along the roller conveyors). Each of such two plates is provided with another pneumatic cylinder with a suction cup at its extremity. The cylinder is pushed forward so as to put the suction cup in contact with the cardboard surface of the lower flap. The cup sticks to the carton using the vacuum effect, and simultaneously the cylinder is withdrawn causing the flap to be pulled diagonally and flexed. Before the release of the yielded flap, an actuator on the 7th axis inserts a cylindrical pin in the area immediately below it so as to guarantee that it remains forcedly open once the suction cups are deactivated and the robotic arm is cleared and can proceed to the pick up of the following carton.

The 7th axis is now in full control of the open box and proceeds to lower it on the water heater which has reached a stop in a station where it is blocked so as to guarantee its positioning with respect to the axis. Using as a reference the normal direction of motion of the water heater, the 4 flaps of the box are handled in the following way:

- The front and rear flaps are, as just explained, held in position by cylindrical pins inserted below the flexed flaps
- The flap on the side of the 7th axis is stuck on a suction cup that is actuated by a pneumatic cylinder
- The flap on the side facing the robot is opened by another external axis, a small column with a pneumatically actuated plate atop. The plate has a diagonal orientation so that while the cylinder pushes it upwards it causes the carton flap to slide on it and slightly open. When the 7th axis proceeds to lower the whole box, the flap keeps forcedly sliding along the plate and gets bowed all the way up, remaining fully open at the moment of insertion.

The repeatability in the positioning of the product is guaranteed by a series of stations along the roller conveyor aimed at correctly center the water heater. Each station is constituted by a cadenced section of rollers and an actuated plate that comes out of the rollers in front of the product to contrast the polystyrene pad in which the product is fitted. Overall, the stations are four and in each of them the product is centered with respect to the roller conveyor by using a couple of pneumatically actuated plates, pushed on the lateral sides of the polystyrene pad so as to center it on the rollers: two of such stations show additional features.

The first one is used for the identification of the product, as along the final lines of the plant over 300 variants of electrical water heaters are assembled. Each finished product code is assigned a specific carton code: even if some variants of similar products share the same box, there is still over 100 different carton codes available. Because of this huge number of different product/packaging combinations, it would be problematic to require an operator to manually insert the correct production data in the automation: mistakes or misdigitations are far too easy and this could create micro-stoppages of the production. The solution that has been found is that of storing in the PLC of the automation a database containing all the finished products code and the box that they require for the assembly. The automation then employs a barcode scanner placed aside the identification station on the rollers to verify when the product running on the conveyor is changing: if a model change is detected, the machine is therefore able to change configuration and prepare to pick up carton from the correct bays. The management of the supply of the correct carton codes is more complex and will be explained later.

The third station is the bracket centering, where the bracket of the water heater is aligned to the external side of the polystyrene pad. As it is an operator that manually fits the pad at the bottom of the product while it is still descending from the transport chain it can happen that the bracket is slightly phased, and this can cause problems during the insertion operation: the carton may cling on the protruding metal piece and rip off.

The fourth station is the one in which the 7th axis descends during the insertion. At this point the product is perfectly oriented and positioned in the reference frame of the automation and therefore the repeatability of the operation can be ensured. Once the box is completely lowered on the water heater, it can evacuate the automation by using a conveyor belt that accelerates it and reconnects it to the shutter conveyor of the main line.

The supply of cartons to the loading bays is performed with the use of two AGVs per each line. Every AGV trains a cart composed itself of three distinct loading bays. A lot of 60 cartons is placed on the correct bay in the picking area with the help of a forklift truck. Only the second and third bays are loaded, the first is left empty so as to give it the ability to unload any residual carton that remained unused in the automation. If, for instance, water heaters are removed from the conveyor because of esthetical defects or other problems, the robot will remain with a bay loaded with the unused carton and the automation requires to be able to deal autonomously with this kind of situation. The AGVs are remotely controlled by the PLC, that sends a radio signal whenever two bays are empty and prompts the vehicle to leave the picking area and reach the assembly line. Because of, again, the problem of having a large number of codes for both products and boxes, the automation and the logistic system are interfaced with the production management software of the factory that creates a tight exchange of information between the interlocutors so as to guarantee that the right carton will reach the automation at the right time and will be inserted on the correspondent product (again, this will be detailed in a specific paragraph).

The robot

The robot that has been selected for the application is an ABB 6700-175. This 6-axis anthropomorphic arm has a reach of 3.05m and a handling capacity on the end effector of 175Kg, the wrist torque capability is 1179Nm. The ABB 6700 robots family is the 7th generation of large arms and, with respect to its predecessors, it shows an improved robustness, higher performances and an easier maintainability. ABB tried to improve the performances of their large robotic arms and focused most of their attention in the increase of the lifetime or their manipulators, while also reducing the LCC (in terms of maintenance cost, and improved lifetime). The implementation of a new generation of motors and gearboxes allowed to increase each axis speed, thus guaranteeing fast cycle speeds improved by 5% even for high payloads, while at the same time reducing the power consumption of the manipulator of around 15%.

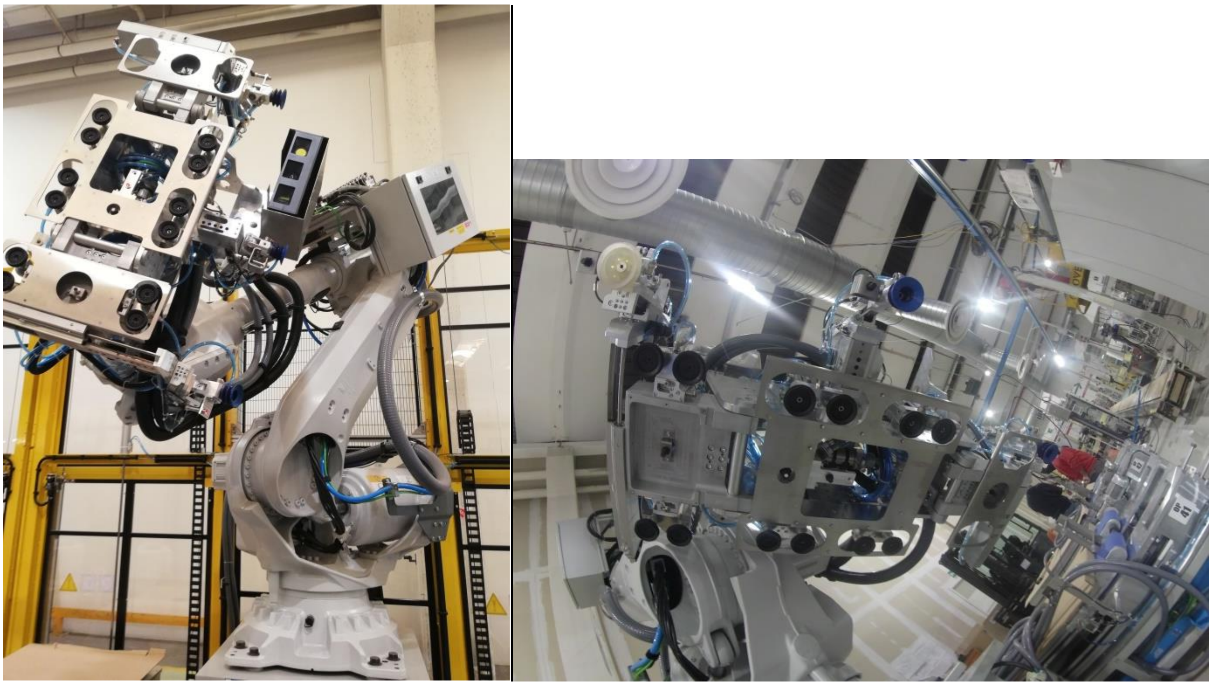
 

Being the box a very light item, with a typical weight of 1.50Kg circa, one can wonder what is the need of using such a cumbersome manipulator to perform the packaging operations. The other robotic arms used in the plant at Genga, belong at a much lower capacity class, with typical handling capacity between 20 and 50Kg. The answer lies in two main problematics brought by the process of carton insertion:

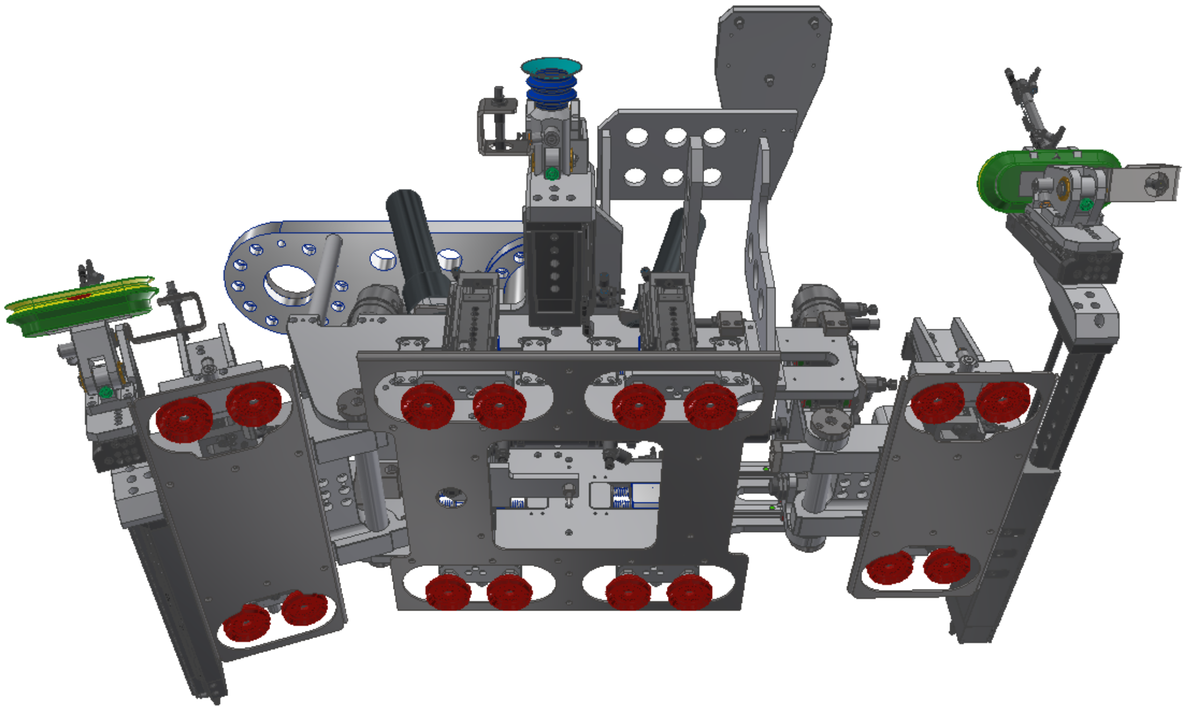
- The automation is supplied by 3 loading bays which, as the layout shows, are found at the lateral sides of the robot. Even if extremely lightweight, the flattened boxes are cumbersome because of their planar extension, so the problem was in trying to find a suitable location for the loading bays that allowed easy pick up and, at the same time, did not excessively increased the dimensions of the layout. In the layout two of the bays are in the immediate neighborhood of the robot, while the third is more far away: if the third bay was to be placed closer to the anthropomorphic arm, for instance behind it, the average distance of the bays would have turned out to be much lower. In such case, anyway, the lateral extension of the installation would have increased enormously and would have interfered with the so called "logistic area", a large corridor found on the external side of the final assembly lines, where AGV move between the flow racks. Similarly, this kind of configuration would have required a much more complex system for the automatic supply of the boxes. So, because of this layout constraints, the third bay has to be placed further away from the robot than the other two, and this requires and increased reach capability for the arm which has been obtained by selecting the 3.05m version of the ABB 6700. It is worth noting that the price of the robot manipulator is not excessively influenced by its dimension, so despite the evident dimensional difference from other smaller arms, the total cost is not significatively larger.
- A second important reason for the necessity of using such a large manipulator resides in the required handling capacity. Sure, the box weight is only 1.5Kg, but the manipulation of the flattened carton requires the implementation of a suitable end effector that realizes a series of operations on it. The box requires to be opened

before being actually inserted on the product and, this implies that a series of actuators are mounted on the wrist of the robot that provide tools for achieving the goal. In a few words, the weight of the carton was not a consideration during the selection of the proper robot, while the weight of all the tools on the wrist was largely the problem.

The most critical part of the robot resides therefore on the wrist. The end effector is constituted of a metal plate, screwed to the flange of the wrist which works as a support for all the tools that are found on it. The amount of operations that take place on the end effector is large, the easiest way to envision the working principle of each phase is to break them down to the individual function that is performed on each section of this support plate.

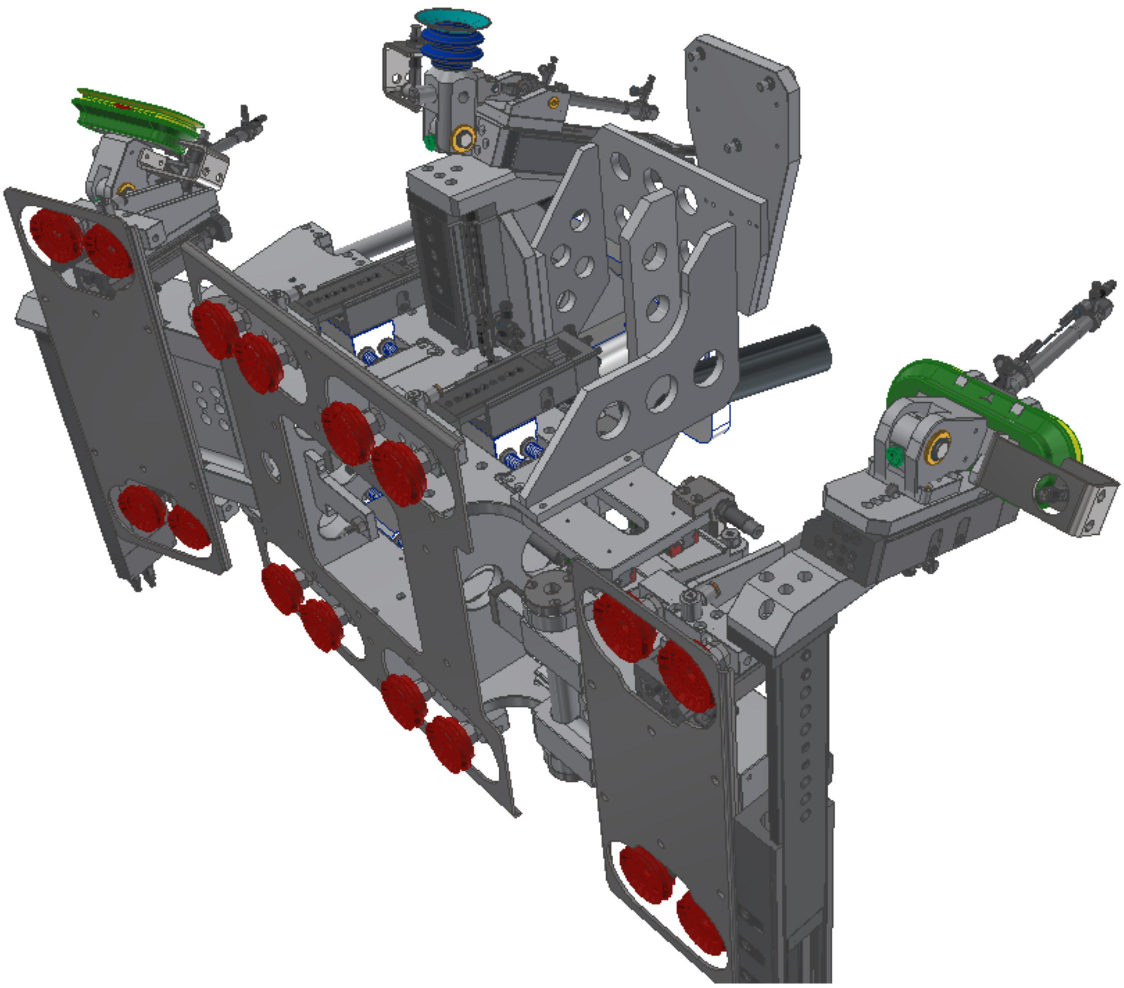


The central section of the end effector has the only goal of holding up the box during all of the working phases: this section focuses its sucking action on the side of the carton that faces the robot which is the one that will be aligned to the 7th axis during the insertion. Since the box is flat on the loading bay at the beginning of the cycle, two faces are found on the upper side and two are facing the bottom of the pile, this means that the central section is not placed symmetrically with respect to the center of the flat carton. This, together with the fact that vision is required to be placed above one of the corners of the box (thus laterally with respect to the center of the end effector) and that the lateral sections that pick up the remaining exposed face of the box get very close to the safety barriers of the automation, requires the tool support structure to be connected asymmetrically to the wrist of the robot. This is the only way in which the robot can perform all the operations quickly and without getting too close to the barriers. Initially, it was thought to mount the tool symmetrically with respect to the wrist, but this would have required the pick up phase to take place in two distinct steps: the visions system, in fact, would not have been aligned at all times with the corner of the box, thus requiring the robot to first position itself to perform the scan and then reposition for the pick-up phase. Requiring the robot to reposition for the vision phase and for the pick up operation would excessively increase the cycle time of the automation, therefore during the analysis, modeling and simulation performed with RobotStudio, it emerged that an asymmetrical end effector provided faster operation. The downside of having such a large support structure, with all the required tools placed asymmetrically with respect to the wrist of the robot resides in the increased stress due to torque and vibration placed on the wrist because of the fact that a large portion of the tools is at an increased distance from the fulcrum, i.e. the flange on the robot. But this was not considered as a huge problem, as the total weight of the structure was low compared to the total wrist handling capacity of the robot and, at the same time, the center of gravity of the end effector was not excessively displaced from the wrist and within the operational limits suggested by ABB.



The central section of the tool is the only one that is required to hold the whole weight of the carton at a certain point during the cycle. During pick up, two faces are facing upwards: one is pulled by the central section, while the other is held by one of the lateral sections.

Opening the carton requires the lateral section to release the carton so that the junction between the two faces can be folded until being 90°. Because of this requirement, the central section has the highest number of suction cups: 8 total suction cups are used, they are found in aligned couples on the four corners of the plate. The central plate also hosts a small hole through which a laser sensor comes out. This laser sensor is used during the first cycle on a new carton lot on one of the bays to measure the height of the pile so as to correctly position the vision system at an adequate and safe distance. After every cycle, the robot will automatically reposition 15mm lower than the previous cycle thus maintaining the same distance from the carton that needs to be scanned and lifted and avoiding to measure the height of the pile at the beginning of every cycle. The laser measurement is also performed after a reset of the robot, where the robot position all of its axes at their zero for a perfect reconfiguration and "forgets" all the previous operations.



The lateral sections of the structure are a bit more complex: they are smaller in size, and they do not require a particularly strong sucking action since they are never required to hold the whole carton by themselves. Rather, they are used to hold the front and rear face of the box once it is opened, while the central section is holding the lateral one. To do this, they are hinged to the central section so they can rotate relative to it until being perfectly perpendicular. This rotating motion is generated by two pneumatically actuated cylinders placed behind the central section that push laterally the rear portion of the lateral sections. This linear motion is transformed into a relative rotation because of the hinge an allows the lateral sections to close as a clamp around the box while it is being opened.

As stated earlier, the opening of the carton is performed by leaning the lateral face of the box held by the central section of the end effector only against the 7th axis, where a set of suction cups holds the opposite lateral face. At this point the robot pulls the carton open by performing a 90° arc backwards motion: during this motion the lateral faces are attached to the automation, while the two free faces (the front and rear ones) are able to rotate relative to the junctions of the faces and to fold the box open. During this arc motion, the lateral sections of the end effector are not sucking the faces of the carton as they need to be free to rotate, but they are rotated so as to clamp those sides using suction cups as soon as the opening is completed.

On the rear side the lateral sections of the support plane, two vertically sliding pneumatic pistons are placed, pointing downwards. The actuation of these cylinders causes a sled to move downward, pushing about an hinge so as to allow another functional block to rotate about it. This functional block is, in turn, provided with a smaller piston, a single suction cup at the end of it, and a capacitive sensor. This block is normally placed on the lower rear side of the section, therefore hidden so as to avoid causing interferences during the pick up phase. When actuated, it rotates as as to come up on the lower front side of the section. When this happens the suction cups comes out and points directly on the lower portion of the open box, where the flap is found. The flaps are, at this point, still close and aligned with the face of the carton: they need to be pulled open so that they will not interfere with the conveyor rollers at the bottom. To do this, it is only required to pull them enough that the cardboard at the junction of the flap yields and becomes flexible. At that yielding point, the flap is flexible enough to fold outwards as it gets in contact with the rollers: the 7th axis, which performs the insertion, can therefore lower until the carton is fully inserted and the flaps are parallel to the conveyor.

When the box is opened it is held by both the robot central section and the 7th axis suction cups, at this point the small pistons connected to the additional suction cups are extended until the rubber of the cup gets in contact with the lower flap. At this point the vacuum is activated and the suction cups start sucking the flap. The piston is then retracted so as to pull the flap open. Being each face of the carton held still by the robot and the 7th axis, a bending force is present between the face and the flap and this cause the flap to yield and folds open.

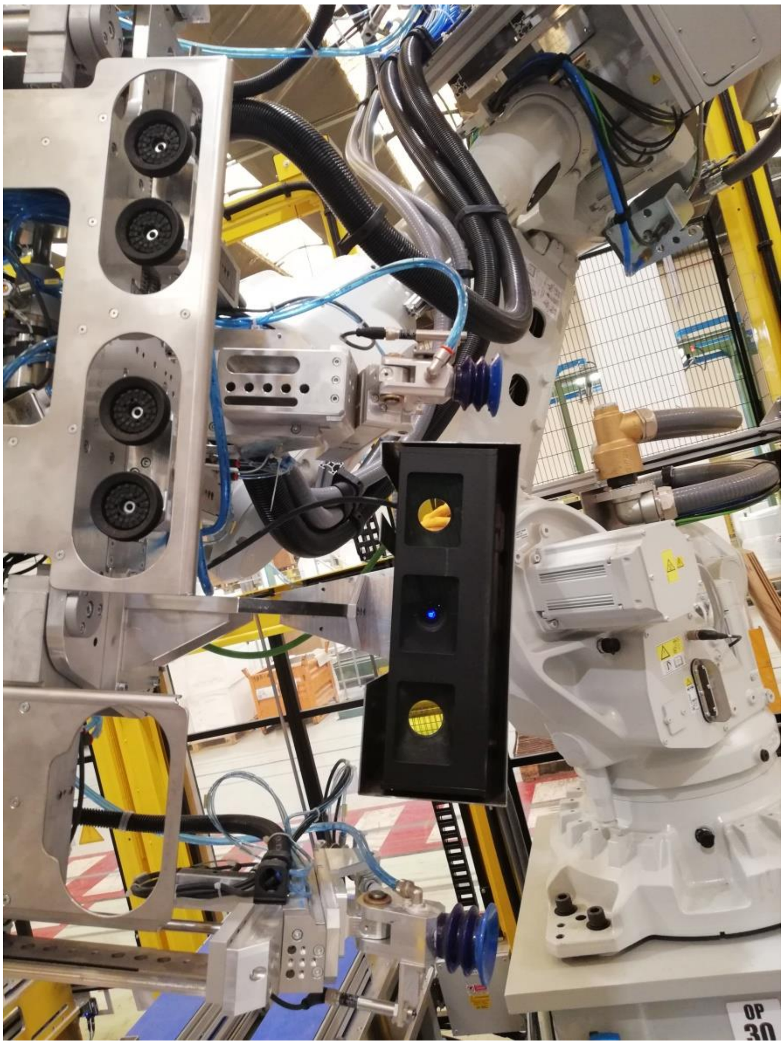
The inductive sensor which is placed close to this suction cup is used to verify whether the flaps on each side have been correctly opened or not. Once the contact between the sensor and the cardboard is verified, the robot proceeds to release all of its suction cups, thus handing the opened box entirely to the 7th axis and finishing the cycle.

In the solution initially proposed by the supplier, the robotic arm participated also to the insertion phase. When the opening phase was completed, the robot and the 7th axis lowered simultaneously on the water heater. This was initially thought to be required to guarantee a smoother insertion, but also brought a significant downside as the total cycle time of the automation is totally dependent on the set of operations performed by the robot. If the robot has to be responsible for the identification of the box, its picking up and opening and finally also of his lowering and insertion, then the robot is the bottleneck for the total cycle time. Simulations performed using RobotStudio showed that the minimum achievable cycle time with this configuration was around 16 seconds, 4 seconds higher than the required value. This is of course due to the fact that once the box is opened, the robot is required to lower, realease the box after the insertion and then go back to the pick up position (which is further away).

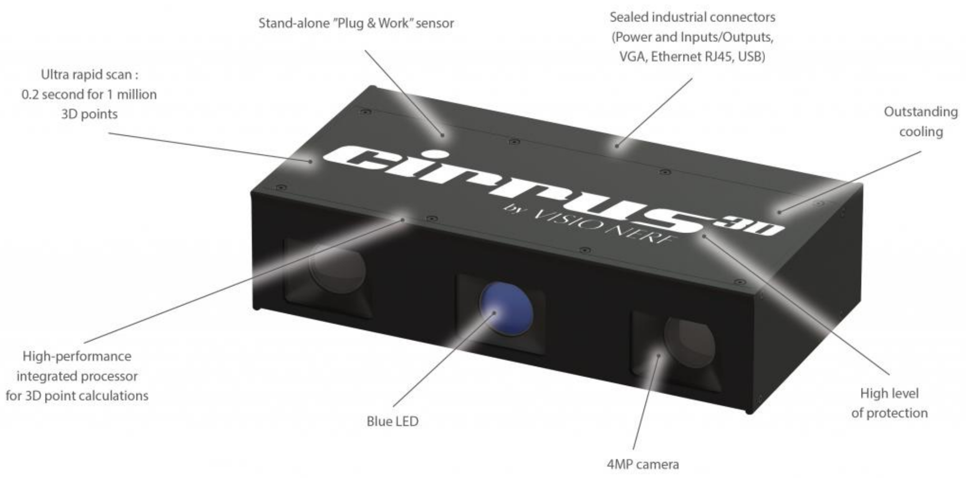
Imposing the 7th axis to be the sole responsible for the insertion allows the robot to clear from the carton earlier during the cycle: so while the lowering of the 7th axis takes place, the robot can start a new cycle and prepare to scan and pick up the following box. The analyzed simulation proved this to be a much more feasible configuration for the operation as separate phases can take place simultaneously, in masked time.

The vision system

The reasons for the choice of a three dimensional vision system that uses projected structured lights over a two dimensional one has already been explained earlier: 3D vision is a more expensive technology, but it also ensures a greater quality of operation, without the negative influence of ambient light to reduce its performance. The main supplier decided to rely on a third supplier for the hardware implementation and software development of the vision system.



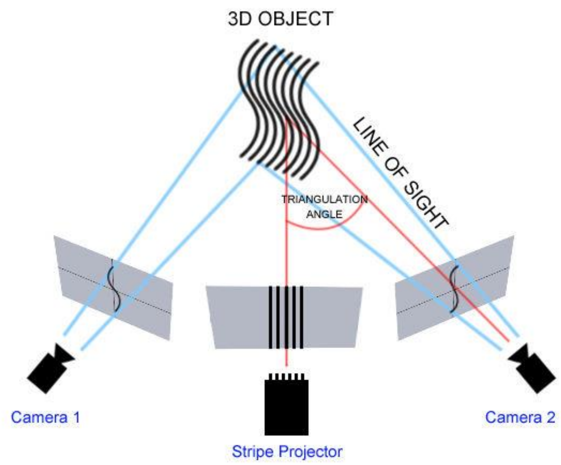
The adopted vision system is a Cirrus 3D sensor, developed by Visio Nerf with the specific goal of being an extremely performant solution for the process of artificial vision. The plant has some previous experience with the adoption of various vision systems in different automatic applications around the factory, but the specific choice of which product to install depends on a wide range of parameters such as the process that has to be performed, the object that the system needs to identify, the distance from the object and the required speed of operation. Also, different automation supplier tend to rely on different brands of vision systems depending on their previous experience, and as a result of all these variables, the technical specification does not indicate any particular brand name as a favorite, but case by case, the decision is made with the supplier.



The Cirrus 3D vision system possesses some innovative features: it integrates a computer, which makes it extremely flexible and "plug and work" as it is already prepared and calibrated in the factory, thus not requiring any project-specific development. The vision system is extremely robust and developed so as to be able to work effectively in any industrial work: the success of its scanning process is entirely independent from environmental light, colors, or presence of dust or dirt. The acquired image has an extremely high resolution: during a 0.2s scan it can map a cloud of a million points, which is then compared with a CAD image of the item that has to be identified.

Despite not being a product designed specifically for robotic applications, Cirrus 3D can be easily interfaced with robots: the scanned cloud of points is communicated immediately to the robot that can act accordingly in the ideal trajectory, avoiding any interference or contact with other parts that are found in the surrounding.

The process used to digitally reconstruct the three dimensional model of the scanned object consist in the projection of one or more patterns of structured light (typically blue stripes) on the surface where the item is located. One or more cameras, which are found at a certain baseline distance from the point where the structured light is emitted are used to catch back the reflection of the light: the projected light pattern is distorted by the presence of the object, and the integrated computer uses all the above information to digitally reconstruct its shape and position. The image captured by the cameras is digitized so as to create a three dimensional set of points as a representation of what the vision system "sees". This cloud of points is processed and the 3D object is created and then compared to the CAD model of what the system "should see" or "expects to see".



Regarding the specific application, the vision system is mounted on the end effector of the robotic arm and is used as a mean to identify the position and orientation of the flattened cartons in the loading bay: once this localization has been completed, the robot can proceed to pick up the carton and perform the subsequent operations.

The robotic arm places its end effector so as to have its X axis pointing downwards, vertically above the loading bays at the beginning of each working cycle. The first time the robot works with a new pile of boxes (or after a reset of the robot to its "zero" position) it places itself at a certain safe height from the pile and uses a laser sensor to measure the distance: this process allows the robot to compute the distance from the end effector to the first box on the top which is important for the correct location of the vision system during the scansion. Being each pile of 60 boxes about 80cm tall (the height may vary of a couple of centimeters depending on the carton supplier), and due to the fact that an high quality of the 3D reconstruction is accomplished only when the scanning is performed at a relatively close distance from the cardboard surface (about 300mm), the robot always tries to place the vision system at the ideal working height. During preliminary analyses, it was tested the possibility for the robot of measuring the height of the pile at the beginning of each cycle, but this proved ineffective as it significatively raised the cycle time as the operation required a couple of seconds. The alternative solution, which has been implemented, was that of measuring this distance only at the beginning of the operation and then allowing the robot to automatically position itself 1.2cm lower at each subsequent pick-up, thus accounting for the reduced number of piled boxes as more and more are used.

The vision system has been placed in a position that allows the 3D scan to take place with the robot in the same configuration as that used during pick up, thus enormously reducing the amount of time used for any eventual repositioning. The scan is aimed at one of the lower corners of the cardboard, on the surface of one of the flaps. This region was selected because the identification of the corner allows to know exactly the position and orientation of the whole box and act accordingly. At an early stage of design, tests have been performed in order to verify whether the software was able to reconstruct the shape of the cardboard by simply analyzing the corner: unfortunately this was not the case. The problem lies in the fact that the corners of the box tend to be the most easily damaged part of it: despite the piles being protected by an additional cardboard sheet on both the upper and lower end, the multiple manipulations to which the lot is subject might cause some small damage on the corners. Manipulation include forklift loading and unloading from trucks, storage in the warehouse and transportation to the picking area (using, again, forklift trucks). Whenever the cardboard corner is damaged, the vision system encounters problems during the reconstruction of the image, it is therefore unable to proceed and gets stuck, blocking the process and requiring the intervention of an operator. So, even if the number of defective boxes is relatively small (typically around 3% which represent the topmost and lowermost cartons only, which are the one mostly exposed to manipulation), the number and the duration of the caused micro-stoppages in unbearable and incompatible to the desired OEE of the installation.

The exact process used by the integrated computer to reconstruct the 3D image of the box starting from the cloud of points scanned on its surface is an implementation of the Hough transform algorithm that tries to fit the surface of the reference CAD model to the set of points that have been acquired and processed by the camera. The Hough transform is used when it is necessary to detect the presence of particular features, such as simple geometrical shapes like lines, circles or ellipses in the three dimensional space, starting by a cloud of points. The algorithm adopts a two dimensional array with a dimension that depends on the number of unknown parameters. A mechanism called voting is used: each edge (or other feature) in the image is fitted to a set parameters that can describe its model, as more and more points are analyzed, some models will receive an higher number of votes than others. The highest scoring parameterizations are those that best fit the feature of the image. In few words, for every two points along an edge a line exist that fits through them and correctly represents the feature: the parameters of this line constitute a vote. In the end, the highest voted parameters are those that best represent the edge. When the carton is damaged, the edges are not cut perfectly straight, but are slightly jagged. As it is true for every fitting model, the algorithm performs some approximations during its recursion, therefore any scanned point that is found on an indented edge is at risk of compromising the exact localization of the corner.

After a careful review of the test results and a better analysis of the posit ion and type of the jaggings found on the edges, a new approach was adopted: instead of scanning directly the corner of the box, the vision system focuses its reconstruction efforts on the analysis on a diagonal band which is basically constructed by drawing a 45° degrees inclined line to virtually create a triangle with the two edges of the box and the resulting corner, then a second line is taken parallel to the first one, a band is created and the corner of the box is excluded from the analysis. The band therefore contains a portion of each of the two perpendicular edges, and the regression algorithm still allows to identify the corner of the cardboard. This process proved much more effective and almost completely resolved all of the vision related issues: the analyzed segments of the edges have, in fact, a much higher quality since they are not damaged during transport or manipulation.

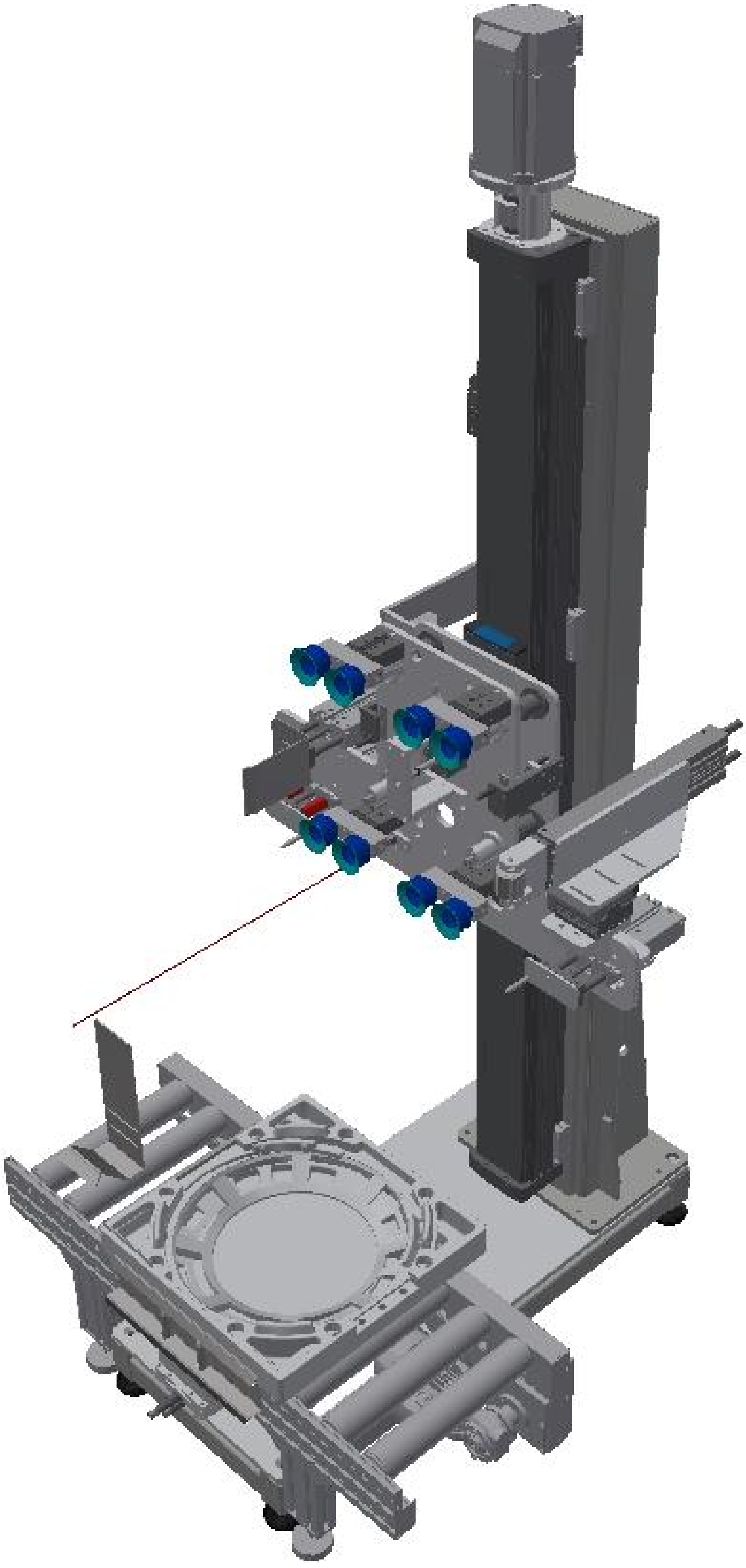
The vision process represents a bottleneck operation for the robot. The 3D scan has, in fact, to be performed while the robot is perfectly stationary above the box and no other motion can be performed by the arm at the same time. As a result, the reduction of the amount of time spent in the projection and analysis was an important consideration in the overall attempt of fitting all the necessary operations in the tight 12 seconds of cycle time. As a further complication, the necessity of having the robotic arm totally stationary while scanning is not a pure matter of stopping the robot, preventing any motion until further command. The rapid movements of the anthropomorphic arm combines with the significative weight of all the actuators that are found on the end effector, generates an important inertia: whenever the robot stops moving, some residual vibration remains for about 0.3s and this requires the vision system to wait for half a second so as to guarantee that the scan takes places while the vision box is completely still. The small vibration of the robot joints gets also slightly amplified by the compliance of all the parts of the end effector and the support of the vision system.

Further testing was used to optimize the pattern of the projected light as a mean of improving the overall quality and rapidity of the scan. Initially, two separate projections of vertical and horizontal stripes of light was adopted, but later a single shot of moving vertical stripes has proven a quicker option.

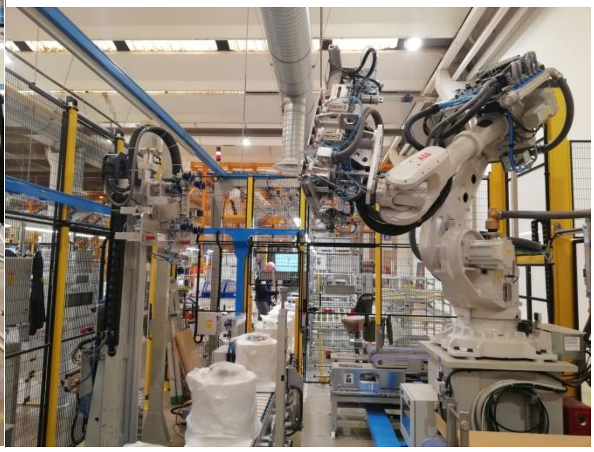
So, as a recap of the whole localization procedure: the vision system projects a blue structured light on the surface of the cardboard, then the two cameras placed on the sides of the lamp are used to capture a the three dimensional cloud of points; the integrated computer is in charge of reconstructing the shape of the corner of the box using a regression model and trying to fit it to the memorized CAD version of the box; as the corner is recognized, the information is passed to robot that uses it to determine the position and orientation of the box in its reference frame; the robot moves its effector just slightly to align its suction cups with the computed pick-up zones and, during the lowering, the wrist of the arm also rotates with the purpose of aligning with the same orientation of the box.

The 7th axis

The 7th axis is basically a vertical column with a shaped profile that acts as a rail where a metal support structure is able to slide along its length. This column is placed right in front of the station on which the water heater stops for the actual insertion operation.



The term 7th axis is used here even if technically incorrect, since in the earliest design stages the column was commanded by the robot controller as it needed to be able to work simultaneously with the anthropomorphic arm during their lowering in the insertion phase. When it was determined that the insertion operation was to be performed by the tools found on the column only, the control of the movements was assigned to the PLC. At this point the column is totally independent from the robot, therefore it cannot be considered anymore a true 7th axis, but the term remained during the design stages.



The tools used to hold the carton open during the insertion are found on a support structure that is able to slide up and down the rail of the column. The actuation of the movement is performed using brushless electric motors that guarantee an high precision of the vertical motion. The structure is mainly constituted by a metal plate that supports (as was the case for the central section of the robot end effector) four couples of suction cups placed on the corners which are used to hold the weight of the carton while it is lowered on the product. The rest of the structure hosts a series of pneumatic actuators that are used to manage the operations of a set of tools:

- On each side, a small L-shaped metal plate is present and is moved sideways as the carton is delivered to the 7th axis. These plates are moved so that they can lean on the front and rear faces of the box, thus keeping it open. When the robot is holding the box, it holds it open by sucking on three of his faces with suction cups, but to guarantee the same result on the 7th axis, it is sufficient to have a mechanical contact with the surface that pushes on either side and avoids the carton closing on itself during the insertion

- Two long and sharp pins are found on the sides. They are actuated so as to move forward and insert in the space just below the front and rear flaps. This space is "created" when the robot pulls those flaps open. As the flaps are released they are at risk of closing down completely, going back to their vertical orientation, aligned with the corresponding face of the box. If this happens, the flaps can hit the roller conveyor and rip off.
- On one of the sides, a horizontal cylinder pushes a small roller in contact with the front face of the box. This is used at the end of the opening phase to keep the box in the correct position, similarly to what the lateral L-shaped plates do.

As the robot finished opening the box and all the actuators on the 7th axis have been actuated to keep the carton in the correct position, the structure slides down the column until the lower side of the faces of the box (not the flaps) are in contact with the lateral surface of the conveyor: at this point the insertion is completed, the box has slide along the polystyrene pad and is locked in position by the friction with it. The 7th axis actuators are retracted, the box is cleared and the structure rises back up vertically to its original position. The rollers are driven and the packaged water heater can proceed to move out of the automation.

As a brief side note, the actuators required to hold the box in position during the insertion where initially foreseen in the design analysis. Anyway, the simulation of the carton behavior once it is released by the robot is very hard to predict: as the robot is still holding it together with the 7th axis, multiple sets of suction cups are working on each of the four sides, allowing a perfectly repeatable positioning. Unfortunately, as the robot releases the box and prepares for another cycle, it was hard to predict the small motions that it would have performed upon release, so the actual choice of the lateral L-shaped plates, the side roller and the sharp pins was more a result of the tests done during the construction phase than the result of preliminary design.

Product identification

As outlined earlier, two stations along the roller conveyor are respectively employed for the identification of the incoming water heater and for its centering. Both of these operations are fundamental for the success of the carton insertion.

As stated earlier, there are over 350 different variants of electric water heaters that are assembled on the final lines 1 and 2: they are categorized mainly by capacity (50, 75, 80 or 100 litres), orientation (vertical or horizontal), esthetics of the cap, brand name (as Ariston Thermo Group is a corporation that produces water heating systems under various brands such as Ariston, Chaffoteaux, Elco, Ecoflam, Radi and many more), type of thermostat (mechanical or electronic) and electronics. A specific box code is assigned to each product code, but in many cases, similar water heater variants share the same packaging and as a result the overall number of carton codes is about one third of the total of products available. Because of this huge number of variants of products and cartons, it would be far from error proof to ask to an operator to manually set production codes on the the automation to operate. The daily production order for the final lines is, of course, not random: a careful planning determines which variant of water heaters has to be produced, when and in which quantity. This production order is initially imparted to the pre-assembly departments, where the enclosing shells are mounted on the boiler and the top and bottom caps are flanged to it. At this point the pre-assembled product is hooked to a conveyor chain which will move through the varnishing department before reaching the final lines. As the water heaters are loaded on the chain, they are counted and memorized by the management software which prepares the order of production for the final lines, which the products will reach just a few hours later. The line managers receive such data and use it to properly organize and predispose the preassembly, the model change is in fact performed on the go, without stopping the lines. During a change of production, all the new assembly parts (such as thermostats, cables, caps, screws...) have to me immediately available to the operators, also, it may happen that operators join or leave the line since not all the products require the same number of workstations to be employed. It would unwise to require the line manager, or another operator to set up the correct production recipe for the robot in the exact moment in which the new water heater variant arrives at the automation.

The ideal solution to this would have been to allow the robot to independently identify any of the incoming products and to select the correct carton to insert from one of the three available bays. The best way to achieve this result is to place a barcode scanner in a station at the entrance of the automation gates, suspended above the conveyor at a suitable height and inclined downwards so as to aim at an identification label that is placed on the top of each water heater in the sloped area of the cap where the hole for polyurethane injection is found covered by a plug (note that "top" here is used with reference to the position and orientation of the water heater along the conveyor; in reality this area would be at the bottom of the mounted product or on the side in case of horizontal systems). The label uniquely identifies the product using a 21 figure number, where the first 7 figures are used to identify the water heater model. This solution has been tested and proved rather unsatisfactory: the height at which this barcode is found varies for different products (50 liter products are, obviously, much smaller than 100 liter ones, despite the diameter being the same) and the system cannot automatically regulate the height of the barcode reader before identifying the product passing below. Also, being the label placed on the plug of the polyurethane injection hole, the surface below it is irregular and the accuracy of the scanning greatly impoverished. Needless to say, there is no possibility to modify the structure or position of the label without the permission of many other functions of the company, so the option is discarded.

Another solution, that is in a similar way applied in other departments of the plants, would have been that of using the data from the factory management software to anticipate any incoming product on the line. This however can work perfectly in the departments where the products move along a transport chain and are never removed from it. Such is the case, for instance, in the varnishing department: here, any scrap pieces or products that require being reworked (because of some kind of defect or problem) are signaled by using a metal palette attached to the hook that links it to the chain or using another metal piece inserted in the polyurethane injection hole. Those signaling instrument are sensed by various automations downstream that are able to filter them out without processing them. What happens is that the order of production remains the same (a lot of 60 water heaters at the beginning of the line, remains a lot of 60 components at the end of the lines) as pieces are never discarded and unloaded from the conveyors, but are rather recognized as defective at the end of the line and therefore sent back at the beginning of the department following the return course of the conveyor chain. This just would not work along the final assembly lines as there is no clear and defined way to signal that a product has been removed from the conveyor. If, for the sake of example, a water heater fails to pass the electric test, the operator proceeds with removing such piece from the line. The line manager tries, when possible, to repair it by replacing the faulty components and then manually test it again: the product can at this point be reloaded on the conveyor or discarded totally, in the latter case traceability of the piece is lot and there is no way to know in the stations immediately downstreams that the incoming lot is missing a piece. The number of scrapped and reworked pieces is instead signaled manually to the factory management software.

The adopted solution was determined by trying to find a functional compromise between all the requirements of identification and the general problems found in the assembly lines. Whenever a change of model has taken place, the line manager is instructed to print a single extra identification label and to stick it on the lateral surface of the bottom polystyrene pad that carries the first water heater of the new production. The barcode scanner of the automation is placed low, just on the side of the rollers: all the incoming products are stopped in this identification station, are centered thanks to a couple of lateral plates that are pneumatically actuated to push the lateral sides of the pad towards the center of the conveyor and at this point the barcode scanner is activated. It aims at the bottom polystyrene pad and searches for the presence of the label on every single product. When the label is found and the corresponding code is read, the robot prepares for the change of model by starting to pick up cartons from the new bay. To summarize: every product is scansioned in search for the label, but such label is only placed on the first water heater of the new lot and therefore, if the scanner does not find the label it just means that the model is always the same as before and no operation is required.

Centering station

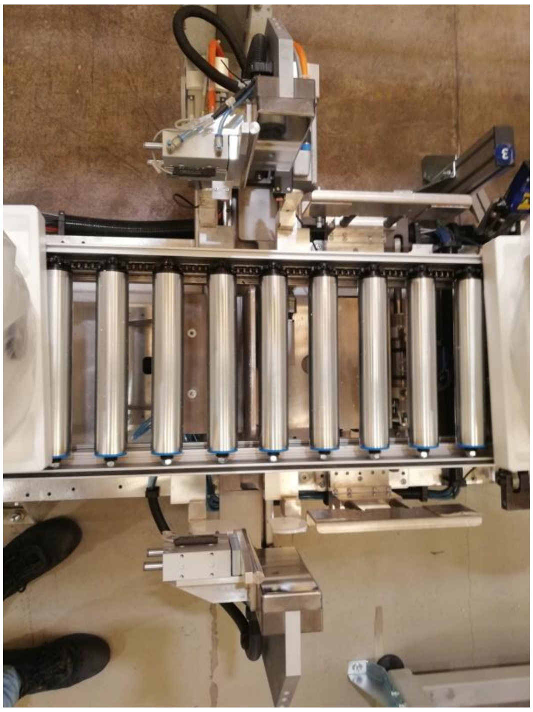
The implementation of a product centering station along the rollers of the automation represents a good example of the problems that can be caused by late found issues. During the preliminary design, it was clear that the water heater needed to be stopped in a very specific position so as to allow the robot to correctly insert the carton. Guaranteeing the repeatability of the position of the product on the rollers, allows the 7th axis to lower quickly and always in the same manner during the insertion of the carton. If this was not the case, some kind of vision or sensing system should have been anticipated to allow the automation to work properly. Unfortunately these kind of systems tend to be expensive, slow and can generate a lot of variable issues, therefore their use should be limited to the most critical processes, where it is not possible to do otherwise (as in the case of box pick-up). These centering stations were presented simply as a couple of pneumatically actuated plates pushing on either lateral sides of the polystyrene pad so as to align it to the direction of motion and allow it to stop exactly where required.

This was the simple conclusion of a preliminary analysis of the variabilities of the process. The operators on the line do not need any kind of support system during the operation: the water heater moves along the line, and even when it is slightly rotated in one direction or the other, the operator can easily adjust for the misalignment and rapidly insert the carton without any trouble.

But this was not the case for the robotic arm, as a new process variable emerged during the preliminary tests in the detail design step: even when the polystyrene pad is perfectly oriented along the roller conveyor, the water heater sitting in it can be slightly phased with respect to it. The fitting hole in the pad is round, and the insertion operation is performed by an operator at the beginning of the line which tries to perfectly align the edge of the pad to the support bracket of the water heater. Unfortunately, the operation is not always performed perfectly, so it sometimes happen that the water heater is rotated relatively to the squared position of the polystyrene pad. This was never an issue for the human operator, as it was possible for him to simply adjust the box by moving it slightly sideways alternatively to fit it around the bracket. But now that the 7th axis is expected to drop vertically towards the pad, the same kind of adaptive motion can not be repeated.

During early tests, instead, the 7th axis lowered on the product anyway, and the cardboard on the inner side of the box got hooked to the brackets as due to its relative rotation with respect to the pad, it now emerges from the vertical projection plane of the front edge of the pad thus obstructing the correct path of the carton.

The implemented centering station has been placed between the identification station and the carton insertion point. There, the water heater pad is stopped against a metal plate coming out of the rollers and again, as for the identification, a couple of oppositely pushing pneumatically actuated plates, orients the polystyrene pad with respect to the direction of motion. At this point the pad is tightly held in position and another actuator comes into play: it allows to push on the two external edges of the bracket, thus causing its relative rotation with respect to the pad and its centering. A single actuator was used for the self-centering clamping device was initially implemented to cause the rotation of the product. The surfaces that enter in contact with the bracket are covered in polyethylene in order to avoid scratching the surface of the product or otherwise ruining the varnishing: this is a common practice in the plant and it is the result of previous MP-Infos.



The first tests demonstrated that some inaccuracies in the process were still present as the final orientation was not perfectly oriented. Another solution proved functional and reliable, giving no further issues during the project: the clamping device has been substitute with two independently actuated jaws, controlled by the analog reading of an analog sensor that verifies the exact position at which the jaws have to be at the end of the operation.

ARISTON THERMO GROUP	MP INFO: Maintenance Prevention Information	Type:	PROCESS	Solution Status:	Not Tested

Title:	Component presence check before welding								
Author:	Bagarin Nicolò	Plant:	Genga	Date:	04/10/2017	Number MP INFO:	PM 112	Impact:	Operability
Pillar:	PM								

This part is Obligatory for Process MP Info				This part is Obligatory for Product MP Info	
System:	Electric	Process:	Packaging	Product Family:	
Machine Type:		Manufacturer:		Product Name:	
S.no:		PROBLEM IDENTIFIED IN:	Detail Design	PROBLEM IDENTIFIED IN:	

PROBLEM / NEED or GENERAL PRACTICE	SOLUTION / BEST PRACTICE
The product centering device of the automated packaging system (see PM-Info PM 111) does not work properly whenever the bracket of the package is not perfectly alligned. This can happen when the bracket is slightly deformed or rotated with respect to its normal condition (see picture). In such case, the claws of the centering system are not able to recognize the problem and therefore output the bracket rotated with respected to the orientation required by the robot. The number of micro-stoppages to manually rearrange the product on the conveyor.	A new sub-system is introduced to compensate and correct the deformations and misallignments of the bracket. Two independently actuated linear pistons act the opposite faces of the bracket so as to guarantee its original allignment. The absence of deformations and rotations of the bracket allow the self-centering system to work properly and therefore the robot can proceed to package the product without undesired stoppages and human intervention.

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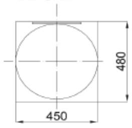

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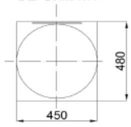

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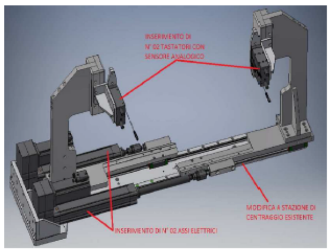

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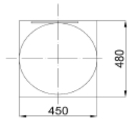


OK

The following part is mandatory in case the MP Info comes from an existing problem, discretionary in case of best practice

BEFORE					AFTER				
PERIOD	INDICATORS			NOTES	PERIOD	INDICATORS			NOTES
	OEE	94	%			OEE	95	%	
STANDARDIZATION ESTENSION				INVOLVED REQUIREMENTS			signature		
							NAME		

Loading bays, logistics and AGVs

The loading bays are the three stations placed on the sides of the robot platform (inside the automation barriers) where the lots of boxes are found, ready to be opened and inserted. Each bay is constituted by a supporting platform at its base and a motor that pulls both the conveyor belts that are placed on the top. These belts are spaced from one another and the carton lays on the top of them and are used for the loading and unloading of the bays.

Each lot of cartons that is found on the bays contains 60 unities: the automation is therefore capable of hosting a maximum of 180 boxes at a time, which correspond to 36 minutes of full-paced production with a cycle time of 12 seconds. Any bay can be completely emptied in just 12 minutes which highlights how a constant supply of cartons needs to be provided to the automation. Before the project, the operator performing the packaging received the lots of 60 cartons thanks to a series of carts pulled from the picking area by a vehicle driven by another operator. The carts contained the various components required for production such as caps, cables, thermostats, polystyrene pads and so on. Maintaining this kind of feature resulted to be impractical as no simple and quick way to take the boxes from the cart and place them inside the automation was determined. The loading bays are found really close to the robot, and any loading operation needs to be performed while the robot is moving: this makes impossible any carton manipulation that involves the operator and the operation needed to be completely automatized.

The solution was found by redesigning the vehicles that bring the carton lots on the final lines under two major guidelines:

- Making the supply trains able to safely and automatically load the cartons on the bays of the automation. This has been achieved by designing a system in which each bay is able to hook on one of the 3 bays of the train and pull it inside the automation where the boxes are ultimately loaded. This will be described in greater detail in a moment.
- Making the trains autonomous via the adoption of AGVs (Automated Guided Vehicles). This is an important requirement which is due to the way the automation works and not because of the necessity of improving the efficiency in some way: one could, in fact, imagine that the introduction of AGVs is done so as to remove the operator that drives the electric trains. This is not the case, rather AGVs are a logistic necessity: being the trains different from the ones used previously (as explained in

the above point) it would be required to have the same operator performing an additional trip for the supply of the cartons. The picking area is already one of the busiest places in the plant and this solution could potentially generate more trouble. The best alternative is letting the robot be autonomously able to “call” the AGV for supply at the exact moment when it needs it as it knows the number of cartons that are available at any time.

The designed logistic trains were basically composed of three loading bays attached to one another (not to be confused with the three loading bays of the automation). The bays are separated from one another by metal planes and the cartons are placed on three parallel support bars that are covered in plastic wheels identical to those of typical flow racks to allow the boxes to slide in and out of the train without friction. The spaces between the support bars are intentionally designed with a double purpose:

- allowing the operator to nimbly load the lots of cartons on the train using a forklift truck
- allowing the automation to pull the carton inside the barriers of the automation

Each loading bay is identified by a QR code on its side and by another one placed just below it, along a shaped column. The QR code is used to allow the automation to recognize each of the bays of the train and its content. As the operator completes the loading operation it uses a wireless barcode scanner “pistol” to communicate to the automation which train has been loaded and with which boxes. The operator is simply required to load the cart with what instructed by the monitors of the factory management software, and then scan the QR code of the train to confirm the operation. At this point all the information about the loaded boxes is transferred to the automation.

The flow of material from the picking area to the final assembly lines and the automation is managed in the following way. Operators from the picking area receive on a monitor the information regarding the order of production for each of the final lines, in particular, the factory management system automatically indicates which box lot has to be loaded on which bay of each cart. The operator, accordingly, selects the proper lots from the stockage are and places them on the trains.The trains are parked in a specific point of the picking area, alongside a metal railing which has been specifically designed so as to fit the train dimension while providing a useful visual guide for the forklift truck driver that needs to properly place the lot on the loading bays. The driver is only required to load the second and third bay of the train, the first one is always left empty so that the AGV is able to also perform the unloading of the automation from any residual box that has remained on it.

As already told multiple times, production lots are composed of 60 water heaters and all the assembly material is provided accordingly to the various departments. This is a necessary requirement for both the Workplace Organization and the Logistics Pillars, which aim at reducing as much as possible the amount of inventory that is stacked in the plant and the number of components leftover on the lines at the end of the production of a specific model. Most commonly, each of the final lines will host a lot of 120 or 180 water heaters for each model, but it is also likely to have a production of 300, 600 or even more identical products in the same workshift: the only limit is in the fact that the amount of pieces outputted is always a multiple of 60 units. Whenever the production runs normally, the carton insertion automation receives therefore a number of boxes which is identical to the number of incoming products. Sometimes, unfortunately, it might happen that a few water heaters are discarded and removed from the final lines conveyors because they present some kind of defect, or maybe they need to be reworked or fixed because of a missing or faulty component. Obviously, if any of the water heaters in a lot is for any reason remove from the conveyor, only 59 products will be packaged by the robot, thus resulting in a single box remained unused on a bay. The installation has to be able to deal with such inconveniences in an effective way: asking an operator to manually remove any residual cartons at the end of each production lot would just be senseless as the operation would require the machine (and as a consequence the whole assembly line that passes through it) to be stopped, thus causing an huge inefficiency. The easiest solution in this scenario is therefore that of leaving one of the bays of the train that brings the boxes to the robot to remain empty so that it can unload any residual unities from the automation. As the second and third bays of the train empty by loading the cartons on the automation, they also become available to take any residuals from other bays. This makes possible for each logistic train to load two bays of the automation while picking up the residuals from all of the other bays. During normal functioning the robot will be interacting every few seconds with one of the loaded bays, thus making it unavailable to the logistic train, but this is not a problem as the AGV will be still able to unload and reload the other two bays without stopping the automation operations.

Once it is loaded by the forklift truck driver, the logistic train is then able to leave the picking area and reach the final lines. When the automation senses that only a single bay is remained with available cartons on it, it "calls" the AGV using a radio signal. The AGV is provided with a NICE radio controller that outputs a start signal for the vehicle as soon as the radio message is received.

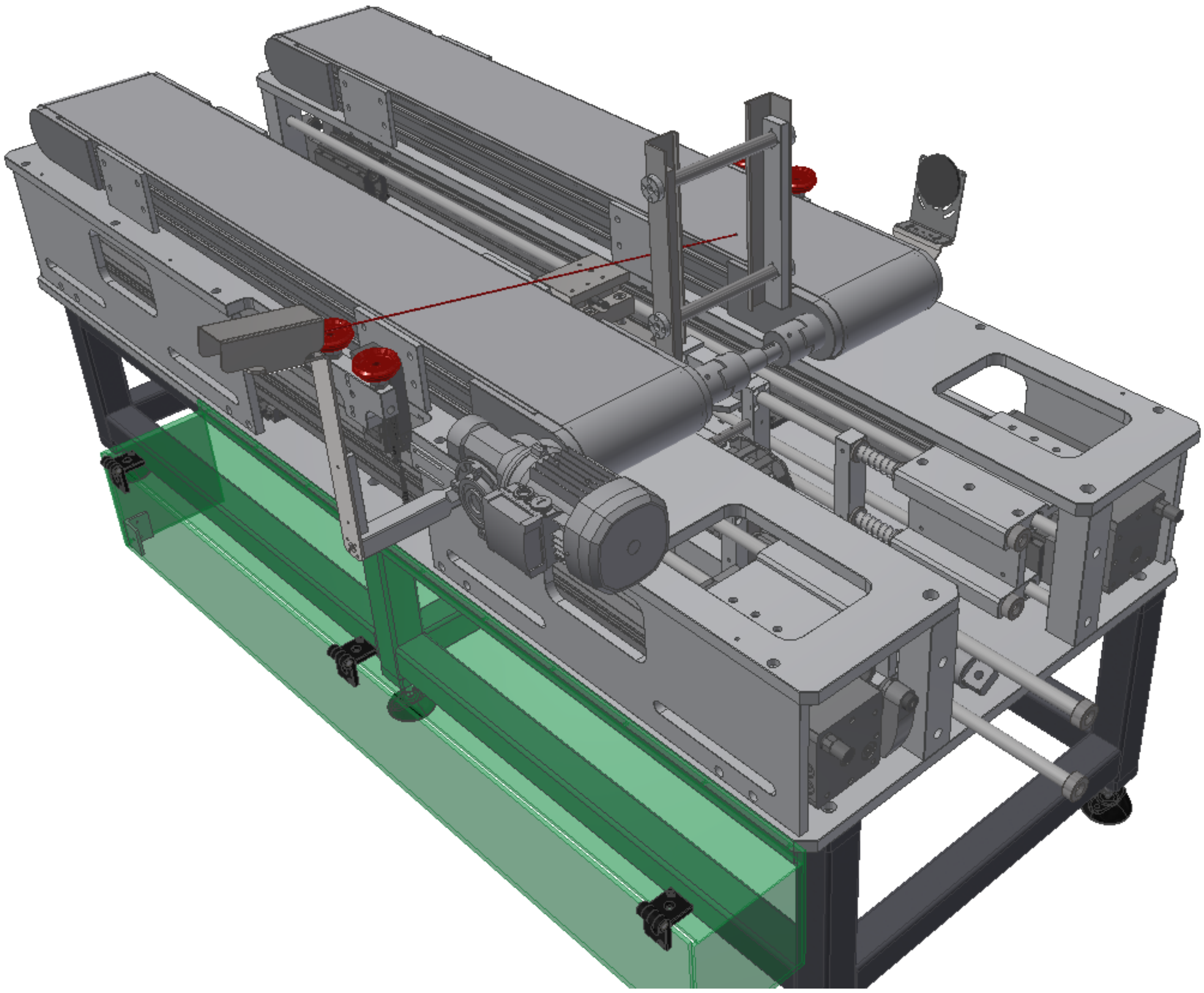
The AGV is an Indeva Tunnel, a relatively small box-shaped vehicle that is able to tow a cargo of up to 750Kg (more than adequate for the application as the cart weight is about 150Lg and the weight of each carton is around 1.5Kg, totaling a maximum material weight of less than 200Kg) which, as the name suggests as the particularity to be able to insert itself under the cart it needs to train. The Tunnel AGV possesses a pin-hook on its rear that can be programed to rise above the surface or the vehicle or to hide beneath it at specific moments of its operation. The lifted pin locks on a V-shaped metal plate fixed at the front end of the train so that it becomes able to pull it. This features has an enormous advantages as it allows to use a single AGV for multiple cargo trucks: in this case there are two trains for each lines and the AGV alternately works with one of the two. The AGV locks on the first train, moves it across the plant towards the final lines, performs the loading and unloading operations then comes back to the picking area where the other train has been prepared. The empty train with the AGV leans on the loaded train and pushes it out of the parking area, taking its place. At this point the Tunnel AGV lowers its pin and frees itself from the empty truck, slips out of it and inserts under the now full train placed in front of it. At a certain point during the insertion, the pin is raised again and the AGV can lock on the plate of the new train and pull it towards the final lines. This proves a fundamental feature for two main reasons:

- The AGV speed in the plant is limited for safety reasons at 10m/minute and the distance between the picking area and the automation is significative, especially for the final line number 2. This means that the whole trip back and forth lasts about 8 minutes. Being each train loaded with 120 boxes, it accounts for a minimum of 24 minutes of production, therefore the time window remain to the forklift operator if a single train was used would be excessively small.
- Forklift truck drivers from the picking area have multiple responsibilities other than loading the trains, and therefore they might not be immediately available to load the emptied train as it comes back to its parking spot

The cons of using a total of four trains is in the amount of space they occupy. The empty trains have to be parked in the picking area, in front of the aforementioned rails, while the loaded trains wait stationary until the radio signal in another parking area: for the first line this area is outside the picking area, just at the beginning of the final line, for the second line the train waits just in front it empty counterpart.

When one of the AGVs is called, it starts moving towards its destination. The Indeva AGVs move across the plant along paths established by magnetic bands sticked to the ground. There are a few more AGVs other than the two used for the carton insertion automation that are used to automatically supply the final lines of all the necessary assembly materials. Each AGV has its own path between the flow racks, but some major tracks are shared by all of the vehicles. The magnetic bands are identical for each AGV, but the method that a vehicle adopts to pick a particular track and not another is via the use of markers. Markers are slices of magnetic bands that are placed perpendicularly to the main path and that represent a step in the programmed sequence for each vehicle. At every step the AGV is imparted a particular command regarding either its speed, the direction it has to follow or the sensibility required to its safety obstacle sensing device. A simple example of the sequence of actions that are programmed on the AGV is the following: the AGV is parked and receives the start signal from the automation, thus beginning its programmed cycle of operations by rising its pin and starting to move forward, once the train has been hooked the AGV follows the magnetic band out of the picking area; at every turn or required change of direction a marker on the ground instructs the AGV on which side of the magnetic band to follow and at which distance; various markers are used to set the correct speed for the vehicle, normally the train can proceed at the maximum speed allowed in the plant for AGVs of 10m/minute, but due to its weight and dimension it is required to slow down in proximity of turns so as to reduce its curving radius; as the AGV approaches the automation its speed is reduced and the safety distance at which the laser scanner stops the vehicle is lowered thus allowing to align the side of the cart to the bays of the automation; a total of 9 markers identify the locations where the vehicle is required to stop to align each bay of the train to each bay of the automation so as to perform loading and unloading, after every step is completed the automation uses the radio signal to start the AGV; finally the vehicle drives all the way back to the picking area, where it encounters the other undriven train; the AGV slows down and align on the back of the other train, then turns of its laser scanner and starts pushing the second train out of the parking spot; finally the AGV lowers the pin, slips out of the first train and enters the second, where it gets ready to start another cycle.

The safety of people and of the AGV is guaranteed by a laser scanner optic sensor that identifies the presence of any person or object around the vehicle within a distance that is set at each step of the program (depending on the speed on the vehicle and on the operation it is performing). When something enters the safety area of the laser scanner, the vehicle immediately stops until the course in front of it is cleared. Being the AGVs electrically driven and therefore particularly silent, their approach can pass unheard by people, therefore they are programmed to play an alert music whenever they are in motion, so as to be easily heard.



The loading operation, where the carton lots are transferred from the AGV train and the bays of the automation is the most complex of all the logistic activities required for the proper functioning of the installation. As the train approaches the automation, it slows down and accosts the barriers. In order to guarantee the correct alignment, a rail is found on the portion of floor just outside the barriers: on the same side the cart wheels have been drawn towards the inner of the train, while three couples of rollers have been mounted on the edge, with the axis vertical with respect to the floor. This system allows the cart to slip in the rail smoothly and align perfectly to the barriers of the automation.

The train then moves alongside the loading bays of the robot through a total of 9 steps: each step represents a station in which one of the bays of the train is aligned with one of the bays of the installation, and only a vertical shutter separates the two. The train arrests its motion at each step, clicking a limit switch with a cam on its edge. The PLC knows which of the three bays of the automation is requested an operation and accordingly activates a barcode scanner aimed at the bottom of the train, where a QR code is placed to identify the bay of the train: the result of the reading is that the bay of the trainis matched to that of the automation. At this point the software matches the information present on the train with that on the automation and determines which operation has to be performed. Each bay of the train can be in one of three states:

- Loaded with a new lot
- Loaded with leftover boxes withdrawn from the automation
- Empty and therefore available to be loaded

Similarly, the state of each bay in the automation is defined by two variables:

- Unloading required: unloading of the bay is required when the robot has finished picking up from it, either due to having already used all of the available boxes and therefore having only left the bottom cardboard sheet used to protect the lot from the forklift manipulation or due to having leftover boxes residuals from the production lot
- Loaded or empty: which boxes, if any, are present on the bay.

Every empty bay of the train is used to withdraw leftover boxes or the protection cardboard sheet used to avoid the bottom box to be damaged during forklift transportation. The second and third bays on the train are instead loaded with a full lot of cartons which are transferred to the two bays of the automation from which the robot is not actually picking up cartons.

The actual transfer of the boxes between the bays is carried over by an automated mechanism. For simplicity, the operation of loading cartons from the train to one of the loading bays will be described, but the same working principle also applies to the reverse operation. Once the barcode scanner has allowed the automation to identify a loaded bay of the train placed alongside an empty bay of the robot station, the shutter that works as a safety barrier separating the working area of the robot from the external environment is lifted pneumatically. As the shutter motion is completed, the PLC signals the automation bay to begin with the pick up: a pneumatic sled in between and parallel to the two transport belts that constitute the region where the boxes will be hosted moves outwards, through the opened barriers and towards the train. A small vertical cylinder at the end of the sled pushes upwards and locks onto a hook found below the central bar of the bay in the cart. A sensor signals the correct coupling between the two components, and the pneumatic sled is retracted so as to pull the bay of the cart, which slides laterally on mechanical rails, passes below the opened shutter and enters the automation. As outlined earlier, the cartons on the train are placed on three bars that are covered with small plastic wheels that allow nimble motion of the lot, the bars are in a trident formation and are complementary to the inner structure of the bay, so that when they are pulled in the automation, the central one fits the space between the two belt conveyors, while the other two slide along their sides. When the pneumatic sled is retracted to its original position, the PLC activates the belts which drive the boxes further into the automation and away from the train, this motion is facilitated by the frictionless wheel on which the cartons initially lay. A photocell is placed on the innermost edge of the bay, so that when the pile of boxes reaches it, a signal is sent to the PLC and the belt conveyor is stopped. Now, the pneumatic sled is actuated again, pushing the three bars out of the barriers and back into the train, the frictionless wheels slip below the cartons so that the pile remains in position. Similarly to what happened earlier (but in reverse), when the piston of the sled is completely extended, the smaller piston on the hook is released, this is signaled to the PLC and the sled is retracted, thus uncoupling train and automation. At the end of everything, the shutter barrier is lowered again and, as safety is again guaranteed, the train can move on toward the successive station.

Despite a lot of interactions between the PLC and the pneumatic actuators happen during these operations, the total time required to load the bay is relatively low, about 25s, with the total transit time of the AGV through the stations of about 3 minutes (as not in every station it is required to open the gates).

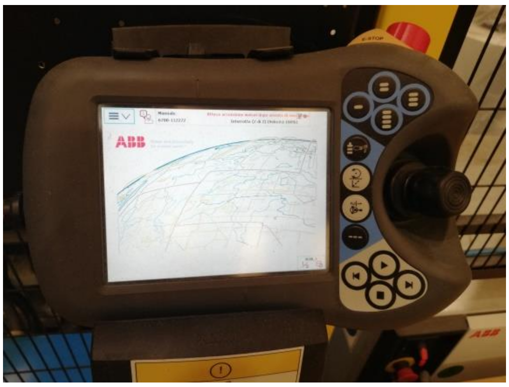
Operator panel

The operator's control of the automation is guaranteed via a control panel mounted outside the automation, facing the inner side of the line. During normal operation it should not be necessary to use it, but its presence is fundamental to manage the various daily situations that can take place during production, as line starts and stops.

The outside panel can also be used as a manual override in case problems appear during production. It could be, for instance, necessary to exclude the automation when maintenance operations are performed on the robot or on one of the loading bays: in such case, it is still possible to keep the line running with a backup operator that manually inserts the boxes. This does not represent a normal working condition, but since there is a single conveyor that brings the water heater from one side to the other of the production line, it has to be possible to exclude the automation, if necessary, while the product can still safely travel through it.

From the control panel it is also possible to visualize statistics regarding the production such as current cycle time, AVG cycle time and efficiency in a given shift, plus a set of data regarding the recent lots of production. Specific pages on the software allow the visualization of the data that has been "written" on the logistic trains or on the loading bays. As a precaution, there's also the possibility to manually overwrite wrong information so as to guarantee that production can run smoothly even in cases where the factory management software is offline. Again, this is not something that can happen frequently, but still it is better to have a plan B to avoid the onset of issues.

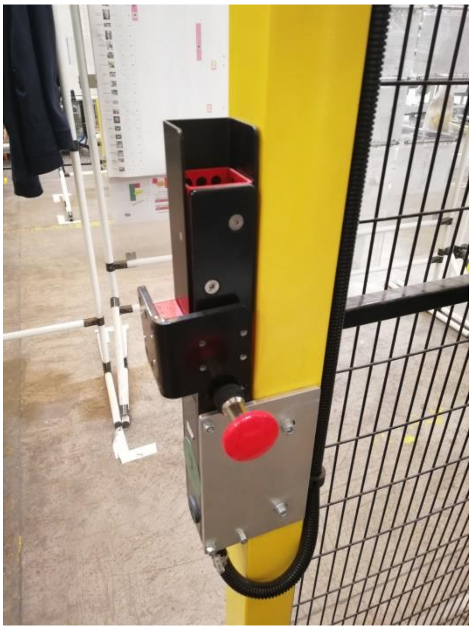
Another form of control over the automation is represented by the ABB Teach Pendant, a small touch screen monitor with a joystick that can be moved around the layout of the automation to verify the functioning of the robotic arm. It is possible to use it to display the software program running on the robot or to see the status of the sensors on the end effector. Additionally, the Teach Pendant can be used to reprogram the robot, by modifying working points and instruction. Diagnostics and problem identification is made possible thanks to the possibility to simulate the rising and falling of sensors or of external inputs, so as to verify the behavior of the robot under various conditions.



Protections and barriers

There is no much to say about protections and barriers, since they are almost completely standardized so as to be 100% law compliant. The automation, including the loading bays and the conveyor are basically caged between four yellow colored grid barriers supported by columns.

Being this cage found across the conveyor, and since it is not allowed to cross the conveyor by foot for safety reasons, three doors have been placed to guarantee to the operators and the maintainers a full access to the various regions of the crowded space. The doors are connected to the PLC so as to enforce safe lockout operations. To gain access inside the automation, the operators are required to turn a key on the door panel; as the request is forwarded to the PLC software, a light starts flashing as an indication of the start of the procedure; at this point the robot is still working, and access is not granted until the working cycle has been completed and a safe neutral position has been reached by the anthropomorphic arm; now the flashing light remains turned on and the door is unlocked; the operator can now slide the door sideways and enter to perform the required operations; whenever the door is opened, the automation is completely stopped and no movement takes place as long as the door remains open; when the operator has finished its work, he can get out of the barriers, slide the door closed and press a button to request the reactivation of the automation, this can only be done while all of the doors are closed; the green button at the button starts to flash as the operations are completed successfully and, to reactivate the automation, it is now only required to press the green button and keep it pressed until the light remains green.



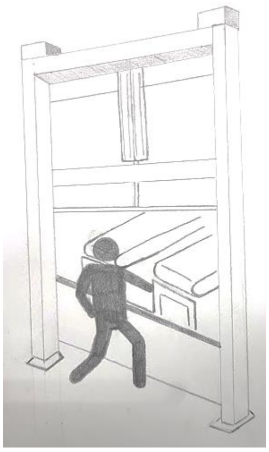
Additional emergency stop "mushroom" buttons are located outside of each door, on the main panel, and inside the barriers so that in any case in which a person is at a risk of being harmed the automation can be instantaneously halted and blocked completely.

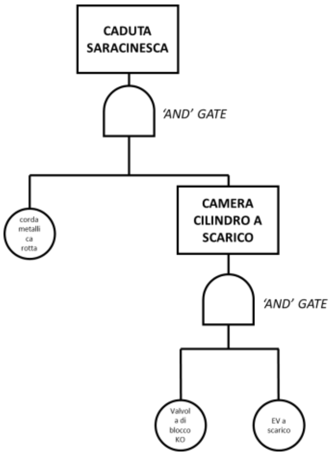
What normally represents a safety concern in a robotic platform is the presence of any areas where a person is able to pass through and enter the barriers to reach inside the automation. The countermeasures adopted to guarantee the safety of the "standard" entrance gates have already been showed, but there are a few additional zones where a person can theoretically enter the automation (even if this is not allowed, nor expected during regular operation of the machinery):

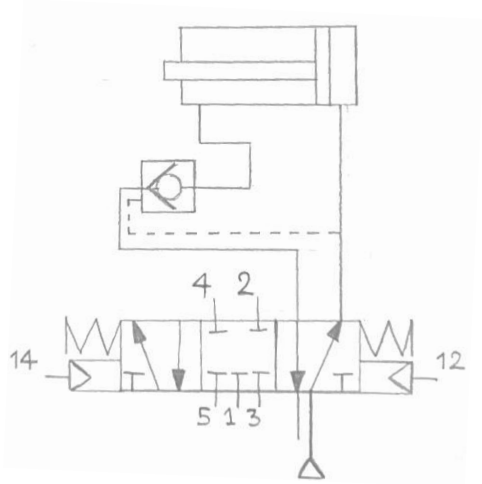
- Two openings in the barriers are found in the area where the conveyor rollers enter and exit the layout of the automation. The water heaters have to enter the machine in order to be processed and then to exit, and in this area two openings in the grid allow their passage. The openings are large enough to allow a person to fit through it
- Each loading bay is connected to the logistic area behind the automation via a large opening in the barriers. As explained earlier, a vertically sliding gate is normally used to seal this opening and it opens only when the AGV train is on its side and loading or unloading is requested: during such operations the gate slides open, but the cart behind it blocks any passage for a person, so that safety is normally intrinsic. However, the manutentors are allowed to open such gates manually via a specific command in the control panel when they have to easily access the loading bays mechanisms for inspection and routine maintenance. In such cases, the machine has to be stopped (otherwise the gates would not slide open), but there might be a risk if the gates were to close while someone is passing under them. The gates are heavy and fall vertically from an height of about two meters, making them extremely dangerous in this type of situation.

The solution for the first problem has been the introduction of muting barriers. These barriers are not "physical" barriers, but rather photoelectric beams that cross a particular open region, thus leaving an existing passage. These barriers can be either activated or excluded depending on what is passing through the photoelectric sensors. In this case, the barriers are able to recognize the passage of a water heater: being the diameter of all the products either 450mm or 470mm and the speed of the conveyor 4m/min, the transit time of the product is between 6.5 and 7 seconds. If the photoelectric barriers detect anything that crosses it in a lower or larger amount of time, an intrusion is detected and the machinery is stopped for safety.

The second problem has been analyzed using a tool called Failure Tree Analysis (FTA) which allows to examine the causes for the happening of the final failure that generates a safety concern starting from the low level events that are connected with the arising of the high level fault. The sliding of the gate either open or closed is controlled by a electric pulley with a metal cord, but an unsafe condition is present, as the snapping of the rope would immediately cause the sudden fall of the gate and potential damage is someone was to pass below it in the moment. The solution found to improve the safety of the system was in the implementation of a pneumatically actuated double acting cylinder as a system in parallel to that of the metal rope. This cylinder has a one way valve connected to the discharge chamber, so that air cannot be discharged from it during normal operation. This provides an efficient safety system as the presence of at least two faulty conditions is required to cause the fall of the gate and, similarly, two fault causes have to be present to cause the failure of the pneumatic system.







Another unsafe condition introduced by the working principle of the working bays was due to the fact that a small air gap is present between the cart and the loading bay during the boxes lot transfer. If an operator inserts his arm or hand in this area he is at risk of being crushed by the moving mechanisms. The unsafe condition had to be eliminated and to do so, a special type of barrier was used that consisted in the mounting of two rotating bars at each side of the gate. When a person tries to insert is arm or hand inside the small gap between the train and the barriers, the bar is rotated and a magnetic sensor is activated. The activation of the sensor immediately stop all the movimentations of the loading/unloading mechanism thus eliminating the risk for the operator of being cruhed in the machinery.

Step 3 modifications list

A few issues have emerged during the detail design of the equipment. Ideally, step 3 is the moment during which most of the problems are found. This is due to the fact that the process is analyzed in greater detail and the functional blocks are designed. Once things can be visualized in detail on CAD/CAM applications, it should be much easier to diagnose any problem. The more issues are found at step 3, the better, as everything is still "on paper" and not fixed in a definitive way, so the cost for modifications is reduced.

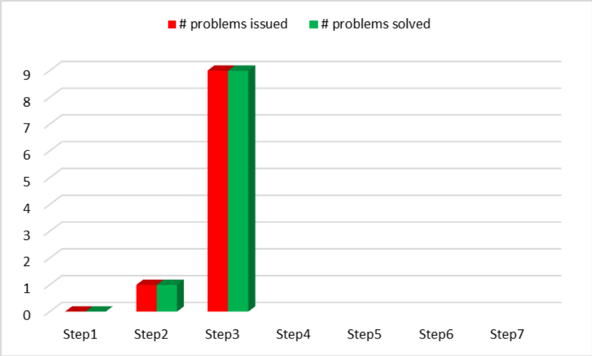
Because every issue found from step 3 on can result in economical losses or delay, the WCM methodology imposes to track down every modification that has been implemented to the project, so as to verify how the total cost of the project evolved through the steps. Here follows a list of the implemented modifications, a sample from the original document, and the graph showing the trend of the cost of the project over time:

- Implementation of the bracket centering station (explained above)

- Modification of the bracket centering station via the introduction of two independent jaws, controlled by a couple of analog sensor as an alternative to the less precise self-centering solution devised earlier
- Asymmetrical positioning of the robot's tool with respect to the 6th axis so as to optimize the movements through the various phases of the cycle
- Increase of the stroke of the 7th axis of 200mm so as to allow to work in masked time even during the insertion of the larger boxes
- Increase of the stroke of the pneumatic pistons that control the grip of the 7th axis as a way to ease the manipulation of larger cartons
- Modification on the logistic trains in which the wheels are brought towards the inner of the cart, thus leaving enough space at the edge for the mounting of sets of wheels with a vertical axis with respect to the ground that can ease the alignment of the train on the rail of the automation
- Addition of a supplementary cadenced station on the roller conveyor with the purpose of reducing the waiting time between the processing of two consecutive water heaters
- Inversion of the position of the barcode scanner station and the product centering station, so that the identification can be performed in advance: this allows the software of the robot to be reprogrammed so as to know earlier which model of product will have to be processed and can work faster during the change of model

EEM CD Data Collection
Carton insertion project

PROJECT	ITEM	ITEM DESCRIPTION		CONTRACTOR	€ APPROVED	COMMENTS
Carton box insertion	06	Centraggio staffa con assi indipendenti	CENTRAGGIO STAFFA CON ASSI INDIPENDENTI	Robotech srl	€ 1.073,60	Sostituzione della pinza autocentrante con una pinza con corse delle due ganasce indipendenti al fine nella posizione del prodotto. La quota di chiusura è definita in funzione dei valori letti da due sensori
Carton box insertion	13	Decentramento tool robot	DECENTRAMENTO TOOL ROBOT	Robotech srl	€ 596,60	Disassamento del tool del robot rispetto al centro della flangia del 6° asse al fine di ottimizzarne i mo
Carton box insertion	01	Intoduzione perni allineamento carrelli imballi	INTODUZIONE PERNI ALLINEAMENTO CARRELLI IMBALLI	Robotech srl	€ 586,80	Modifica dei carrelli imballi con inserimento di 3 perni di allinamento per ciascun carrello al fine di ev
Carton box insertion	22	Sollevamento 7° asse	SOLLEVAMENTO 7° ASSE	Robotech srl	€ 478,80	Incremento dell'altezza del 7° asse di circa 200 mm per permettere di depositare l'imballo in tempo m maggiore
Carton box insertion	02	Applicazione slitta maggiorata su 7° asse	APPLICAZIONE SLITTA MAGGIORATA SU 7° ASSE	Robotech srl	€ 408,00	Introduzione di una slitta con corsa maggiorata su 7° asse per permettere un contenimento maggiore maggiori
Carton box insertion	19	Modifica albero traino rulliera	MODIFICA ALBERO TRAINO RULLIERA	Robotech srl	€ 331,50	Modifica geometria cava linguetta su albero di traino rulliera ingresso impianto per evitarne la rottur
Carton box insertion	08	Introduzione apertura porte a saloon	INTRODUZIONE APERTURA PORTE A SALOON	Robotech srl	€ 306,00	Previste delle portelle con apertura su due direzioni rispetto alla cerniera cui sono ancorate per evita l'operazione di carico dei pacchi di imballi all'interno delle baie
Carton box insertion	17	Aggiunta di un cadenzatore supplementare	AGGIUNTA DI UN CADENZATORE SUPPLEMENTARE	Robotech srl	€ 259,50	Aggiunta di un cadenzatore supplementare per ridurre lo spazio di traslazione tra la stazione di inseri inserimento
Carton box insertion	04	Spostamento barcode reader a monte del centraggio staffa	SPOSTAMENTO BARCODE READER A MONTE DEL CENTRAGGIO STAFFA	Robotech srl	€ 229,50	Anticipo della fase di lettura del barcode, necessaria ai fini dell'identifcazione del modelli in lavorazic subito la quota di accostamento più corretta con la stazione di centratura della staffa



Step 3 checklist

Of the total 1780 items in step 3 checklist, 1368 were successfully passed during the review, 403 were not applicable to the project and 9 were failed.

Step 4: Construction

Once the detail design of the automation reaches its completion, the final concept is released and approved for construction. At this point it becomes possible to upload the GANTT and specify the intermediate milestones of the construction that will bring to the testing and finally to the acceptance of the installation from the plant.

The supplier organization structure is very lean, it consists primarily of a technical department which is composed by most of its employees. The operative personnel is instead small in number (just a few mechanical and electric technicians), which is joined by third party operators that are specialized in either assembling, installations. The same is true for the vision system of the robot, which was developed by an external company, whose technicians were constantly present during the construction for the programming of the application. At the same time, the workshop of the company is used just as an assembly area: all the mechanical lavorations of parts and components are ordered to third party specialized companies and workshop. While this can be beneficial for the supplier, as it can rely on a small number of employees, it can create problems to the plant: the delegation of so many aspects of the construction can result in delays due to the availability of external companies personnel, and to the production time for custom parts and components of the assembly.

For all of the above reasons, the supplier initially started to order and prepare components since the late stages of step 3, when some aspects of design were already locked. This is particularly true for the standardized components and, in general, all of the parts that were designed early in the project. The robot, its controller, the roller conveyor, the barriers… all of these are significative portions of the automation that have been clearly defined at the beginning of the designed stage, after the initial simulations and analyses.

The opposite was true for mor "custom" components, developed at later stages. In particular, the structure of the support structure for the pneumatic actuators on the end effector of the robot and of the 7th axis required a more focused design, as the kinematics of all the mechanisms required to perform the opening of the carton and of the flaps was to be carefully modeled and analyzed.

The construction was divided into a few major parts, at the end of which a milestone on the GANTT was reached:

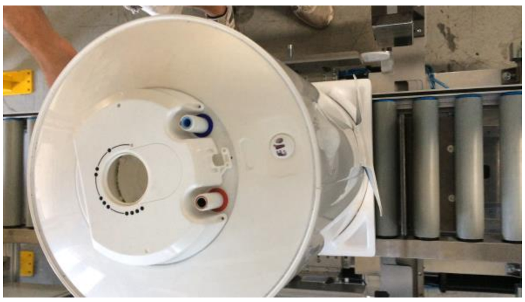
- Construction of the basement: a carpentry structure built with the purpose of hosting the anthropomorphic arm on top of it. The basement places the robot about 1m above the height of the ground, allowing it to have the proper reach and maneuverability
- Construction of the end effector: installation of the robot on the basement and assembly of the structure and the tools found on its wrist

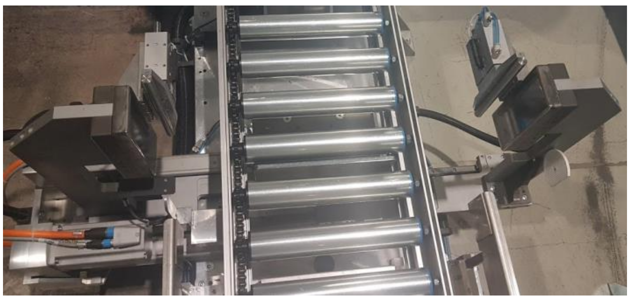
- Carton loading system construction: assembling and positioning of the loading bays, installation of the mechanisms required for the loading and unloading operations, installation of the safety gates on the protection barriers
- Internal conveyor and intermediate stations construction: installation of the conveyor in front of the robot and assembling of all of its substations such as the identification station, the centering station and the intermediate cadenced sections of rollers where the water heaters wait to enter the successive operation

The construction phase began in September and took place in the following months until the beginning of December. At the end of October the first production tests were possible.

The plant followed carefully the various stages of the construction by sending a few people every couple of weeks at the workshop of the supplier to verify the status of advancement of the project and the overall characteristics and quality of the parts and the assembly. Typically, a group of 4 or 5 people would reach Northern Italy for a couple of days, where a series of checklists was examined to verify the compliance of procedures to best practices. The group was generally composed by the EEM Pillar Leader, its support, the head of mechanical and electrical maintenance, and the line manager from the final assembly lines.

The EFMEA document developed at the beginning of the detail design is integrated with any additional concern or problem emerged during the construction of the machine, thanks to the observation from the various members of the plant.

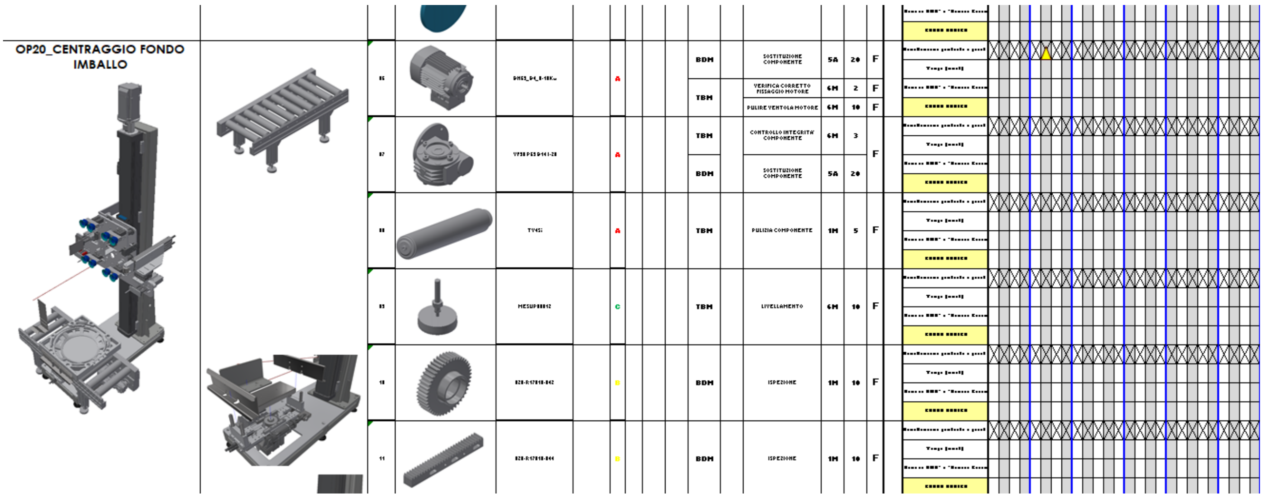




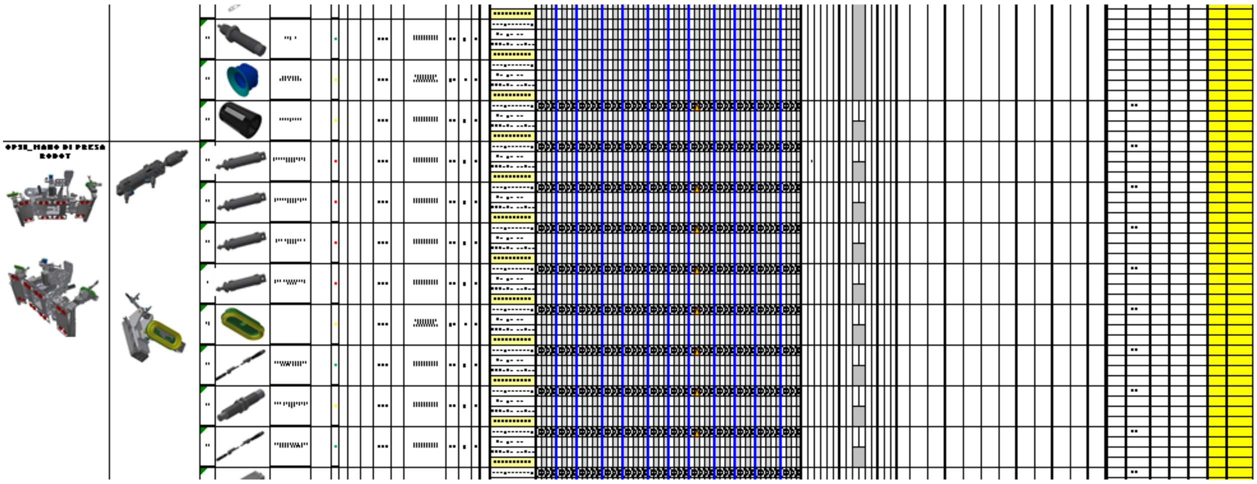
During step 4, the technical department of the supplier has finished the design of the equipment and therefore it can start to work on the documentation required by the WCM methodology, and that is explicitly delegated to the supplier in the technical specification sent with the order. The machine ledger provides an important guide to the Professional Maintenance Pillar for what concerns all of the maintenance activities that are required to keep the machinery running and avoid any type of failure. All of the new installations need to be predisposed for, at the very least, preventive maintenance: the maintenance of components or their substitutions has to be programmed on a time (or cycle) base or on a condition base.

The machine ledger provides the PM Pillar with tools to deal with this type of maintenance. The entire installation is subdivided into its main functional blocks:

- OP10: roller conveyor entrance
- OP20: polystyrene pad centering station
- OP30: robot's end effector
- OP40: loading bays
- OP50: logistic trains



Every functional block is then divided into its constituent stations, and finally every station is decomposed in all of the parts and components it is built of. Every component is assigned a name and given an identification code. Its brand and model is specified, the number of such component used is specified, the cost of a unit is specified. To every component, a set of maintenance activities is enlisted: it ranges from simple activities such as inspection, cleaning and more lubrication, to more complex ones such as repair or substitution. Each activity is assigned to either the Autonomous or Professional Maintenance pillar depending on its complexity and on the skill level required to execute it, and finally a frequency of repetition is given. Certain activities are added, or increased in frequencies also depending on any eventual concern resulting from the EFMEA.



According to the assigned frequency, the PM Calendar is developed: it will show all of the above information and act as a guide for the maintainers during their routine operations. How each activity has to be performed is specified in the Standard Maintenance Procedure documents, which is basically a step by step guide with the instruction on how to carry out the activities.

Another important aspect of the machine ledger is in the fact that it allows to create a warehouse of spare parts specific for the new installation. A verification on all of the used parts, allowed to verify that, among the 228 components used for the construction of the equipment and described in the machine ledger, 206 are standardized commercial components from brands that were indicated as favorite in the technical specification. Such components are used on other machines across the plant, and this allows to reduce minimum required stock level in the maintenance warehouse.

Production tests

As the construction of the machinery reached its completion, it was possible to start testing the equipment to verify the correct execution of all the required operations, as well as the effective cycle time. One of the major problems that arise when this type of testing is performed lies in the fact that the supplier can only simulate, and not replicate perfectly, the assembly line of the plant. This is due, of course, to the limited amount of space available. In this particular case, the major limitation to the testing activity was in the fact that the entry and exit portions of the roller conveyor were cut and disconnected. As a result, it was possible to only load on the initial part of the conveyor a maximum of 4 water heaters that travelled through the automation, got processed by the robot, and sent out on the other end of the conveyor. There, an operator removed the boxes and loaded the water heaters on a small cart, that was manually pushed back at the beginning of the line, where the products could be reloaded on the conveyor for another cycle. This condition was not ideal, as it was possible to see just less than one minute of operation of the machine, with a couple of minutes of break required to set up everything again. A better solution would have been that of creating a looping conveyor around the barriers for the automatic recirculation of the water heaters, but this was not possible for reasons of limited space available in the workshop.

Testing activities started with a slow pace: initially every independent functional block was tested alone to verify the correctness of operation, then the automation as a whole was set to operate. For instance, numerous tests have been performed on the identification and centering stations, despite their functions being relatively trivial, they are of vital importance for the rest of the automation. Similarly, vision system was tested individually to proper calibrate the scanned images to the memorized 3D models of the cartons. Manual motion of the robot via the joystick controller has been used to specify the correct points for carton pick up on the loading bays and for carton opening in front of the 7th axis. Templates have been built about the chosen points so as to guarantee an easy replication of the programming once the equipment was moved and installed in the plant.

The 7th axis required at this point particular attention since, as explained earlier, it was not completely clear from the detail design stage, what would be the behavior of the carton as it was released from the robot end effector and held up only by suction cups on the column. Initial testing allowed to verify that the set of tools described earlier (lateral L-shaped support plates, sharp elongated pins and the lateral roller in contact with the face of the carton) proved effective in keeping the box in the position in which the robot left it after the opening stage. When all of the pneumatic cylinders on the 7th axis are extended, the tools are all found in contact with either the faces or the flaps of the box and this allows the axis to lower on the water heater without any problems, guaranteeing a smooth insertion even with a tolerance of about a centimeter on the exact position of the polystyrene pad. The carton can, in fact, slip on the surface of the pad without getting stuck on it.

So, while the actual insertion of the carton performed during the lowering of the 7th axis was initially considered to be the most critical moment of the cycle, it turned out to be relatively easy to set up properly and to guarantee its smooth operations. Instead, problems were found during another operation that was initially thought to be much easier to carry out: flaps opening. As explained in step 3, the opening of the front and rear flaps, as well as that found on the side facing the 7th axis, are all done using a pneumatically actuated cylinder with a suction cup at its extremity. When the box has been opened and locked in position by the rotation of the lateral sections of the end effector, these small cylinders are pushed forward to bring the deformable cup in contact with the lower flap. At this point the suction begins and the flap is pulled backwards during the retraction of the small cylinder. A series of problems emerged during the testing of this small functional block: the main one was in the fact the force required to yield the cardboard junction between the face and the flap was not constant for all the models of boxes. Sometimes the flap would fold open without any problem, while other times it would resist the moment exerted by the pull of the cup, detaching from it. Further analysis showed that sometimes the suction cup did not properly lean on the surface of the cardboard before starting the pulling action, therefore compromising it. This positional mistake was a result of the tolerance of the vision system: because of the nature of the boxes, which are typically produced with a low quality and relatively high tolerances, the vision system can sometimes tell the robot to pick up the box from a position a little more on the left or on the right of the ideal one, and the result is that even in the insertion can still be performed correctly, it can prove hard to open the lateral flaps.

The found solution was in the correct set up of the pneumatic cylinder position and orientation with respect to the flap, as well as in the speed with which it pulled backwards. This positively affected the whole operation. As an additional safety measure, a capacitive sensor was added parallel to the suction cup with the role of verifying the presence of the flap sucked on the cup surface: if the flap is not detected, it means that something went wrong during the folding and a signal was sent to the robot to repeat the last operations. The robot can therefore, make 3 separate attempts to open the front and rear flaps, if also the third attempt is failed, then the robot has detected a faulty or out of tolerance box and is able to dispose of it adequately: the robot stops the sucking action of the suction cups, thus leaving the 7th axis alone to hold the box, then it proceeds to reverse the opening motion, folding the box back to its initial flat position. When the flattening is complete, the robot regains control of the carton by activating once more its suction cups and finally proceeds to transport the carton to a corner of the layout where a cart is placed and releases it in this area. This operation allows the automation to spontaneously deal with defective or otherwise problematic boxes by discarding them to a waste area: the machine can therefore continue its normal working without the intervention from an operator. During breaks, stoppages or at the end of the daily production, the operator can access the layout of the machine and easily remove the cart containing all of the defective cartons that have been discarded by the robot.

Acceptance testing

The conclusive moment of step 4 is in the acceptance testing performed during a visit of many members of the plant and of the company: the plant manager, the plant buyer, the EEM Pillar and members from the other pillars.

The plant acceptance of the automation and the “ok” to proceed on the installation depended on the successful compilation of a series of checklists. Safety of the equipment is evaluated at first with a standardized checklist that allows the machinery to be verified for compliance with the law. Then a series of production tests has been performed on various type of products, in particular 50L, 80L, 100L and SEF models so as to observe the behavior of the equipment with the different products heights and diameters. No blocking problematics were identified and the plant accepted the equipment, even if some minor issues remained unsolved and waiting for a solution.

ARISTON THERMO GROUP

Report date 21/12/2017

Test and commissioning report

	Description of equipment	Serial number	Quantity produced	Cycle Time, sec	Spare parts list checked	Instruction book & drawings	Preventive maintenance scheme	Training
1	Impianto inserimento imballo R11		52	11,9	OK	OK	OK	NA
2	Impianto inserimento imballo R12				----------	----------	----------	----------
3					----------	----------	----------	----------
4					----------	----------	----------	----------
5					----------	----------	----------	----------
6					----------	----------	----------	----------
7					----------	----------	----------	----------
8					----------	----------	----------	----------
9					----------	----------	----------	----------
10					----------	----------	----------	----------

The commissioning test result is positive

	Participants	*Company*
1	Meletani Daniele	Ariston Thermo Group
2	Apolloni Samuele	Ariston Thermo Group
3	Bagarin Nicolo	Ariston Thermo Group
4	Quadrelli Michele	Robotech srl
5	Castano Marco	Robotech srl
6	Furini Fabio	Robotech srl
7	Sauli Gaetano	Robotech srl

Dates of test: 15/12/2017

Place of test: Robotech Automazioni Srl, Via Cesare Battisti, 79, 21020 Daverio VA

Other comments:

Affidabilità su prodotti SEF (scatola larga) da migliorare
Il layout effettivo non è conforme a quello condiviso su carta (impianto più lungo e largo rispetto a quanto inizialmente previsto)
Da verificare ripetibilità nel posizionamento del cartone su 7° asse

Still pending issues:

1	Irrobustire supporto 7° asse (asse vibra durante lo scambio del cartone col robot)
2	Irrobustire staffe sostegno sistema visione (allentato durante test effettuati)
3	Verificare punti accostamento baie (in alcune occasioni pinza robot in collisione con scatola srombata su 7° asse)
4	Migliorare gestione nastrino evacuazione pezzo (pezzi "saltellano" quando entrano su nastro lento)
5	Separare cavi profinet da quelli di potenza all'interno delle canaline
6	Sostituire slitte di squadro cartone su 7° asse con slitte più lunghe
7	Migliorare movimento di apertura per snervamento della falda di fronte al robot (falda sbatte su sistema divisione)
8	Verificare corretta analisi della porzione di imballo esaminato da sistema di visione
9	
10	

Ariston Thermo Group:

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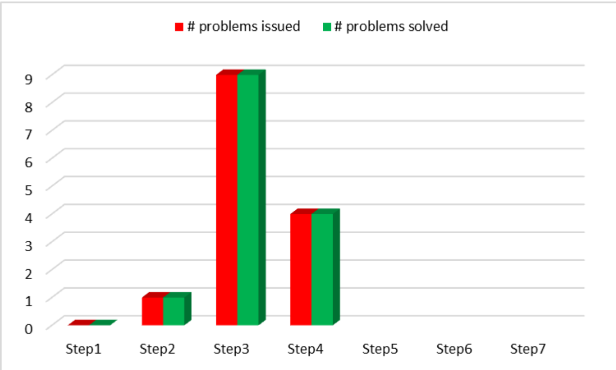
The still pending issues where mainly related to the robustness of some components found on either the robot's end effector or the support structure on the 7th axis. Testing showed that some actuators were subject to excessive vibrations and as a result it was requested to strengthen the supporting structures with proper carpentries. Some small problems related to the vision system also persisted, as the area in which the carton was scanned had an excessively tight tolerance: during the tests on the supplier, the carton lots were placed carefully on the loading bays, but it was noted that this might not be the case during production. As a result, a larger tolerance on the position of the flat box on the bay has to be considered by the vision system, so that the robot's end effector can make some small lateral adjustments to pick up even the cartons that are not perfectly aligned in the lot.

List of modifications

Not all that seems perfectly functional on CAD and simulations turns out to be working correctly in the real application, once the equipment is assembled. A few issues have been founded during the construction and early testing of the robot:

- Modification of the area examined by the 3D scanner. As explained earlier, the analysis of the corner of the flat box did not always allow to correctly determine its position and orientation. Once extensive test were possible as the machine was built, it has been possible to determine that the best area to scan is away from the corner and along two separate edges of the box
- Shortening of the cable carrying that runs along the protection barriers: it was excessively close to the furthest point that the robot can reach during the pick up phase, so it was moved to avoid any future interference
- Removal of the rubber coating of the rollers in the conveyor as it caused both problems during the movimentation of the products due to the excessive grip and also generated a large amount of unwanted noise due to the screeching of the polystyrene on the rubber
- Change of the type of suction cups adopted on the end effector of the robot from cups with two and a half bellows to cups with only one and a half: this allows to improve the repeatability of the operations by reducing the compliance of the actuated parts

Robotech srl	€ 327,00	Sostituzione ventose del gripper del robot, passando da ventose a due soffietti e mezzo a ventose ad un soffietto e mezzo per migliorare la ripetibilità sul prelievo dell'imballo	Y	€ 327,00	Step4	Equipment does n fulfill technical requirements or general specificatio
Robotech srl	€ 306,00	Modifica del software di localizzazione dell'imballo passando dall'analisi dell'intero spigolo a quella dei due lembi situati a 5 cm di distanza dal vertice della falda inquadrata	Y	€ 306,00	Step4	Process Complexi
Robotech srl	€ 301,80	Accorciamento canalina per evitare l'interferenza col gripper del robot durante il prelievo dalla 1° baia	Y	€ 301,80	Step4	Facilities Modificatio
Robotech srl	€ 102,00	Rimozione del rivestimento in gomma dai rulli del nastro trasportatore al fine di ridurre il grip e permettere una migliore gestione del flusso dei prodotti	Y	€ 102,00	Step4	Incorrect Building/Designin (Manpower)
		PF Investment (BIW)				
		PF Investment (Paint)				
		PF Investment (Assembly)		1036,8		
		PP&L (Loss of Authorization)				
		PP&L (Training)				
		PP&L (Pilot Cost)				



Step 4 checklist

1015 of the total 1417 items in step 4 checklist have been successfully completed. 4 have been found to be not ok and have been reviewed, while the remaining 398 were not applicable to the project.

Step 5: Installation

Installation begun halfway through December and continued for about three weeks until the end of the Christmas holidays. The selection of this period for the installation was not a random result of the duration of the previous phases, but rather the expected result of the initial planning. Since the two robotic platforms have to be installed along the final assembly lines, the stoppage of such lines is a requirement: the active shutter conveyor required to be removed and substituted, and all of the automation substations have to be mounted and tested on it. An activity foreseen to last more than one week, implying that performing the installation during a single weekend was not a feasible option. Instead, an extended period of stoppage of the production was more suitable. The Christmas holidays provided a period in which the plant expected to halt the production for a total of 16 days, which were reduced to 12 days by considering the "red on the calendar" holidays, a suitable amount of time for the performance of all the installation operations.

Towards the end of construction the GANTT for the installation was prepared. A series of arrangements had to be performed to guarantee the quickest installation possible. The plant was in particular responsible for the creations of descents for any type of supply required by the installed equipment, in particular electricity and compressed air. The supplier was instead responsible for the registration of the contract required by safety law to track the provision of services by external companies inside the plant of Genga: personnel of the supplier company has, in fact, to join the maintenance operators of the plant during the installation.

The equipment arrived at the plant via 3 trucks loaded with all the material in the last two days of production before the holidays and was offloaded and stored in stockage bays. The installation then started with the removal of the shutter conveyor along the final lines. Laser measure instruments were employed to trace the layout of all the automation stations on the floor, then holes were drilled in the ground in correspondence of the fastening points for the carpentry. The robots arrived at the plant site already mounted on their basements and because of the their huge dimensions and weight, an overhead crane (which is normally used in the plant during the loading of the metal sheet coils on the machines) was used to lift it and position it on a large capacity forklift truck rented specifically for the purpose. The truck was slowly moved through the plant and released the robot on its installation location. The installation of the loading bays and the roller conveyor followed immediately. Finally the safety barriers, doors and gates were mounted.

The next step consisted in the electrical wiring of all the components to the robot controller and to the PLC. Similarly, tubing for compressed air and vacuum were predisposed.

As everything was mounted successfully, the replication of the PLC software was performed an tested.

No particular issues were encountered during the installation stage, as all the concerns regarding layout were all solved during the earliest steps of the project.

Step 5 checklist

Out of the 817 items in this checklist, 729 have been completed successfully, 2 were reviewed and the remaining 86 were not applicable.

Step 6: Production tests

Production tests take place as soon as the construction of the machine is completed and are required to set up properly the equipment to the factory environment. The logic applied is very similar to that used previously at the end of the construction step: the various stations and functional blocks of the installation are activated to verify their proper working. At the beginning of testing, a checklist is followed to guarantee that every aspect and functionality of the automation is able to work perfectly after being installed in the plant:

- Safety systems are tested first. Any successive test will require the movimentation of the various organs and mechanisms of the automation, therefore if there exist any kind of unsafe condition, it has to be identified and resolved as soon as possible. It is often the case during early set up of working points for the anthropomorphic arms that a qualified operator controls the robot from within the barriers so as to correctly verify the correct position and orientation of the end effector with respect to other parts of the equipment. Even if all such operations are performed at extremely low speeds of the manipulator and using safety measures such as dead man's switches on the robot's joystick, it should still be possible to successfully halt any organism by pressing any of the emergency mushrooms in and outside of the barriers
- Functionality tests are performed on all of the stations in the automation. Every actuated mechanism is tested to verify the correct execution of movements and strokes, the speed at which they are performed and the precision of their positioning
- The Autonomous and Professional Maintenance Pillars then proceed to verify that the activities described in the machine ledger can be performed easily and without major obstacles, they also check if the best practices developed after the compilation of MP-Infos have been implemented. The duration of CILR cycles has been tested to last about 39.6 minutes every week, which means that the cycle is extremely optimized: inspection and other routine maintenance operations performed by the operators of the AM is quick and not time consuming.
- As all of the functional blocks have proven their functionality and correct operation, the programming of the robot can begin. Of course the software was already developed during the construction at the supplier's workshop, nonetheless the working points of the robot have to be verified and eventually modified, as there is no guarantee that the installed layout is identical to the millimeter to that that was used during construction. During step 4, some templates have been constructed to simplify this stage of operations
- The equipment is finally started up and the first complete cycle is performed. The operative speeds in the initial cycles are generally really low, so as to avoid that any mistake during the installation can result in damage during the working cycle. Due to the fact that the machinery has been installed during a production stop, initial testing was performed in a similar fashion to the tests at the supplier's workshop, i.e. by using a few finished products which were manually brought back at the beginning of the conveyor after every cycle

- As more and more products are processed through the automation, it becomes possible for the Quality Control Pillar Leader to verify the characteristics of the outputted water heater. In this case, the quality of the operation is dictated by whether the carton has been inserted correctly and without damaging the water heater surface. Despite a few cartons being ripped off during the initial tests due to the necessity of improve and fine tune the setup of the machine, no quality concerns have been highlighted
- As the correct execution of a complete cycle has been verified to be positively working and not generating any quality related problem, the machine has been set to work continuously in automatic mode to verify the arising of any complication
- Finally, the latest testing activities regard the verification of the manual operability of the individual stations. For maintenance purposes in fact, it might become a necessity in the future to verify the correct functioning of a component after its substitution or repair. Because of this, a typical requirement from Ariston on the technical specification is the possibility of manually control individual actuators in the automation and to reverse their action with respect to their normal functioning for testing purposes. Similarly, it is required to implement in the software a function that allows to stop the machine after every line of code is executed, so that controls on the correct operation of the cycle can be performed when a problem is detected

Again, no major issues were detected during step 6. As a negative note, it was not possible to test continuously and extensively the automatic operation of the equipment until the production started running again on the 8th of January. The reasons for this lie in the fact that with the production halted, there was no constant supply of assembled water heaters to be processed through the automation. The only feasible way of testing was that of processing a few products in sequence, then stop the automation, remove the cartons from the water heaters and bring them back at the beginning of the conveyor manually. Extensive testing became possible only during the restart of the production and caused some losses to the plant, due to the microstoppages caused by the automation as it was optimized and tuned to be perfectly working, and due to the necessity to keep a backup operator at the outlet of the automation to perform the packaging while the robot program was being developed.

Step 6 checklist

280 items are found in the step 6 checklist, apart from the 49 not applicable ones, all the other were successfully completed.

Step 7: Start-up

The production tests took more time that was initially expected and this delayed by a couple of weeks the actual start up of the equipment. The main problem lied in the fact that this was the first big robotic platform ever installed along the final lines, and there was no previous knowledge on how the production tests would have impacted the actual production. As explained earlier, due to the fact that the roller conveyor passing through the layout of the automation is the only mean by which the water heaters can reach the end of the assembly line and then proceed to the final warehouse, it was not possible to test the machine extensively without negatively impacting the production. This was partly taken into account during early stages of the project, but it turned out to much more problematic than initially thought.

Most of the earlier installations took place in other departments of the plant, where even if cycle times are the same, the highest number of micro stoppages provides a realiable buffer tat avoids to affect the production in an excessively negative fashion. The final assembly lines are also the most manpowered department of the plant, and this causes every microstoppage in them to be more expensive in terms of wasted money, as the cost of lost work for a large number of operators is impacting even for the smallest stoppages.

The most reasonable way of working has therefore determined to be alternating cycles of intensive production with the automation excluded, and cycles of production testing for the robot, so as to guarantee a set of breaks of operativity of the automation sufficiently large to compensate for the time spent on setting up the equipment and optimizing the software.

An additional negative impact on the testing, was due to the simultaneous installation of two robots: most of the times it was possible to test only a single machine, and then replicating the operations on the second one before proceeding with testing it.

During testing, line managers, operators and manutentors have been trained to use the automation and to deal with the most common issues: start-up, stoppages, resets, and so on. The process of starting up the automations was further complicated by the necessity to coordinate many different people inside the plant simultaneously: the proper working of the equipment is guaranteed only when the flow of material is guaranteed from the picking areas. New actions are asked to both the final lines managers (placing the identification label at the beginning of each new lot of production) and to the operators in the picking area (use of the monitors to select the proper boxes from the warehouse, placing of the boxes in the correct order on the logistic trains, scanning of the correct barcodes on the train to confirm the loading operation by sending the information to the robot,…) so at the very beginning errors were common. The set of procedures required to solve the results of such common mistakes and the best practices to avoid them have been taught to the operators and after the 15 days of start-up, the equipment is properly functioning.

Project Review

The EEM Pillar activities do not conclude with the start-up of the new equipment. As the automations have been started up, it is possible to collect the data about its performance, and the reaching or missing of the goals set at the beginning of the project can be verified. The parameter that required the most work and focus by both the plant and the supplier was the cycle time. Most of the design decisions and the later modifications to the project have been implemented because of the necessity of fitting the tight requirements of the 12 seconds per each cycle, which has turned out to be the most crucial parameter to achieve final success.

Missing the target of the cycle time would have negatively affected all of the other Key Performance Indexes (KPIs) of the project. If the machine is not working with the same rhythm as the other machines and the operators along the conveyor, microstoppages would be caused regularly due to the accumulation of water heaters at the entry of the automation. This would negatively affect the OEE as well due to the non complete usage of the available productive time, and due to the fact that the production capacity of 300 units per hour could not be attained.

The cooperation of the robot and its 7^{th} axis have been modified so as to make them independent, thus allowing the actual insertion to take place in masked time with respect to the carton pick up phase; the vision system has been positioned asymmetrically with respect to the 6^{th} axis of the robot, so as to be always in the best position for the scansion without the requirement of being repositioned at the beginning of each cycle; the adoption of so many small actuators on the end effector of the robot so as to perform as many operations as possible simultaneously; all the above are examples of how the most complex aspect of the process, and therefore the core focus of the work, was the reduction of cycle time.

As of the installation, the cycle time is below 12, with an average of 11,6s per cycle. Every cycle has a slightly higher or lower cycle time, and this is due to a series of factors including the exact position and orientation of the carton on the pile that inflluences the pick up movements required by the vision, the number of boxes left on the pile, as the robot has to move higher or lower during each operation depending on whether the lot is full or empty. Also, the three different loading bays positions requirethe robot to perform significatively different movements and orientations to reach the correct pick up position. The central bay, OP41, is the one which is easier to reach and there the cycle time is much lower, around 11s and sometimes even below that threshold. The bay on the other side is at the same distance, but in order to properly preapare the scanning and pick up phases, the robot has to rotate the end effector on itself, meaning that the cycle time here is around 11,5s on average. The third bay is the most distant one from the basement of the robot, and because of this its cycle time averages 11,9s as the time required to reach it is slightly higher.

It is worth pointing out how apparently small differences in the processing can have a huge impact on the efficicency of the equipment. A small increase in distance can cause an increase of the cycle time of a few tenths of seconds and this can bring the machine out of the tolerance range for the cycle time. This same issue was also analyzed previously, during the description of all the problematic aspects of the vision system, as the requirement to "wait" 0.3s after the correct scanning position has been reached before actually projecting the structured light on the box, with the intention of ensuring that any residual insertial vibration of the robot has ceased and will not impact the process.

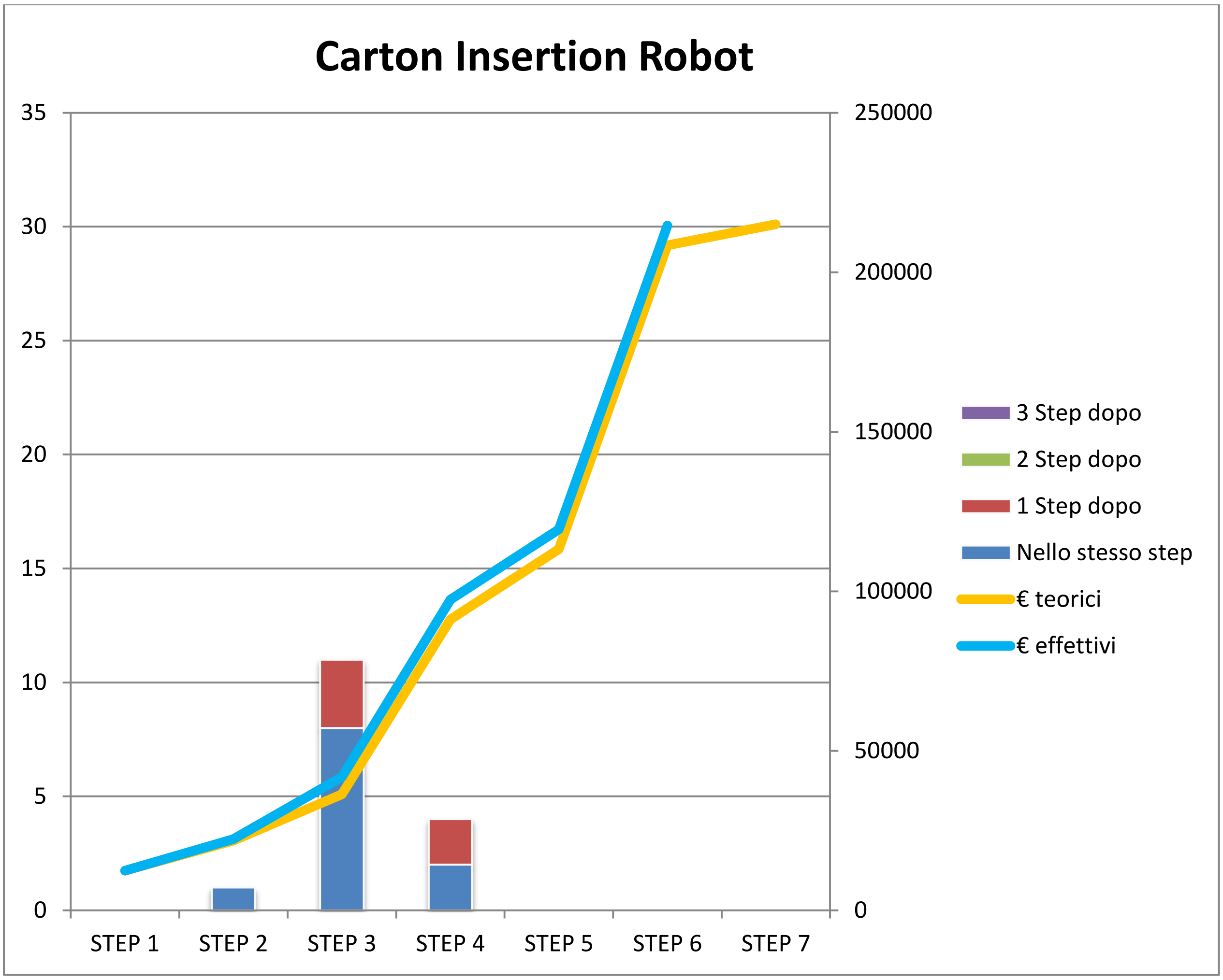
As of the quality aspect, the robot per se is not responsible for the introduction of any defect in the product. Conversely, problems in the insertion (including, unfortunately, the complete ripping off of the box in some occasions), depend mostly on the intrinsic characteristics of the boxes, especially when they have been somehow ruined during previous transport and manipulation.

A review of all the work done during the project is performed with the purpose of identifying the critical issues that have been during each step. Some critical issues could have been found at the beginning of the project, for example the necessity to center the product's bracket with respect to the bottom polystyrene pad. Some other problems could not have been found out until the last moment, as it was the case of the difficulties in the proper identification of the position and orientation of the carton by the sole inspection of the corner.

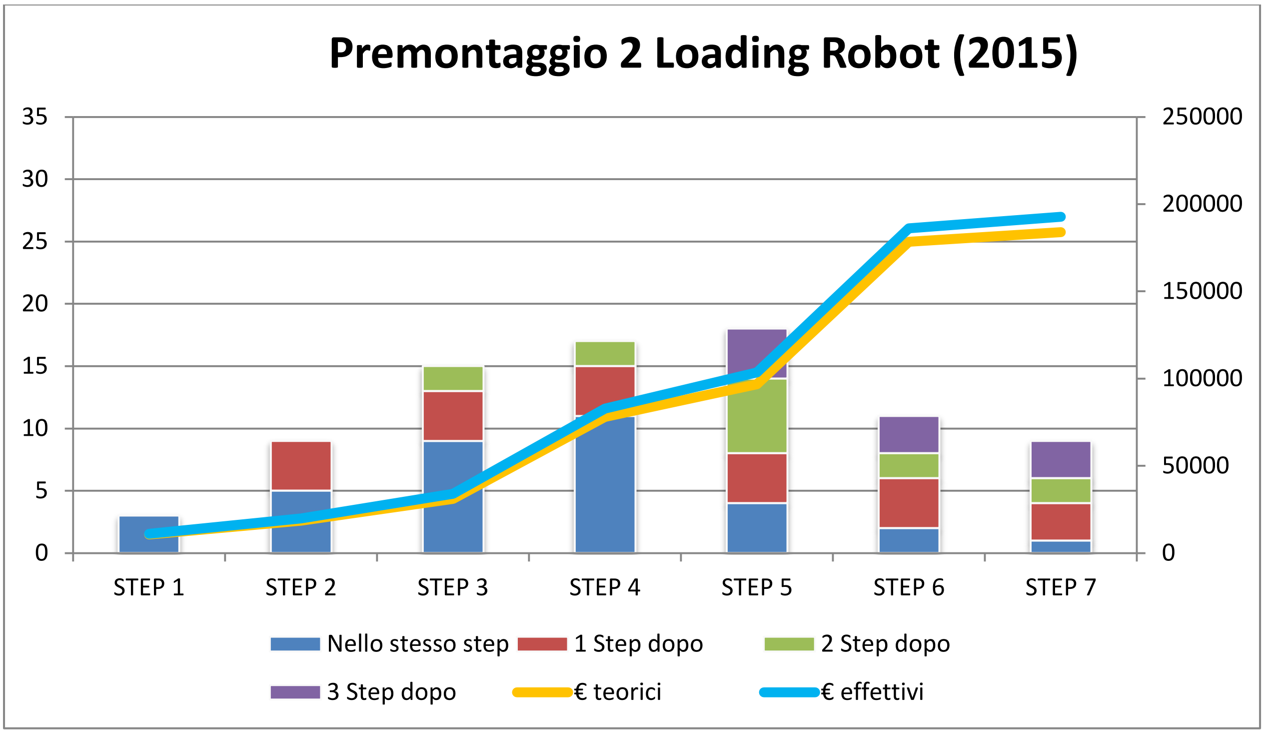
During this stage, all the documentation regarding the project is collected, reviewd and archived for future reference. A set of new MP-Infos (some of which are reported below here) is issued so that other plants of the group can benefit from the acquired knowledge.

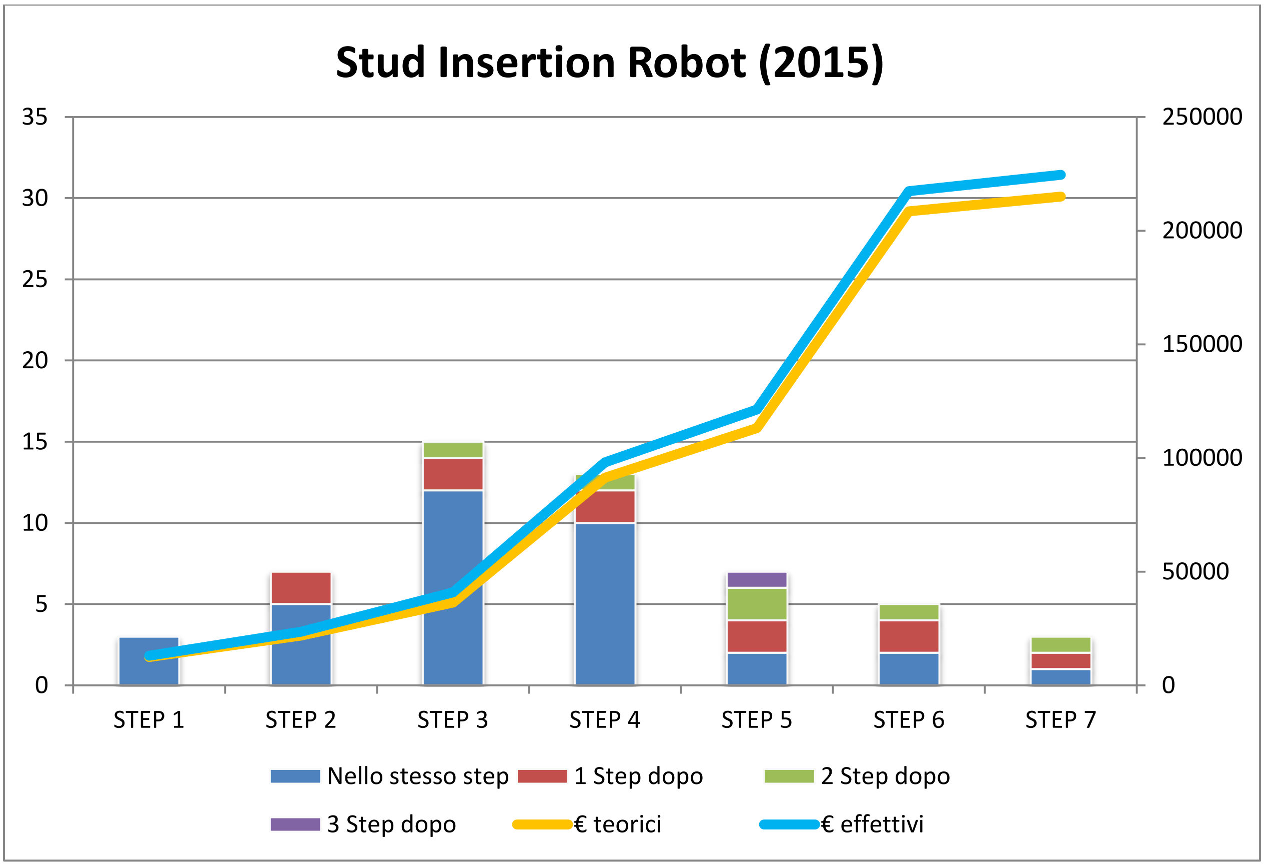
The general outcome of the project has been positive, with no major late-found issue after step 4, meaning that the equipment left the supplier's workshop ready to be working in the plant. Any problem found during installation or later could have been extremely problematic for the plant both in terms of additional costs to bear and in terms of schedule, since as explained earlier, the production stoppage of the Christmas holidays was just a brief window of available time that allowed operations to take place without negatively affecting the production.

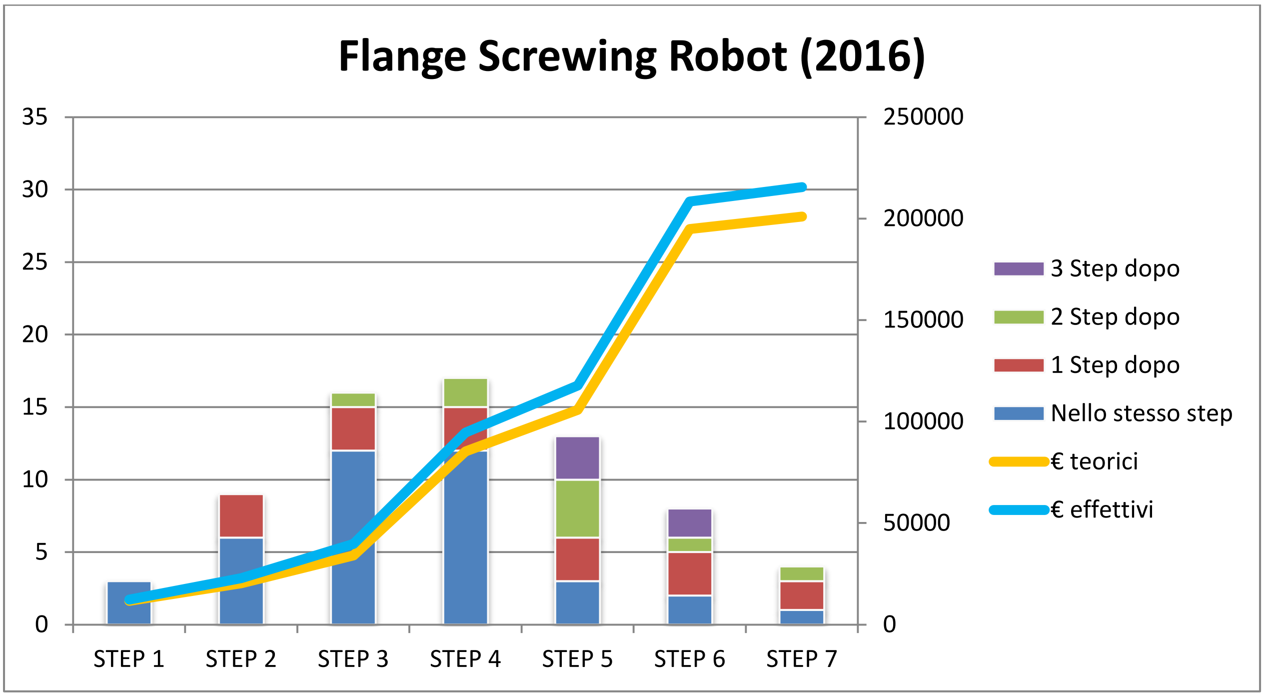
As it is possible to see from the graphs, this project performed much better than any previous one in terms of the containment of additional costs related to the late onset of problems. Having most of the significative problems been found between detail design and construction, most of the possible harm was avoided. The same was not true for installations of the previous years, as it is visible in subsequent charts.


Carton Insertion Robot
35
30
25
20
15
10
5
0
250000
200000
150000
100000
50000
0
STEP 1
STEP 2
STEP 3
STEP 4
STEP 5
STEP 6
STEP 7
3 Step dopo
2 Step dopo
1 Step dopo
Nello stesso step
€ teorici
€ effettivi

Below, a series of graphs and charts showing the progress of a series of projects developed in the years 2016 and earlier. The number of modifications implemented at each step is shown, as well as the resulting delta cost of the project.







Flange Screwing Robot (2016)
35
30
25
20
15
10
5
0
250000
200000
150000
100000
50000
0
STEP 1
STEP 2
STEP 3
STEP 4
STEP 5
STEP 6
STEP 7
3 Step dopo
2 Step dopo
1 Step dopo
Nello stesso step
€ teorici
€ effettivi

Final Conclusions

The development of the project for the automatic carton insertion robots along the final assembly lines at the productive plant of Genga, represents a perfect case study for the application of the WCM methodology regarding the industrialization activities of the EEM Pillar. In this comparatively old productive site, the necessity of constantly increasing the transformation efficiency competes with the contraints imposed by an infrastructure crowded by old and new machinery, and even the seemingly easiest projects can turn out to be much more complicated.

The continuous increase of the level of automation of the plant throughout the years, brings the EEM Pillar to face new challenges with every new installation. The carton insertion represented one of the most ambitious robotic platforms ever installed in the plant, but the experience acquired during the years in which the WCM methodology has been impolemented and developed allowed a successful completion of the project. What is evident, especially in light of the gradual increase of the quality of the results achieved at every new installation throughout the years, is that the WCM methodology is not a magic wand that can miraculously solve any problem. Rather, it helps in creating a standardized set of procedures for the plant to follow during each project, and teaches the use of a series of instruments and tools that can strengthen the capacity of the EEM Pillar to deal with every scenario it has to face.

As it is possible to see from the previous charts, showing how many modifications were implemented in the projects of the previous years, the performance and the level of success of every new project is improving. The total number of modification is getting lower, and therefore the delays and additional costs due to their implementation decrease in magnitude as well. Similarly, the rising awareness that finding problems at early stages is the key for containing costs and delays, has brought the highest percentages of issues found and solved in the detail design step. The late found problems and issues relative to construction, installation, testing and start-up have consequently dropped in number as they are found earlier and earlier during the analysis.

The magnitude of the delta cost at the end of the project, i.e. the difference between the initially estimated investment required to start-up the equipment and the amount of money that gets actually spent is lower for each new installation. The main reason for this however, is not in the lower number of problems found, but rather it is a consequence of the fact that issues are found earlier, where their identification is harder, but their solution can be quicker and cheaper. The WCM methodology promotes the use of tools and instruments, even simple ones as are the checklists, that permit to constantly monitor the activities of the plant and of the supplier.

What comes next? While the automatic carton insertion project was reaching its conclusion, new projects were already underway. New machinery has been installed in the pre-assembly departments with the goal of dealing with the requirements brought out by the launch of a new product. Other ongoing projects have the goal of revamping older machinery to improve its efficiency. Along the final lines, two robotic platforms for the automatic electric testing of the water heaters are being designed and preliminary tests about the possibility to automate the polyurethane injection on the third final line are being performed.

The plant focuses on continuous improvement of the equipment with the goal of increasing the efficiency and of becoming an Italian excellence in the world of manufacturing. The WCM approach laid solid foundations for the plant to achieve these results.

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