SCUOLA DI INGEGNERIA INDUSTRIALE E DELL'INFORMAZIONE

Laurea Magistrale In Ingegneria Meccanica

A discrete event simulation study for optimization of an automated guided vehicle (AGV) system

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1 Problem presentation

1.1 Overview

The thesis is carried out during an experience of a seven months internship in Magneti Marelli s.p.a. I developed my thesis in the Corbetta plant, the head-quarter of the company. Magneti Marelli has 8 business unit and in Corbetta there are Electronic System, Motorsport, Powertrain and After Market Parts and services. My focus will be around a logistic issue regarding the Logistic pillar of WCM (World Class Manufacturing), a methodology that will be presented in this document.

In the Corbetta plant there are AGVs (Automated Guided Vehicles) used to move raw material from the warehouse to the processing lines. My mission was to implement new routes for semi-finished products that nowadays are moved by operators in the powertrain area of the plant, assessing their KPIs.

During the development of this document the methods of WCM will be described, as the pillars involved, to provide how this target has been attentioned. As a WCM specialist I was mainly concerned with the Focused Improvement pillar that aims at attacking a particular loss affecting the overall cost of transformation.

The company and the methodologies of the production system used will be introduced at the beginning of the document to clarify the environment in which this study was conducted. The pillars mainly involved in the implementation of this study will be presented in order to understand the way in which the company operates.

The real system will be presented to let the modelled system to be introduced from a broader point of view, as well as the process steps of the product will be explained to illustrate how the data were obtained and therefore the objectives to achieve. The methodologies for estimating the performance of the real system will be introduced by literature, then applied to data coming from the production system, taken directly from the production lines. Subsequently, the reasons that led to the evaluation of the system through simulation will be illustrated, providing a description of the limits and potentialities associated with this methodology.

The results of the study will be presented and the techniques used for the evaluation of the results will be introduced and applied to the data obtained. The document provides details on the software used for this study and when algorithms have been used.

1.2   Introduction

The production system deals with a "pull" material planning approach, called "on demand management" where materials production requirements are issued in order to satisfy a finished product requirement. Internal handling costs (which can referred to as losses, as will be explained later) can be lowered through a focused project related to the implementation of vehicle to carry out the material handlings issues, thus replacing the time needed by operators to move materials.

As will be described in detail in the document, the aim of this problem is to change the way in which the material handling of a product is currently carried out.
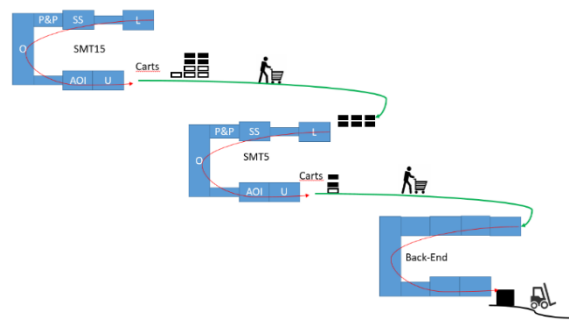
Figure 1-1 Overview of the process

In accordance with the methods described, the movement of a product within the plant is often regarded as "non-value added activities". In fact, during the movement between the various production lines, nothing happens for which the final customer is willing to pay. To limit this type of cost, it is possible to proceed in different directions:

1. The first, which will be described in more detail in the document, provides for moving the lines to make the movements as short as possible. However, this solution has limitations from the production point of view as it involves a series of effects for which it is not always advantageous.

2. The second one is instead the one proposed in this case study, that therefore of not using the available time of the operators preferring therefore an automated movement of the materials.

A similar solution is present in the plant as regards the supply of components that are taken from the warehouse to the production lines by means of automated guided vehicles (AGV). The task is to extend this solution to other movements, starting from a standard product, and then applying the same methodology to the largest possible number of products.

The product in question is produced on three separate lines (shown in Figure 2-5), between which the products are brought manually.
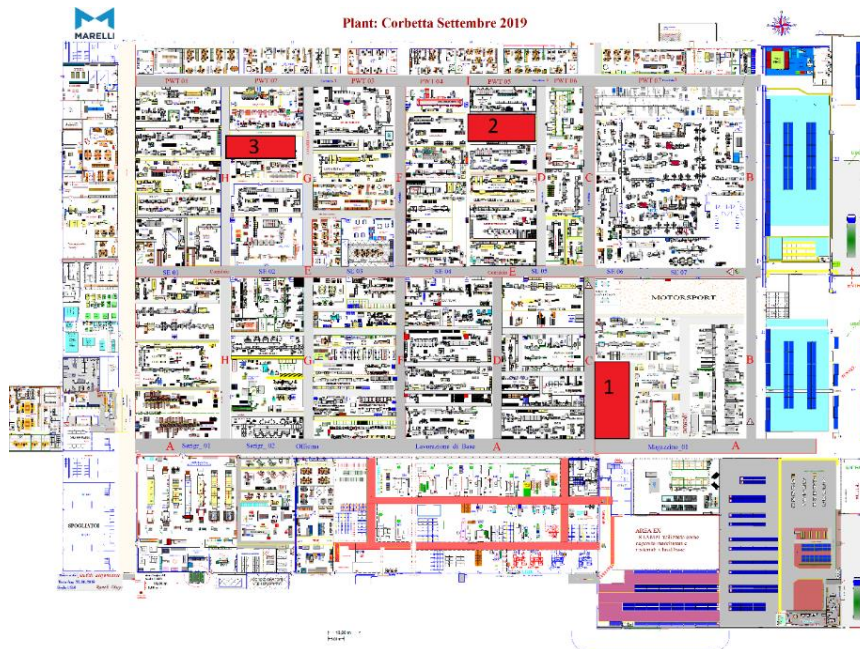
Figure 1-2 Production lines highlighted inside the plant

An example of the cost the company is facing due to this operation will be illustrated in the following chapters of the document. Due to the distance between these three different phases, the operators must abandon the production lines in order to be able to carry out these operations, thus causing an additional cost which, although "hidden", will be avoided by using the solution proposed during this internship. The production process will be presented with more details in the next chapters.

2 Company and methodologies

2.1 The company

Magneti Marelli is an international company founded in Italy in 1919, committed to the design and production of hi-tech systems and components for the automotive sector with it headquarter in Corbetta, Milan, Italy.

With about 44,000 employees, 85 production units and 15 R&D Centers, the Group has a presence in 20 countries all over the world. Magneti Marelli is a supplier of all the leading car makers in Europe, America and Asia. The company has recently been sold to Calsonic Kansei Corporation, a Japanese society operating in the automotive sector too.

Figure 2-1 Magneti Marelli logo

Through a process of constant innovation and improvement, Marelli aims at optimizing transversal know-how in the electronics and its competences field in order to develop intelligent systems and solution that contribute to the advancement of mobility, according to criteria related to the environmental sustainability, safety and quality of life on board the vehicles, while providing the offers at a competitive price.

Marelli's business areas are divided into several business areas:

- Electronic Systems
- Automotive Lighting
- Powertrain
- Suspension Systems
- Exhaust Systems
- Motorsport
- After Market Parts and Services

In the Corbetta Plant Electronic Systems and Powertrain business line are present, along with a Basic Operation area and an Hybrids shop.

History of the company

Figure 2-2 Ercole Marelli

In 1891 Ercole Marelli (Figure 2-2) started to build scientific devices in Sesto San Giovanni, Milan. During World War I the industrial production of magnets for the army, and in 1919 with the collaboration of FIAT the company was founded. Initially Magneti Marelli was producing devices for aviation and military trucking , developed electric equipment for the automotive, motorcycle, naval and railway industry.

The first logo was formed out of two words written in an oval form, during the history this has been revised deveral times until 2019, when the brand changed radically; the new logo consists of two geometric shapes that symbolize engineering precision and technological skills. The shapes, two arrows pointing upwards represent progress and the future, their union expresses the fusion of
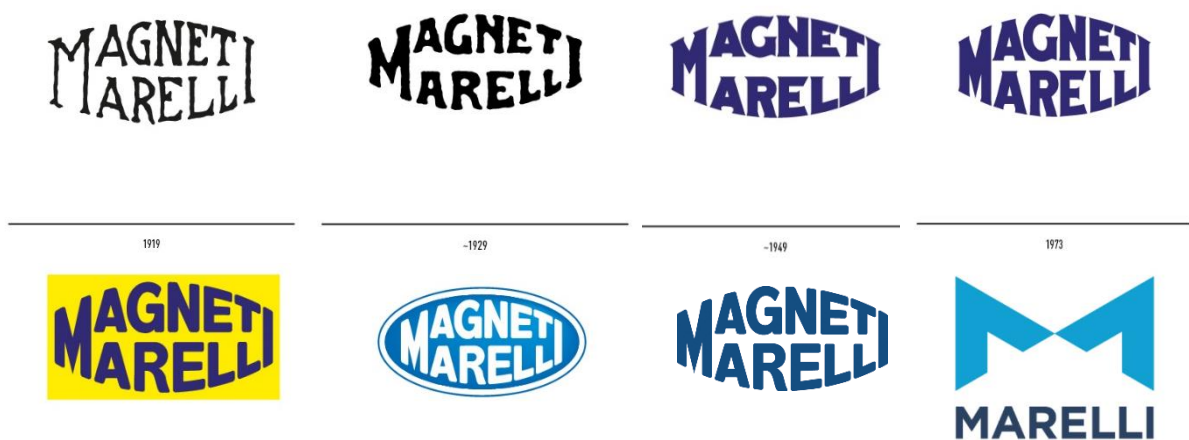

Figure 2-3 Logos evolution

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two strong companies, which are fused in a partnership in the sign of collaboration.

After having started with automotive components, the activities enlarged in an international field by opening offices in Paris, London and Brussels diversifying production to lighting and sound warning systems for vehicles but also in the construction of radio and TV with the creation of RadioMarelli and Fivre (Italian Electric Valve Radio Factory). Throughout its history Magneti Marelli also manufactured alternators, car batteries, coils, control units, navigators, dashboard, electronic systems, ignition systems, exhaust systems and suspensions for cars and motor vehicles. In 1939 the company realized a first emperiment for TV connection and as said before, continued in the field of telecommunication with Radio Marelli until 1963 when leaved the sector.

During World War II Magneti Marelli lost part of its factories by bombing and after a period of crisis the company came out quite quickly and in 1967 Fiat acquired the shares held by Ercole Marelli, later becoming shares in the Fiat Chrysler Automobiles group. Over time, the group has absorbed other companies such as Automotive Lighting, Carello, Solex, Weber and Ergom automotive. Throughout the years the automotive sector became the core business of the company also thanks to the merge with Gilardini in the 90's, in the same period the headquarter was moved to Corbetta and Marelli's plants opened in America and Asia.

The multinational has production facilities on four continents in the world, the most important are in Italy (which is the country with the greatest concentration), but it is also present in: Argentina, Brazil, China, Korea, France, Germany, Japan, India, Malaysia, Mexico, Poland, Czech Republic, Russia, Serbia, Slovakia, Spain, United States, Turkey and Morocco. This capillarity allows the supply to all the most important car manufacturers in the world.

[1], [2], [3].

2.2   World Class Manufacturing

World Class Manufacturing theory has been developed in 80's and continuously uploaded and refined till nowadays; I will introduce the development of the theory

and then its diffusion, how it spread until today influencing the way MM operates. Finally pillars (mainly the technical ones) will be introduced and also why they have requested to address the core problem of my thesis.

World Class Manufacturing (WCM) is a structured and integrated production system that embraces all plant processes, from safety to the environment, from maintenance to logistics and quality. The aim is a continuous improvement production performance, through a progressive elimination of waste, so as to guarantee product quality and maximum flexibility in responding to customer requests, through the involvement of the people working in the plants. The areas of intervention of the WCM are divided into 10 technical and 10 managerial pillars, for each of which incremental levels of improvement are expected, with clearly identified and measurable results. [4]
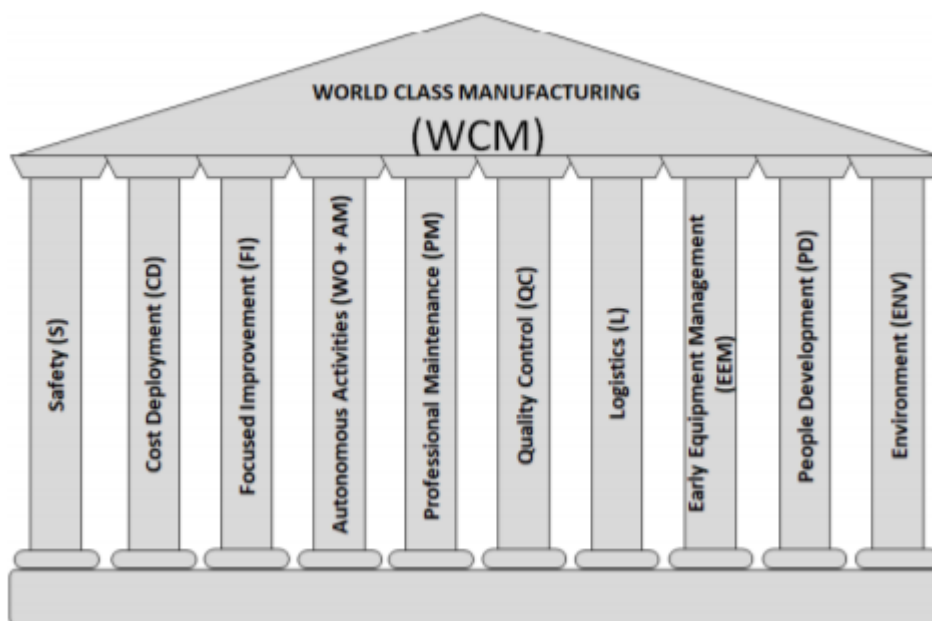
Figure 2-4 Technical pillars of WCM

2.3 The origin of WCM

The World Class Manufacturing methodology meshed up several known methods, e.g *Value Management* and *Business Process Re-engineering* aiming at reaching the excellence in processes. The main methodologies behind the WCM are:

- Total Productive Maintenance (TPM), methodology aimed at reducing downtimes (Zero failures);
- Just in Time (JIT) and the Lean Production, methodologies aimed at reducing stocks (Zero Stocks);
- Total Industrial Engineering (TIE), methodology oriented at reducing wastes (Zero wastes);
- Total Quality Management (TQM), methodology aimed at achieving quality at every stage of the production process and at reducing defects (Zero Defects).
- A brief description of these methodologies will be provided in a short chapter.

The paradigm of WCM production is based on the nine Zeros:

- Zero customer dissatisfaction;
- Zero misalignment;
- Zero bureaucracy;
- Zero shareholder dissatisfaction;
- Zero wastes;
- Zero work that does not create value;
- Zero failures;
- Zero lost opportunities;
- Zero lost information.

One of the important features for the purpose of the thesis is represented by Figure 2-5, where it can be seen how the displacement is considered a non-value added / semi-value added operation. This information is fundamental for the purpose of the thesis since the displacement and the relative costs are classified in this way, they can be understood as real losses for the purposes of the internal projects. They are in fact of the way that the company is forced to face in the set of transformation costs, but which can be avoided and are therefore categorized as losses.
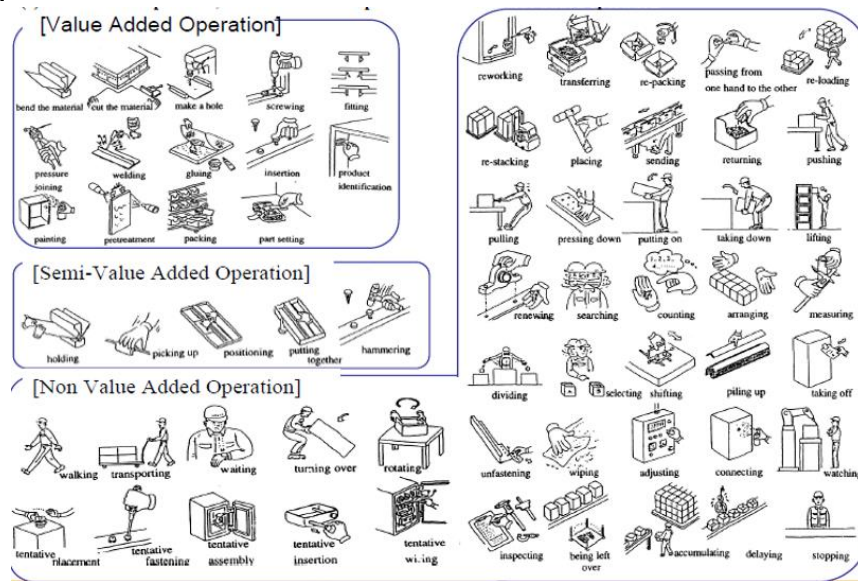
Figure 2-5 Classification of operations according to WO

Data gathering is carried out through the OEE (*Overall Equipment Effectiveness*) that is obtained as follows:

$$OEE = Availability \cdot Performance \cdot Quality$$

So the main advantages in using the OEE is to be able to "track" the performance of the plant, detailed in every single line. [5], [6]

The advantages in using the solution proposed in this document can be found in an higher performance factor and thus in an overall higher OEE.

2.4   WCM pillars

Some pillars of the WCM will be presented as they will be involved in carrying out this thesis. However it will not be the focus around which the work will be done but will determine the environment and the conditions to identify the main losses

that have been identified. The main aspects and the methodology will then be presented to understand the approach used in this particular type of study although the WCM methodology can be used to interpret and attack any type of loss in the establishment.

The intent is to present the 3 principally involved pillars which are: Focused Improvement, Logistics, Cost Deployment.

2.4.1 Focused Improvement

This pillar will consist using a continuous process of small improvement projects targeted at small or large areas where various tools will be used.

Focused Improvement is a technical pillar dedicated to attack major losses of Cost Deployment having a strong impact on budget and plant KPIs. FI activities are focused on solve specific problems not attackable with 7Step approach, but with the application of specific projects to find solutions and eliminate losses. A very important objective of the pillar is spreading the WCM methodology within the plant in order to reduce losses with method.
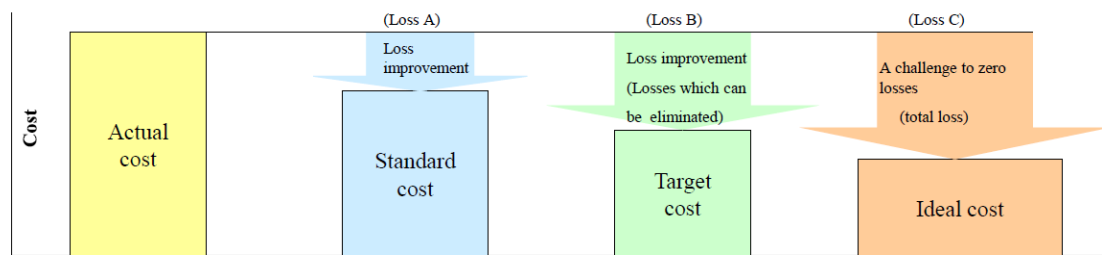
Figure 2-6 Cost's prioritization

FI pillar works through the application of methods and tools provided by WCM methodology to find not only solutions but also to analyse causes that generate problems. This approach allows to restore standards with continuos improvement activities following the PDCA (Plan Do Check Act) circle as problem-solving tool.

- Plan: find the solution
- Do: make a trial
- Check: check results
- Act: standardize and dissemnitate knowledge

FI results are related to obtain savings on specific projects to reduce losses, but also to spread the WCM knowledge inside the plant, by involving people in the application of the methodology.

There are two main type of approaches, the systematic one and the focused one. Both approaches attack major losses defined with Cost Deployment. Systematic approach is related to the application of WCM 7Steps inside an area or as extention from a model area to other ones. A the beginning it is more relevant the application of WCM methodology and the use of systematic approach to spread knowledge on the shopfloor.

As all the other pillars of WCM Focused Improvement approach is based on a 7-Step methodology but there are also 7 Levels: they are a route map to apply and expand the FI activity in the plant, in terms of areas / people involved, methods and tools level, phase from reactive and preventive to proactive. They are different from 7 Steps of the pillar that explain the way to apply the pillar.

The pillar Key Performance Indicators can be resumed as follows:

1. Focused Project Benefits [k€]
2. Blue collars involvement [number of people]
3. White collars involvement [number of people]

7 Steps approach:

Step 1: Define the scope of the work. FI defines areas to attack according with the analysis made particularly by Cost Deployment with C Matrix. Other parameters can affect the choice of an area depending on priority given, like safety issues (S Matrix) and client requests for quality (QA Matrix).

Step 2: Identification of losses. To define where a plant can attack losses, it is necessary to go deeper in detail in the analysis about the definition of the smaller unit involved. The analysis consists on starting from the main plant loss, going to define its weight inside the Operative Units, Lines, till WorkStation level.

Step 3. Plan the project. Defined the area to attack, FI chooses the theme/topic more relevant inside that area, for example per type of problem or product always

using the Pareto approach. Focused Improvement is in charge to help other pillars to give the methodological support to apply WCM tools. Tools and Methods definition is one of the most important topic for FI pillar: they can be Basic, Intermediate or Advanced.

Step 4. Team selection. The project will be set up by selecting the necessary project team with the necessary skills requested by the type of tools used.

Step 5. Project Development. Here the PDCA approach will be implemented and used on field.

Step 6. Analyze costs and Benefits. Results need to be evaluated and B/C is calculated.

Step 7. Standardization. The solution is approved and deployed on other lines presenting the same type of problems. [7]

An example of the Pareto classification of the losses is presented in Figure 2-7.
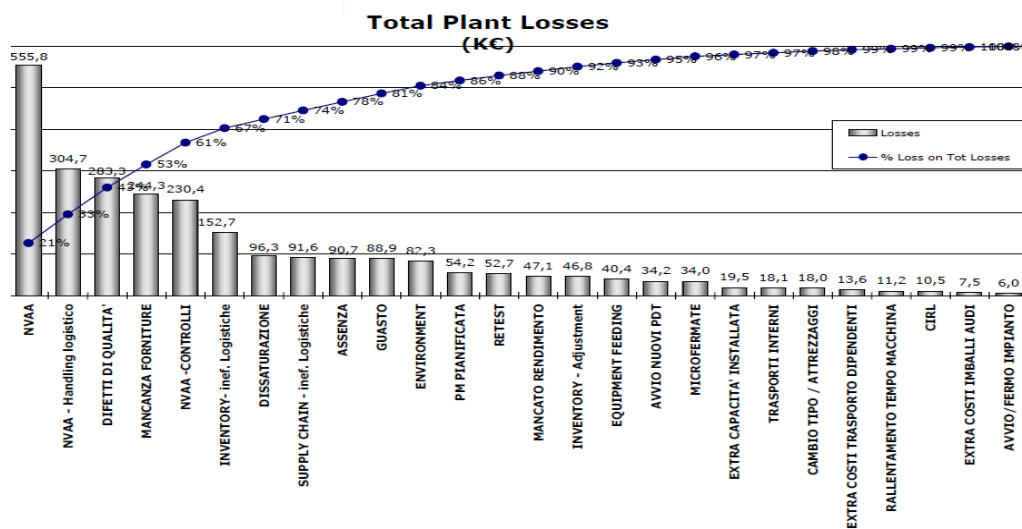

Figure 2-7 Pareto graph

2.4.2 Logistic Pillar

Logistic pillar aims at synchronizing production to market demand in order to fully satisfy the customers, to minimize inventory to create a continuous flow and to minimize the WIP and material handling. There are four main points around the solution to hit those targets:

1. Create conditions for continuous flow production in the plant and with suppliers.
2. Reduce significantly stocks, highlighting irregular flow.
3. Level volumes and production mix and increase saturation.
4. Minimize external transportation (e.g: direct deliveries from suppliers to the line).
5. Integrate sales, distribution, production and purchasing.

As the other pillars, also the Logistic one has an approach based on 7 Steps:

Step 1: Re-engineering the line to satisfy customer. Visual stream Map are used to build a vision of the business flow that allow for a better view of the line in order to reduce the tied-up capital of the finished goods. All the activities of unpacking, picking from supermarket, kit preparation, line feeding must be moved from production to logistic operators in order to guarantee the reduction of the NVAA (Non Value Added Activities). This will results in a high level of standardization in terms of cycle time. An other target is to reduce the capital cost due to line-side stock reduction.

Step 2: Re-organize internal logistics. The activities related to this step are:

- To create a pull system from assembly to warehouse
- To put in place appropriate call off systems and delivery systems in order to move the material line side to the warehouse (implementing supermarket)
- To eliminate the patrolling and the forklift as handling method
- Create a cyclic feeding with high frequency of delivery in order to reduce the lineside stock.

Step 3: Re-organize the external logistics. Particular attention is paid on incoming flow and outgoing flow.

Step 4: Level the production means. Activities are resumed as: react to the demand fluctuation establishing a level of daily production. Avoid the stock peaks and manage the changeover with specific projects. The main target of step 4 is to operate with the lowest level of safety stock.

Step 5: Improve the internal and external logistics. Internal flows are enhanced thorough an improvement of internal call off system aiming at reducing the time of handling. One more method is to reduce the supplier distance and projects to optimize the frequency of delivery, increasing the saturation of means in order to establish a synchronization.

Step 6: Integrate sales, distribution, production and purchasing. The objective is to establish the synchronization between different functions in order to achieve the JIT in the entire supply chain. The main activities of step 6 are: purchasing involvement in the standardization during the sourcing phase, production based on lorry transportation delivery schedule and the levelling of loading customer truck.

Step 7: Adopt a sequence-time fixed scheduling method. The objective is to establish a scheduling for the daily production according to the sequence of the customer and to provide the same sequence to suppliers and pre-production in order to create a controlled flow in the entire supply chain. [8] [5]

2.4.3 Cost Deployment Pillar

The main objective of this pillar is to translate in financial costs the quantified physical losses (work-hours, kW, products). Cost Deployment is a method to establish in a rational and systematic way a program of cost reduction thorugh the collaboration between production and administration and control. The aim is to develop a plan to improve with the best methodology that can fit the problem the most relevant losses.

What is a loss? A loss is any resource (workers, materials, machines, energy) to which a cost is associated, that do not add customer-perceived value. From a productive point of view a waste is a particular losses that happen when more input resources are used with respect to those strictly necessary to produce the requested output.

Of course, also the CD pillar is developed on a seven steps approach:

Step 1. Costs perimeter definition and quantification. Transformation cost is the cost part on which WCM can act through the improvement activities.

Step 2. Qualitative identification of the losses. For this purpose the A-matrix is used in order to highlight the losses and the sub-processes.

Step 3: Identify the causes of the losses. Matrix B of the system is used to relate the losses with their category. The goal is to identify the cause (e.g: breakdowns) and the effect (extraordinary maintenance) relationships.

Step 4: Losses quantification. For this purpose the C matrix is used to identify losses in financial terms, relying on the effective cost of the plant. The C-Matrix highlights the costs coming from causal losses of the processes and so the losses leading to major costs, using a Pareto graph.

Step 5: Methods identification to save losses. Again a matrix is used, the D-Matrix. This tool is used to identify the methodologies and the knowhow necessary for assigning to pillars the responsibility and the priority with respect to the single losses.

Step 6: Estimate the benefit/costs ratio and identify a project team. The goal is to present a priority on a cost basis and to measure projects with respect to objectives and PDCA. Different type of saving are classified as follows:

- Hard saving: effective costs reduction with benefits in terms of workers, scraps, energy and so on.
- Virtual saving: this type of saving is explained with an example. The benefit of the improvement activity is not visible because for example an NVAA reduction has been carried out on a station that is not the bottleneck. This lead to a saving that is not "visible".
- Soft Saving: It's a benefit relying on a real saving that can be guaranteed during the production period. Working in a proactive way during the design phase losses can be minimized.
- Cost avoidance: it's a cost incurred in order to avoid a greater loss. The preventive maintenance is a cost avoidance activity.

Step 7: implementation of improvement plan. The F Matrix allows to keep under control the progress of projects month by month, realizing the benefits obtained. The goal is to establish an improvement plan and to manage its progress. [9]

3 State of the Art

3.1 Input Data Analysis

The state of the art for data analysis is to be found, obviously in statistics. There are several methods present in the literature for data analysis. In particular, when the object of the study is a series of data which has to be attributed to a certain statistical distribution, there are different methodologies and tests that can be used. The interest is oriented at modelling a sequence of times according to a known distribution that can then be used to construct a behavioural model of the system. To do this there are several methods that provide information on the degree of similarity of the data to a known probability distribution function. It can't be said that data in question follow a known distribution even when analyzing a sample generated ad hoc. It can in fact be asserted, depending on the test results, a degree of "similarity" of the data to the distributions that tests are trying assign to it based on the information found, and then decide whether to accept or not the risk that these do not belong instead to that given distribution. The techniques used for the case in question will therefore be briefly illustrated with the main statistical tools most used for this type of analysis.

3.1.1 Chi-squared test

A chi-squared test, also written as χ2 test, is any statistical hypothesis test where the sampling distribution of the test statistic is a chi-squared distribution when the null hypothesis is true. Without other qualification, 'chi-squared test' often is used as short for Pearson's chi-squared test. The chi-squared test is used to determine whether there is a significant difference between the expected frequencies and the observed frequencies in one or more categories.

In the standard applications of this test, the observations are classified into mutually exclusive classes, and there is some theory, or say null hypothesis, which gives the probability that any observation falls into the corresponding class. The purpose of the test is to evaluate how likely the observations that are made would be, assuming the null hypothesis is true.

Chi-squared tests are often constructed from a sum of squared errors, or through the sample variance. Test statistics that follow a chi-squared distribution arise

from an assumption of independent normally distributed data, which is valid in many cases due to the central limit theorem. A chi-squared test can be used to attempt rejection of the null hypothesis that the data are independent.

Procedure:

1. Partition the *n* observation into *k* cells.
2. Compute N_i ,the observed number (frequency) of data in the *i-th* class (identified by extreme points r_i and l_i) and $E_i=np_i$, the expected frequency of the same cell. P_i is the theoretical probability associated with class *i*, under the postulated distribution:
   - If the theoretical distribution is discrete, $p_i=p(x_i)=P(X=x_i)$
   - If the theoretical distribution is continuous,
   $$p_i = \int_{l_i}^{r_i} f_x\ (x)dx = F_x(r_i) - F_x(l_i)$$
3. Compute the test statistics:
   $$\chi_0^2 = \sum_{i=1}^{k} \frac{(N_i - E_i)^2}{E_i}$$
4. Choose the significance level α of the test and find the corresponding critical value $\chi_{\alpha,k-s-1}^2$ on the Chi-Square tables.
5. Set the test:
   - H_0: the random variable *X* conforms the postulated distribution with parameters estimated from the input data.
   - H_1: the random variable *X* does not conform.
6. The null hypothesis H_0 is rejected if $\chi_0^2 > \chi_{\alpha,k-s-1}^2$.

To set the number of the cells *k,* the expected frequency should higher than five observations. Since the probability for *k* cells correspond to $p_i = \frac{1}{k}$ for each interval, the following condition holds: $E_i = np_i = \frac{n}{k} > 5\ \rightarrow k < \frac{n}{5}$. [10]

3.2   Simulation techniques

Once the behaviour of the modelled system has been defined and analysed, and the data necessary to study its behaviour are collected it remains only to decide

how to conduct this study. Different methodologies are possible to conduct this type of analysis, a code that replicates this behaviour could be implemented in almost all programming languages and then study the results. Optimization programs could also be used to investigate which of the many policies described above is the best in terms of performance. Another way is by discrete event simulation using software: this is the path that has been decided to follow. in fact, using simulation software, it is possible to transfer the logic model to a built-in algorithm and to obtain the quantities to be determined as outputs. These software allow to be more easily interpreted by different people and to be able to apply the different policies more immediately by changing the parameters. On the other hand, a code would be faster in performing calculations than simulation software but implementing the code would make it more laborious and more difficult to interpret by different parties. Moreover with the simulation software it is possible to control the behaviour of the system through animations that provide information on the system's real-time behaviour. Although this is not the case, some software has integrated three-dimensional models in order to carry out more advanced animations, an aspect not to be overlooked when these studies are conducted to provide managers or management with more awareness in making decisions based on the behaviour of the model. This is not the interest of the company -at the moment-, but the possibility of being able to develop animations allows people who are not practical to use software to better understand the aspects they want to highlight. The simple two-dimensional animations make it very easy to identify construction errors in the logical model, without having to wait for the end of the simulation to detect them. All these aspects make discrete event simulation more usable but in terms of performance it is more expensive in terms of computing capacity than traditional systems. Another aspect that has made the choice of the discrete event simulation preferable is that the model constructed, however articulated, should not require an excessive calculation load, especially if some measures are used to improve the efficiency of the calculation performance.

3.2.1 Focus on simulation

The term *simulation* refers to a vast choice of methods and applications that aim to mimic the behavior of real systems, usually performed on computers with appropriate software. In fact "simulation" can be a really general term from the moment when this idea can be applied in different fields, industries and applications. Nowadays simulation is more used, employed and powerful than ever thanks to the fact that computers and software are objects of continuous improvement.

Simulation, like most analytical methods, involves systems and their models. Systems are often studied to measure their performance, improve the way in which they operate or design them if they are not -yet- present (exactly the case of the study of this document). Managers and controllers of a system may also want readily interpretable help for day-to-day operations, such as helping to make decisions about actions to be implemented in a factory if, for example, an important machine stops working. It could also happen that managers who requested the construction of simulations were not really interested in the results, but in the primary objective to focus on understanding how their system worked. In fact, simulation analysts often discover that the process used to define how the system works, an action to be taken before being able to start developing the simulation model, provides really important advice on which changes may be useful. Rarely a single manager in charge of understanding how the whole system works. In fact, there are experts in machine design, material handling, processes, and so on but not in the daily operations of the system.

In this particular document the type of model that will be studied and that has been exposed in the previous paragraphs, is a logical model of the system. A model of this type is a series of approximations and assumptions (hypotheses), both structural and quantitative, of how the system behaves or how it will behave. Usually a logical model is represented in a computer program to investigate how the model behaves. If the model built behaves as the real system, the objective is to get more information on the true trend of this. Since the model aims at experimenting and observing the reflection of how the real system should behave, this will not involve real resources or facilities, making simulation an inexpensive

tool. It is easy to have a quick answer to a large number of questions about the model and the system, by simply changing the inputs and the form provided to the program. The most advantageous part is that of being able to experiment and make mistakes on the program, where mistakes can be corrected and do not count, rather than on the real system where they do. As in many other fields, the recent spikes in the computational power of devices (and a decrease in computational cost) have led to an increase in the possibility of conducting computer analysis of logical models.

After carrying out the hypotheses and approximations necessary to evaluate the target system, it's necessary to find a way to handle the model and analyze its behaviour. If the model is simple enough, traditional mathematical tools like queue theory, differential equations, or linear programming could be used to get the answers needed. This is an optimal situation because simple formulas could respond to the investigations and can simply be numerically evaluated; dealing with formulas (for example using partial derivatives with respect to input parameters) those could provide useful information. Even without using defined formulas, an algorithm could be developed to generate numerical answers to the system under analysis, but there would still be precise answers rather than estimates subject to variability and uncertainty. However, as the present case, many systems which need to be idealized, so to be studied, are rather complicated to be modelled through simple formulas, or they require proportionally difficult algorithms such as the system. For these models that may are not perfect mathematical solutions, those are the cases in which simulation is preferred.

3.2.2 Method selection

In fact, simulation is the method used to model the system, as the policies that guide it and consequently the output variables are complicated to model through simple formulas. In fact, extremely important parts for evaluating the performance of the system are the waiting times for transport, which in turn depend on the position of the vehicle itself. Also the total crossing time of the products is a function of both the positions of the AGV and its state of use, as well as its use depends on the number of trolleys that want to be transported. Also the possibility

of interrupting the AGV run if this were to use advanced software would depend on the point reached by the vehicle and whether this should have passed or not the node from which the transport request are released. Building these dynamics in a mathematical way using formulas or with an algorithmic method would indeed be very complicated, as well as managing policy changes to appreciate the resulting output changes. These difficulties, combined with a more versatile use of simulation software, make it preferable to use the latter also to help understand the behavior of the model, which, if presented with pure equations, would be difficult to understand for those people who have not developed it or do not know the methods.

As stated in [11]:

"Conventional approaches used in modelling manufacturing systems can be divided into two types: Analytical models and simulation models. Both technique defines the system as mathematical equations and it can optimize the system. However, since modelling a system as mathematical equations requires a lot of assumptions about the system and the more assumptions are considered the more the system becomes unreal. On the other hand, simulation technique may not give optimal solutions. It investigates a system's long-term behaviour. In spite of the fact that generating a solution about a system is more time-consuming in simulation technique, it is more convenient in modelling complex systems than analytical technique."

3.2.3 Computer Simulation

The term "computer simulation" refers to the methods to study a great variety of models of real world systems through numerical evaluation using software in order to imitate the operations or features of the system, often in the long term. From a practical point of view, simulation is the process to define and create a computer model of a real or proposed system with the aim of carrying out numerical experiments to provide a better understanding of the behavior of that system under a set of hypotheses and given conditions. Although nothing prevents from using it to study simple systems, the real advantage is to use this technique to evaluate and study more complex systems. It must be pointed out

that simulation is not the only tool with which to study the system, but it is often the method chosen. This is due to the fact that the simulation model could become more complex as the precision associated to the model look like the real system increases; and despite this complexity it could still be used simulation analysis. In fact, the model used in this document was created with the intent to carry out a first analysis to move towards a right direction, before implementing decisions from which it is impossible to go back. The model object of the study could also be seen as a starting point from which it is possible to evaluate other alternatives in a fairly simple way. Other methods may require hypotheses too simplifying to approximate the system and allow its analysis, action that could invalidate the validity of the model under analysis.

The reason why the simulation has become so widely used is its ability to manage very complicated models corresponding to equally articulated systems. This is what makes the simulation a versatile and powerful tool. Another reason for the increasing spread of the use of these methods is also the improvement of the performance / price ratio of computer hardware, making it cheaper what was excessively expensive from a computing point of view. Furthermore, advances in the power of simulation software, flexibility, and ease of use have made it easier to move from low-level programming methods to newer, faster and more valid ones in decision-making.

3.2.4 Important aspects

However, particular attention must be paid because many real systems are subjected to different uncontrollable and randomic inputs, so their simulation models involve random or "stochastic" components which generate random outputs. These sources of randomness propagate within the logic of the model causing for example cycle times and random throughput as well. Doing just one run of a stochastic simulation is like running a physical experiment only once: probably doing it a second time, you will probably see something different. In many simulations using a longer time horizon the results trend will prove to be more stable but it will be difficult to determine the duration to be considered long enough. Furthermore, the model could be interrupted by a particular condition (as will be the object of our study). Therefore attention must be paid to the design

and analysis of the simulation experiment to take into account the uncertainty of the results, especially if the simulation time horizon is relatively short. Even if the output of the simulation is uncertain the uncertainty can be managed and even reduced through simplifying hypotheses. However, care must be paid to not over-simplify the model to obtain valid and reliable results.

3.2.5 Different type of simulations

It is possible to classify the types of simulation models in different ways, but a particularly useful categorization is the following:

1. Statics vs Dynamics: a type of static simulation can be conducted on the results provided by an experiment with dice. In such a performance, time does not play an important role as it does in operational models where operations are emulated, which are instead dynamic.

2. Continuous simulations vs. discrete: In a continuous model the state of the system is free to change continuously over time. A typical example may be the level of a tank that changes with the outflow of oil. In a discrete model, on the other hand, changes can only take place in places that are specific to time, such as in a production system with the arrival or the departure of the parts to be worked, the states of the changing machines and so on. You can have both continuous and discrete elements in the same model that are therefore called mixed-continuous-discrete models. An example could be a laboratory in which constant temperature changes in the ducts cause them to break and therefore a decrease in their number.

3. Deterministic vs. Stochastic: Models that do not have random inputs are deterministic. For example, a system with a fixed calendar of events is a deterministic model. Stochastic models, on the other hand, operate with at least one random type of input, as can be the arrival of clients at a restaurant that have different service times. A model can present both random and deterministic inputs: which are of a type and which of the other depends on the level of accuracy and realism desired. [12]

3.3 Warm-up period

As for the analysis of the results, it is necessary to explain how these were treated. For each replica, there will be a situation consisting of a warm up time and a period where the system remains "fully operative". The model will initially be always in a state of empty and idle when simulation starts. This is due to the fact that the model has no entity in the system and all resources, including the vehicle, are free. Since it is not possible to know the necessary duration to bring the system up to a steady state, and guessing it may lead to evaluation's errors, it is also difficult to determine the total duration of the simulation. The final estimate of performances could be biased from the first period in which the state of the system was under or over estimated.

Even if it is not possible and not convenient to guess it before running the model, one solution may be to fill the system with a finite number of entity. It is not a good solution since no methods are available to identify how many entities to place in buffers, and

after all, this is one of the question the simulation is supposed to answer. In Figure 3-1, a general representation of a performance's phases is presented.
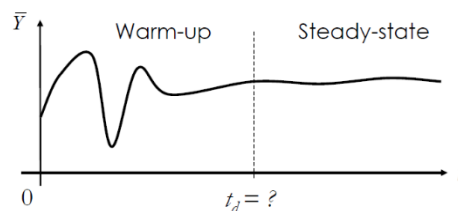

Figure 3-1 General trend of a performance

Other solutions are available such as running the model for a very long time so that the initial bias would be overhelmed by the other data. This may be effective in models where the biasing effects of the initial conditions wear off quickly. However, another method is to get the model going and let it "warm up" to the point where the effects of the initial conditions have vanished. Once reached this point the statistical estimators can start, accumulating statistics from then on. By doing this, the system state would not start on an idle and free state.

3.3.1 Welch Method

To identify the warm up period, different methods can be used, one of which is the Welch method. This is a qualitative method, intuitive subjective and quite easy to use.

1. Run *n>5* replications and collect Y_{ij} measures (replication I, measure j).
2. Calculate the average of each sample *j* using *i* replicaitons.

Measure	1	2	3	.	.	m
Replication						
1	Y_{11}	Y_{12}	Y_{13}	--	--	Y_{1m}
2	Y_{21}	Y_{22}	Y_{23}	--	--	--
3	Y_{31}	Y_{32}	Y_{33}	--	--	--
.	--	--	--	--	--	--
.	--	--	--	--	--	--
n	Y_{n1}	--	--	--	--	Y_{nm}
	Y_1	Y_2	Y_3			Y_m

Where: $Y_j = \dfrac{\sum_{i=1}^{n} Y_{ij}}{n}$

3. Trace the mobile average with windowing through *w* samples (where $w<=\frac{m}{4}$)

$$Y_j(w) = \begin{cases} \dfrac{1}{2w+1} \displaystyle\sum_{k=-w}^{w} Y_{j+k} & w+1 \leq j \leq m-w \\[2em] \dfrac{1}{2j-1} \displaystyle\sum_{k=-j+1}^{j-1} Y_{j+k} & 1 \leq j \leq w \end{cases}$$

4. Select *d* to be the value after which the mobile average seems to be converged.

3.4   Notations and methods

The following notation will be used to conducts the output analysis:

- n: is the number of replications.
- Y: performance estimated through simulation.
- Y_i: Performance measured from replication i (i=1, … ,n)

The mean is calculated by:

$$\hat{\mu} = \bar{Y} = \frac{1}{n} \sum_{i=1}^{n} Y_i$$

Sample variance of the measure Y:

$$\hat{\sigma}^2 = S^2 = \frac{\sum_{i-1}^{n}(Y_i - \bar{Y})}{n-1}$$

The variance of the sample mean:

$$Var[\bar{Y}] = Var\left[\frac{\sum_{i=1}^{n} Y_i}{n}\right] = \frac{1}{n^2} Var\left[\sum_{i=1}^{n} Y_i\right] = \frac{1}{n^2} \sum_{i=1}^{n} Var[Y_i] = \frac{1}{n^2} n \sigma^2 = \frac{\sigma^2}{n}$$

Thus replacing σ^2 with S^2:

$$Var[\bar{Y}] = \frac{\sum_{i=1}^{n}(Y_i - \bar{Y})^2}{n(n-1)}$$

And the t-statistic is:

$$t = \frac{\hat{\mu} - \mu}{\hat{\sigma}(\hat{\mu})} = \frac{\bar{Y} - E[Y]}{S/\sqrt{n}}$$

From the statistic:

$$\frac{\bar{Y} - \mu}{S/\sqrt{n}} \approx t_{n-1}$$

The probability to stay in a given interval:

$$P\left(\bar{Y} - t_{n-1,1-\frac{\alpha}{2}}\sqrt{\frac{S^2}{n}} \leq \mu \leq \bar{Y} + t_{n-1,1-\frac{\alpha}{2}}\sqrt{\frac{S^2}{n}}\right) = 1 - \alpha$$

Where $t_{f,1-\frac{\alpha}{2}}$ is the $100\left(\frac{\alpha}{2}\right)\%$ percentile of the *t*-distribution with *f* degrees of freedom. Thus the interval estimation is:

$$c = t_{n-1,1-\frac{\alpha}{2}}\sqrt{\frac{S^2}{n}}$$

Where α, the significance level at which the confidence interval has been calculated, set to 5%. The *t*-interval is wider than the interval built with normalized distribution, so if data are not normally distributed the *t*-interval is approximated. If data were not normally distributed, the t statistic used for the test would be approximately be t-distributed for the Central Limit Theorem and thanks to a large amount of data. [10]

For evaluating the confidence interval, when more than one performance is estimated from the same experiment, a global type I error needs to be considered. In the construction of the confidence intervals an $\alpha = 2\%$ has been used.

Denoting with Is the $1 - \alpha_s$ the confidence interval of μ_s (with $s = 1, 2, ..., k$), the probability that all the confidence intervals contain their respective true measures is equal to:

$$P(\mu_s \in I_s, \forall\, s = 1, 2, ..., k) \geq 1 - \alpha_s$$

3.5 Bonferroni approach

For the purpose of comparison the Bonferroni approach will be used. It rely on the hypothesis that one of the scenario is a "standard".

- The standard variant is named 1 and the other 2,3, … ,*k*.
- This procedure aims at building *k*-1 confidence interval for the differences: $\mu_2 - \mu_1$, $\mu_3 - \mu_1$, ... , $\mu_k - \mu_1$ with an overall CI $1 - \alpha$.
- Each individual confidence interval is constructed at level $\frac{1-\alpha}{(k-1)}$.
- System *i* differs from the standard if the interval $\mu_i - \mu_1$ misses 0.

$$\mu_i - \mu_1 \in \bar{Y}_i - \bar{Y}_1 \pm t_{1-\frac{\alpha}{2},v}\sqrt{\frac{S_i^2}{b} + \frac{S_1^2}{b}}$$

$$v = \frac{(b-1)(S_i^2 + S_1^2)^2}{(S_i^2)^2 + (S_1^2)^2}$$

Being b the number of observation.

For the analysis an overall $\alpha = 1\%$ will be used. [10]

3.6 Subset selection

This procedure aims at selecting a subset of systems that includes the best choice, it delivers a set of feasible scenarios $I \subseteq \{x_1, x_{2,}, \ldots, x_k\}$ with a guarantee that

$$P(x_B \in I) \geq 1 - \alpha$$

1. Given $n_i \geq 2$ observation from scenario x_i, set

$$t_i = t_{(1-\alpha)\frac{1}{K-1}, n_i - 1}$$

   The $(1-\alpha)^{\frac{1}{K-1}}$ quantile of the t-distribution with $n_i - 1$ degrees of freedom for $i = 1,2, \ldots, K$.

2. Calculate the sample mean and the sample variance

$$S^2(x_i) = \frac{1}{n-1}\sum_{j=1}^{n_i}(Y_j(x_i) - \bar{Y}(x_i; n_i))^2$$

   for i=1,2, …, k and the threshold:

$$W_{ih} = (t_i^2\frac{S^2(x_i)}{n_i} + t_h^2\frac{S^2(x_h)}{n_h})^{\frac{1}{2}}$$

3. Form the subset

$$I = \{x_i : \bar{Y}(x_i; n_i) \leq \bar{Y}(x_h; n_h) + W_{ih} \text{ for all } h \neq i\}$$

4 Problem Statements

4.1 Process description

To facilitate understanding of the phenomenon under study, the behaviour of the system will be illustrated schematically. In fact, the phenomenon to consider is the materials handling between one line and the next; this operation is currently carried out by human operators, they take the carts and bring them to the next stations walking in the plant. This operation is required to let the processing phase of the downstream process takes place.

The first and second lines (which are surface moulding technology) are not lines dedicated exclusively to the product under study. In fact, the first line has a production capacity that is almost twice the capacity of the Back-End line. The three lines, where the processing of the product takes place, are scheduled to the production of this ECU for a different number of shifts during the course of the week.

The plant contains several SMT (surface moulding technology) lines; however, when the production line of a product is changed, it must be "validated". This feature is necessary for industrialization issues and often is requested by the customer; this implies that, in addition to the cost of validation, the SMT lines associated to the products are moved only in extreme cases or to face extraordinary scenarios that may involve the launch of new products or particularly serious faults. A further constraint is given by complications related to the components that will be used to populate the boards: those must be inserted in the lines with dedicated instruments (Feeder of Reels) that serve to feed the Pick & place machines present on the lines. Furthermore, a logistic change is involved because these components are supplied through autonomous driving vehicles (AGV) which are programmed. A shift in production lines is therefore allowed but subject to several constraints which therefore requires the involvement of several figures, careful control and planning to coordinate all the necessary operations.

At the end of the first phase the products are placed in the racks, each of which can contain a total of 25 cards. The racks are then placed in the cart: it can carry

4 racks simultaneously for a total of one hundred motherboards (two hundred products). On the line there are up to 12 trolleys, capable of meeting production needs at times when product requirements are particularly high. From an Engineering point of view the high number of carts on the line to store the products act as dampers of variability as far as the production capacity is concerned. This guarantee that the first line is never in the condition of blocking, and at the same time to the second line of never being in a state of starving.

The populated PCBs then arrive in groups of one hundred ordered in the carts, where then in the second phase of the process the racks are prepared in the loading station which has the function of extracting the individual cards from their seats and then inserting them in the processing line. As mentioned before, within the second line, in the second phase of the processing, the electronic components are picked up by the reels to populate the second side of the PCBs and the connectors are added in a line station. Since each card will then be divided, two connectors are mounted on each product, one for each product that will be obtained. However, these devices are much more voluminous and reduce the number of products that can be allocated in the racks, bringing the maximum number of products per rack to less than half compared to those that could be previously allocated. In fact, if before each rack could hold twenty-five cards, now the maximum number is reduced to ten products per rack. Each trolley containing the products leaving the second line therefore carries four racks for a total of forty cards carried, against the hundred of the previous ones.

Figure 4-1 Input and output batches on second line

For the purposes of the study case it is very important to evaluate this phenomenon in which a redistribution of products takes place in the carts; the displacement action performed by the operators ceases to exist, when, on the third line, the finished products are taken from a shuttle by a logistics operator. He picks up the finished products that have been packed on the line and, by

means of a towing, hook up to the warehouse the load. The production process can then be considered completed and the products will be stored in the warehouse or, preferably, shipped immediately.

To provide a rough estimate of the time needed for the displacements, consider a batch of four hundred pieces in which the movements are made by hand by the operators. These four hundred pieces were originally therefore two hundred cards that require a displacement of two carriages from the first to the second line, and of five carriages from the second line to the Back-end. In total there are seven sections that at best (no interference and a displacement speed of about 1.9 meters per second moving the cart) lead to considerable labor losses, considering that operators should subsequently return to the line from which it comes.

These costs are calculated as follows:

- Batch constituted of four hundred pieces, and therefore two hundred cards.
- The carts brought from the first line to the second are therefore two.
- The trolleys carried from the second line to the final line are therefore five.
- Distance from first line to second line: 140 meters.
- Distance from second line to Back-End: 130 meters.

The distances must be traveled twice, the outward when the operator brings the cart full and then to the return when he brings instead an empty cart.

Identifying with D_{12} the total distance to be covered between the first and second line and with D_{23} the distance to be covered between the second the Back-end is therefore:

$$D_{12} = 140 * 2 * 2 = 560 \ [m]$$

$$D_{23} = 130 * 5 * 2 = 1300 \ [m]$$

$$D_{tot} = 560 + 1300 = 1860 \ [m]$$

The total amount of time needed to carry out the material handling operation is therefore:

$$T_{tot} = \frac{1860 \ [m]}{1.9 \ [m/s]} \cong 980 \ [s]$$

Therefore a total travel time for each product is calculated:

$$T_{tot} = \frac{980 \ [s]}{400 \ [pieces]} = 2.45 \ [s/piece]$$

Considering a monthly production of about fifty thousand (50'000) products, the total time taken in a month to move this product is:

$$T_{tot} = \frac{50000 \ [pieces/month] * 2.45 \ [s/piece]}{3600 \ [\frac{s}{hour}]} \cong 34.03 [h/month]$$

since this amount of time is used by operators, it needs to be valued with an average cost of twenty-seven euros per hour obtaining the total labour losses:

$$L_{mod} = 34.03 \ \left[\frac{h}{month}\right] * 27 \ [\frac{€}{h}] = 920 \ [€/month]$$

These losses can be calculated on an annual basis by attributing to each month a weight of one, except for August, whose weight is considered 0.25 and December which weighs 0.75 instead.

$$L_{mod\_Y} = 920 \ \left[\frac{€}{month}\right] * 11 \ [\frac{working \ months}{Year}] = 10120 \ [€/year]$$

The calculations shown relate only to the product presented, it must be taken into account that there are other products for which the processing cycle involves the handling of inter-operational material. The AGVs already present in the company serve in fact to supply the various components of the lines taking them from the warehouse and bringing them to the lines. This study wants to be the first step towards an automation of product movements starting from a sample product and from this proposing a method that can be easily repeatable and extensible to products that, like the example taken, suffer this kind of waste of labour losses. From previous chapter the time for the handling of materials falls within the category of non-value added activities (NVAA) and then should be avoided.

4.2 Process overview

In order to provide information about the model the real system is introduced. The aim of this paper is to evaluate different policies and dispatching rules driving the future applications; each policy has a related set of KPIs and costs.

A process flowchart will be presented to identify the main phases and the hypotheses used to build the model will be explained; the details of each line will be briefly presented in order to explain how the data used as input in the simulation model were taken. The limits within which the system will be examined and then presented; a more abstract model will be used to assess the impact of decisions within the considered sub-system.

In particular, the product object of the study has been observed and it includes several sub-products: it is an engine control unit which can have different variants depending on the customer requirements. The production process is divided in three main phases carried out on different lines in the Corbetta plant.

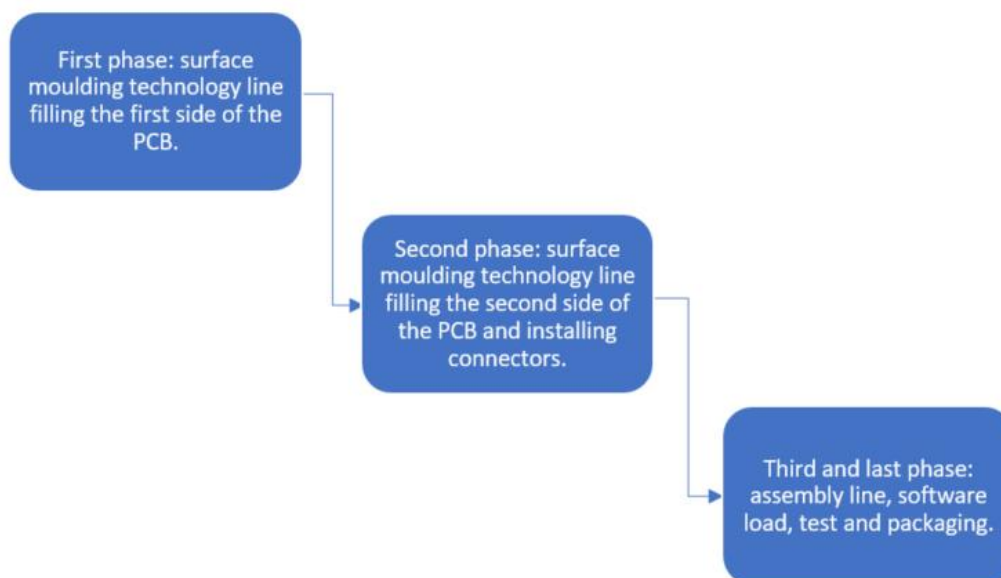A process macro-flowchart is provided in Figure 4-2.

Figure 4-2 Process flowchart
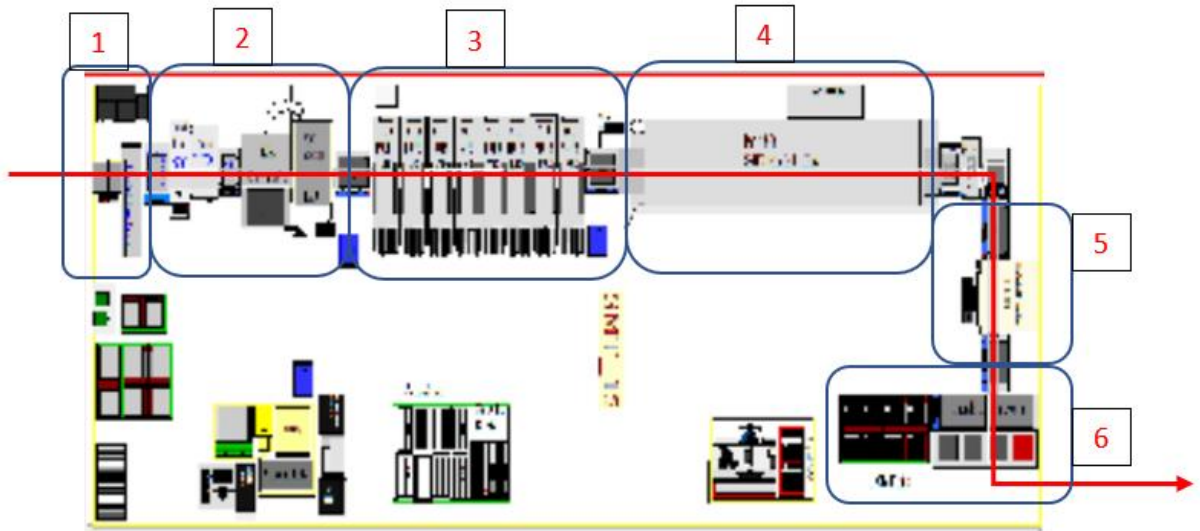
4.3 First phase

Figure 4-3 Layout of the first line

The first line is a surface moulding technology line where the printed circuit boards (PCB) are fed on a load station by an operator. Six main operations are carried out on this type of line:

1. An automatic loading machine take the PCBs and put them on a conveyor.
2. The boards are supplied with solder pastes through a silk-screen machine.
3. In this operation the first side of the board is populated through different Pick & Place machines, fed by a series of feeders for the electronic components that will then be installed on the printed circuit.
4. Once all the components have been positioned it is time to subject the product to the effect of the oven whose task is to fix the components on the board by drying the paste underneath them.
5. At this point the product is completed, through the conveyor belt it then reaches a station where visual checks are performed by an AOI (automated optical inspection) machine which judges whether the product is good or scrap.
6. In the last phase the products are then unloaded and the good pieces are divided from the fail by stacking them in different racks.

After the process is finished the first side of the card is completed and the racks containing the cards are moved on carts dedicated to their movement: the

process of the first phase can be considered finished. Operators are in charge of bringing the filled carts to the second line.
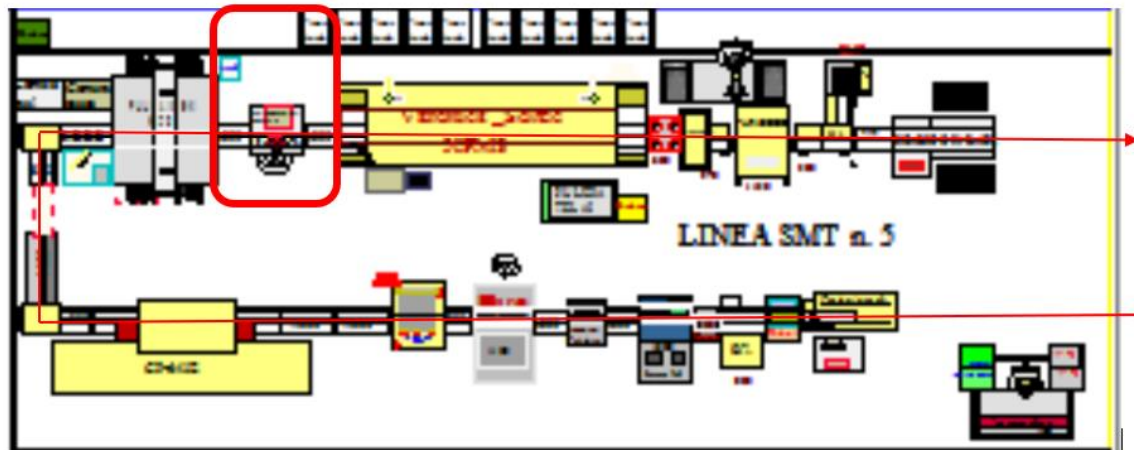
4.4   Second phase

Figure 4-4 Layout of the second line

The second phase of the process is completely similar to the first one apart for a further operation that is carried out before the products pass into the oven. In fact, a connector is also assembled to the PCBs which will be used once the products are mounted in the car. The second side is then populated, the products are again subjected to a visual inspection by the AOI machine and again the fail pieces are separated from the good ones. At the unload station they are then placed again in the racks where, however, the number of products that can be carried in the racks decreases considerably due to the fact that the connector mounted on the products makes them larger.

The second side of the board is therefore completely populated and all the hardware parts are now positioned for the control unit to function. All the products have been visually inspected by the machines, the pieces judged fail will then be inspected later; if they were to be good, they will then be put back into the process and marked as "not trouble found" NTF.

Once the racks have been placed on the carts they are ready to reach the third and final phase where the process is completed, this line is called Back End.
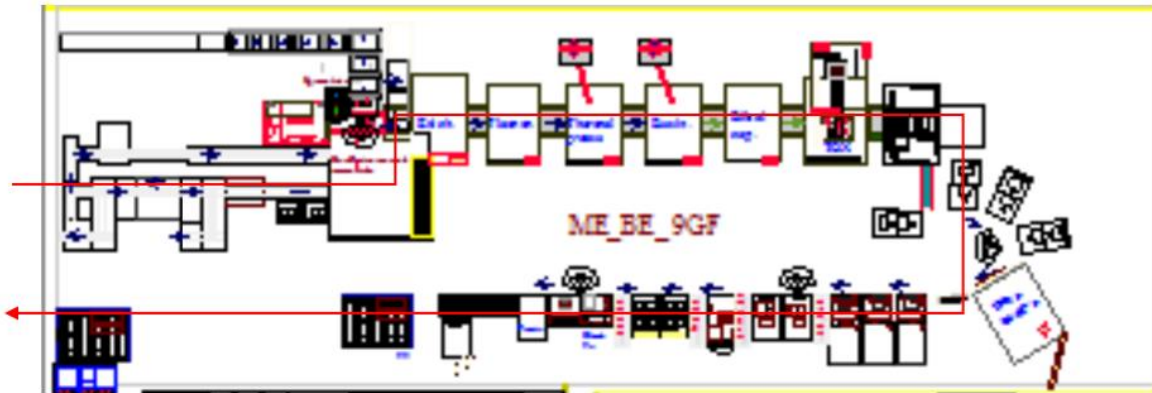
4.5 Third and last phase

Figure 4-5 Layout of the third line

The product is completed on the Back-End line where the PCB boards are separated. In fact, each individual card is made up of two pieces and in this line they are separated by a milling machine. One station is dedicated to controlling the circuit and carries out an ICT test (In Circuit Test), again the pieces judged to be fail are separated from the line by a by-pass that will allow the product to be subsequently inspected. The mechanical parts are then assembled, in particular the thermoformed cover which has the function of isolating the board and protecting its function by hermetically closing it. The piece is then tested to evaluate the hermetic seal, then followed by mechanical tests to evaluate the piece under stress and simulate the environment in which it will then have to guarantee performance in a working condition. The software is also loaded according to the versions that are being produced, and after a further test the pieces are then labelled, recorded in the logistics system. Products are packaged and ordered in boxes ready to be picked up and taken to the warehouse to be then shipped out.

4.6 Processing times

The first line, a SMT line works as described before and here summarized briefly: the printed circuit boards are fed on a load station by an operator. After that an automatic loading machine take the PCBs and put them on a conveyor, then the boards are supplied with solder pastes through a silk-screen machine, then are subjected to the action of several Pick & Place machines. Once the electronic

components have been placed the boards pass through an oven whose tasks is to fix the pastes. At the exit of the oven an Automatic Optical Inspection (AOI) machine carries out a visual inspection to check if components are in their correct position. The machine, after an inspection carried out on the product, records an xml file containing various information fields. Those files are used to be processed and read by software of the testing department and by the technologists, but also by the quality pillar.
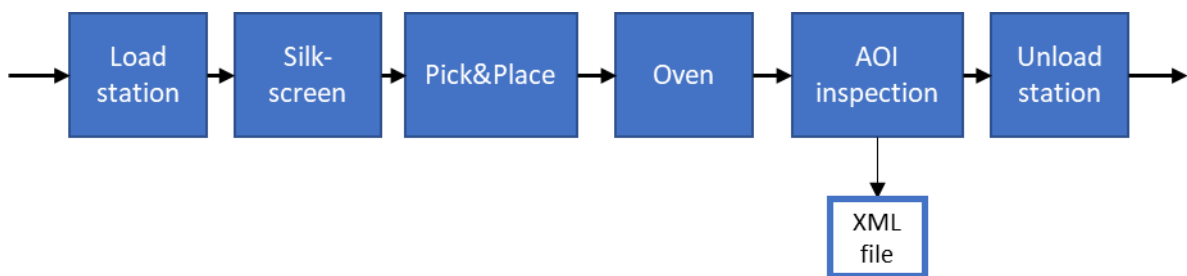

Figure 4-6 Linear representation of the line

The xml file is built with some fields explained here:

- Alphanumerical code corresponding to the variant of the product
- The test results
- Date
- Time
- Other info regarding the state of the machine

```xml
<?xml version="1.0" encoding="utf-8" standalone="no" ?>
<vCheckTester xmlns:xsi="https://www.w3.org/2001/XMLSchemainstance" xmlns="Valor.vCheckTester.xsd" Version="4.0" OperationNumber="BOTTOM" OperatorNumber="ValorUser">
  <Unit Timestamp="2019-06-13T14:13:04" SerialNumber="BY-Y+8D6V" StatusCode="PASS" UnitNumber="BY-" UnitRevision="" DateTimeStart="2019-06-13T14:13:04" Sequence="1">
    <Header TestProgramName="BY--2-2-TOP" />
  </Unit>
</vCheckTester>
```

Figure 4-7 Structure of the XML file

Since the output file was designed to be processed by software belonging to the testing department, whose task is to extrapolate the various types of errors reported by the machine, the xml file could not be extracted directly by Microsoft Excel.

44

Figure 4-8 Excel sheet layout

It was therefore necessary to implement a VBA code that could take multiple xml files and fill in the fields assigned. It is useful to provide technical information, which means that for each inspected product one file is created once the tests are carried out and then the products released. It was therefore possible to proceed to extrapolate the data regarding the times in which the products left the inspection machine with the related test results. Since the machine downstream of the AOI is a simple unloader of, it can be asserted that from the data obtained

Figure 4-9 Section where data are collected

there is a memory of each piece leaving the line. Therefore, taking advantage of the data obtained with this procedure, key information is provided for the purpose of modelling the system.

Since each card consists of two products, the extracted files are in fact consistent with what has been collected up to this point. In fact, the times taken from the spreadsheet report the same time two by two because they are checked together belonging to the same PCB. It is therefore immediate to collect useful data in a simple and immediate way.

For the second line the extrapolation of samples is completely similar, apart from the fact that the data relating to the products are collected in a text file that once again shows the results of the tests but above all the one that is most useful for the purposes of the studies, times. The machine on the second line is older but this allows to easily pick up the text file that can simply be backed into Microsoft Excel to perform the operations already shown for the time data related to the first line.

The analysis of the data will be shown later but to complete the information relating to the collection of these data it is necessary to better illustrate how these have been made "usable". Since the study is dealing with capital intensive lines,

it could be intended that the time required to produce the pieces should in some way be considered deterministic: there are a large number of factors suggesting that those may aren't. The output times are not constant for reasons listed below:

- The first is that they are lines that use almost totally automated technologies but require the presence of at least one line conductor. The conductor must in fact always be present also for safety reasons (think of the problem of a product stuck in the oven), and for productive reasons. In fact Pick & Place machines require the intervention of the conductor to replace the reel that feed the line with the electronic components.

- The second is that the operator can be absent; at times when no one is present, on the the machines of the line must be mandatory stopped and emptied of the products, with particular attention must be ensured that no products are stuck in the oven, because it may start a fire. There are therefore moments in which the line, although available, must stop production.

- A third reason that leads to longer or shorter interruptions are the production pauses in which operators go to the canteen or temporarily interrupt production. Even during shift changes, the times between one product and the next suffer peaks.

- A fourth reason may be due to the large number of machines that make up the line: a more or less long failure of one of these in fact once again affects the times between one product and the next.

- A fifth reason is that the product in question (but applies to all products) has some micro-variants that provide for a diversity in terms of hardware and therefore makes the cycle time slightly different.

- A sixth reason can be attributed to the number of operators present on the line, in fact as these increase the production times decrease (in a non-linear manner) as the operations necessary for production can be carried out simultaneously, such as the change of reels, pauses disjointed and so on.

For these reasons, which are just some examples of the reasons why a line does not continuously produce production times, they were not considered

deterministic also because of their size (tens of seconds) which makes it very easy to depart from its model frequency.

An advantage of the VBA code created is to intercept and divide the times based on a set limit. This information can be very useful for maintenance engineers in order to set dynamic maintenance problems. A further use can be to provide information to supervisors and to the quality body: this in fact could correlate a prolonged interruption to a particular type of defectiveness. An example may be that of solder paste that could become dry but the field of application is rather vast.

For the sake of completeness, an example is given in Figure 4-10 of how the times between one product and the next are extracted:

Stringa data	Stringa ora	data	Ora
20190613	000007	2019/06/13	00:00:07
20190613	000007	2019/06/13	00:00:07
20190613	000032	2019/06/13	00:00:32
20190613	000032	2019/06/13	00:00:32

Figure 4-10 Data gathering file

As can be seen, the times are equal to two by two for the reason explained previously (two products per board inspected).

Figure 4-11 shows instead the sheet where the calculations are performed.

Interarrival time BY-	Clean data BY-	Fermi BY-	Fermi in minuti BY-
25	25		
47	47		

Figure 4-11 Separation of data

The aim was to separate the times exceeding a certain limit to isolate the phenomena described above (failures, breaks, and in general non-standard working conditions).

As far as the third line is concerned, the production rate can be obtained from the logistic software in which the products are inserted by the barcode reader once they are finished and then ready to be packed. For reasons that will be better explained in chapter 4.8, this type of data, although easily obtainable, was not the object of the study. As far as future models are concerned, it is worth mentioning that this datum could be obtained with the same methodologies explained here.

4.7   Routes and distances

Once collected data concerning the productive part for the purposes of the study in question, a further fundamental data is that concerning the routes and the distances between the lines. In fact the part under study concerns precisely the movement of materials between the lines and even if it seems obvious it is good to remember that the distances and the paths that can be followed play a fundamental role in the model that has to be built. The only way to get a clear view of the distances was to examine the building's layout to identify and map the distances involved.

To understand the vastness of the plant the area has dimensions of about 310 [m] x180 [m] and is as large as about six football fields.

Once acquired data on distances it is time to identify the constraints that had to be respected: in fact the shuttles and vehicles already present are forced to circulate respecting a series of rules that impose one-way traffic for logistical and security issues. For this purpose the next step was to inspect the constraints provided by the logistic pillar to have a clear idea of the rules under which the vehicle must operate.

Since the guided vehicle needs a guided network identified by a magnetic strip installed on the floor of the plant, less degrees of freedom were concerned in defining the shortest possible routes.
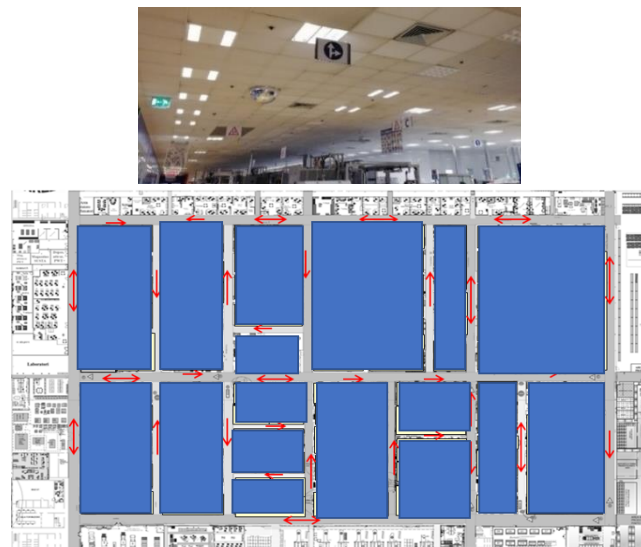

Figure 4-12 One-ways imposed on the plant

As shown in Figure 4-12 the corridors that can be travelled by the automated guided vehicle are already been supplied with the magnetic strip, and four other vehicles are used.

Given that the production system is based on a pull-driven organization, AGVs usually do not have scheduled departures, but the high frequency products (HFP) are feed on a daily based calendar because a large number of products are sharing the same electronic components. The pull type organization is carried out through a series of Kanban tags with its own bar code on the lines. These tags are read by line operators through a reader that scans the tag (production kanban) and sends a kitting list to the warehouse which will be loaded on the first available shuttle that supplies the line.

Even if many components are shared among more products, Marelli deals with a very large number of product variation and the picking activities assumed a central role in the production system.

As said before, AGVs are following a magnetic strip that has been installed on the floor of the plant, they approach the feeding zone by means of a marker, and the turning zones are preventively sized considering the maximum amount of carts they can bring.
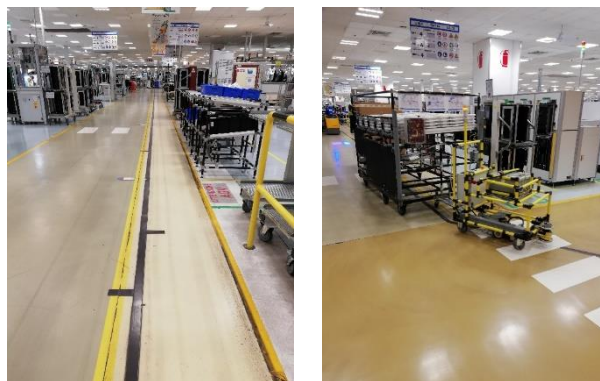

Figure 4-13 Magnetic strip and an AGV

Once all the constraints relating to the passages have been defined, the shortest possible route had to be defined, proceeding in a heuristic way, thus finding the shortest distance that respected the one-way constraints.

4.8 The model

The model that this study wanted to build aimed at investigate the performances of interest of a possible AGV used in the movement of the products. Although in the real system the lines work at different rates and therefore with a different number of shifts worked during the week, the performances of main interest are the productivity rate and the utilization of the AGV. The constructed model has therefore taken into consideration the objectives of the study to make it easier to appreciate the results.

To give a better understanding of how this model was built Figure 4-14 shows how the real system has been assessed in the study.
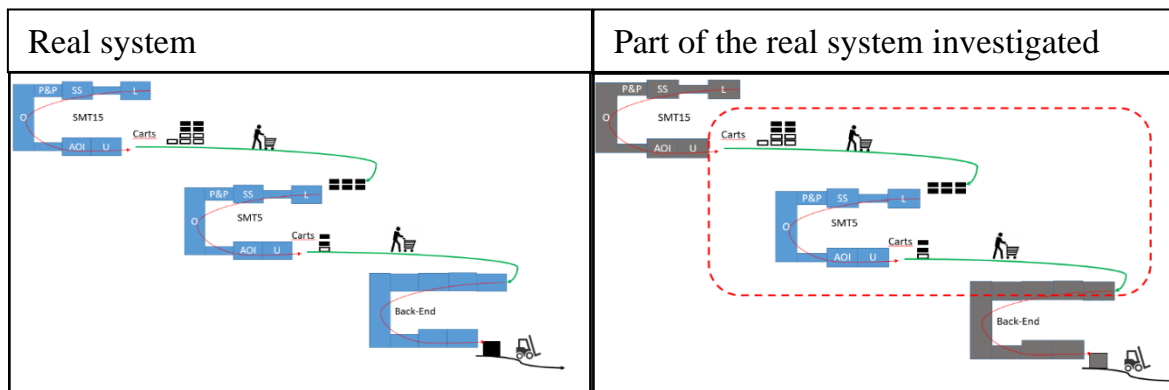

Real system	Part of the real system investigated

Figure 4-14 Process and the section considered

Only the highlighted subsystem in Figure 4-14 was considered, since for the purpose of the investigation there were no interest in the whole process because the focus was mainly on the material handling between the lines.
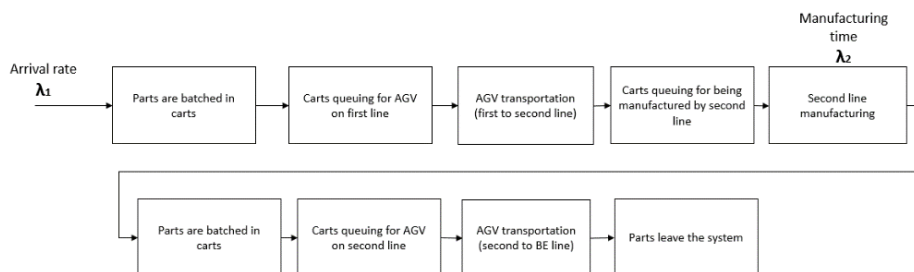

Figure 4-15 Flowchart of the overall process

From the flowchart: λ_1, λ_2 are times that belong to the distributions estimated in the previous paragraphs. It is in fact the times with which the parts leave the first

line and the second. As for the first batching in the carts, the cards are collected in groups of one hundred, while after the second line in groups of forty. Travel times depend on the routes that have been identified with the methodologies set out above. the route that can be taken by the self-driving vehicle will be illustrated shortly. The times with which the products arranged in the carts are moved can be deterministic in the first approximation, as they depend significantly on the distance and speed with which the AGV can move, both fixed.
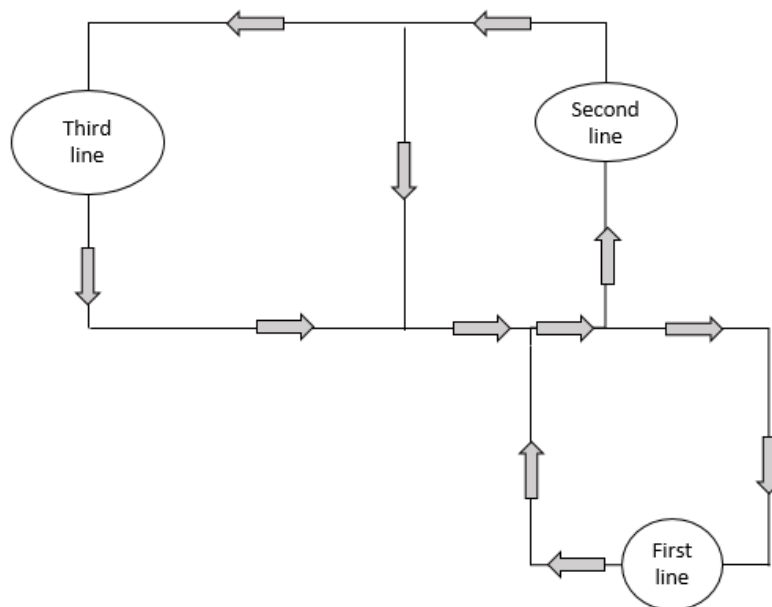

Figure 4-16 Representation of the paths available for the AGV

The current system does not have particular path because there are no constraints on the one-way streets since the movements are made by means of the operators who move along the plant. The case that instead wants to be investigated will have to present an established path on which the self-driving vehicle will have to move. The result is a combination of closed loop between the three stations in which the processing is performed, under the assumption that the AGV is moving between them. Further hypotheses will be explained better later.

4.9 Policies

4.9.1 Preconditions

Before using a tool to study the behavioural model of the system it is good to define which aspects are of interest and which will be less attentive because of a lower interest. In particular, the company wants to replace the movements made by the operators with an autonomous driving vehicle which will follow the magnetic strips already installed in the plant.

Before explaining the policies that will guide the study, it is useful to emphasize that the interest is directed to the performance of productive cadence, generated by the best set of possible decisions. Another aspect of the study that will be of crucial importance is the total amount of time in which the vehicle is used. In the real system it is necessary to foresee moments of stop for the vehicle, whether for the replacement of the battery or for the following reasons: a vehicle excessively saturated by requests is more likely to cause production delays, while one with a lower level of utilization will, at least from the model, provide better system performance. Another reason for assessing the vehicle's utilization is that this performance could lead the AGV to serve more than one product, thus extending the studies of this system on more production lines in the future.

Another aspect linked to the use performance is that relating to costs. In fact, a lower absolute saturation of the vehicle implies less time spent in the movement of material, an activity deemed to be of no added value; therefore the level of vehicle utilization will be as important as the production rate.

4.9.2 Position

One of the decisions focused on in this study is where the vehicle should be stationed. After discussing the decision to be made it was decided to investigate two main positions. In fact, each choice of this decision is associated with a cost because, now, there is no bay where it is possible to place the AGV in a state of waiting anywhere in the plant. In fact, the vehicles that are involved in components supply always make a complete turn and then return to the warehouse without waiting anywhere ready for parking. Since the object of this study is a first analysis of the performances it was decided to limit the possible parking places only on the two lines from which the requests for transport can start. Under those assumptions it was therefore decided to analyze three variants of this policy, namely:

- Create a waiting bay on the first line
- create a waiting bay on the second line
- create a waiting bay on both lines

Indeed, holding a waiting bay on the Back-End line would be counterproductive since each request, whether it started from the first or second line, should wait for the time necessary for the vehicle to travel on one of these lines before the truck can be taken in charge of the AGV. Furthermore, management did not want to immediately hypothesize a station inside the plant not involved in the process because this would affect non-interested production units that would undergo layout changes to accommodate the vehicle.

It will not be possible to exclude in the future a position at the center of the plant to minimize distances, in fact the study aims to provide a first analysis of the performance generated by a radical change in the management of displacement flows. After completing a first study, assumptions that are closer and closer to the optimal point will certainly be developed in the future, that is a cost minimization and production optimization.

What can be expected, only from the first hypothesis, is that there will be a trade-off between the costs of installing the systems and the costs of moving. In fact, as installation costs decrease, thus reducing the possible parking points, waiting

times are expected for higher displacements and therefore slower production. On the contrary, by increasing the installation costs, thus making the network on which the vehicle can circulate more dense, waiting times are expected for the shorter trips, therefore also associated with a reduction in the time required for production. In the particular of this study, however, the choice has been limited to the stations of interest even if the interest seems to be directed towards a wider investigation.

Maybe by creating a parking bay on the second line the performances could be better since, as shown in the previous chapters, for a fixed number of products, the number of trucks in exit from the second line is greater than that of trucks exiting the first. Conversely, the time necessary for the products to leave the first line to reach the second line to be processed will be greater. The purpose of study object of this document in fact is to investigate this aspect.
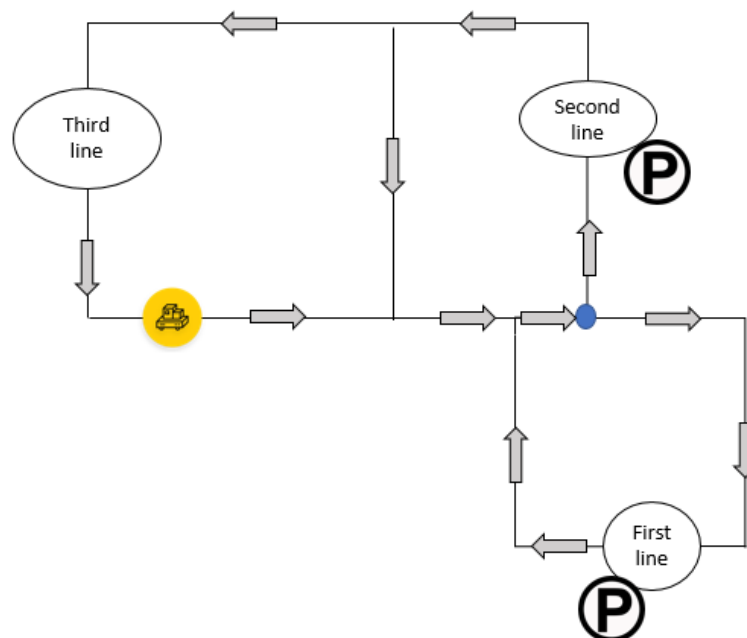

Figure 4-17 Parking identification

4.9.3 Number of carts

Another decision to be made is the number of transportable trolleys per route. The starting hypothesis is that this decision will have a very strong impact on the performance of the system, in particular on the saturation (or utilization) of the vehicle. This decision will also translate into a cost since the type of trolley is determined whereas the type of trailer present on the agv will have to be decided, the greater the number of trolleys that want to be transported the greater the cost of the device needed to attach the trolleys . Furthermore, it should be remembered that in the factory there are strict production rules and therefore once established these are followed less than extraordinary conditions. If in fact the preferred policy should be to transport two trucks per route the trucks should be understood as a single entity to be transported and it will become a rule to determine whether to issue a transport request. In fact, in the establishment, the aim is to to standardize the methodologies trying to optimize them; leaving to the free will the decision whether to wait for the presence of two trolleys or only one will not be admitted under standard conditions. For "standard conditions" it mean normal production, if this should vary it could in fact become necessary again to manually move the products in the trolleys. The performances of the model will therefore be investigated under the hypothesis of transporting only one trolley or two trolleys for each movement. It could be assumed that the level of vehicle use should be half in one of the two cases but the variability of the processes makes this first hypothesis less probable and less certain. The results will confirm that there is no certain prediction of this relationship.

Figure 4-18 Capacity of the vehicle

4.9.4 Software

The third decision to make is the type of software and the type of usage is allowed to make of the vehicle. Two types of decisions can be made: the first is that the software used can allow software to interrupt the travelling of the vehicle if this, moving towards its parking position, passes the node where the one way imposed rules of the plants do not allow it to return. A higher customization of the management software would in fact lead to an increase in the cost of an entity that cannot be estimated without a purchase request. Depending on the service provider it could in fact be much more expensive or have a slightly higher cost. In addition to the cost, it is also necessary to consider the fact that this operation would require training exactly as it requires operating with other machinery. The other hypothesis is that of a vehicle that, after having made the necessary movements, always returns to a position that it recognizes as a "base position" and from there to check for further requests. This hypothesis would in fact require a very low level of integration at the software level and could be used as a first approach for the transition to the automation of internal material handling. This type of hypothesis is assumed to be of impact only if the station designated as parking were to be the first line since, during the return to its bay, this vehicle should pass through the node where, if passed, it would have a longer travel.
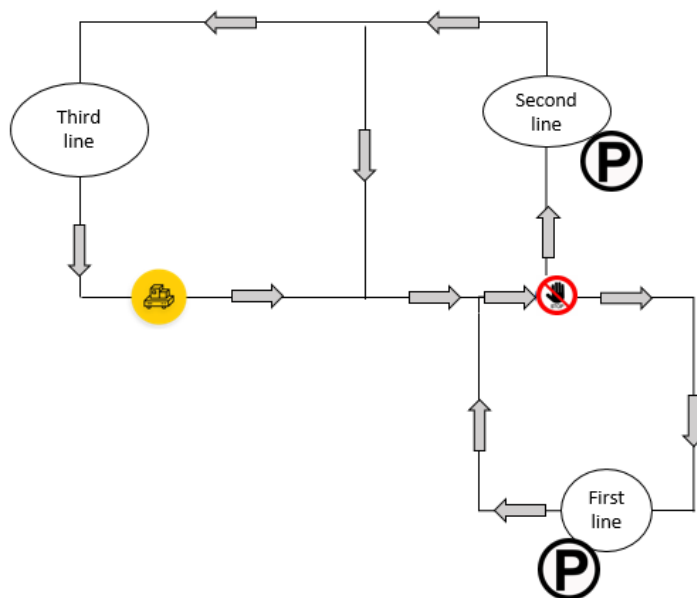

Figure 4-19 Node where decision must be made is highlighted

4.9.5 Preferred parking

This policy is to be considered in the event when it has been decided to install parking bays on both lines from which requests can be made. If in fact the vehicle should get freed on the third station it should choose where to go to position itself. The selection criteria will be both investigated; for what has been said so far it is thought to be a better policy to prefer the second station to the first. Given those statements, the logic will have to decide if, once leaving the third station, the vehicle will go to the first or second line. If instead the vehicle had to complete a mission from the first to the second line, as this is equipped with parking it could accommodate the AGV.
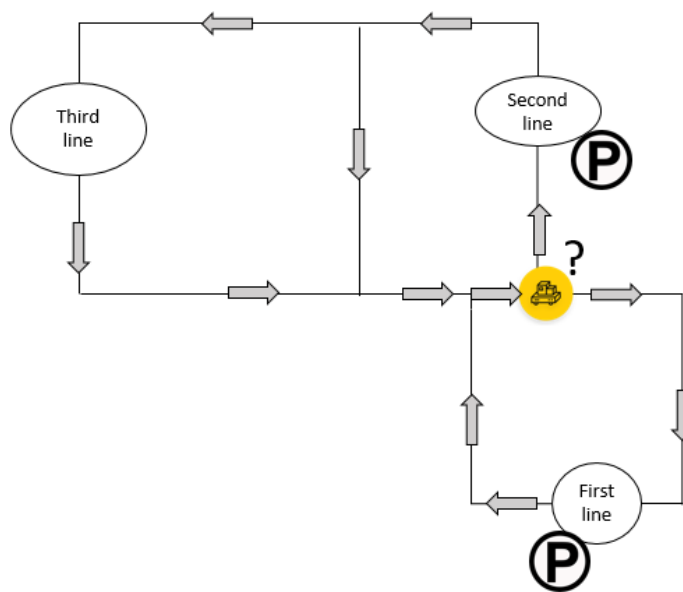

Figure 4-20 Scenario with two available parking station

4.9.6 Priorities

This last policy gives rules when the vehicle has to satisfy multiple transport requests simultaneously. Since there are no considerations about which of the two policies could be the best, both are investigated. Preferring the second line's requests means to make a delivery on the output and then the disposal of the entities from the system, while satisfying the request on first line could increase the size of the buffer entering the second line reducing the entering parts.
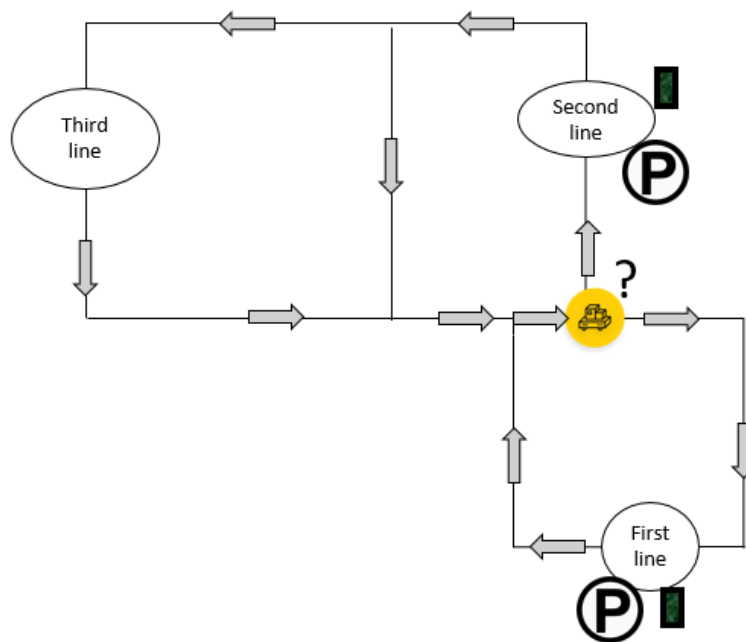

Figure 4-21 Scenario in which priority need to be defined

4.10 Scenarios

Starting from the above statements the problem has been formalized as the variation of these five policies.

With the combination of those five policies different ouputs would be given and they have to be tested. Since there are several available policies, each combination must be evaluated.

Table 4-1 Policies

Policies	**Level 1**	**Level 2**	**Level 3**
Parking Position	First line	Second line	First or second lines
Software type	One carts	Two carts	//
Request priority	Basic	Advanced	//
Preferred park	first line	second line	//
Number of carts	One per track	Two per track	//

As can be seen from Table 4-1, the decisions to be made on the waiting position are 3 while for the other variables there are only two possible decisions. The type of "preferred parking" levels should be evaluated only if the vehicle is allowed to park on both the stations; in the other two cases, in fact, the value of the preferred parking lot would not be important, as this is the only one. From the possible combinations of these policies a total of 32 scenarios were obtained in which each of the possible decisions was studied.

Each decision variable has been coded to better control the evolution of each scenario as follows:

- The parking variable is divided into two variables, both used only in the scenario in which two parking lots are used. When only one parking is used, the variable that identifies the second position is set to zero: [0,1,5]
- Type of software: only two variable, zero if basic, one if advanced: [0,1]
- Priority: two variable, one for each priority: [1,5];
- Preferred parking: it is set to zero if only one parking is used: [0,1,5]
- Number of carts: [1,2]

The total list is shown with the criteria already discussed in the previous pages.

Table 4-2 List of possible scenarios

| Scenario index	Park1	Park2	Software	Priority	Preferred Park	# of carts
1	1	0	1	1	0	1
2	1	0	1	1	0	2
3	1	0	1	5	0	1
4	1	0	1	5	0	2
5	1	0	0	1	0	1
6	1	0	0	1	0	2
7	1	0	0	5	0	1
8	1	0	0	5	0	2
9	5	0	1	1	0	1
10	5	0	1	1	0	2
11	5	0	1	5	0	1
12	5	0	1	5	0	2
13	5	0	0	1	0	1
14	5	0	0	1	0	2
15	5	0	0	5	0	1
16	5	0	0	5	0	2
17	1	5	1	1	1	1
18	1	5	1	1	1	2
19	1	5	1	1	5	1
20	1	5	1	1	5	2
21	1	5	1	5	1	1
22	1	5	1	5	1	2
23	1	5	1	5	5	1
24	1	5	1	5	5	2
25	1	5	0	1	1	1
26	1	5	0	1	1	2
27	1	5	0	1	5	1
28	1	5	0	1	5	2
29	1	5	0	5	1	1
30	1	5	0	5	1	2
31	1	5	0	5	5	1
32	1	5	0	5	5	2

4.11 Logic flowchart
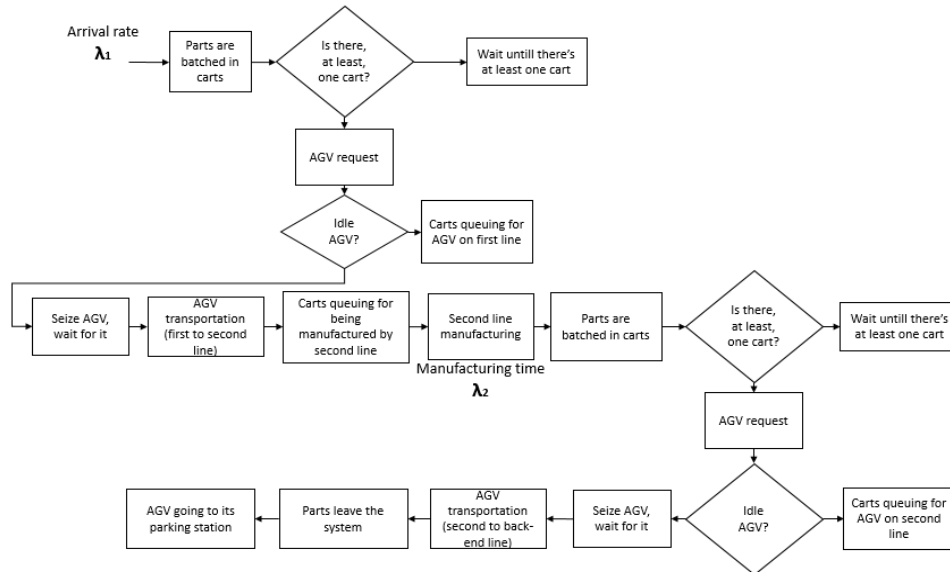
Figure 4-22 Basic software's logic

The logical model has already been presented but the variables that will guide the study are those shown in Table 4-2. To present in detail how the model must behave, flowcharts will be presented to represent how the system should work. General policy with basic software, one cart moved per track:

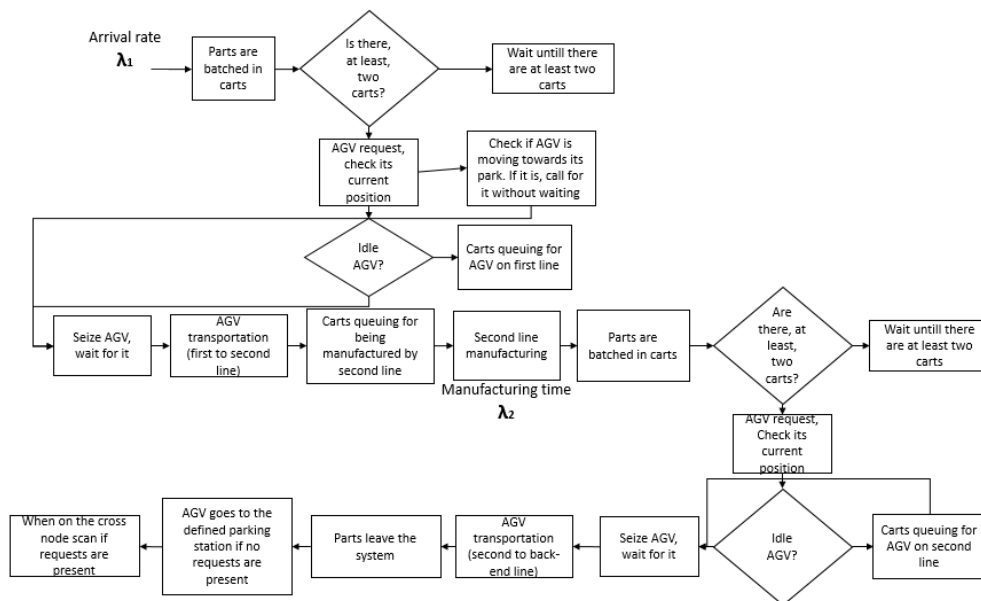Policy with advanced software, two cart moved per track:

Figure 4-23 Advanced software's logic

The logic used for moving the AGV is proposed in Figure 4-24:
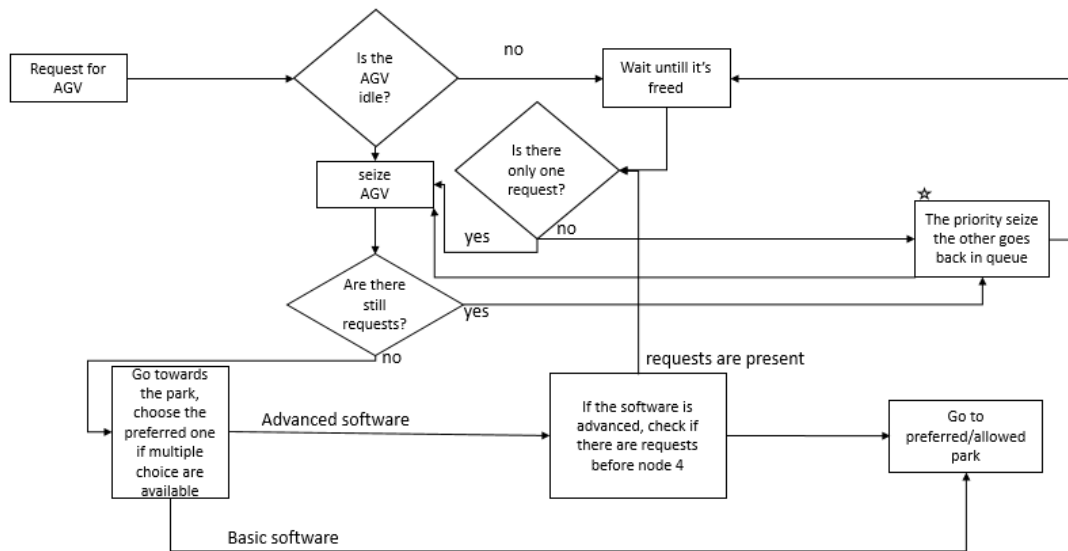

Figure 4-24 Steps of AGV driving logic

There is a particular situation that needs to be described. The vehicle can be parked on the first station and find both lines with a request. Should this condition occur, the vehicle is specifically indicated to take the cart on the first line and move towards the second; this because if he didn't do it, he would still make the route without bringing anything. Otherwise, the priority of the requests is always respected, even if the vehicle arrives to park on the second line and find both requests present.

5 Definition of the DES Model

5.1 Input data analysis

The input data that were used for simulations are obtained from the AOI machines at the end of the first 2 lines and in the code-assignment machine in the Back-End.

By creating a VBA code for extracting all the information about the time and date inter-times were considered, since will be then used for modelling the system, as the aim is to identify the delay time of the line as the real system, considering the variability of the process.

So now it's necessary to extract all the inter-time between each PCB and save the file to define a series of data to be processed. Furthermore a limit was imposed while extracting the inter arrivals times since, as mentioned before, the line is stationary while the operators are having lunch or pausing and the datum of interest is only relative to the moments of full productivity.

A sample of data has been considered and a different number of classes was used to identify the frequencies for a first analysis, as shown in Figure 5-1. The times of a single product variant drawn on the first line were considered; the data proposed are related to the test result released in the inspection machine, for individual boards (which again are being made up of two products).
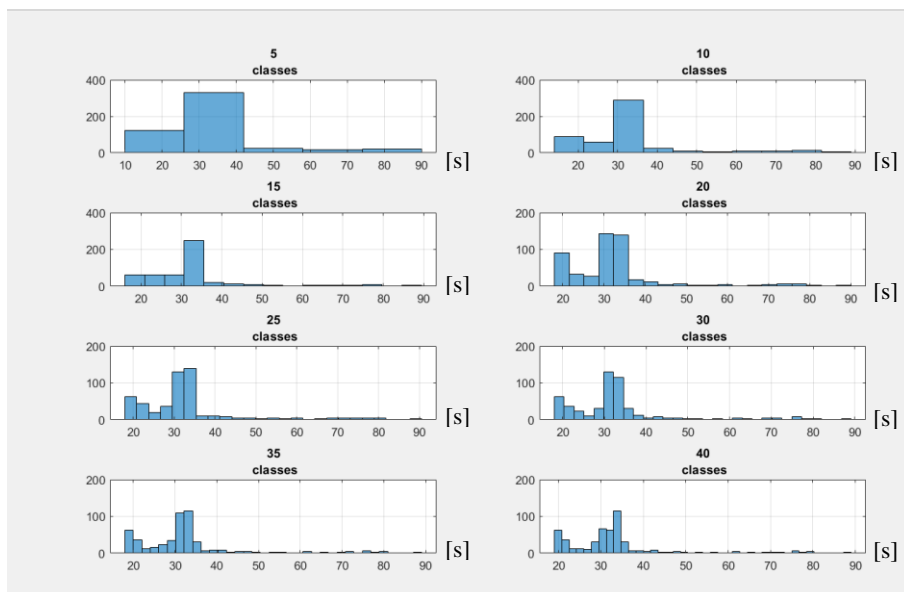

Figure 5-1 Histograms with different classes

Further analyzes have been carried out since, as can be seen from the graphs, the sample from a first and rapid evaluation could belong to different statistical distributions.

The initial idea is in fact to identify one or more types of known distribution that make up the data series and then insert them into the model that will be used to assess the system.

An algorithm has therefore been created in Matlab to inspect and divide the sample obtaining two separate series as illustrated in Figure 5-2. The aim is to separate the two possible modes identified by the histogram, thus obtaining two sub sample on which a distribution fit is may possible with good results.
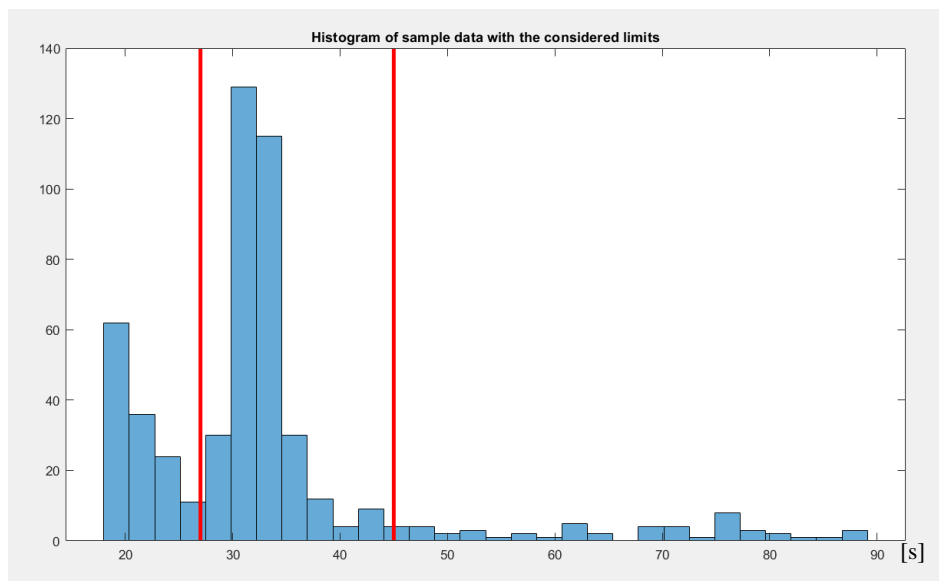

Figure 5-2 Bounds used to separate sample

If this type of analysis turns out to be positive once the statistical distribution of the sub-samples has been defined, the number of observations in the samples will be taken into consideration and a composite probability density function will be defined as follows:

$$F_x(x) = \frac{n_1}{n}F_1(x) + \frac{n_n}{n}F_2(x) + \cdots + \frac{n_m}{n}F_m(x)$$

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It is useful to remind that at the end of the lines a large number of buffers act as a damper of the variability of the distribution. Continuing with the analysis of the input data, an algorithm was applied to each sub-sample to identify the probability distribution function that could best approximate the sample. The algorithm thus produces a histogram of the sample to which the probability density functions are superimposed, thus making the comparison of the sample with its hypothetical distributions, simpler and more immediate.
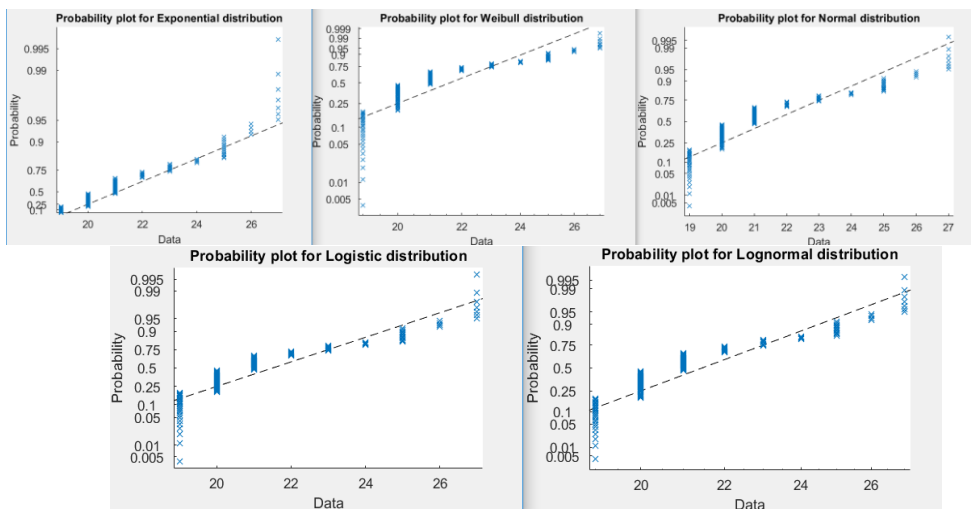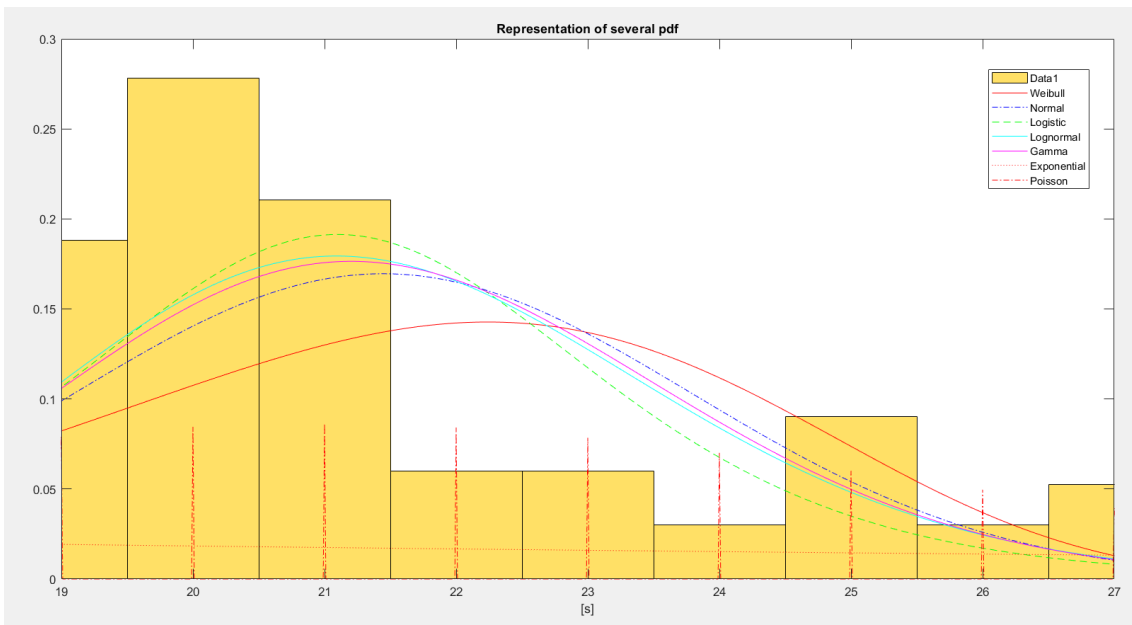

Figure 5-3 Results from Matlab algorithm

In Figure 5-3 the left tail of the histogram was considered. As to check the fitting of distributions Q-Q plots are then created and a plot is provided.

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5.1.1 Application of Chi-square test

For carrying out a Chi-square test the sub-sample data were considered and methodologies applied.
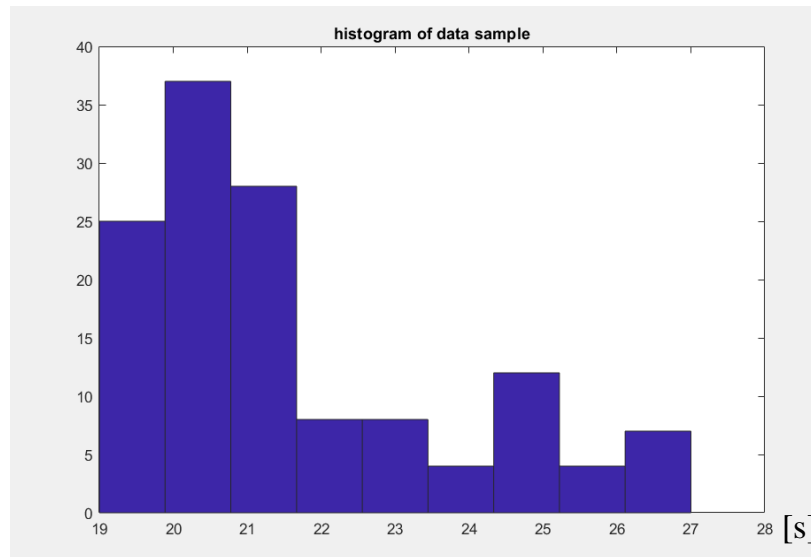

Figure 5-4 Histogram of the sub-sample

Using data obtained from production lines, the method illustrated in chapter 3.1.1 was used. To conduct the test, Matlab software was involved to perform more comparisons at the same time. The continuous distributions (Poisson, Exponential, Gamma, Lognormal, Logistic, Normal, Weibull) were all used for comparisons with the sample, so the output of the function is reported.

Since the sample was constituted of 133 observations, nine classes were used for the test. The test showed that data did not follow the distributions tested. Other tests are available in literature, (e.g Anderson-Darling, Kolmogorov-Smirnov), but a different solution was adopted in order to not "force" data.

5.1.2 The adopted solution

The examples proposed above were samples belonging to a single product variant. The hope was to be able to attribute to each product a known distribution, perhaps composed, and then model the alternation of the various products. Since it was not possible to assign a continuous probability density function to any of the sub-samples considered, it was therefore decided to continue using the times

of all the variants, and from these obtain an empirical distribution. This methodology was adopted to study the behaviour of both SMT lines.

It was decided to adopt a continuous and non-discrete distribution, for the following reason: the input data provided by the inspection machine record the time with a definition of one second (for example twenty-five or thirty-one seconds). In reality the inspected products do not only come out from the AOI at the end of the seconds but are registered as such since a further definition would not be convenient for the purposes of those machines.

An example of how the software that will be used to make the logical model work will use a continuous rather than a discrete distribution is provided: Figure 5-5 shows the two types of distributions, discrete and continuous, first superimposed then separated to show their equivalence.
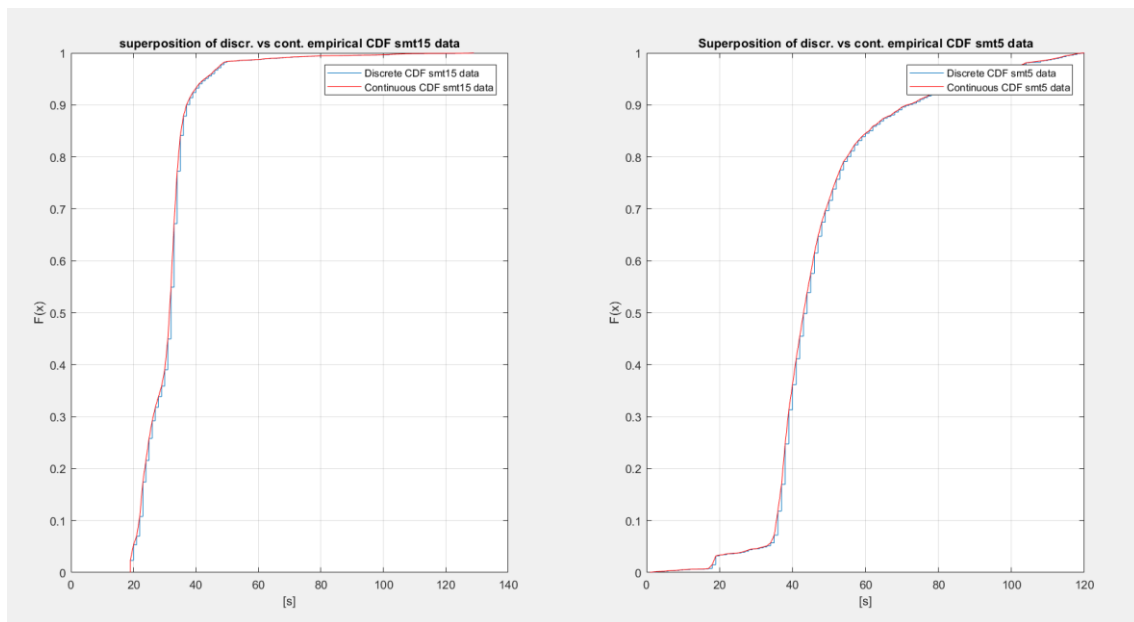

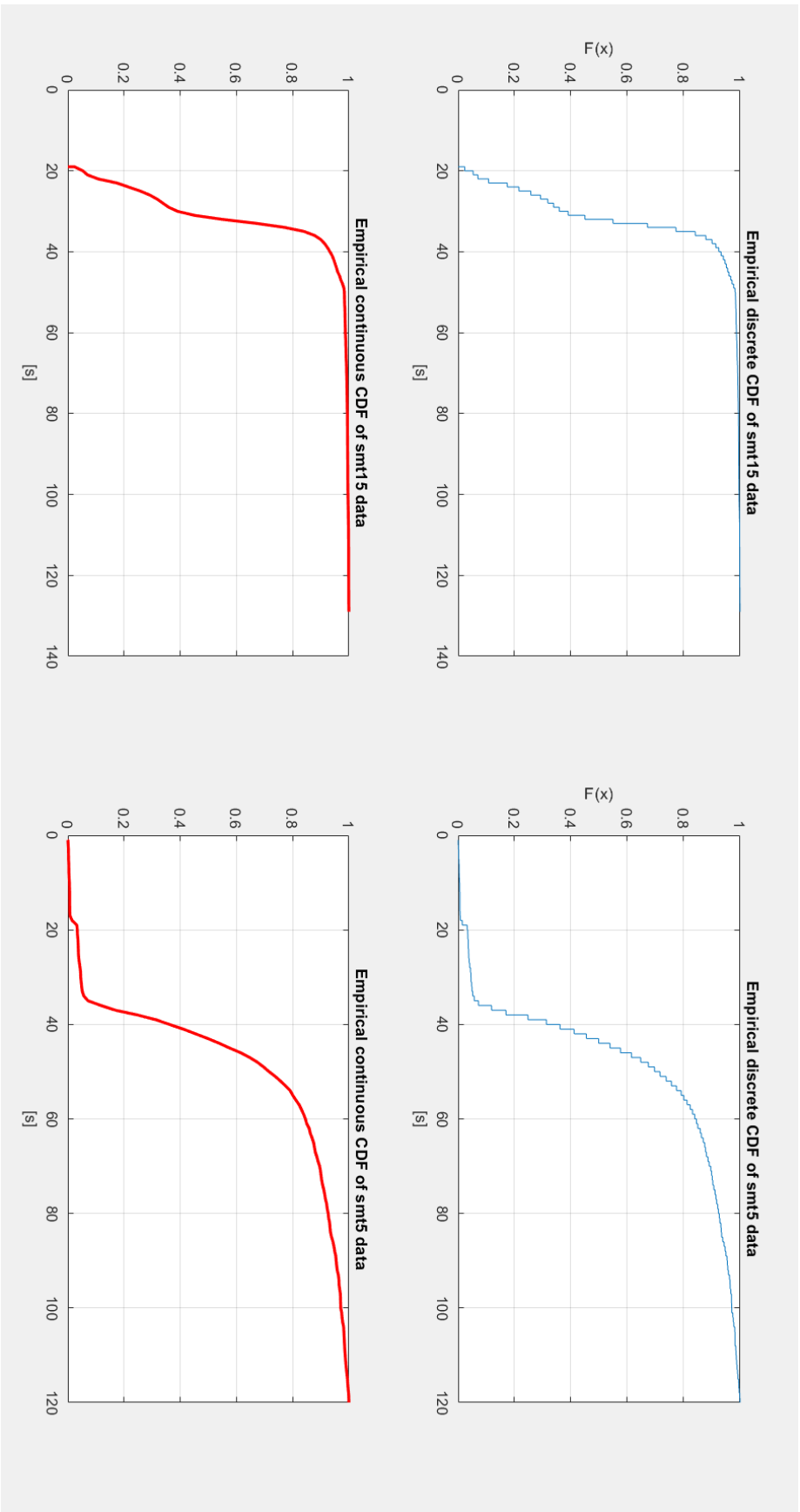*Figure 5-5 Cumulative distribution functions*

Figure 5-6 Discrete and continuous CDF of the sample

5.2   Building the model

5.2.1   Introduction

The software that was used for the simulations is Arena Rockwell. Arena is a discrete event simulation software produced by Systems Modeling and acquired by Rockwell Automation in 2000. It uses a proprietary simulation language, SIMAN. In the simulation environment of this software the user constructs an experimental model using the modules displayed as boxes representing the logical processes. Then there are lines that connect these blocks, these are the path followed by the entities that flow into the model. Each module has its specific function relative to the entities from which it is traversed, and operates on the time and flow variables, allowing the modeler to operate an approximate representation of the system to be constructed. The output data generated by the software can be recorded in files with a proprietary extension or even in text files, as well as reports can be customized. This software is also used by large companies in the field of sizing of production systems, optimization in general, and in the field of decision-making. Some examples of applications can be found in simulating different types of operations such as: call centers, or sizing of servers in the telecommunications field where the flow of data packets is simulated, batch size optimization in the food & beverage field, can find application also in the field of financial engineering for market operations.

A field in which it can be very useful is the industrialization of new products, in fact in designing a line made up of different machines the big advantage is in being able to estimate the starving / blocking conditions and the size of the buffers, but above all the machine that acts as a bottleneck of the line.

Model's assumptions

The model was developed using the Arena software which provides the great advantage of having the ability to manage transport activities with a dedicated section. The assumptions under which the model was developed are summarized below:

1. The parts are created with a source of randomness distributed according to the empirical distribution of the first line.

2. The first line produce so to never starve the second line.

3. The first line is never failed.

4. The parts are created if the carts waiting to be worked on the second line are less than four, corresponding to four hundred board, eight hundred products.

5. Parts are collected in a temporary entity that represents the trolley to be transported consisting of 100 cards (or, depending on the scenario, the two carts).

6. When the carts have been filled, the transport request is made.

7. The vehicle transports the cart.

8. The vehicle is never failed.

9. The trolley arrives at the second line and the parts inside it are instantly divided.

10. The vehicle is released and returns to the parking area designated by the scenario, if there are no requests.

11. The separated parts wait to be worked in a virtual buffer.

12. Parts are worked in the second line with random times that follow the empirical distribution of the second line.

13. The second line is never failed.

14. Parts are grouped in the cart entity at the end of the second line which carries 40 parts (or two carts depending on the scenario).

15. When the carts are full, the transport request is issued.

16. The cart arrives at the last line.

17. The vehicle is released again and returns to its designated parking base based on the scenario.

18. The cart exits the system and the data are collected.

The times with which the vehicle picks up the transport request thus depend on the policy that defines the parking station and the type of software; the quantity of parts that are transported depend on the policy used too.

5.3   Model's development

In this section of the document it will be shown how the model was constructed using the pre-set software blocks. The methods with which the blocks were built and the related input data that have been supplied to the system will then be highlighted. It will then be shown how the difference between the two types of software was implemented, since from the architectural point of view it is interesting to understand how the vehicle is called to the assigned base as a parking lot.
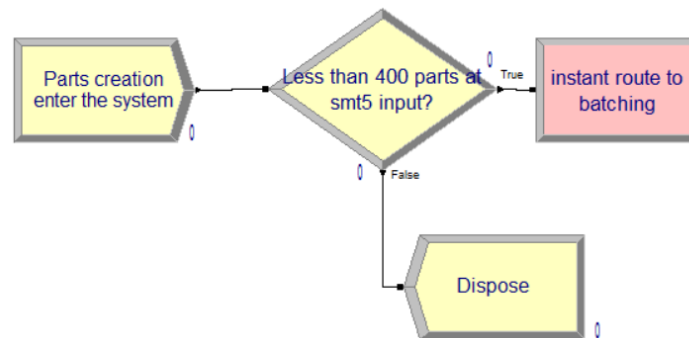
5.3.1   Product creation

Figure 5-7 Blocks used for creation process

As shown in Figure 5-7, in this set of blocks, the parts are generated and then enter the system. As soon as they are created, a check is performed: if there are already four carts, the equivalent of four hundred products, waiting to be processed by the second line, the part just entered immediately exits the system and is disposed with a delay in terms of time equal to zero; in this way it is as if the part had never entered the system. In the contrary case, the parts are sent immediately to the batching process that takes place at the exit of the first station.

A possible alternative to this type of verification is to model the production capacity using schedules, since the software allows you to enter periods of non-productivity using schedules. The three main ways in which it is possible to interpret the capacity reduction are illustrated despite the use of another type of verification for the studied model.

The software can read reduced capacity information through a given schedule of the capacity associated with the resource. There are three types of capacity reduction:
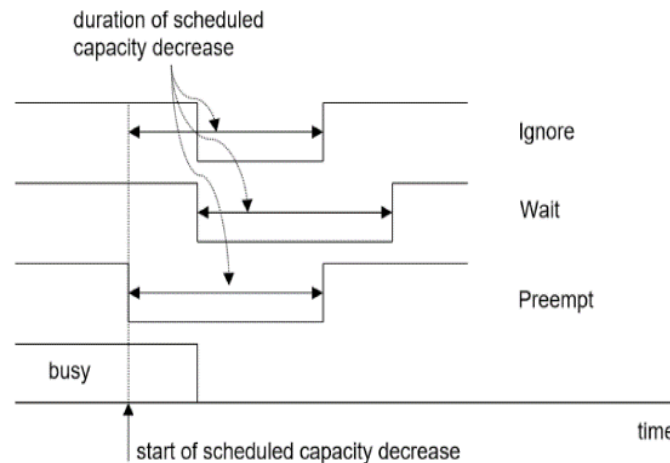

Figure 5-8 Different capacity decrease policies

Ignore schedule rule: with this rule the resource suffers a decrease in capacity as soon as the work in progress is finished. The duration in which the capacity is decreased therefore depends on the progress of the work in progress when the capacity reduction was expected: part of the break is in fact lost.

Wait schedule rule: the capacity decrease occurs when the processing in progress is finished. The duration in which it results in decreased capacity is fixed, because the pause occurs with a defined duration, the beginning of this period is a function of the progress of the work.

Preempt schedule rule: The capacity decrease is instantaneous and the work is interrupted. It will be resumed after the end of the period in which the capacity is reduced.

Despite this alternative it was decided to maintain the creation of the parts according to the buffer level at the entrance of the second line.
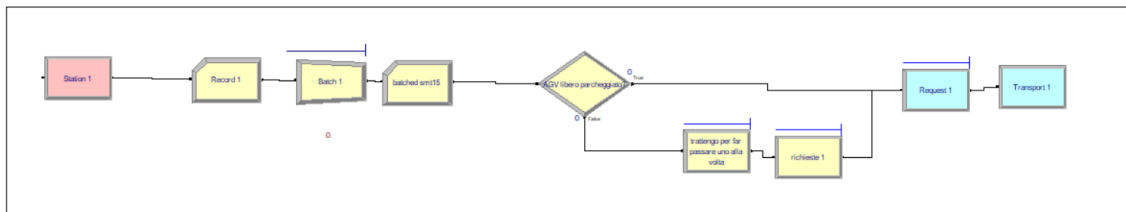
5.3.2 First Batching process

Figure 5-9 Blocks used for batching process

Figure 5-9 shows the parts enter the station, in this case used only to accommodate the products. A block records the entered parts, used in the construction of the model. Hence the batching in groups of one hundred boards (or more, depending on the policy being tested) at the end of which the temporary "trolley" entity is released. It is not permanent since the batch will be divided, differently from what will be seen in the second line. This entity then makes a call to the vehicle, waiting in the queue if this should be busy. The request is issued instantly only if the AGV is in idle status. When the vehicle arrives in line after the call, the parts are taken over by the vehicle and then the transport begins. It is necessary to remember that the part of the system considered goes from the exit of the first station to the entrance of the third and last station as it is the section of the system affected by the change in the type of transport to be implemented. At this point the first part of the system is modelled and shown in Figure 5-10.
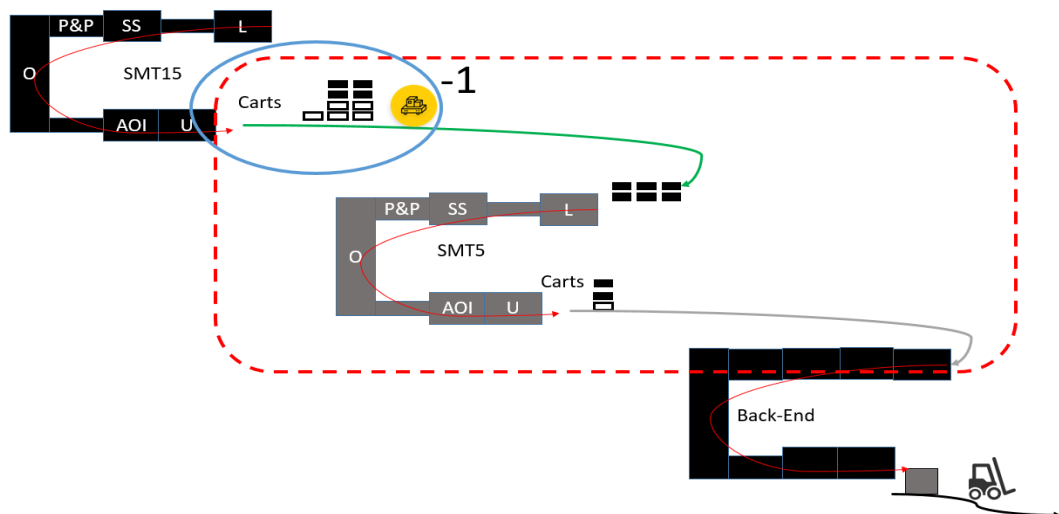

Figure 5-10 Modelled part of the system
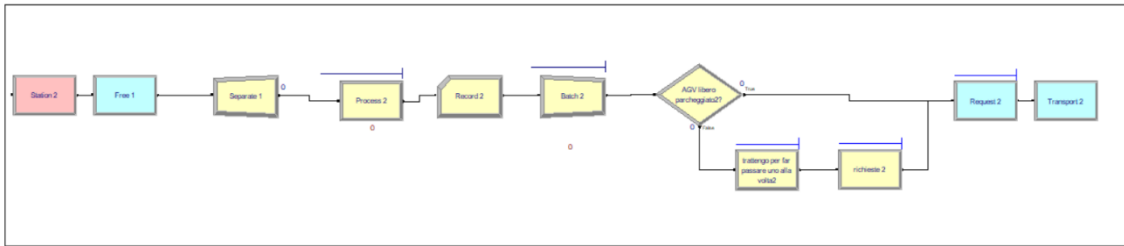
5.3.3 Second line

Figure 5.3.3.11 Blocks of the second line

The second line has, like the first, an entry block. Immediately afterwards, a logical operator frees up the transport vehicle, after which the products in the carts are separated and return to constitute different entities. After the products go through a single block that works like four separate ones: queue, seize, delay, release. These four summaries in one server to simulate and model the second line, in fact this one has a queue in which the products wait for the machine to be free, at this point they occupy it and therefore they are virtually worked with a delay set as explained before.

At the end of this delay they pass from the release block which reassigns the "free" status to the machine and then parts undergo a batching process identical to what was seen for the first line, except for the fact that the "cart" entity is now permanent and the number of product batched is different. The second part of the system is represented in Figure 5-11.
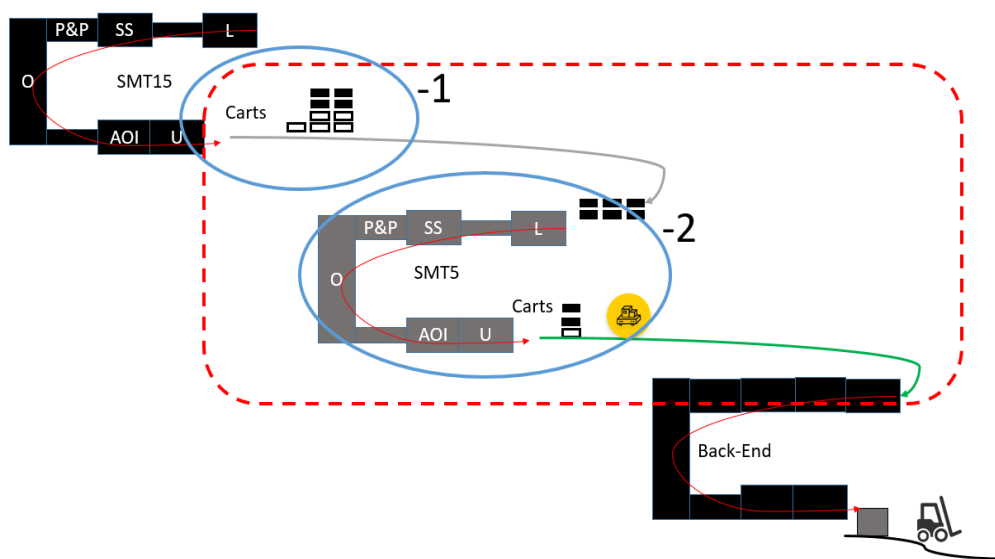
Figure 5-11 Modelled part of the system

5.3.4 Third line
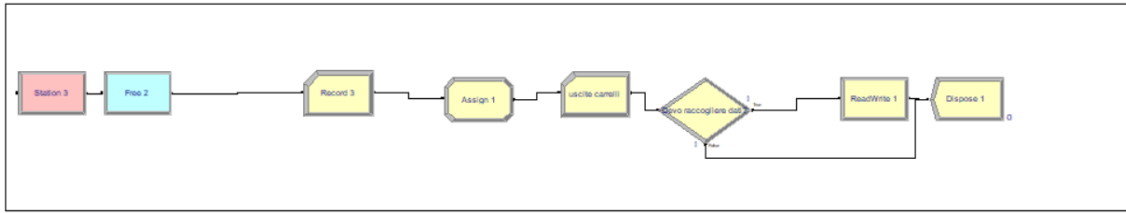
Figure 5-12 Third line blocks

The carts enter the last station and the vehicle is released immediately. The cart entity has been set as permanent because it is not necessary to re-divide the products and therefore the memory required for the calculations can be saved, reducing the number of entities in the system. In fact in this last station the outgoing products are counted simply by tracing the number of trolleys delivered in this last station. Then several blocks are gathering data about the performance, and the parts are then destroyed.

Figure 5-13 The modelled part of the system

5.3.5 Transporters

As mentioned at the beginning of the paragraph, the great advantage of using the Arena Rockwell software is the presence of a module dedicated to transport, making it simpler to simulate its behavior.

There is an advanced transport template where each type of vehicle must be declared. In fact, there are different types of ways in which materials can be moved: by conveyor, by free route vehicles, and - as in the case considered - guided vehicles.

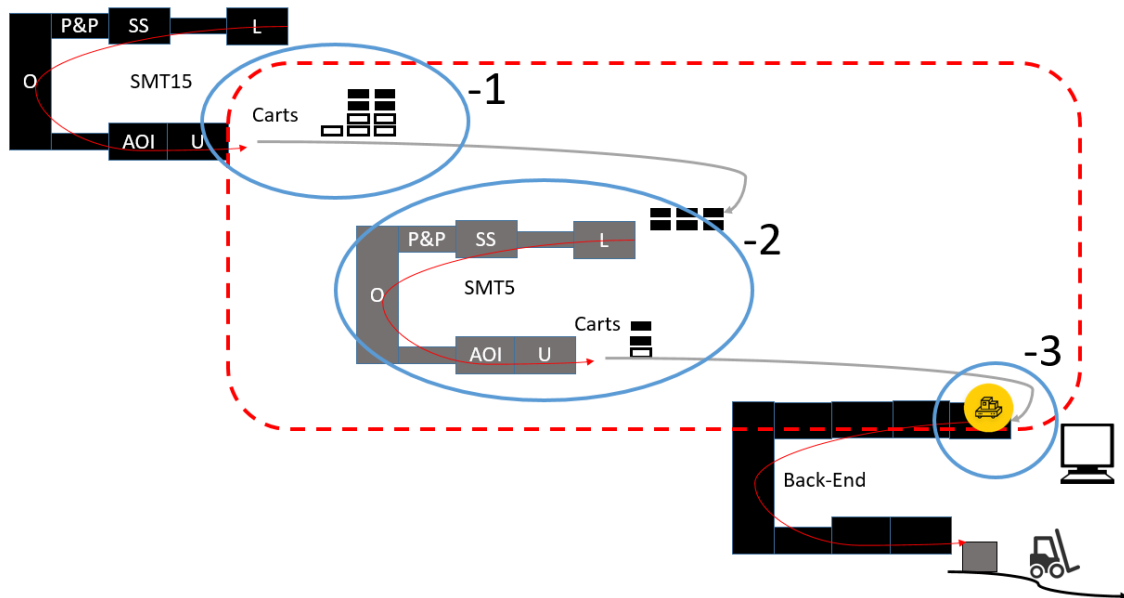*Table 5-1 Input data for vehicle*

Name	Number of units	Type	Network Name	Velocity	Units	Turning velocity factor	Zone control Rule	Report Statistics
agv	1	Guided	Network 1	25	Per minute	1.0	Start	y

As shown in Table 5-1, it is necessary to make a series of statements. The name given to the vehicle is "agv", consisting of a single "guided" unit. The speed is 25 [units / minute]. Arena does not allow to declare units of measurement and it is therefore necessary to remain consistent if it is necessary to make more declarations of measures involving length. It is also possible to set acceleration and deceleration when the vehicle approaches intersection zones, just as it is possible to provide a deceleration coefficient for when facing curves. Since a curve is declared as such in the software only if it corresponds to an intersection it was decided not to use this function which would lead to an increase in intersections and therefore of complication for the purposes of the simulated calculation. Instead, it was preferred to round up the declared lengths which will soon be presented. Another feature of the declared vehicle is the type of control that this presents on the occupied areas. It can be in fact of two types: control zone at start and control zone at the end. There are two different methods of giving vehicles control over the zones traveled, in this case the "at start" method will be used. Figure 5-14 shows the operation of the two different ways in which the vehicles take control of the zones:
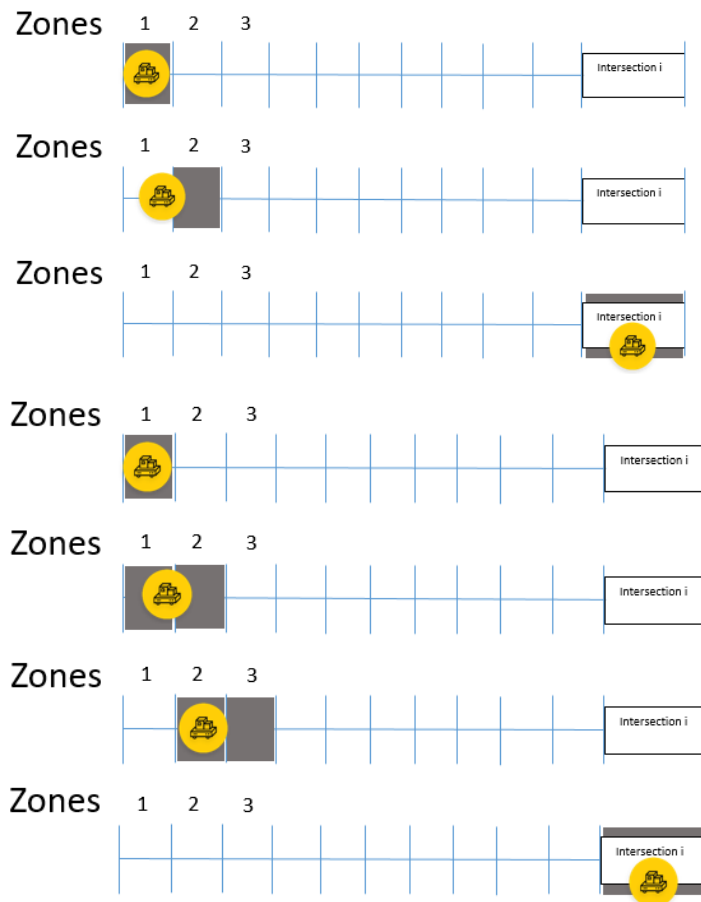
Figure 5-14 Seizing policies of zones

With the "release at start" policy it can be noticed how the zones are freed as soon as the vehicle engages the next zone. As shown in Figure 5-14, the zone 1 is released as soon as the vehicle approaches the zone 2 engaging it. Once the intersection is reached, it is in turn seized so that the vehicles cannot overlap on the same areas at the same time.

With the policy of "release at the end" the area previously occupied is released as soon as the vehicle reaches the end of the next zone. In this way there are always two occupied zones, except when the vehicle occupies an intersection for some type of operation where, as in the previous case, only the intersection is seized. Since in the model only one transporter is used the policy "released at start" is used even if there will be no problems about seizing zones.

5.3.6 Network Links

The information referring to the trajectories is then provided to the software: each station is associated with an intersection and a link between each intersection is requested by the software. A representation of the network is provided in Figure 5-15, its information are resumed in Table 5-2 Links and properties.
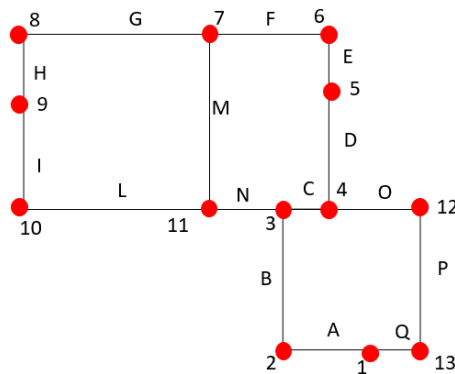

Figure 5-15 Network link used by the AGV

Name	Type	Beginning intersection	Ending intersection	Zone length	Velocity change factor
Link A	Unidirectional	Intersection 001	Intersection 002	34	1
Link B	Unidirectional	Intersection 002	Intersection 003	52	1
Link C	Unidirectional	Intersection 003	Intersection 004	12	1
Link D	Unidirectional	Intersection 004	Intersection 005	42	1
Link E	Unidirectional	Intersection 005	Intersection 006	14	1
Link F	Unidirectional	Intersection 006	Intersection 007	42	1
Link G	Unidirectional	Intersection 007	Intersection 008	52	1
Link H	Unidirectional	Intersection 008	Intersection 009	21	1
Link I	Unidirectional	Intersection 009	Intersection 010	36	1
Link L	Unidirectional	Intersection 010	Intersection 011	53	1
Link M	Unidirectional	Intersection 007	Intersection 011	57	1
Link N	Unidirectional	Intersection 011	Intersection 003	30	1
Link O	Unidirectional	Intersection 004	Intersection 012	62	1
Link P	Unidirectional	Intersection 012	Intersection 013	52	1
Link Q	Unidirectional	Intersection 013	Intersection 001	43	1

Table 5-2 Links and properties

Table 5-2 shows the information that has been transmitted to the simulation software. As mentioned before, the length of each segment does not have a unit of measurement. The vehicle speed has been declared in [m / minute] and therefore the lengths are declared in [m].Other information can be entered, not shown in the table; the constraints of the real system concerning the one-way systems are reported in the software by means of the "unidirectional" information which therefore blocks the direction of travel of the sections.

Once all the connections have been created, it is therefore possible to proceed with a network in which the newly established routes can be used in various combinations and then assigned to the vehicle. In the case considered, there is only one AGV, so only one network is declared. It is possible, in the case in which more vehicles are present, to form networks forming sets with some of the declared connections.

5.3.7 Vehicle's logic

At time Zero a single dummy type entity is created for driving the moving logic of the vehicle. This entity will remain in circulation in the system for the whole duration of the simulation, it is unique and is never disposed. In a single logic block the entities are held until the following conditions are found:

- If the vehicle is not on the designated parking position
- if the vehicle is idle
- if there are not request for transport

If all these conditions occur at the same time (if the vehicle should therefore be free on a station without parking and without requests) then a transport request is issued by this dummy entity. If conditions are matched the vehicle will be called to the designated parking area and the dummy entity will be transported to the same station; the entity will be then routed back to the hold block with a time delay of zero. Basically if there are no requests a "trick" is used, the AGV is called on the parking lot and here the entity instantly transports itself freeing the vehicle. At the end of this activity the condition "if vehicle is not on the parking lot" will no longer be matched and the recall entity will remain in the hold position again.

In the *advanced software* type of logic the path is more articulated. In fact, the operation is similar to the basic version since at time zero a single dummy type entity is created and is intended to circulate in the model for the duration of the simulation, without ever being disposed. The difference consists in the fact that the check is carried out with the same previous logical conditions but the entity is called up in two steps: a first call occurs if no requests are present and the vehicle start moving toward its parking station. When the vehicle arrives at the node in which the path for the two station is separating a further check for requests is performed, in case a presence of those, this will be immediately taken over by the AGV. Otherwise, If these are not present, the vehicle then chooses the designated parking space and moves towards it.

Figure 5-16 Block used for driving the vehicle

Figure 5-16 shows how the logic driving the AGV has been implemented, with several blocks, in order to drive the vehicle according to the scenario considered.

The model has been built in order to repeat a number of replications that is an integer multiple of the total scenarios. At the beginning of the simulation a series of blocks assign to the variable their values, by cycling an index and taking them from a matrix saved as a variable.

6 Application to the industrial case

6.1 Identification of the Warm up period

Since the main performance driving the simulation is the vehicle utilization, the expectation is that this performance will start at a low level thus increasing and keeping itself near a steady state level. The second performance driving the simulation is the time between delivered carts at the third station although the suspicion is that this does not undergo enormous variations in the different scenarios. To demonstrate what has been stated in chapter 3.3 the principle explained above, an image where the trend in vehicle utilization is clearly recognized is presented, and the solution to this warm-up period identification will be proposed. Results from the method will be shown later, along with the techniques used for this purpose.

```
Time definition: 1 min.
First observation: 0 min.
Number of replication: 1
in this analysis the following scenario is analyzed: 5
Second check of scenario:  5
```
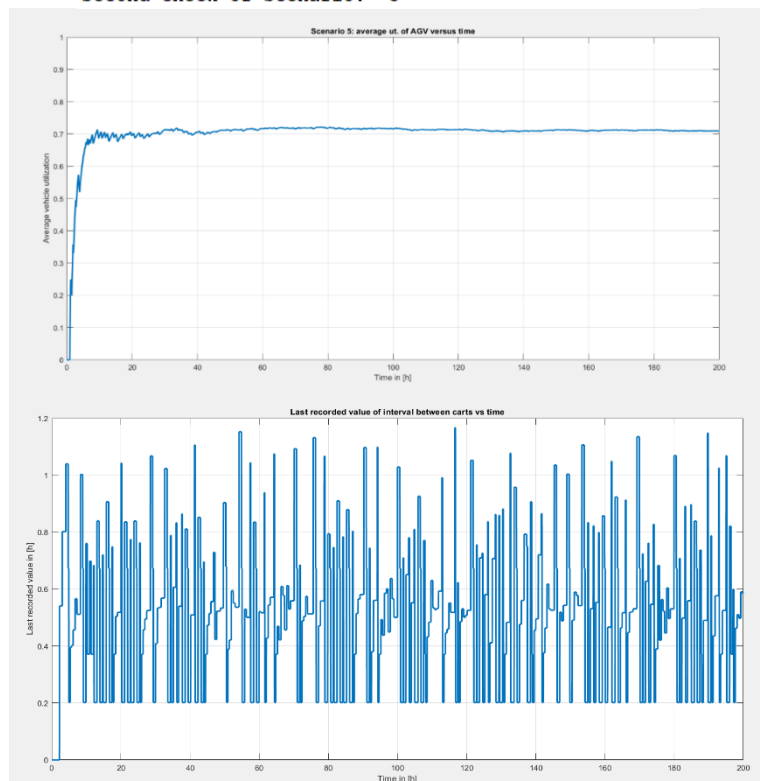

Figure 6-1 Trend of the AGV utilization and time interval between delivered carts

As can be seen from Figure 6-1, what has been stated in chapter 3.3 is confirmed by the results. It should be pointed out that the graph presented is only a

demonstration of the presence of a warm up period and belongs to a single replica of a single scenario: in particular scenario five in which only one cart is transported. Another phenomenon that can be noticed is the fact that the value of the interval time between the carts takes much less time to reach its steady state equilibrium.

In discrete event simulation, variables such as vehicle use are obtained by integrating their state over time. The same applies to variables such as resource usage or the average number of products in the queues.
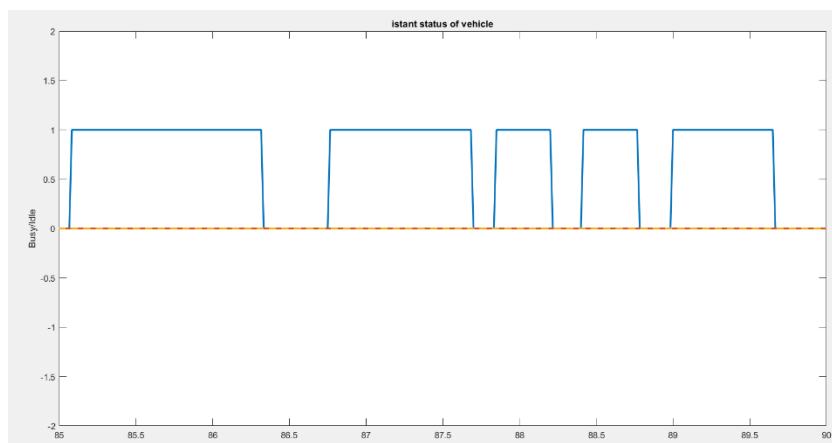

Figure 6-2 Values assumed by vehicle's state

$$Average\ state\ variable = \frac{\int_0^T Q(t)dt}{T}$$

6.2 Welch method application

After having selected the warm-up period this can be easily inserted in the Arena Software to clean the statistics collected until the end of the calculated time. Since the variables that the model tries to estimate are the utilization and the time elapsed between the delivery of the carts to the last station, both have been studied through the Welch method. The moving averages with windows of different value are shown in Figure 6-3: the limit that will be imposed is subjective but based on the analysis. Help in selecting the limit is given by the smoothness of the moving average.

```
Time definition: 15 min.
First observation: 0 min.
Number of replication: 10
In this analysis the following scenario is analyzed: 5
Second check of scenario:  5
```
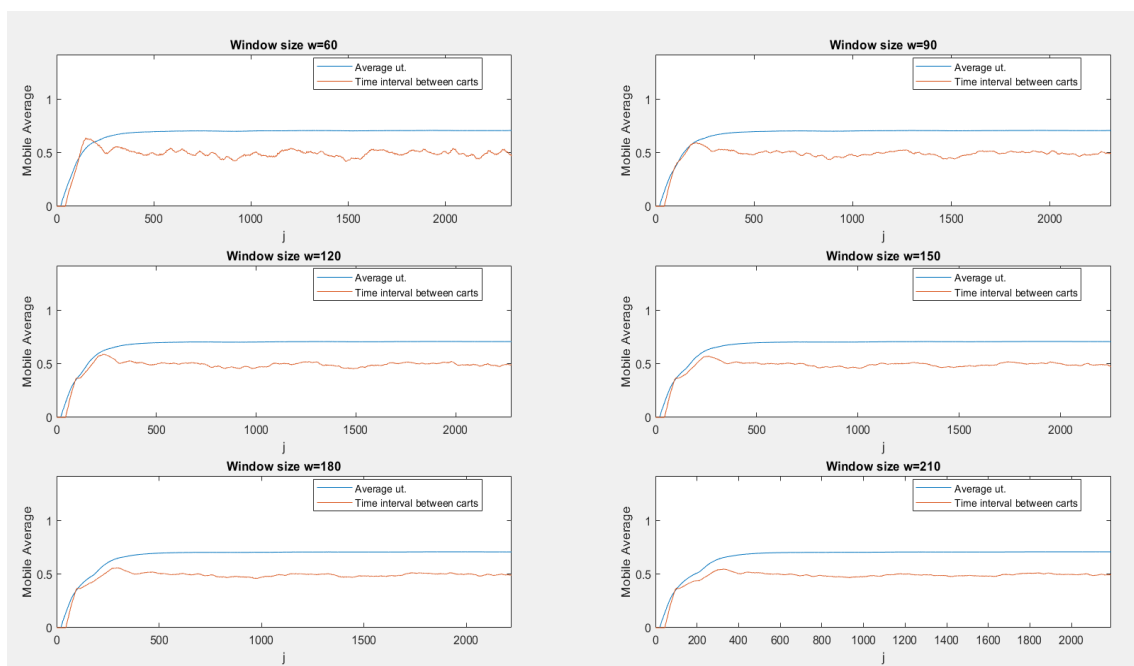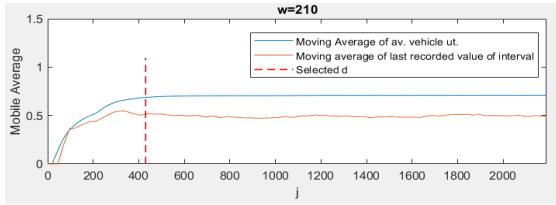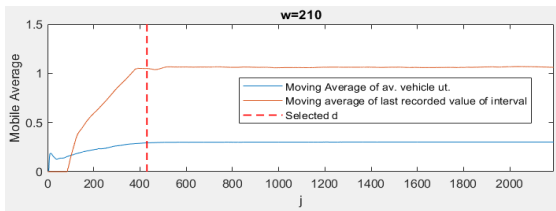

Figure 6-3 Moving average with different windows

The results shown in Figure 6-3 belong to only one scenario; since the choice of policies used heavily influences the outputs, in particular the average utilization value will have to consider other scenarios and use a single warm up time for convenience. Please note that the highest window is obtained out of a period of 52.5 [h], even if from initial conditions the warm-up period seemed to be shorter.
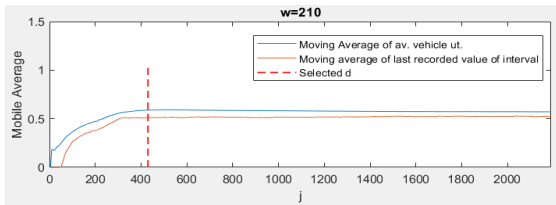
The time between deliveries is expected to change significantly too, but the carts will be in pairs, thus halving the value of the measured delivery interval.
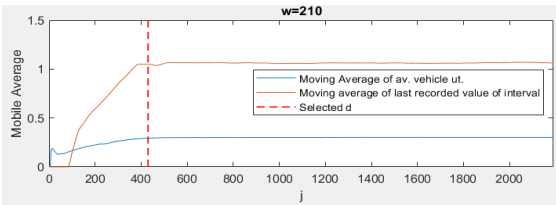

Figure 6-4 Some scenarios with moving averages

The analyzes carried out for different scenarios are reported, with the aim of seeking a warmup time that satisfies the "slowest" of the scenarios. From the

86

images it is shown how the 430th sample, corresponding to 107.25 [h], was chosen as the term for the common warmup.

6.3   Replication parameters

For each scenario the simulation time unit is set to hours. Warmup has been set to 110 hours, and after that a total simulation time of one working week (120 hours) has been considered. Even if the warmup is too conservative for some scenario, keeping the same for all of them permits to set the collection of data in a uniform way. Every week has been simulated for a total of 500 times for each scenario, thus providing information about means of performance and to study the statistical indicators of the collected data; then further replications may be needed to achieve better estimates.

Once the warmup period has been vanished, the statistics are cleaned and data collected: vehicle utilization, times between delivered carts, production achieved in the simulation time (steady state), and the Work in process (WIP) for each scenario.

A table will resume the main performances of each scenario, thus providing a set of information about each scenario.

Variables are calculated as follows:

- Automated guided vehicle utilization: this variable depends on the total amount of time, in the steady state simulation period, the vehicle has been moving. As the Warmup ends the statistic are cleaned but the buffers maintain their levels, so in the steady state the vehicle has a less variable average utilization.

- $IT(agv, 1, t) =$
$$\begin{cases} 1 & \textit{if the transporter } agv, \textit{unity number } 1 \textit{ is busy at time } t \\ 0 & \textit{if the transporter } agv, \textit{unity number } 0 \textit{ is idle at time } t \end{cases}$$

- $AGV\_ut = \dfrac{\int_{110}^{T_{fin}} IT(agv,1,t) \, dt}{(T_{fin}-110)}$

- Where IT is a SIMAN function indicating the state of the vehicle: 0 if Idle, 1 if Busy. Please note that the vehicle is considered busy also when without a load, moving toward a request.

- $\text{Output Products} = NC(output\ products)$ is a statistic collected in each scenario. NC is an operator coming from the SIMAN language used by Arena software. This variable is set to zero when the warmup period finishes.

- Cycle time: is the total amount of product that the vehicle has delivered to the final station in the steady state simulation time. It is strictly linked to the output products variable.

- $CT = \dfrac{(T_{fin}-110)[h]*3600\,[\frac{s}{h}]}{Output_{products}\,[p]} = [\frac{s}{p}]$

- Work In Process: it is the total amount of products of type "p" in system at time "t":

- $WIP(p,t) = N_{in}(p,t) - N_{out}(p,t)$

- $WIP_{av} = \dfrac{\int_{110}^{T_{fin}} WIP(p,t)\,dt}{(T_{fin}-110)} \qquad [parts]$

- The time between each cart delivered is calculated as the interval between delivery j and j-1. In each replication a mean of this value is collected. In case of two carts transported this value is then divided by two.

$$TB_j = \frac{\left(Time_{delivery_j} - Time_{delivery_{j-1}}\right)[h]}{Number\ of\ cart\ per\ track\ [cart]} = [\frac{h}{cart}]$$

6.4 Output

Results will be resumed in Table 6-1.

Scenario	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
N	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500
AGV_UT	76,142	43,438	76,251	43,425	71,517	43,472	71,447	43,432	56,729	30,193	56,751	30,197	56,713	30,185	56,751	30,194
c_UT	0,086	0,050	0,086	0,052	0,085	0,052	0,079	0,049	0,054	0,019	0,052	0,019	0,053	0,020	0,053	0,020
WIP	489,1	515,3	490,0	515,5	516,1	526,0	520,6	526,1	484,2	519,5	484,2	519,6	487,4	519,6	487,3	519,7
c_WIP	0,239	0,340	0,284	0,315	0,413	0,449	0,383	0,430	0,090	0,086	0,085	0,094	0,163	0,100	0,177	0,108
Interval	0,532	0,532	0,533	0,532	0,533	0,533	0,533	0,533	0,533	0,533	0,533	0,533	0,533	0,533	0,533	0,533
Cycle_time	47,926	47,949	47,931	47,934	47,913	47,968	47,927	47,995	47,934	47,966	47,929	47,959	47,939	47,977	47,937	47,955
c_CT	0,024	0,027	0,023	0,028	0,025	0,031	0,023	0,030	0,022	0,027	0,023	0,026	0,021	0,027	0,021	0,028
Output products	9014	9010	9013	9013	9017	9006	9014	9001	9013	9007	9013	9008	9012	9004	9012	9009

Scenario	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
N	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500
AGV_UT	69,834	35,759	56,780	30,178	69,824	35,726	56,723	30,179	70,858	37,536	56,771	30,183	70,729	37,476	56,741	30,195
c_UT	0,032	0,070	0,049	0,019	0,031	0,072	0,054	0,020	0,056	0,080	0,051	0,018	0,057	0,084	0,051	0,018
WIP	487,4	518,9	484,2	519,5	487,1	518,5	484,2	519,5	495,9	541,1	487,3	519,6	495,0	540,8	487,4	519,7
c_WIP	0,233	0,810	0,091	0,092	0,224	0,825	0,086	0,091	0,429	0,929	0,172	0,096	0,388	0,977	0,172	0,103
Interval	0,532	0,532	0,532	0,533	0,532	0,532	0,533	0,533	0,533	0,533	0,532	0,533	0,533	0,532	0,533	0,533
Cycle_time	47,917	47,923	47,918	47,961	47,924	47,906	47,949	47,971	47,938	47,946	47,917	47,976	47,930	47,917	47,940	47,933
c_CT	0,022	0,026	0,022	0,028	0,021	0,026	0,021	0,029	0,025	0,027	0,022	0,027	0,023	0,028	0,022	0,026
Output products	9016	9015	9016	9008	9014	9018	9010	9006	9012	9010	9016	9005	9013	9016	9011	9013

Table 6-1 Results

6.5 Cycle time and interval between delivered carts

To provide a faster identification, scenarios identified by an odd number are those transporting one cart, the even-numbered are carrying two carts. Thanks to a visual representation explained in Figure 6-5, the results are presented and considerations can be made about the scenarios.
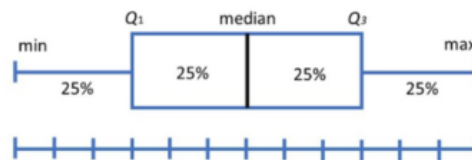

Figure 6-5 Box plot

In the Boxplot representation the main body of the plot is made up from the first quartile (Q1) up to the third (Q3). A quartile is a type of quantile, the first one divide the lowest 25% of the data from the rest, the third one separate sample at the 75%. The external value represents the following value:

$$Lower\ value = Q1 - 1.5 * IQR$$

$$Upper\ value = Q3 + 1.5 * IQR$$

Where IQR is the range between Q3 and Q1. Figure 6-6 will present box plots of cycle time.
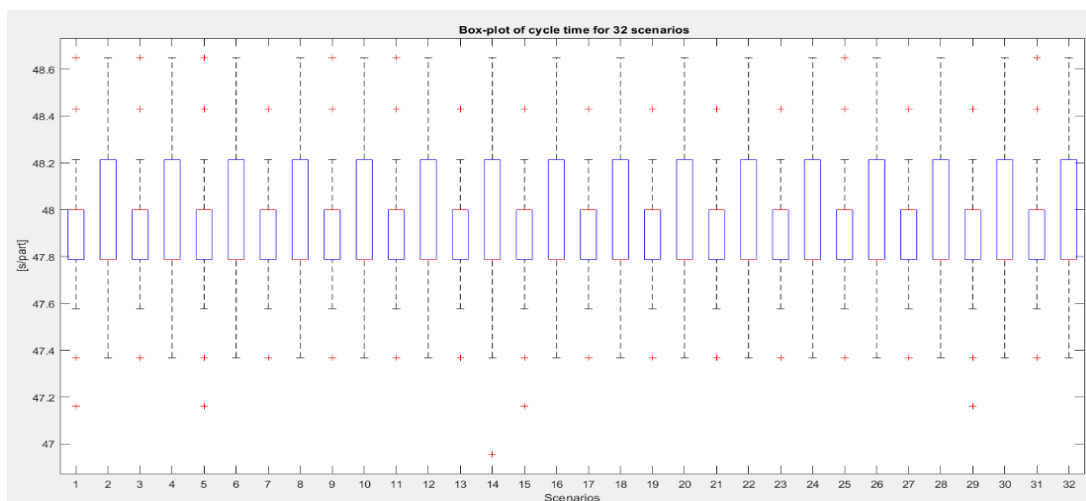

Figure 6-6 Box plot representation of cycle time

Using the Bonferroni Approach the identified standard is scenario 22, since it is the scenario with the lowest cycle time. The results are presented in Table 6-2.

Scenario 22		Interval
vs	Scenario1	[-0,07;0,04]
	Scenario2	[-0,1;0,01]
	Scenario3	[-0,08;0,03]
	Scenario4	[-0,09;0,03]
	Scenario5	[-0,06;0,05]
	Scenario6	[-0,12;0]
	Scenario7	[-0,08;0,03]
	Scenario8	[-0,15;-0,03]
	Scenario9	[-0,08;0,02]
	Scenario10	[-0,12;0]
	Scenario11	[-0,08;0,03]
	Scenario12	[-0,11;0]
	Scenario13	[-0,08;0,02]
	Scenario14	[-0,13;-0,01]
	Scenario15	[-0,08;0,02]
	Scenario16	[-0,11;0,01]
	Scenario17	[-0,06;0,04]
	Scenario18	[-0,07;0,04]
	Scenario19	[-0,06;0,04]
	Scenario20	[-0,11;0]
	Scenario21	[-0,07;0,03]
	Scenario23	[-0,09;0,01]
	Scenario24	[-0,13;0]
	Scenario25	[-0,09;0,02]
	Scenario26	[-0,1;0,02]
	Scenario27	[-0,06;0,04]
	Scenario28	[-0,13;-0,01]
	Scenario29	[-0,08;0,03]
	Scenario30	[-0,07;0,05]
	Scenario31	[-0,09;0,02]
	Scenario32	[-0,08;0,03]

Table 6-2 Pairwise comparisons of scenarios

As can be stated from the results, there are scenarios [8,14,28] where the value of zero is missed. From the Bonferroni approach it can be stated that scenario [22] is better than the above numbered scenarios. The interval are so tight that further considerations can be made; since the comparisons are among *k*=31 scenarios this has an impact on the individual confidence interval used by the method, therefore making it narrower. Other consideration can be made about the seeds used by the software to generate random numbers, in fact replications do not share common random number since the number of replications is imposed by:

$$32[scenarios] * 500 \left[\frac{replications}{scenario}\right] = 16000[replications]$$

Arena repeats the same sequence of seeds when a replication is needed. Given the high number of scenarios, running each scenario in separate moments would have been more expensive in terms of time consuming. Since the higher or lower cycle times can be the result of scenarios where machines were "slow", and since the results shows that mean values are all comprehended between 47,9 and 47,96 [s/piece] it was decided to analyse other performances like WIP and vehicle utilization.

The hypothesis is that the system is dominated by machines and not by the vehicle, since all the scenarios are showing a very similar cycle times.

6.6 WIP

As said in Chapter 4.14.1, for each cart entering the second station there are 2.5 carts exiting the station. The guess was that by keeping the vehicle parked on the second line the system would be able to manage faster the products. Even if there are no benefits in terms of cycle time or delivered products, a benefit in term of WIP can be achieved.

From Figure 6-7 is possible to notice, by parking on the first line, how the advanced software (scenarios from 1 to 4) helps in reducing WIP with all other policies being constant (scenarios [1,3] vs [5,6], scenarios [9,11] vs [13,15]).
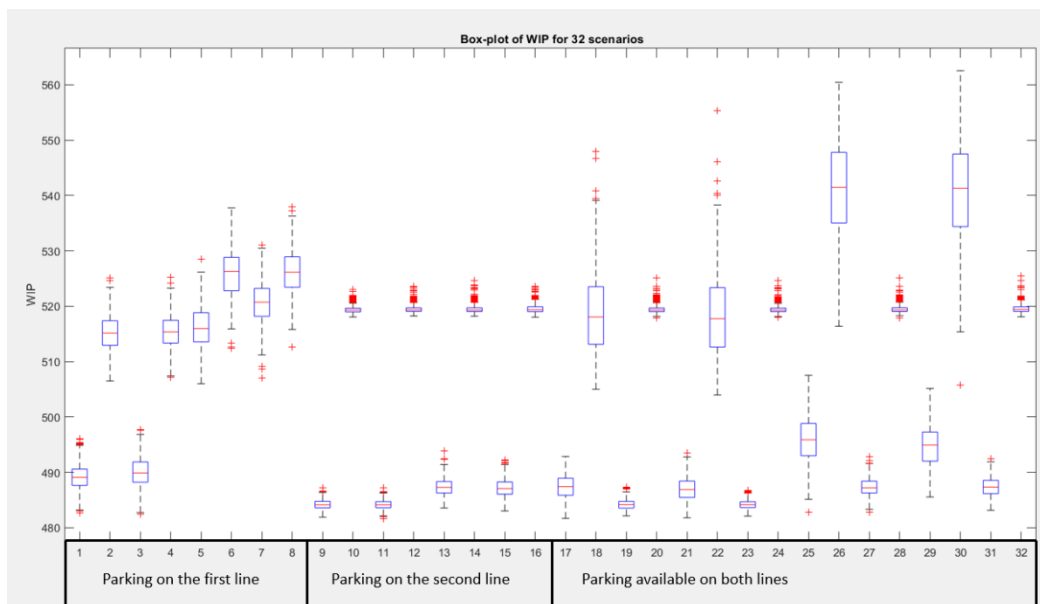

Figure 6-7 Box plot of WIP among all scenarios

The software moving the vehicle is used to detect requests while moving toward the parking station, allowing the AGV to identify the demands before passing the junction after which it should make a section of greater length imposed by the one way. From the box plot diagram it is possible to draw a further conclusion, that the range of values of WIP, maintaining the parking on the second line, is much narrower with all other policies being equal.

Further analysis will then be provided, considering only scenarios with two carts transported, since is supposed that there are no benefits in terms of cycle time by transporting only one cart per track. The aim is to select the scenarios with a lower utilization of the vehicle but considerations about the WIP can provide more information about the effects of the policies.

In Figure 6-8, the box plot diagrams for WIP of scenarios with two carts transported per track are presented.
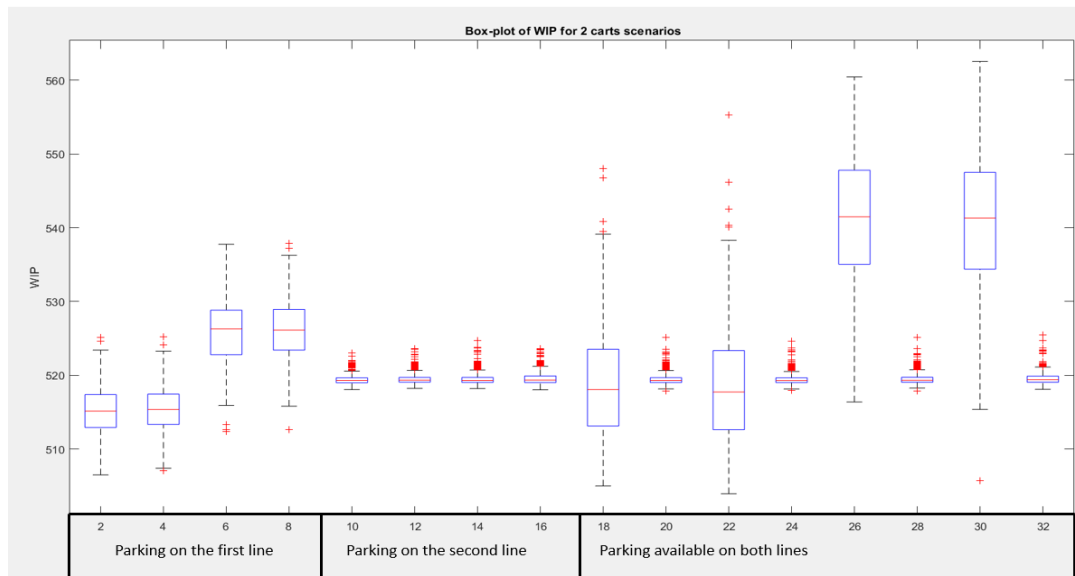

Figure 6-8 Box plot of WIP among scenarios

Considering scenario 2 as the standard because is the one with the lowest WIP the comparison is made through a Matlab algorithm providing the upper and lower bounds.

Scenario 2		Interval
vs	Scenario4	[-0,87;0,49]
	Scenario6	[-11,58;-9,93]
	Scenario8	[-11,63;-10,02]
	Scenario10	[-4,76;-3,73]
	Scenario12	[-4,86;-3,83]
	Scenario14	[-4,86;-3,83]
	Scenario16	[-4,97;-3,92]
	Scenario18	[-4,97;-2,4]
	Scenario20	[-4,8;-3,77]
	Scenario22	[-4,58;-1,96]
	Scenario24	[-4,77;-3,74]
	Scenario26	[-27,3;-24,39]
	Scenario28	[-4,87;-3,84]
	Scenario30	[-27,01;-23,97]
	Scenario32	[-4,95;-3,91]

Table 6-3 Bonferroni approach for comparison

As the results are shown in Table 6-3, scenario 2 differs from all the other scenarios except for scenario 4. This is a strong confirmation that the advanced software would help in reducing WIP when parking on first station is the only available base for the AGV.
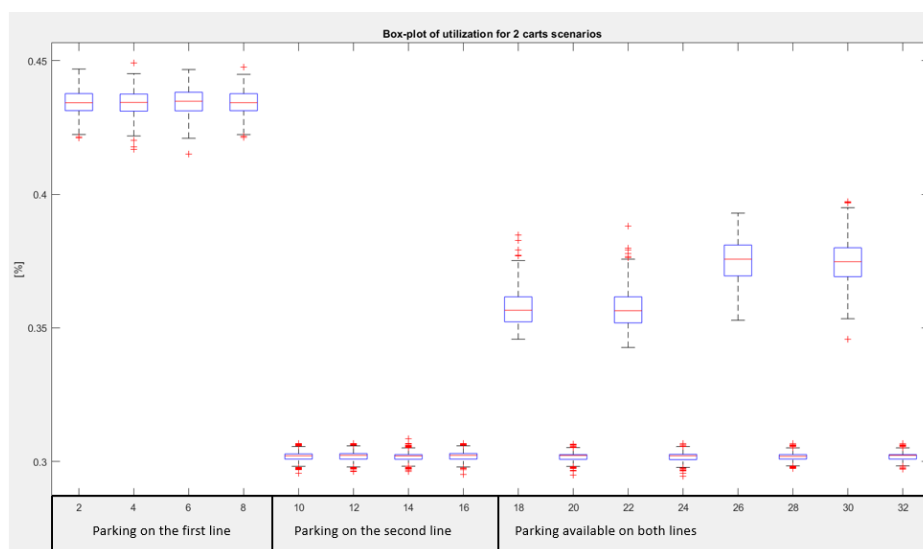
6.7   AGV utilization

Figure 6-9 Box plot of AGV utilization among scenarios

Proceeding in the same way as for the WIP, the lowest mean of vehicle's utilization is for scenario 20: 30.178%. This is considered as the "standard".

Scenario 20		Interval
vs	Scenario2	[-13,34;-13,18]
	Scenario4	[-13,33;-13,17]
	Scenario6	[-13,38;-13,21]
	Scenario8	[-13,33;-13,18]
	Scenario10	[-0,05;0,03]
	Scenario12	[-0,06;0,02]
	Scenario14	[-0,05;0,03]
	Scenario16	[-0,06;0,02]
	Scenario18	[-5,69;-5,47]
	Scenario22	[-5,66;-5,44]
	Scenario24	[-0,04;0,04]
	Scenario26	[-7,48;-7,24]
	Scenario28	[-0,04;0,03]
	Scenario30	[-7,42;-7,17]
	Scenario32	[-0,06;0,02]

Table 6-4

As shown in Table 6-4, what results from the study on utilization is that there are some scenarios where this performance demonstrate significantly lower values. This information is reinforced by the analysis carried out through the Bonferroni method. Please note that scenarios [18,22,26,30] are those with a preferred parking station on the first line. Once again, the guess that keeping the vehicle on the first line was not the optimal choice is confirmed. A further consideration is that scenarios [20,24,28,32] are those with the preferred parking on the second line, but with different priorities of requests. The prioritization has no effect on the vehicle's utilization, and neither on the WIP, according to the results.

It has therefore been shown that the policy for ordering contemporary requests does not seem to affect the system. As for the advanced software, this can help if vehicle has to park on the first line only from a WIP point of view.

6.8 Subset selection

By applying the selection procedures shown in chapter 3.6, once again Matlab is used to implement the procedure. The scenario chosen is, as for the Bonferroni approach, the number twenty, since, it is the one with the lowest utilization. The set found with this procedure is:

$$I = [10, 12, 14\ 16, 24, 28, 32]$$

And scenario number twenty is part of the optimal subset since is the "best" for the comparison that aim at selecting the lowest possible performance.

```
Scenario number 10 is part of the subset respecting the threshold
Scenario number 12 is part of the subset respecting the threshold
Scenario number 14 is part of the subset respecting the threshold
Scenario number 16 is part of the subset respecting the threshold
Scenario number 24 is part of the subset respecting the threshold
Scenario number 28 is part of the subset respecting the threshold
Scenario number 32 is part of the subset respecting the threshold
```

Figure 6-10 Output of subset selection algorithm

This is a further confirmation of considerations made in chapter 6.7.

7 Final considerations

7.1 Model limitation

The study proposed in this document is aimed at identifying the best possible policy to manage the usage of the vehicle. For a wider point of view it should be taken into consideration the fact that shifts in which this product is manufactured can be different for the first line but the target is to never starve the second line, so to never starve the Back End line which is a product-dedicated line. In the real System an higher level of stock can be held at the first line where space for storing carts filled with finished products (from a first line point of view) is available. This was not modelled since the focus was on the usage of the vehicle and the system is "blind" with respect to the real amount of product ready to be manufactured on the second line.

Further considerations can be made upon the vehicle, since the system do not take into consideration the presence of the other AGVs moving in the plant at the same time. It may happens that one of those vehicle represent an obstacle to the following one. Optimization of vehicles departures from the warehouse can be achieved using the same methodology proposed in this document, and further studies will be for sure carried out. The availability of the vehicle is not considered but it may be true that a vehicle is failed (very rare in the real system), thus the availability description can be imposed to the software by methods explained in chapter 5.3.1. The policies used to manage the zones (chapter 5.3.5) assumes a central role for the purpose of studying the interactions between the vehicles.

Moreover the model does not consider the breakdowns of the lines that, even if sporadic, can have effects on each other, causing a series of related events. Since the professional maintenance pillar is always present and the spare parts are kept in a dedicated warehouse, the repairs generally last for a very limited time, allowing the production to start again as soon as possible. It was therefore decided not to consider the fails in this model, which estimates the performance in the conditions of maximum productivity of the lines involved.

7.2 Conclusions

For the purpose of the study the optimal solution can be identified in scenarios where two carts are transported because, even if in some case an higher WIP is obtained, this solution is providing better performances in terms of vehicle's utilization. By keeping this factor at the lowest possible level, other products may be moved through the same vehicle. By installing a parking space on the second line the costs related to re-layout and space required are lower with respect to installing a parking on both the lines even because there are no evident benefits in doing it. Moreover the usage of an advanced software can lead to a reduction in WIP if the vehicle can be parked on the first line while there are no evidences that this could cause some advantages in the other scenarios. Even if this consideration about the advanced software is true in the borders of the study it can for sure bring benefits to the company since there are more vehicles and shuttles moving in the plant during each shift; it could help in managing the departures by knowing their position in real time.

The optimal choice will be to create a parking station on the second line, while no rule about requests are preferable, a FCFS (First Come First Served) policy will be able to manage the single requests, and in case of multiple presence both prioritization can be selected. The cost of the advanced Software is 26,000 €, the company is deciding to buy it in order to manage all the vehicle; so, even if from the study no benefits are present when parking on the second station, this will be an interesting feature for future studies.

As previously announced, the simulation route turned out to be suitable for managing this study, even if other roads could be traveled. Despite a longer time consumption compared to other methods, the discrete event simulation made it possible to construct the model by observing its behaviour and therefore being able to correct it. It also lends itself to a future adaptation, when and if, other factors are to be included within the study; maybe including the whole process and involving all the vehicles could lead to be able to study the interactions and the optimization of times for the machines.

I believe that being able to operate in a company like Marelli s.p.a has been very stimulating thanks to the environment and the management which work in order to create a strongly academic approach to deal with problems and challenges in a deductive way. The work proposed in this document is the result of a deeply radicalized collaboration between the various pillars and can be used to be easily adapted if a similar problem is to be assessed. In fact, in the plant the lines can be moved and what is really important is to provide a winning methodology to deal with problems in a way that has deep roots in academic knowledge and can be understood and used. The repeatability and standardization of solutions are in fact the key to making it easier to solve a type of problem, storing the information and methodologies learned in its resolution.

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