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INDUSTRIAL PLANTS II

Chapter two ï part 3:

Numerical simulation as a tool for optimizing a production system

DOUBLE DEGREE MASTER IN

ñPRODUCTION ENGINEERING AND MANAGEMENTò

CAMPUS OF PORDENONE

UNIVERSITY OF TRIESTE

Numerical simulation as a tool for optimizing a production system

Some applications actually business

Below are some applications in different production realities with the aim of establishing the effectiveness and efficiency of the use of simulation as an indispensable tool for solving problems both in the design phase of a plant and in that of a corporate requalification aimed at continuous improvement.

Numerical simulation as a tool for optimizing a production system

Analysis and improvement of the production activity of a preforming cell

The **analysis of the current configuration** of a production cell through the study of the production factors (machines present, manpower employed, operating practices and flow of materials) allows to detect the needs of the process and determine some operating parameters to evaluate the appropriate improvement actions and the introduction of new processes based on objective data ("what if" situations of the real system).

To do this, a simulation approach is used which involves the **construction of a logical-mathematical model** that represents the system significantly, followed by a verification and validation so that the results obtained with the simulation have a certain level of confidence with those resulting from the implementation of a new process in the production reality. The **objective** is to increase the upsetting operations without compromising the productivity of ironing and optimizing the energy efficiency of the cell, with a view to continuous improvement.

Numerical simulation as a tool for optimizing a production system

Analysis and improvement of the production activity of a preforming cell

AS IS configuration

We analyze a preforming cell of rotor and stator blades for steam turbines and gas turbines, consisting of several machines and having the function of transforming metal bars (billets) into semi-finished products that can or must pass through one or more machines present (electric rotary oven, vertical hydraulic press used for upsetting and a horizontal hammering machine used for ironing operations, while the handling of the pieces is entrusted to manual manipulators). The production system is Engineer To Order with blades having different shapes, weight and dimensions (figure).

Different shapes, weight and dimensions of the produced blades

Analysis and improvement of the production activity of a preforming cell

AS IS configuration

The blade of a turbine consists of:

- **root or foot** (1), which is the part of the blade that allows the keying on the turbine structure;
- **wing profile** (2), which is the cross section of the blade area hit by the flow;
- **apex** (3), which is the terminal area of the blade.

Analysis and improvement of the production activity of a preforming cell

AS IS configuration

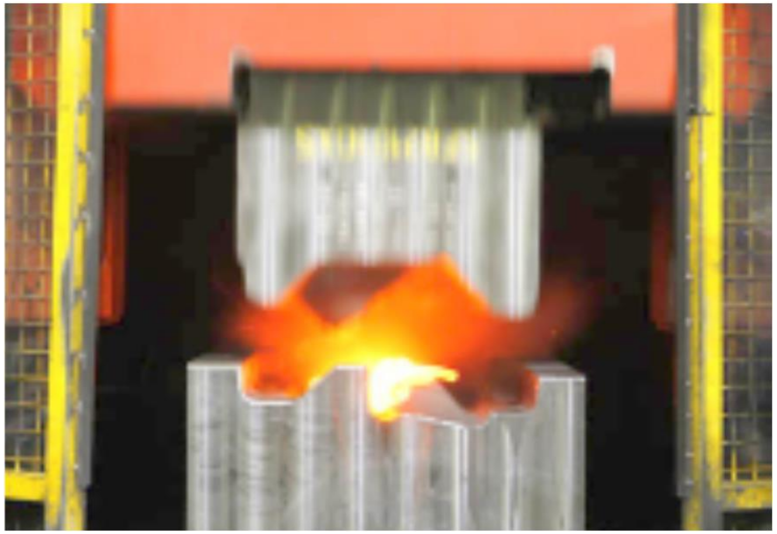
The raw material is made up of square or round billets of various diameters, which are stored in the initial warehouse and then cut to obtain pieces of the desired length. The production is structured in three departments:

- **forging**: the cut billets are heated several times and forged. After being heated, the billet is roughed in the ironing operation, again sent to the heating oven and then to the mallet for the forging operation. This operation can be repeated several times passing from the hammer to heating in the oven to restore the temperature suitable for forging. The rough blades are surrounded by burrs which are removed with the deburring operation followed by the heat treatments (tempering, stress relieving, aging, hardening, solubilization and austenitization). Sandblasting operations can be carried out to eliminate surface impurities followed by quality control;

Numerical simulation as a tool for optimizing a production system

Analysis and improvement of the production activity of a preforming cell

AS IS configuration



Mallet forging

Heat treatment oven

Analysis and improvement of the production activity of a preforming cell

AS IS configuration

The production is structured in three departments:

- **mechanical machining**: the rough blade is positioned and centered. This is followed by the removal of shavings in the machining centers before the foot and then the tip of the blade, passing from roughing to finishing and cutting the top (figure);

Machining center in the machining department

Numerical simulation as a tool for optimizing a production system

Analysis and improvement of the production activity of a preforming cell

AS IS configuration

The production is structured in three departments:

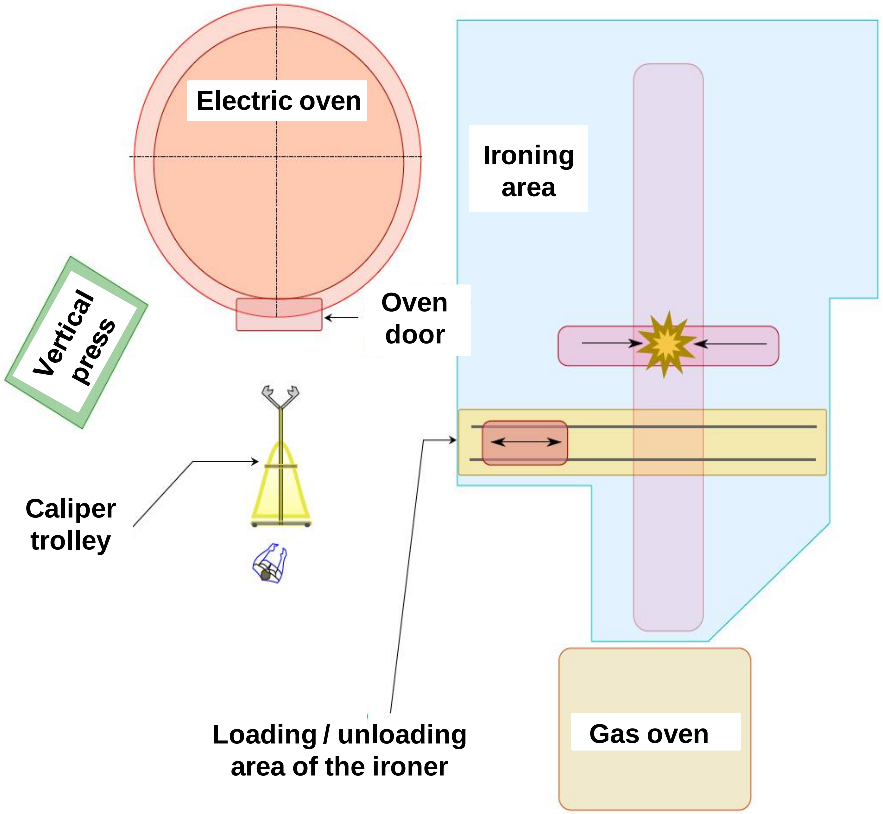
- **finishing**: the blade is subject to taping and polishing. Then there is a final non-destructive (magnetoscopy and penetrating liquid analysis) or destructive sample check (tensile tests, resilience, hardness and verification of the crystal structure).

Numerical simulation as a tool for optimizing a production system

Analysis and improvement of the production activity of a preforming cell

AS IS configuration

In the existing **preforming cell** for ironing operations are present (figure):



Analysis and improvement of the production activity of a preforming cell

AS IS configuration

In the existing **preforming cell** for ironing operations there are:

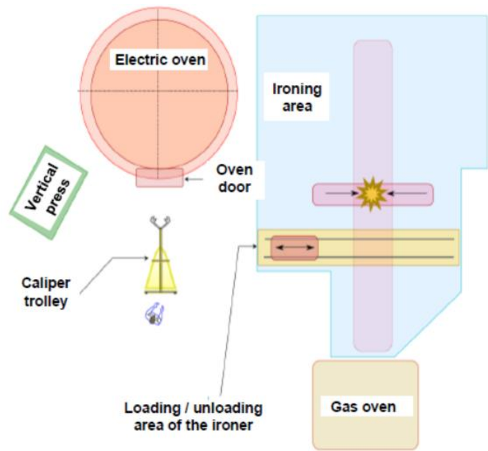
a) **mechanical-hydraulic horizontal hammering machine** dedicated to the ironing operation transforming the billet into a pre-formed one. The machine has an area of 70 m^2 and works one piece at a time. The billet, extracted from the oven, is loaded by the operator on a forklift truck and transported on rails in the machine. The latter is started and automatically adjusts the distance of the manipulator from the hammers and, through a specific ironing program for the blade, performs the processing, reproducing the hammer strike depth and the movement of the piece, gradually reaching the desired shape. At the end, the manipulator unloads the preform into the forks of the trolley which moves to the same loading position as the billet and the operator unloads;

Analysis and improvement of the production activity of a preforming cell

AS IS configuration

In the existing **preforming cell** for ironing operations there are:

b) electric rotary oven, which is used to heat the billets to temperatures suitable for forging (1150°C for steel). In automatic mode it allows you to warn the operator of the loading/unloading of the pieces, by means of a warning light, and giving useful information (counting of the time spent inside, number of pieces in the batch, position of the piece etc.). The basin of the rotary kiln is circular, so each billet has a sector set by the operator (angle, heating time and load rate) and managed by the operation management and control software;

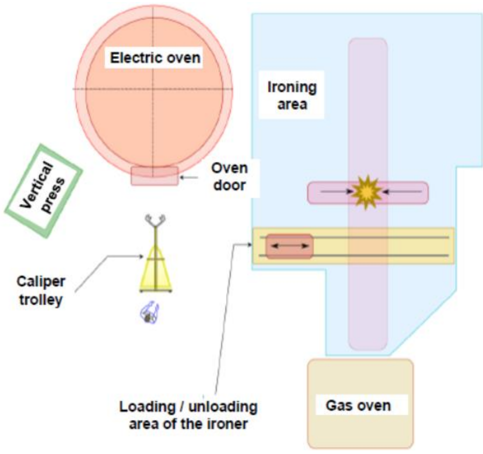


Analysis and improvement of the production activity of a preforming cell

AS IS configuration

In the existing **preforming cell** for ironing operations there are:

c) **manual manipulators**, which are used by the operator for the movement of the pieces between the machinery and the buffers of billets and semi-finished products. These are manual push trolleys equipped with a metal gripper with pneumatically operated gripping system;



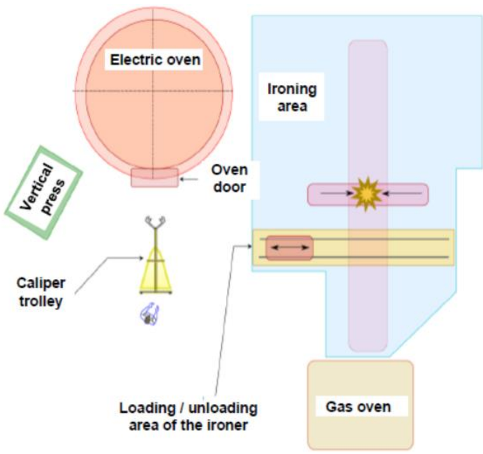
Numerical simulation as a tool for optimizing a production system

Analysis and improvement of the production activity of a preforming cell

AS IS configuration

In the existing **preforming cell** for ironing operations there are:

d) operator, who takes care of the processing (handling of the pieces using the trolleys equipped with pliers, start of the work cycles, control of the processes and setting of the processing parameters). The work is divided into three shifts of 8 hours for 5 days a week. There is a qualified operator who performs the sampling operations for the orders during the engineering phase and fills in the ironing specifications.

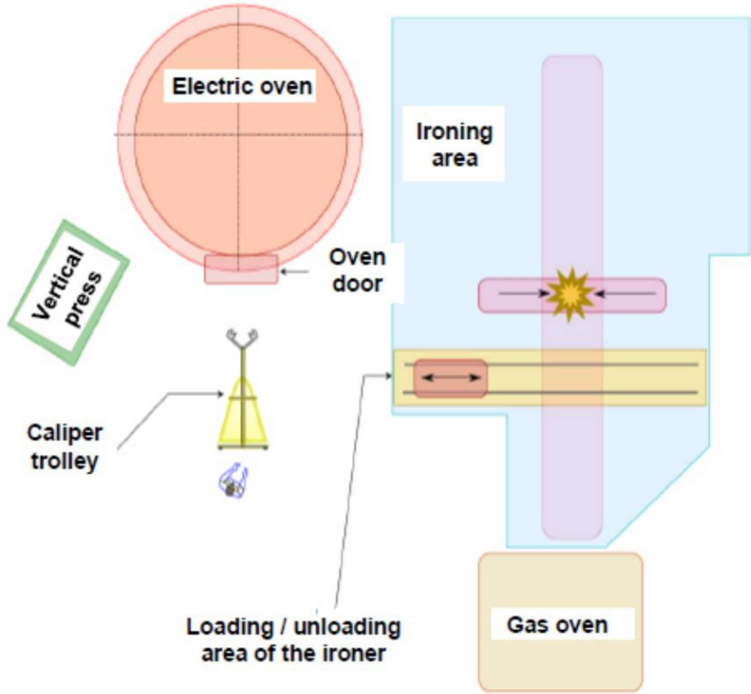


Numerical simulation as a tool for optimizing a production system

Analysis and improvement of the production activity of a preforming cell

AS IS configuration

The company intends to include a new upsetting operation and, for this purpose, wants to use the vertical hydraulic press. In the department there is a gas oven, which could be switched on to maximize productivity, if deemed necessary, in the face of a study on the new needs that the upsetting operation could bring out.



Analysis and improvement of the production activity of a preforming cell

Cell modeling

In modeling the cell we proceeded step by step, considering as a reference the steps that are characteristic of the simulation:

a) **study of the operation of machines and operational constraints**;
b) **study of the processing phases and identification of the sequences of reference operations**

   We keep track of the fundamental operations and actions that all the resources involved in the production cell perform, following a cyclical sequence:

   - the **hammering machine** releases the iron on the forks of the trolley, while the operator grasps the blank with the trolley-gripper and moves it by stacking it in the basket with the others of the job after marking them (1-2 in the figure);

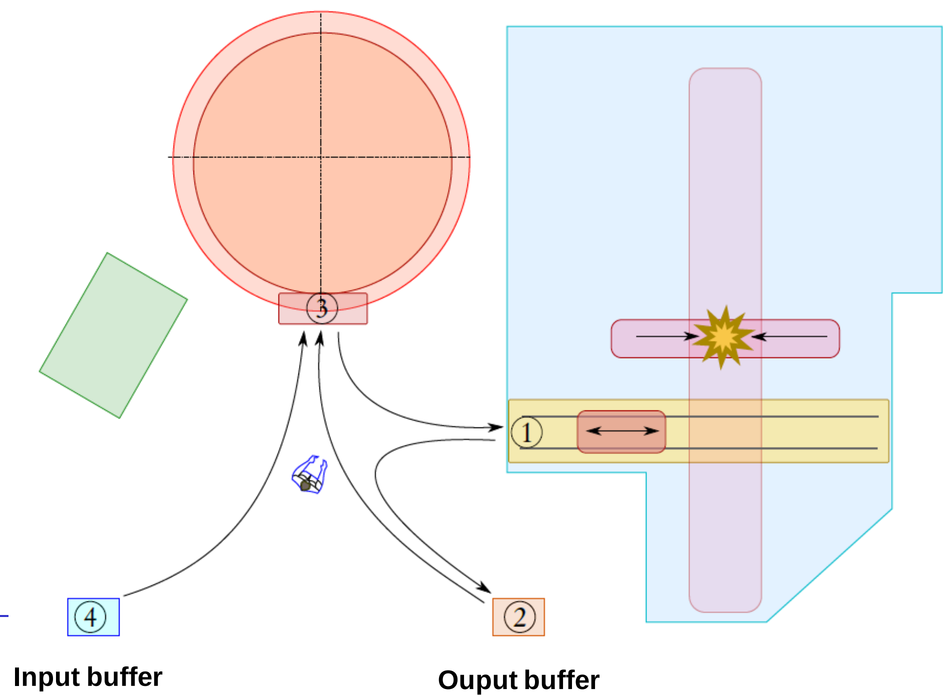
Numerical simulation as a tool for optimizing a production system

<u>Analysis and improvement of the production activity of a preforming cell</u>

Cell modeling

In modeling the cell we proceeded step by step, considering as a reference the steps that are characteristic of the simulation of production scenarios:

b) study of the processing phases and identification of the sequences of reference operations



Analysis and improvement of the production activity of a preforming cell

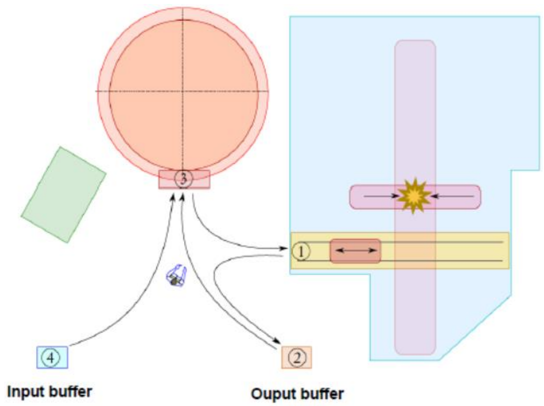
Cell modeling

In modeling the cell we proceeded step by step, considering as a reference the steps that are characteristic of the simulation of production scenarios:

b) study of the processing phases and identification of the sequences of reference operations

We keep track of the fundamental operations and actions that all the resources involved in the production cell perform, following a cyclical sequence:

- the **operator** moves the gripper trolley in front of the door of the rotating electric oven and waits for the end of the connecting rod heating phase to be signaled with the door opening (2-3 in figure);



Analysis and improvement of the production activity of a preforming cell

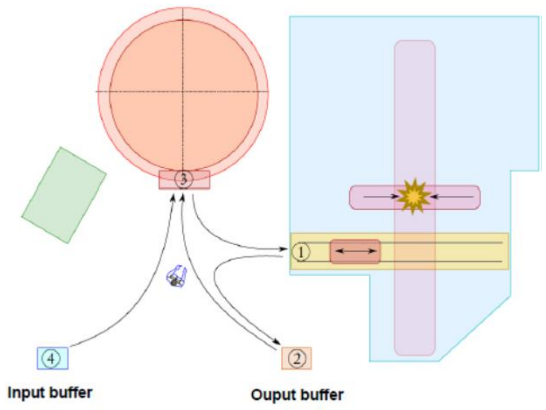
Cell modeling

In modeling the cell we proceeded step by step, considering as a reference the steps that are characteristic of the simulation of production scenarios:

b) study of the processing phases and identification of the sequences of reference operations

We keep track of the fundamental operations and actions that all the resources involved in the production cell perform, following a cyclical sequence:

- the **oven door** opens automatically and the gripper grasps the hot billet and places it in the forklift. The operator starts the ironing sequence and commands the start of the processing cycle (3-1 in figure);



Analysis and improvement of the production activity of a preforming cell

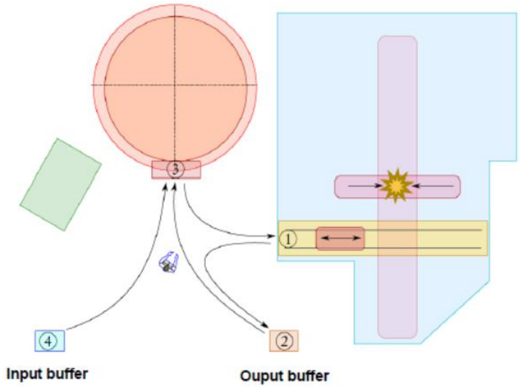
Cell modeling

In modeling the cell we proceeded step by step, considering as a reference the steps that are characteristic of the simulation of production scenarios:

b) study of the processing phases and identification of the sequences of reference operations

We keep track of the fundamental operations and actions that all the resources involved in the production cell perform, following a cyclical sequence:

- at the beginning of the hammering operation, the **trolley-gripper** moves into the input buffer to grasp the billet and position it in front of the oven door for loading into the set sector of the rotating basin, starting the count of the heating time (4-3 in figure).



Analysis and improvement of the production activity of a preforming cell

Cell modeling

In modeling the cell we proceeded step by step, considering as a reference the steps that are characteristic of the simulation of production scenarios:

b) study of the processing phases and identification of the sequences of reference operations

We keep track of the fundamental operations and actions that all the resources involved in the production cell perform, following a cyclical sequence:

- the **trolley-gripper**

  The procurement of billet pallets in the input buffer and the storage in the warehouse of the baskets of processed products from the output buffers is not the operator's task, therefore these operations are considered external to the system.

Analysis and improvement of the production activity of a preforming cell

Cell modeling

In modeling the cell we proceeded step by step, considering as a reference the steps that are characteristic of the simulation of production scenarios:

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We keep track of the fundamental operations and actions that all the resources involved in the production cell perform, following a cyclical sequence:

- the **trolley-gripper**

  The general actions to quantify a standard process were identified both in the sequence of the phases and in the processing times. Some diagrams have been created that have made it possible to create a graphic and descriptive representation of the work cycle, exemplifying the standard reference situation;

Analysis and improvement of the production activity of a preforming cell

Cell modeling

In modeling the cell we proceeded step by step, considering as a reference the steps that are characteristic of the simulation of production scenarios:

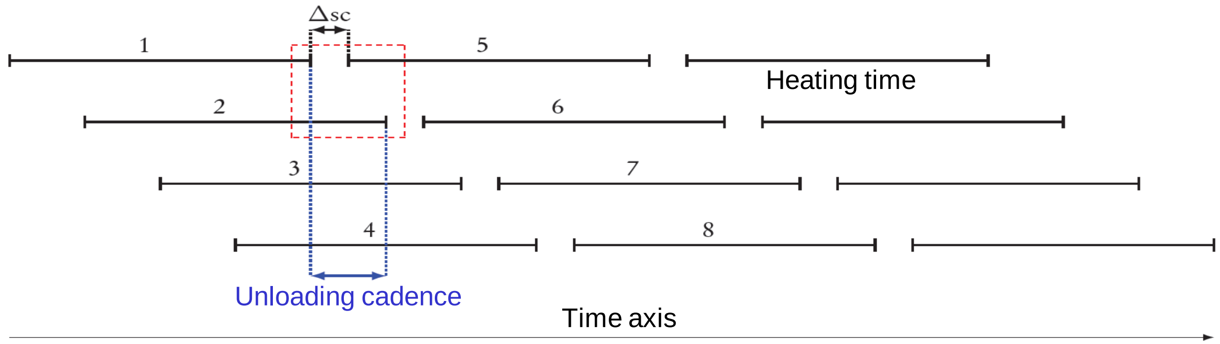
b) study of the processing phases and identification of the sequences of reference operations

We keep track of the fundamental operations and actions that all the resources involved in the production cell perform, following a cyclical sequence:

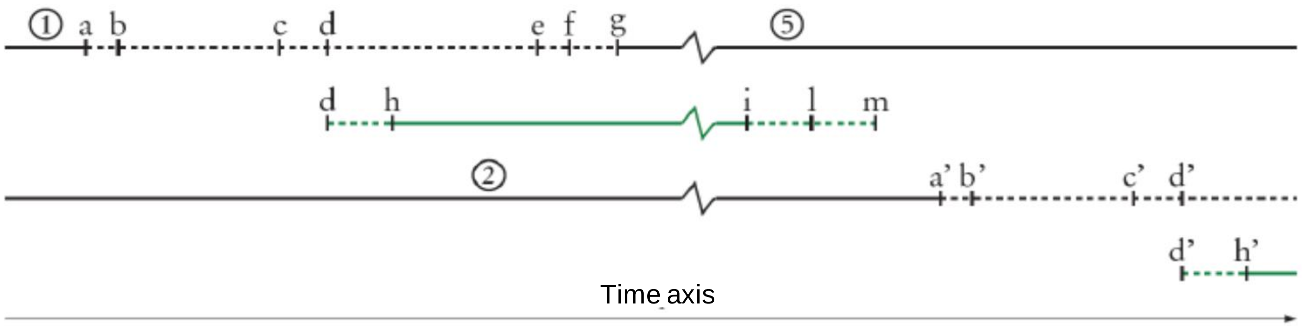
- the **capacity of the oven** over time: the 1st figure shows the ideal situation for loading four pieces when the oven is empty. When the piece 1 has completed the reheating it is ready to be unloaded and is replaced by the 5 only after a delay time related to the unloading-loading (Δsc of the 1st figure), which is the time in which the oven has a lower capacity and it is the sum of some technical times that are highlighted in detail in the 2nd figure;

Analysis and improvement of the production activity of a preforming cell

Cell modeling



Ideal situation for loading four pieces when the oven is empty



Work phases of the ironing cycle (time intervals are not to scale)

a) Turn on the green discharge light; b) Operator calls the unloading; c) The oven door opens for unloading; d) Operator closes the oven door after unloading the hot billet; e) Switching on of the blue charging light; f) Operator opens the door for loading; g) Operator closes the oven door after loading the cold billet; h) Start of the ironing cycle; i) End of the ironing cycle; l) End of marking of the ironed piece; m) Unloading of the blank on the basket

Analysis and improvement of the production activity of a preforming cell

Cell modeling

In modeling the cell we proceeded step by step, considering as a reference the steps that are characteristic of the simulation of production scenarios:

b) study of the processing phases and identification of the sequences of reference operations

We keep track of the fundamental operations and actions that all the resources involved in the production cell perform, following a cyclical sequence:

- the **capacity of the oven in time**

  In addition to the standard processing cycle in the "steady state" condition, there are other transients (filling/unloading the empty/full oven, switching from one job to the next).

Analysis and improvement of the production activity of a preforming cell

Cell modeling

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We keep track of the fundamental operations and actions that all the resources involved in the production cell perform, following a cyclical sequence:

- the **capacity of the oven in time**

  The order change operations are proceduralized which does not correspond to the complete unloading of the basin, which entails a longer processing time and a reduction in the production of pieces due to the inactivity of the hammering machine, but are almost always carried out continuously without ever emptying the oven completely. In this way, a transitional time is established in which two different forms of billets are present in the basin, which could be critical if the billet remains in the oven more than necessary.

Numerical simulation as a tool for optimizing a production system

Analysis and improvement of the production activity of a preforming cell

Cell modeling

In modeling the cell we proceeded step by step, considering as a reference the steps that are characteristic of the simulation of production scenarios:

b) study of the processing phases and identification of the sequences of reference operations

We keep track of the fundamental operations and actions that all the resources involved in the production cell perform, following a cyclical sequence:

- the **capacity of the oven in time**

  Reference is made to the standard sequence of operations at the job order change simulated in the construction of the model and from which it is deduced that the only delay in the processing phases is given by the tooling time and the operations to be performed before ironing the next job. This is critical for the permanence of the billets in the rotary kiln in addition to the due amount, having to unload them following the order in which they are loaded;

Analysis and improvement of the production activity of a preforming cell

Cell modeling

In modeling the cell we proceeded step by step, considering as a reference the steps that are characteristic of the simulation of production scenarios:

b) study of the processing phases and identification of the sequences of reference operations

We keep track of the fundamental operations and actions that all the resources involved in the production cell perform, following a cyclical sequence:

- **collection and processing of characteristic times**

  For the determination of the phase times, the method used is that of direct detection. Given the considerable manual movements and the processing of very different products between the orders in terms of shape, weight and dimensions, the variability of the times is in some cases inevitably large. For these reasons, a definition of standard times has been proposed, especially for the handling phases by the operator.

Numerical simulation as a tool for optimizing a production system

Analysis and improvement of the production activity of a preforming cell

Cell modeling

In modeling the cell we proceeded step by step, considering as a reference the steps that are characteristic of the simulation of production scenarios:

b) study of the processing phases and identification of the sequences of reference operations

We keep track of the fundamental operations and actions that all the resources involved in the production cell perform, following a cyclical sequence:

- **collection and processing of characteristic times**

  As regards the tooling times of the ironing machine in order change, an average time taken would not be significant given the considerable variability of factors that influence the operations. These set-up times were set by interviewing the operators and correspond to a standard time of 15 minutes;

Numerical simulation as a tool for optimizing a production system

Analysis and improvement of the production activity of a preforming cell

Cell modeling

In modeling the cell we proceeded step by step, considering as a reference the steps that are characteristic of the simulation of production scenarios:

b) study of the processing phases and identification of the sequences of reference operations

We keep track of the fundamental operations and actions that all the resources involved in the production cell perform, following a cyclical sequence:

- **number of pieces to be set in the oven**

  In the ideal case of an oven without delays (instantaneous unloading-loading) there is:

$$\text{number of pieces} = \frac{\text{heating time}}{\text{unloading rate}}$$

Analysis and improvement of the production activity of a preforming cell

Cell modeling

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- **number of pieces to be set in the oven**

  In the real case, however, the numerator considers the delay time between unloading and loading the kiln Δsc, while in the denominator it must be added to the unloading rate of the hammer, due to the actual ironing or movement time of the piece from the kiln to the hammer Δt_1, the movement of the same to the output buffer and to the marking operation Δt_2 (figure)

Numerical simulation as a tool for optimizing a production system

Analysis and improvement of the production activity of a preforming cell

Cell modeling

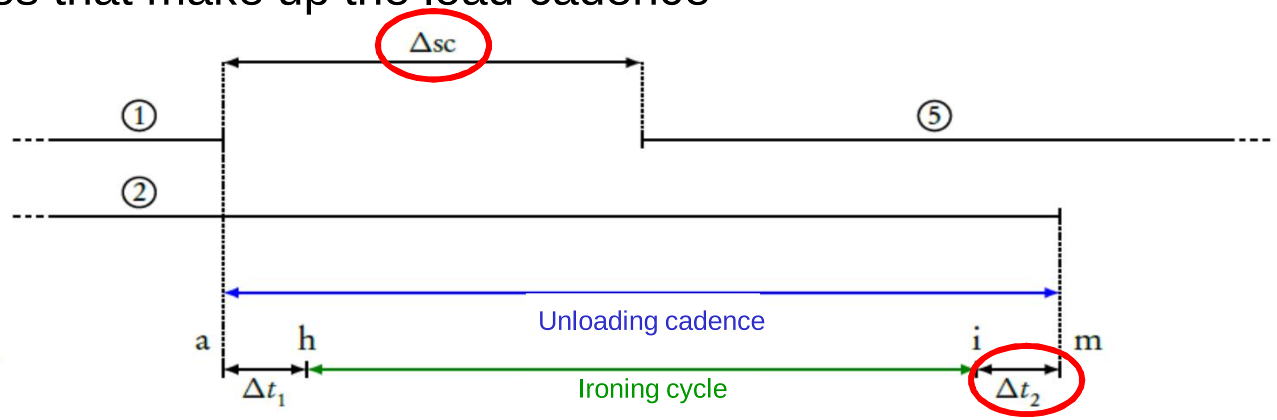
In modeling the cell we proceeded step by step, considering as a reference the steps that are characteristic of the simulation of production scenarios:

b) study of the processing phases and identification of the sequences of reference operations

We keep track of the fundamental operations and actions that all the resources involved in the production cell perform, following a cyclical sequence:

- **numero di pezzi da impostare nel forno**

Times that make up the load cadence



Analysis and improvement of the production activity of a preforming cell

Cell modeling

In modeling the cell we proceeded step by step, considering as a reference the steps that are characteristic of the simulation of production scenarios:

c) construction of the logical-mathematical model

It provides:

- definition of the inputs: characteristics of the orders that are processed over time from the beginning to the end of the reference week (pieces produced, heating time of the billet, ironing time, number of pieces calculated in the oven and load cadence) and times of the processing steps;
- deterministic model as times are fixed;

Analysis and improvement of the production activity of a preforming cell

Cell modeling

In modeling the cell we proceeded step by step, considering as a reference the steps that are characteristic of the simulation of production scenarios:

c) construction of the logical-mathematical model

It provides:

- resources: the oven with variable capacity is modeled according to the order, the operator, who moves the gripper trolley and performs other operations of control, machine start-up and piece marking, has a fixed capacity which is equal to 1, while the ironer or hammer also has a fixed capacity of 1;
- flow chart, which reflects the real sequence of events that occur in the production cell in the reference week (figure).

Analysis and improvement of the production activity of a preforming cell

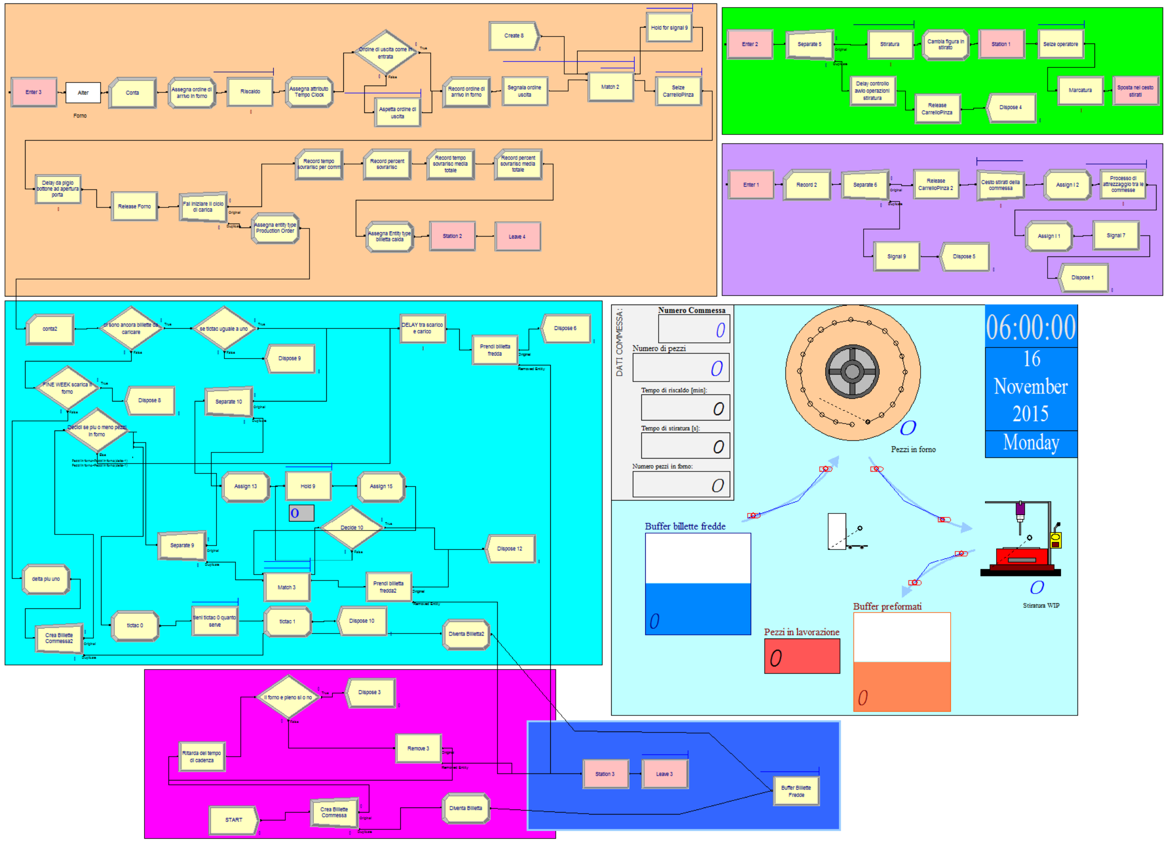
Cell modeling

In modeling the cell we proceeded step by step, considering as a reference the steps that are characteristic of the simulation of production scenarios:

c) construction of the logical-mathematical model

It provides:

flow chart



Numerical simulation as a tool for optimizing a production system

Analysis and improvement of the production activity of a preforming cell

Cell modeling

In modeling the cell we proceeded step by step, considering as a reference the steps that are characteristic of the simulation of production scenarios:

c) construction of the logical-mathematical model

It provides:

- **flow chart** - The areas delimited by different background of the figure are:
  - loading logic of the vacuum furnace with load cadence (fuchsia);
  - buffer of cold billets and their movements (blue);
  - oven logic for unloading and loading time, also between different orders (blue);
  - oven in heating operations and the operator in unloading operations (orange);
  - ironing phases from when the operator loads the machine to when the piece has finished the process (green);
  - unloading operations of the blank from the hammer (purple);

Analysis and improvement of the production activity of a preforming cell

Cell modeling

In modeling the cell we proceeded step by step, considering as a reference the steps that are characteristic of the simulation of production scenarios:

d) **verification and validation of the model**

We checked that the model works correctly (debugging) and compared the results of the model with the performance of the real system by comparing the real production and simulated process times with reference to a fairly large production time (one week). Through the company information system, it is possible to trace the actual processing times which report the start and end status of a job, as well as the pieces produced. The simulated time is that detectable by the simulation model from the first billet loaded in the oven to the last piece worked and placed in the stretch buffer. The comparison is made by defining the **Cycle Time Ratio CRT** (ratio between the standard cycle time and the real cycle time).

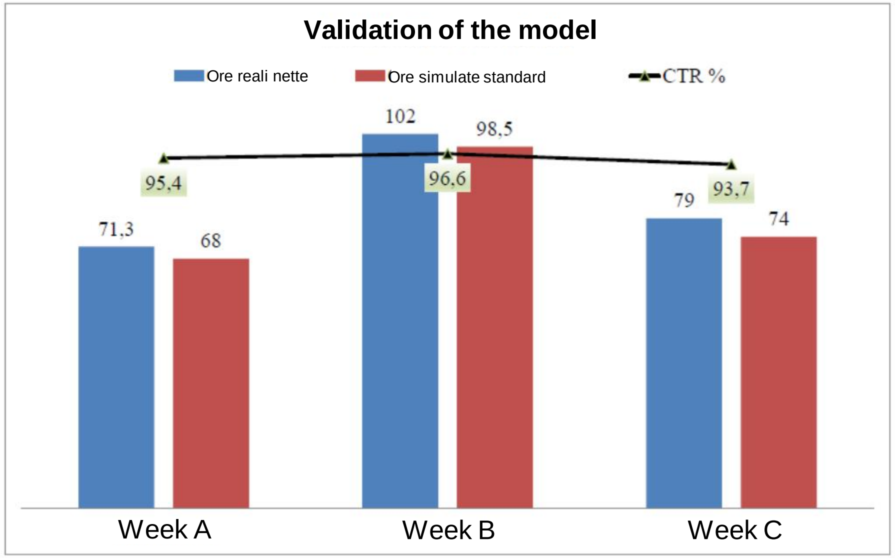
Analysis and improvement of the production activity of a preforming cell

Cell modeling

In modeling the cell we proceeded step by step, considering as a reference the steps that are characteristic of the simulation of production scenarios:

d) verification and validation of the model

The histogram in the figure shows that the simulation times follow the trend of real times well enough, having a CRT of 95.2% in the 3 weeks of validation.



Analysis and improvement of the production activity of a preforming cell

Cell modeling

In modeling the cell we proceeded step by step, considering as a reference the steps that are characteristic of the simulation of production scenarios:

d) verification and validation of the model

The simulated times are always lower than the real ones and the discrepancy of the values around 10% is typical of the validation comparison of a simulation model of this type. The variability of the production of the real cell is attributable to:

- operator, who must call the unloading a few seconds before completing the blank unloading operations;
- machine set-up time, which is highly variable;
- order change times, which must lead to even partial unloading of the oven to avoid too long heating times of the pieces;
- real time count, which underestimates the shift time of 8 hours due to the fact that the oven is empty in the next shift or for other transfer operations to the work cell.

Numerical simulation as a tool for optimizing a production system

Analysis and improvement of the production activity of a preforming cell

Cell modeling

In modeling the cell we proceeded step by step, considering as a reference the steps that are characteristic of the simulation of production scenarios:

d) verification and validation of the model

The validated model predicts the production times of a specific number of orders, having any number of pieces for each and a specific preforming technique. Extrapolates the process data, which can be read based on the simulation results;

Analysis and improvement of the production activity of a preforming cell

Cell modeling

In modeling the cell we proceeded step by step, considering as a reference the steps that are characteristic of the simulation of production scenarios:

e) analysis of the results output from the model

With reference to the simulations carried out for week B, the following were determined:

- minimum, average and maximum times for the heating and ironing processes (table);

	Total time per entity [minutes]		
	Average	Minimum Value	Maximum Value
Reheating	47,22	38,00	65,00
Ironing	2,85	2,13	4,50

Analysis and improvement of the production activity of a preforming cell

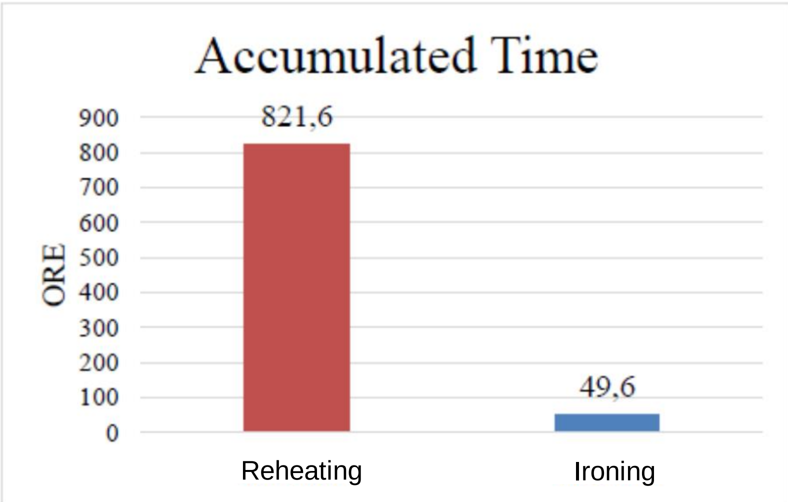
Cell modeling

In modeling the cell we proceeded step by step, considering as a reference the steps that are characteristic of the simulation of production scenarios:

e) analysis of the results output from the model

With reference to the simulations carried out for week B, the following were determined:

- times accumulated on all entities for each process (figure);



Analysis and improvement of the production activity of a preforming cell

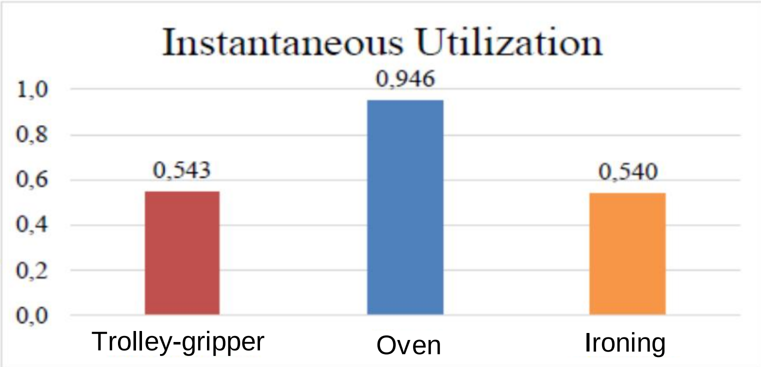
Cell modeling

In modeling the cell we proceeded step by step, considering as a reference the steps that are characteristic of the simulation of production scenarios:

e) analysis of the results output from the model

With reference to the simulations carried out for week B, the following were determined:

- **use of resources**, defined by the relationship between the resources employed and the programmed number (figure). The degree of utilization of resources is one of the most significant data that modeling allows to calculate, as it allows us to understand the effective exploitation of resources with respect to the theoretical potential;



Analysis and improvement of the production activity of a preforming cell

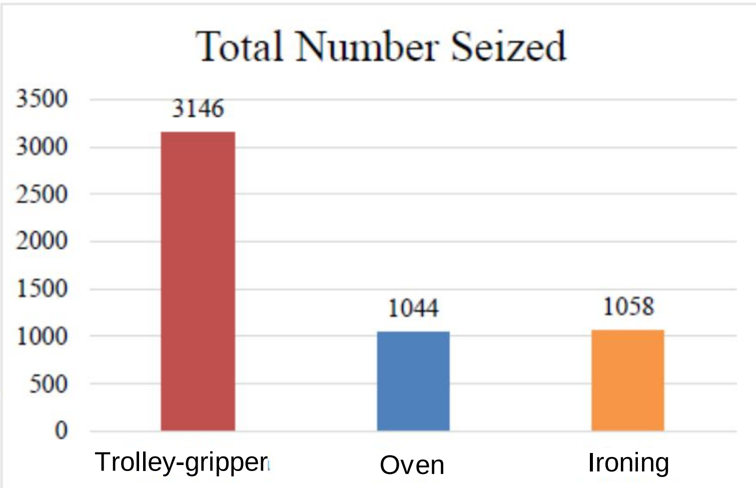
Cell modeling

In modeling the cell we proceeded step by step, considering as a reference the steps that are characteristic of the simulation of production scenarios:

e) analysis of the results output from the model

With reference to the simulations carried out for week B, the following were determined:

- **total number seized**, i.e. the total number of times an entity occupied a unit of resource during the whole simulation (figure).



Analysis and improvement of the production activity of a preforming cell

Cell modeling

In modeling the cell we proceeded step by step, considering as a reference the steps that are characteristic of the simulation of production scenarios:

e) analysis of the results output from the model

With reference to the simulations carried out for week B, the following were determined:

- **overheating time**, which considered a piece having a heating time of 60 minutes, is 10%. It is possible to limit the residence time for the most critical pieces in the oven by means of two options:
  - in the case of a subsequent order with a much shorter heating time than the previous one, the oven is partially emptied even when the two orders have the same number of pieces in the oven;
  - proceed with a "false load", so as to leave the sector empty in the oven and signal the operator to equip the ironer for a new job;

Numerical simulation as a tool for optimizing a production system

Analysis and improvement of the production activity of a preforming cell

Cell modeling

In modeling the cell we proceeded step by step, considering as a reference the steps that are characteristic of the simulation of production scenarios:

f) what-if experiments? and study of possible improvements

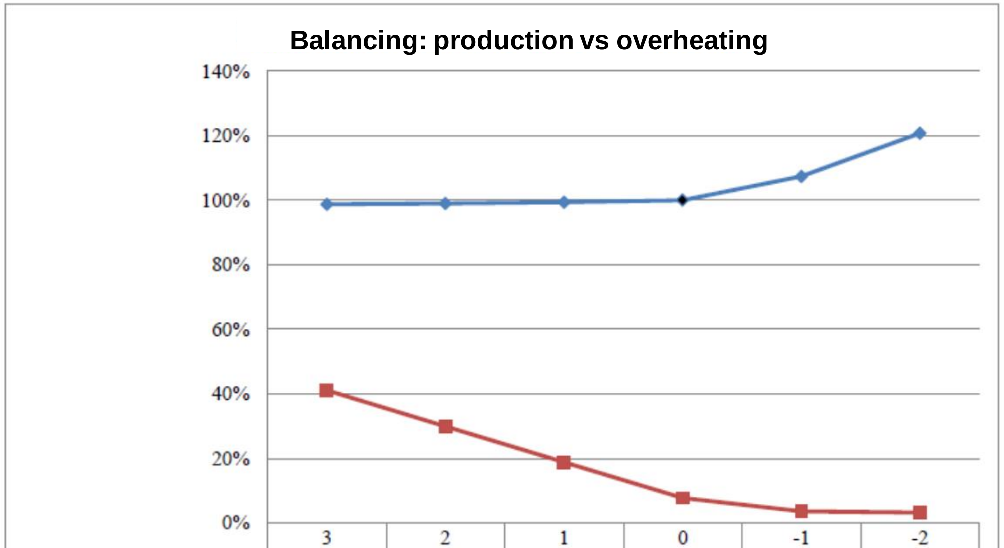
The influence of the number of pieces in the oven and the time spent on the basin changes the production capacity of the cell, which is disconnected from the subsequent processing with the mallet due to the presence of the ironed stock. Neglecting the setup times, figure shows the simulation and overheating times compared to the simulation times as the number of pieces in the oven changes.

Analysis and improvement of the production activity of a preforming cell

Cell modeling

In modeling the cell we proceeded step by step, considering as a reference the steps that are characteristic of the simulation of production scenarios:

f) what-if experiments? and study of possible improvements



	3	2	1	0	-1	-2
Simulation time	98,8%	99,0%	99,4%	100,0%	107,4%	120,8%
Superheat	41,1%	29,9%	18,8%	7,7%	3,6%	3,2%

Comparison of times as the number of pieces in the oven changes

Analysis and improvement of the production activity of a preforming cell

Cell modeling

In modeling the cell we proceeded step by step, considering as a reference the steps that are characteristic of the simulation of production scenarios:

f) what-if experiments? and study of possible improvements

It is clear that:

- by increasing the number of pieces in the oven compared to those determined analytically, the capacity does not substantially change because with the ironing processing times, even if the pieces increase inside, it is always available to provide hot pieces to be baked. The modest decrease in simulation times (just over 1%) is attributable to recovery during the job changeover phases, even if this leads to an increase in the overheating phenomenon;

Analysis and improvement of the production activity of a preforming cell

Cell modeling

In modeling the cell we proceeded step by step, considering as a reference the steps that are characteristic of the simulation of production scenarios:

f) what-if experiments? and study of possible improvements

It is clear that:

- decreasing the number of pieces in the oven: although it seems a paradox to make the cell work in conditions of lower capacity, it is instead useful to identify and quantify the modalities of conduction of the cell with limited capacity to avoid cases of excessive accumulation in the ironed stock and limit the waste of overproduction. It can be noted how the overheating times decrease and the phenomenon is considered almost negligible even with one piece less (3.6%). The decrease of the pieces in the oven entails the advantage of the reduction of the heating times and, if desired, the additional advantage of the productivity adjustment in a pull optic in the department

Analysis and improvement of the production activity of a preforming cell

Cell modeling

In modeling the cell we proceeded step by step, considering as a reference the steps that are characteristic of the simulation of production scenarios:

f) what-if experiments? and study of possible improvements

Following the analysis of the processing phases and cycle time (AS-IS configuration), one wonders if changes can be made to improve the process. Among the various improvement solutions that can be proposed, preference is given to those that bring the least possible transformations to the cell structure, therefore considering maximizing the cost/benefit ratio.

Analysis and improvement of the production activity of a preforming cell

Cell modeling

In modeling the cell we proceeded step by step, considering as a reference the steps that are characteristic of the simulation of production scenarios:

f) what-if experiments? and study of possible improvements

To reduce the processing cycle time, it has been seen what can change by eliminating the constraint of unloading from the ironing machine before unloading from the oven. The new sequences of operator operations are: load the ironer, wait for the piece to be ironed (in the meantime he can be busy loading the oven), call the unloading of a new piece from the oven (before grasping the piece and moving it on the ironing basket) after the piece has been worked, load the hammer with a new piece to be worked and start the ironing cycle, grasp the worked piece and move it on the ironing basket.

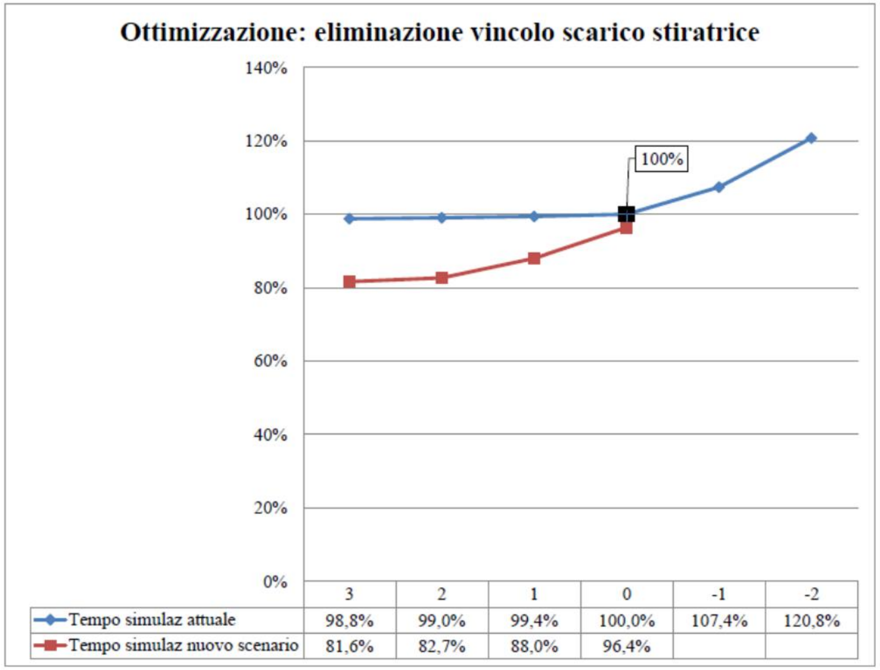
Analysis and improvement of the production activity of a preforming cell

Cell modeling

In modeling the cell we proceeded step by step, considering as a reference the steps that are characteristic of the simulation of production scenarios:

f) what-if experiments? and study of possible improvements

From the comparison between the current simulation times and those with the elimination of the ironer unloading constraint, note (figure - Comparison of the times by eliminating the ironer unloading constraint).



Analysis and improvement of the production activity of a preforming cell

Cell modeling

In modeling the cell we proceeded step by step, considering as a reference the steps that are characteristic of the simulation of production scenarios:

f) **what-if experiments? and study of possible improvements**

From the comparison between the current simulation times and those with the elimination of the ironer unloading constraint, it is noted:

- the simulation time and the cell capacity are almost identical if the same pieces are kept in the oven;
- if the number of pieces in the oven increases, the simulation time decreases and the oven is not used to its maximum capacity. The reference condition for the number of pieces in the oven shifts to 2 more pieces and the time required to complete the production of the orders of the reference week falls by 17%. It is not advisable to increase up to 3 more pieces in the oven because the average heating times increase;

Analysis and improvement of the production activity of a preforming cell

Cell modeling

In modeling the cell we proceeded step by step, considering as a reference the steps that are characteristic of the simulation of production scenarios:

f) what-if experiments? and study of possible improvements

From the comparison between the current simulation times and those with the elimination of the ironer unloading constraint, it is noted:

- decreasing the number of pieces, the production capacity decreases and the simulation time increases.

An increase in production capacity leads to an increase in the exploitation of available resources, while the degree of use of the oven can be considered constant.

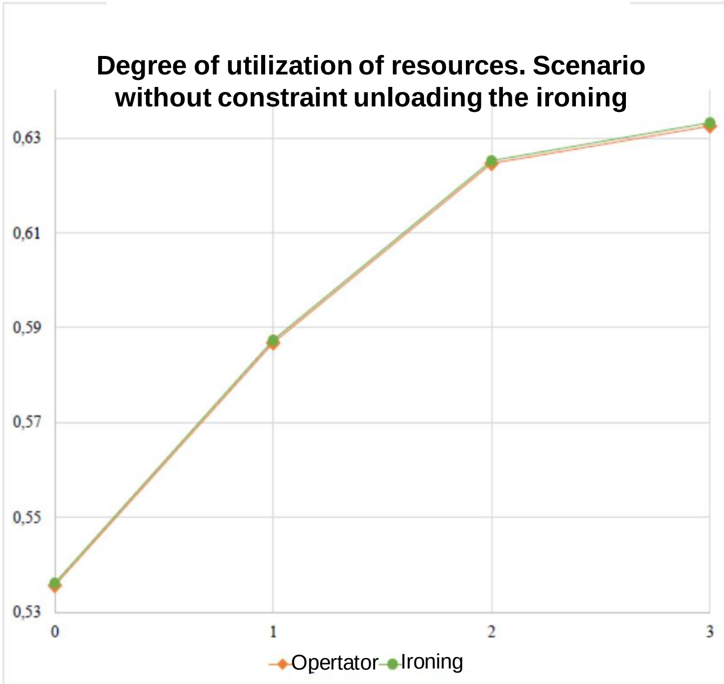
Analysis and improvement of the production activity of a preforming cell

Cell modeling

In modeling the cell we proceeded step by step, considering as a reference the steps that are characteristic of the simulation of production scenarios:

f) **what-if experiments? and study of possible improvements**

The degrees of utilization of the other two resources confirm the trend of simulation times: by increasing the pieces in the oven up to two, the degree of utilization increases (figure - Degree of utilization of the available resources by increasing the production capacity).



Analysis and improvement of the production activity of a preforming cell

TO-BE configuration: implementation of the new cell

The company aims to implement the upsetting operation in the existing cell, which is a process of massive plastic deformation of the open mold material. Unlike ironing, which narrows the sections and lengthens the material, the upsetting compresses it by reducing its height: as the volume remains almost constant there is an increase in the width of the sections. There are three advantages: fewer billet sections to use, reduction of possible defects and expansion of the product range and greater uniformity of the crystalline microstructure.

To implement the simulation model that includes the new operation, the orders already processed in one of the weeks of validation were reconsidered. It is necessary to assume new hypotheses on the timing of future operations, evaluate the operational constraints in the handling and use of the machines in the cell, and set new standards in the sequence of operations.

Analysis and improvement of the production activity of a preforming cell

TO-BE configuration: implementation of the new cell

The macro-operations of reference that are assumed for a job both traced and then stretched can be summarized in two phases:

- **first phase**: picking of billets, heating in the oven, upsetting and storage of upsets;
- **second phase**: picking up the upsets, heating in the oven, ironing and final transfer to the warehouse.

The available database indicates which orders are traced and which are not, also evaluating the order of operations.

Technological constraints are detected and verified with particular reference to the maximum stroke of the swaging gripper and the maximum height from the ground of the trolley with existing gripper.

Numerical simulation as a tool for optimizing a production system

Analysis and improvement of the production activity of a preforming cell

TO-BE configuration: implementation of the new cell

Some times of the new sequence of operations are not directly measurable, as the operations are not yet carried out in the cell. For this reason hypotheses have been assumed:

- **ironing times** were obtained from the roughing technical sheets where the times recorded by the cycles already completed were reported and the new time was estimated given the different section of the initial billet;
- **heating times**, using already available empirical heating formulas for the new sections;
- **handling times of the pieces** to and from the upsetting machine, chosen the same as those to and from the ironing machine since the distances from the oven door are almost the same from the two machines and the movement of the trolley moved by the operator is independent of the shape of the load moved;

Numerical simulation as a tool for optimizing a production system

Analysis and improvement of the production activity of a preforming cell

TO-BE configuration: implementation of the new cell

Some times of the new sequence of operations are not directly measurable, as the operations are not yet carried out in the cell. For this reason hypotheses have been assumed:

- **upsetting times**, obtained by making video recordings on some pilot tests performed in the cell;
- **set-up times of the ironing and the upsetting machine**, which are updated with respect to traditional processing.

From the data available and from those obtained in the manner described, a simulation model has been constructed which implements the future situation of the cell. The implementation of the new operation led to changes both in the structure of the flowchart and in the input file with respect to the model already described.

Analysis and improvement of the production activity of a preforming cell

TO-BE configuration: implementation of the new cell

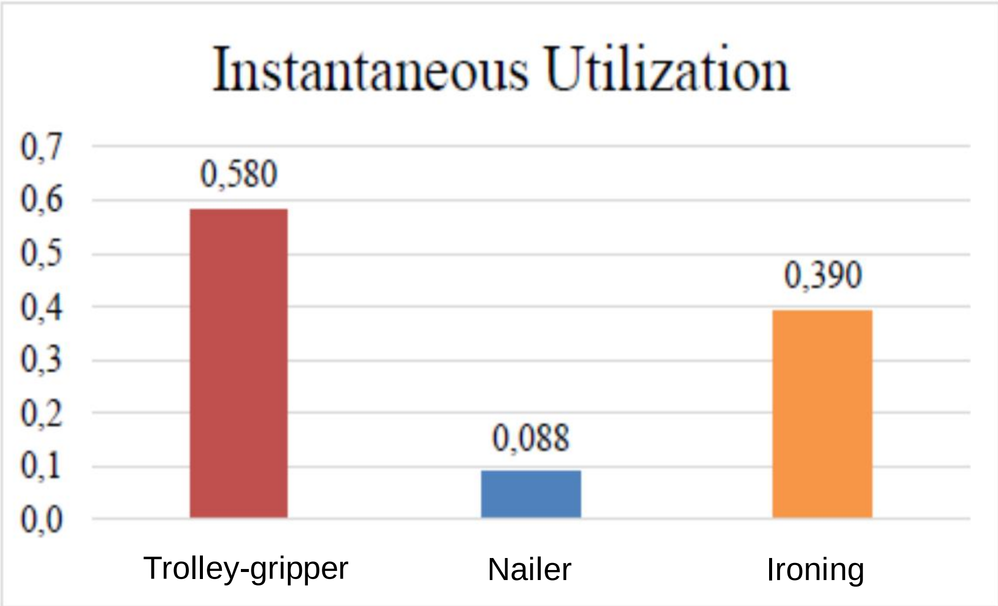
From the model in the new configuration, from the start of the simulation to the completion of all the workings of the week, a time interval of 7,866 minutes (about 131 hours) is obtained. The comparison with the time determined in the week of validation B (98.5 hours) allows to estimate, in the future configuration of the cell for the introduction of the new operation, that the time to process the same week of production increases by 33%. By dividing the simulation time by the average Cycle Time Ratio (CTR) (95.2%), determined during the validation phase, it is also possible to estimate that the actual working hours (not simulated) are around 138.

Numerical simulation as a tool for optimizing a production system

Analysis and improvement of the production activity of a preforming cell

TO-BE configuration: implementation of the new cell

The uses of resources, in the case of model with upsetting (number of resources / programmed number), are shown in the figure.



Resource uses in the model

Analysis and improvement of the production activity of a preforming cell

TO-BE configuration: implementation of the new cell

In this case, the pieces of orders that undergo two processes are subject to two heats: as the logic of the model is built, the overheating time is an average of all the heats performed. The phenomenon of overheating is linked to the load cadence.

Following the results obtained by the new model, we tried to possibly avoid the second passage in the oven.

Since the forgeability of metal materials is a function of different parameters, the most important of which is the temperature that identifies three different categories of forging processes, the operations carried out in the cell belong to the "Hot working" category. It is essential that the pieces are processed at high temperatures (800-1100°C) both because the material in these conditions has the ability to undergo significant deformations by forging without cracking, and for the lower forces required of the machines to impress the changes of shape .

Analysis and improvement of the production activity of a preforming cell

TO-BE configuration: implementation of the new cell

It has been determined for which orders of the reference week the two operations can be carried out (upsetting and ironing) directly without intermediate heating to optimize the flow of material and energy efficiency in the cell, and reduce processing times. To do this, a further constraint on the minimum hot working temperature (850°C) was imposed. Calculated the time between the exit of a piece from the oven and the end of the second preforming process, it is compared with the cooling time of the piece to reduce the temperature from 1150°C (exit from the oven) to 850°C (experimental survey in a test campaign for different pieces - figure 1 - or for different shape ratios - figure 2) and detect if the first is greater in order to avoid direct processing without going through further heating in the oven (figure 3).

Analysis and improvement of the production activity of a preforming cell

TO-BE configuration: implementation of the new cell

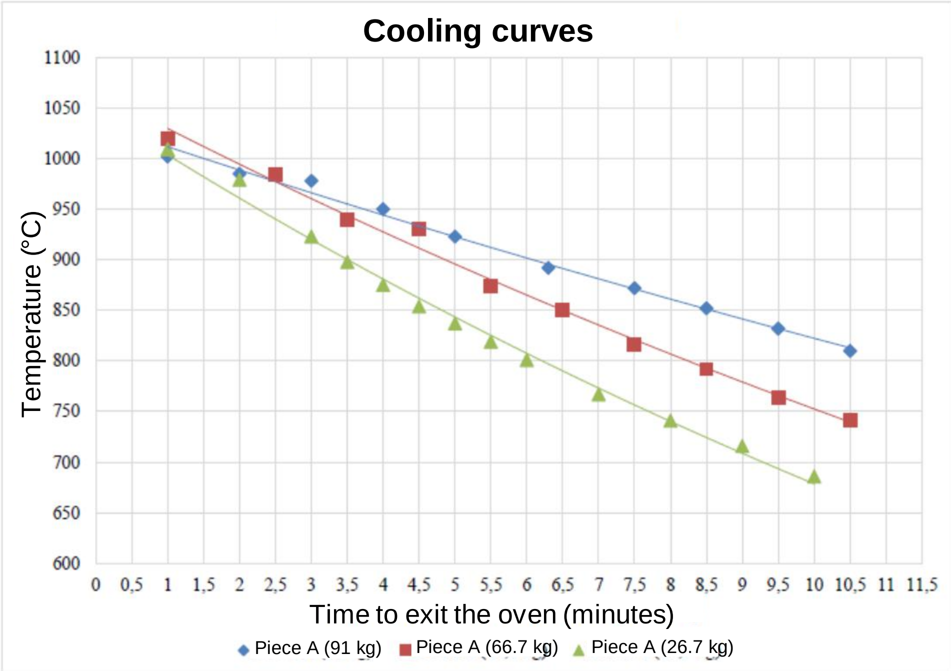


Figure 1: Cooling curves processed by experimental data

Analysis and improvement of the production activity of a preforming cell

TO-BE configuration: implementation of the new cell

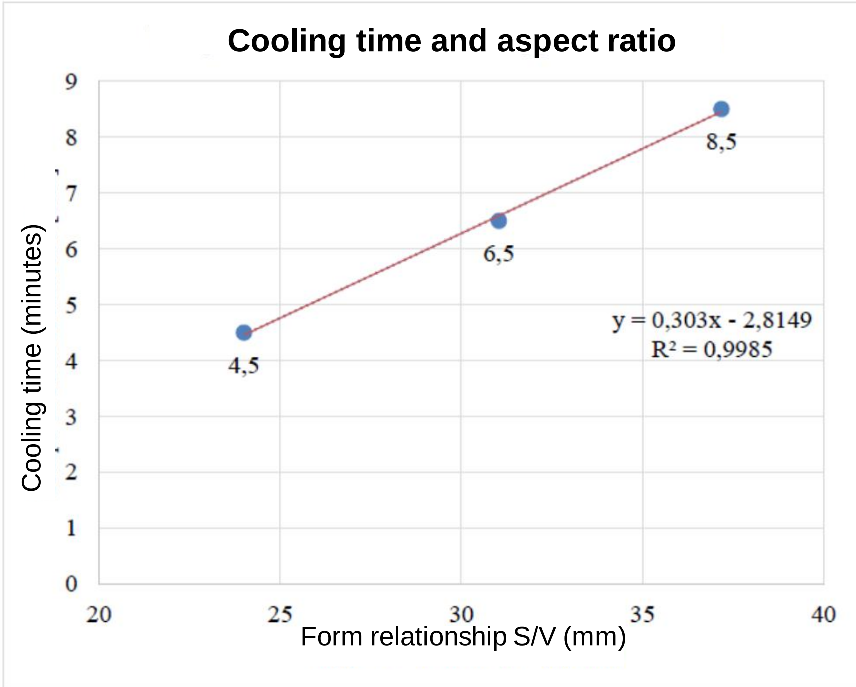
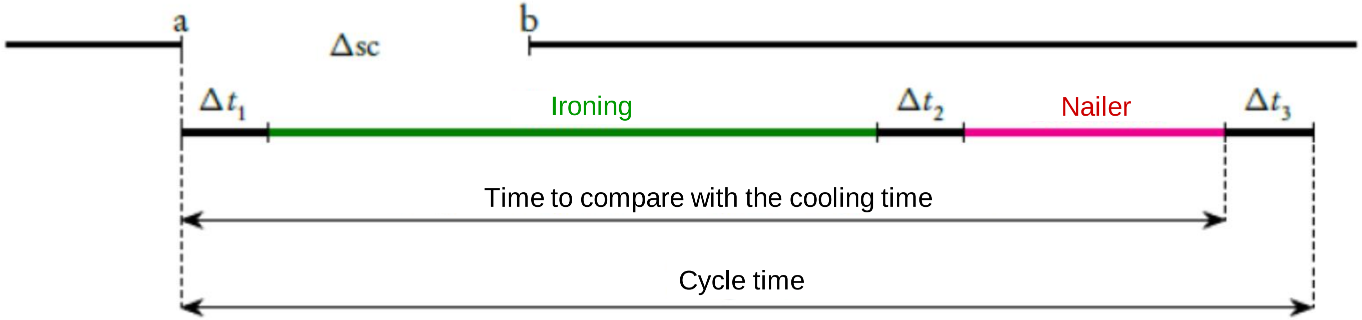


Figure 2: Relationship between cooling time to reach 850°C and aspect ratio

Analysis and improvement of the production activity of a preforming cell

TO-BE configuration: implementation of the new cell



a: unloading the billet from the oven

b: loading the billet eggs into the oven

Δt_1: handling and loading operations of the ironing machine

Δt_2: handling and loading operations of the nailer press

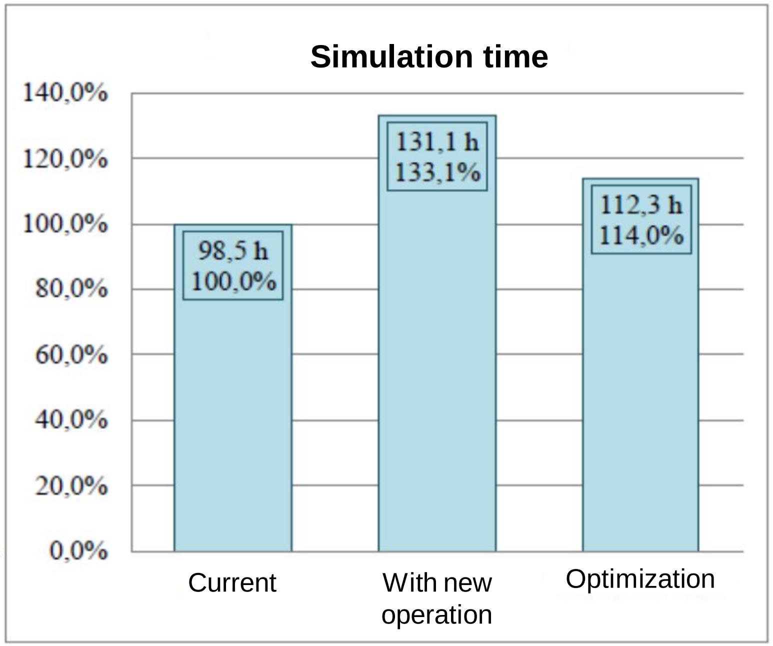
Δt_3: handling and unloading operations of the nailer press

Figure 3: Standard processing steps in the case of live operations (times not to scale)

Analysis and improvement of the production activity of a preforming cell

TO-BE configuration: implementation of the new cell

To process the entire production week with the new configuration, the simulation involves a time of 6,736 minutes (equal to about 112 hours). In comparison with the 7,866 minutes obtained from the previous model, there is a 14% reduction in time. The comparison between the simulation times of the three models, in the current configuration, with upsetting, and with direct operations, is shown in the figure (Comparison of the simulation times for the same week of production).



Analysis and improvement of the production activity of a preforming cell

TO-BE configuration: implementation of the new cell

Compared to the week of validation, the final optimization allows to go from 33.1% more to 14% more, with a consequent considerable saving of working time. In this case, the pieces do not undergo double heating for orders made live, with further advantages in terms of both energy saved and modifications to the crystalline microstructure of the metal.

From the comparison with the previous model, it can be seen that the utilization indices of the upsetting press and the ironer increase. The construction of the simulation models allows to achieve the set objectives: analyze the flow of material within the production cell and, from the current configuration, proceed to implement the upsetting operation that is to be introduced.

Analysis and improvement of the production activity of a preforming cell

TO-BE configuration: implementation of the new cell

The combination of the situation analysis and the simulation results highlights some critical points and some strengths, allowing to orient the improvement choices and to support the decisions with objective data.

The importance of an improvement of the piece handling system emerged which, alongside them, provides for the introduction of automatic systems (use of mechanical robots or motorized trolleys equipped with specific implement devices), which allow to reduce the variability of manual handling times.

The simulation results estimated the permanence in the oven beyond the heating time of each workpiece. The importance of overheating suggests both the introduction of a monitoring system for this parameter and the review of the heating times.

Analysis and improvement of the production activity of a preforming cell

TO-BE configuration: implementation of the new cell

The importance of the heating parameters is evident in the choice of evaluation of the routes with the introduction of the new operation.

In the evaluation of possible improvements, the simulation allowed to highlight the advantages deriving from the elimination of a constraint concerning the unloading of the ironing machine.

Numerical simulation as a tool for optimizing a production system

Analysis and construction of a new assembly line for heat exchangers

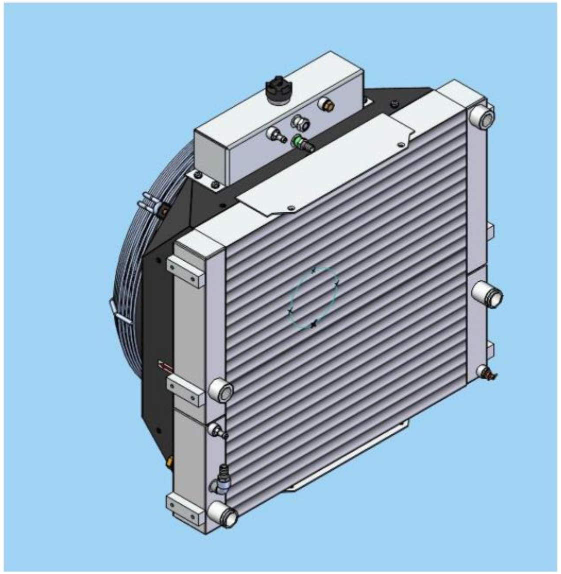
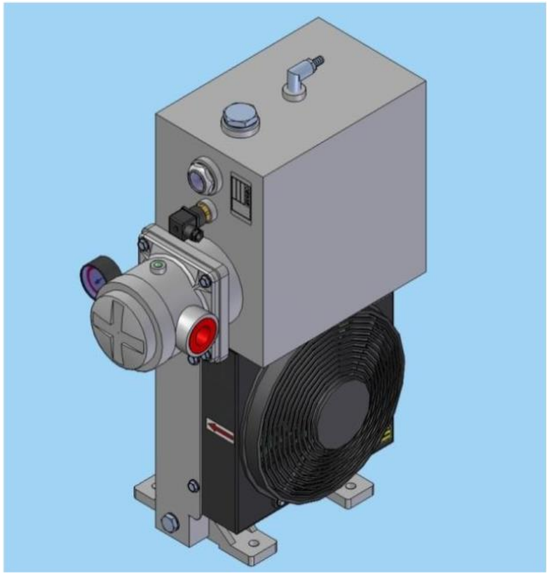
To **implement the Lean Manufacturing methodologies** in an assembly line, a simulation model is used to analyze different alternatives of the original configuration in order to obtain the one that allows to improve the handling of materials and reduce lead time.

The **layout of the future configuration** of the assembly line is dimensioned, identifying the spaces at the edge of the line necessary for the procurement of materials, through the JIT slave supermarkets, and thus eliminating numerous picking and back flow operations.

Analysis and construction of a new assembly line for heat exchangers

AS-IS configuration

The company's core business is the design and production customized to the customer's requests for compact and cross-flow aluminum heat exchangers (figure).

Examples of heat exchangers

Analysis and construction of a new assembly line for heat exchangers

AS-IS configuration

The analysis of the **current situation** was divided into:

a) **objectives of the analysis**, which involves detecting and eliminating the muda (wastes) present and improving assembly efficiency, increasing productivity and reducing the distance in handling and transport, than WIP;
b) **place of analysis**, which is carried out from the central warehouse, where the post welding and painting exchangers are present, and all the elements used for the assembly of the finished product, to the assembly department and the current packaging up to the shipping area.

Numerical simulation as a tool for optimizing a production system

Analysis and construction of a new assembly line for heat exchangers

AS-IS configuration

Data analysis was initially carried out, aimed at understanding the finished product codes and categorizing them. The first analysis concerns the analysis of sales of internal production at the plant in the last 21 months, a period of time considered suitable as it takes into account the trends of the dynamic market in which the company operates.

The quantity sold per finished product code, the amount of the cumulative value in euro per code sold per month of the reference year and the unit prices of the finished products by code were extracted from the company information system. Then the ABC analysis was carried out to obtain the codes that follow the Pareto law of 80/20, concatenating classes A, B and C with reference to the criterion of the amount sold (in ú) and to the criterion of the amount of finished product codes in number of pieces.

Numerical simulation as a tool for optimizing a production system

Analysis and construction of a new assembly line for heat exchangers

AS-IS configuration

From the concatenated final matrix, obtained by connecting the classes, table has been created which shows the breakdown of the same for the 21 months considered based on turnover.

CLASS 1	Total codes	Percentage code [%]	Percentage [%] Euro/turnover	CLASS 2	Total codes	Percentage code [%]	Percentage [%] Euro/turnover
A	83	19,04	70 %	A	72	17,43	70 %
B	178	40,83	25 %	B	177	42,86	25 %
C	175	40,14	5%	C	164	39,71	5%
Total	436	100,00	100%	Total	413	100,00	100%

Breakdown of codes based in turnover

Analysis and construction of a new assembly line for heat exchangers

AS-IS configuration

The finished product codes are divided into classes by production process, based on the unit sales price, each related to the physical size of the product and the process constraints (small, medium, large and huge size - S/M/L/H).
The two matrices are integrated to form the final matrix, which relates the categories of ABC codes with the categories of codes for the S/M/L/H process. 69 out of 410 codes are identified, equal to 16.9% of the total codes, which contribute to 70% of the turnover. 17 ñBest sellerò codes were identified which were related to all the codes divided by P/M/G line both in terms of number of pieces and in terms of sale price.

Numerical simulation as a tool for optimizing a production system

Analysis and construction of a new assembly line for heat exchangers

AS-IS configuration

For each of the 17 codes the production time per piece or per class (sum of the average times weighed per process), which were detected by the IT system by code and verified in the gemba by a diagnostic, and the average time weighed (production time multiplied by cumulative percentage weight divided by the total process percentage).

The Takt Time was calculated divided by S/M/L process families, known the data on sales and the times that were collected by the company information system.

By dividing the characteristic production time of the line by the relative takt time, the theoretical number of operators per process line was calculated. The theoretical number for the three assembly lines is 3.12, therefore 4 operators, divided into 1 operator for the small line, 1 for the medium and 2 operators for the large one.

Analysis and construction of a new assembly line for heat exchangers

AS-IS configuration

The cycle time of the individual activities was determined by measuring the value added activities VA and those not added value NVA in the assembly, kit preparation, packaging and work order preparation phases. For 24 activities (14 at VA and 10 at NVA), a cycle time of 413.7 s/piece was detected (272.4 s/piece equal to 65.8% of the total for those at VA and 141.3 s/piece equal to 34.2% for those with NVA).

The latter percentage represents the improvement that can be achieved without changing the technologies adopted for the activities carried out, which can only be achieved with the reorganization and redesign of the assembly and packaging lines.

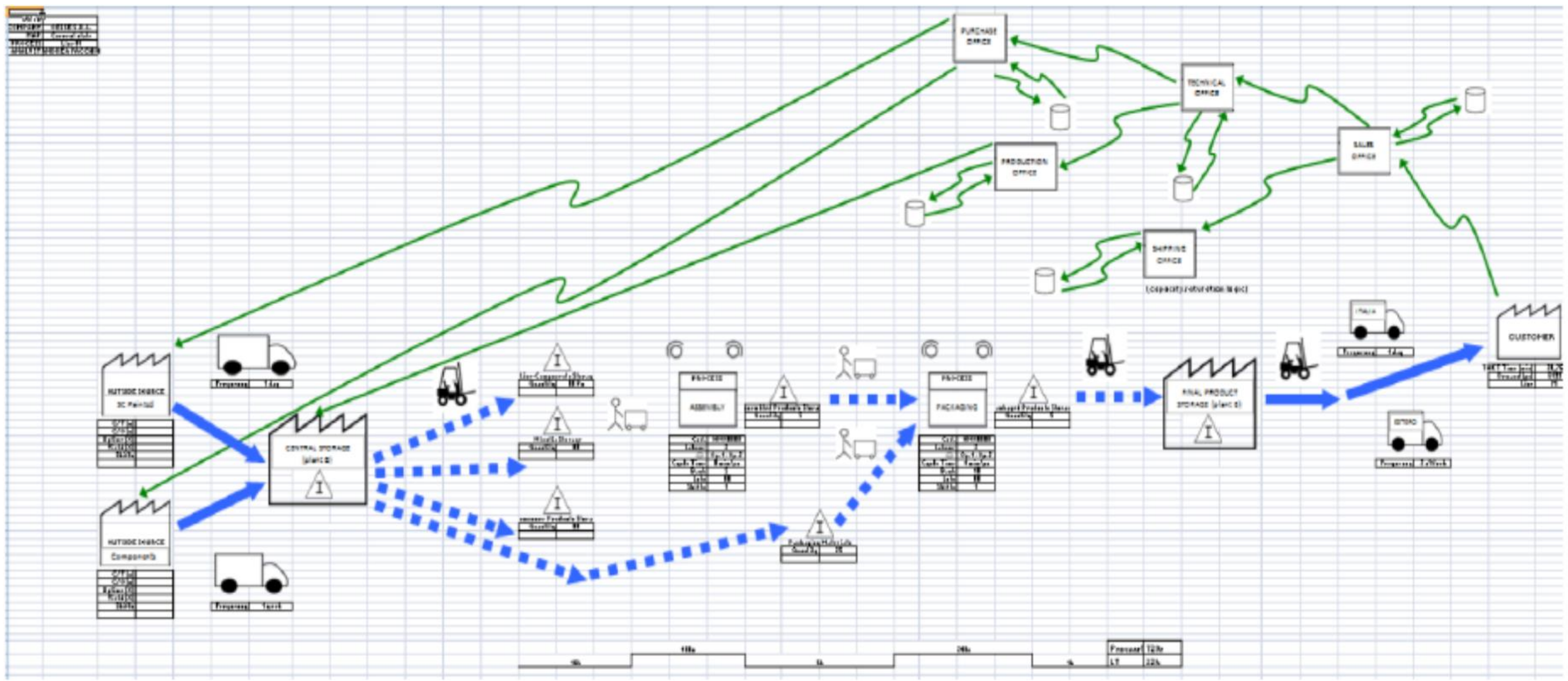
The process was mapped in order to represent its current state to highlight the added value and the muda (overproduction, stocks, expectations, transport, handling, rework, over-specifications).

Numerical simulation as a tool for optimizing a production system

<u>Analysis and construction of a new assembly line for heat exchangers</u>

AS-IS configuration

The Current State Map has been found (figure).

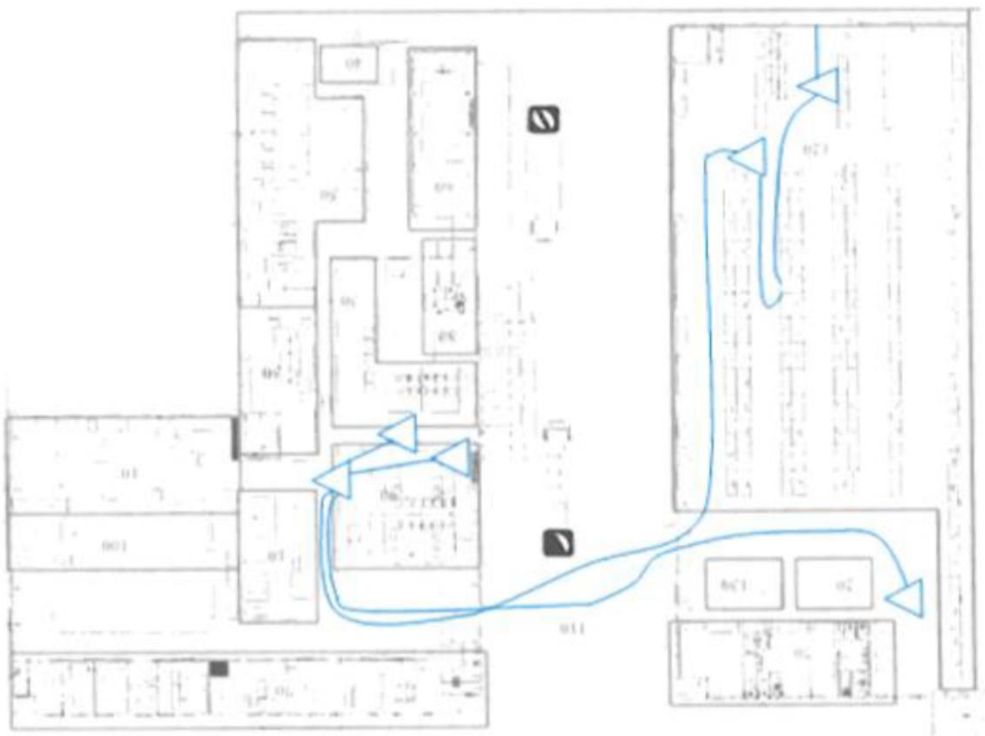


Numerical simulation as a tool for optimizing a production system

Analysis and construction of a new assembly line for heat exchangers

AS-IS configuration

Spaghetti chart in the assembly area and in the handling to the shipping department (figure).



Analysis and construction of a new assembly line for heat exchangers

AS-IS configuration

The figure above shows a single transport of a pallet from the warehouse to the assembly department and, when everything is assembled, from the latter to the shipping department. The distance traveled by the warehouse worker on a forklift is considerable and he is obliged to go back and forth several times, moving the goods from one shed to another, and then moving it again to the shipping department in the central warehouse.

Analysis and construction of a new assembly line for heat exchangers

AS-IS configuration

The main activity mapped for each single code is the following:

a) physical picking with a forklift from the reception to the shelving units of the central warehouse;

b) picking up the material following the picking list of the work order and moving it to the "WIP Area", where the material, having a specific code, will wait to be transported to the assembly department. The wait is due to the fact that workers are busy on coded materials already transported, which are being assembled, and the lack of space where the new coded material should queue. The activity is repeated based on the number of pallets/coded material and pieces/pallets (heat exchanger, conveyor, fans, grids, etc.);

Analysis and construction of a new assembly line for heat exchangers

AS-IS configuration

The main activity mapped for each single code is the following :

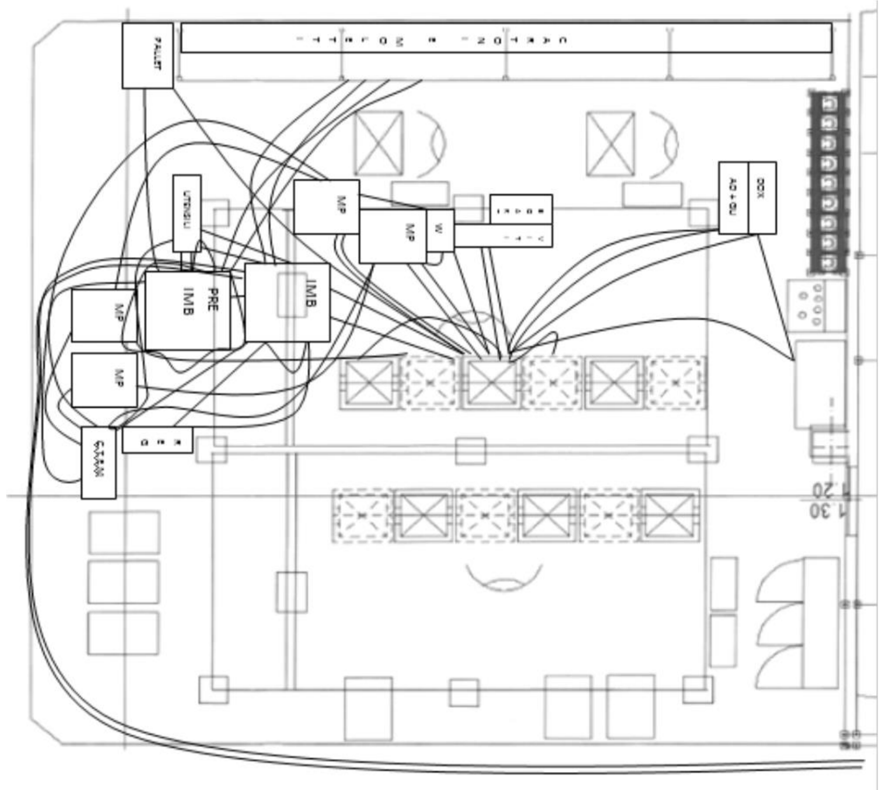
c) when the operator announces the completion of the final pallet of the previous coded material, the next pallet is taken from the "WIP" area and moved to the assembly-packaging department. The activity is repeated based on the number of pallets to be moved (movement between the plants);
d) deposit of the pallet of coded material to be assembled. The activity is repeated based on the number of pallets to be moved;
e) removal of the previous coded, assembled and packed material;
f) movement to the shipping department. The activity is repeated based on the number of pallets of the finished product to be moved from the assembly-packaging department (movement between the plants).

Numerical simulation as a tool for optimizing a production system

Analysis and construction of a new assembly line for heat exchangers

AS-IS configuration

The inefficiencies of the process are detectable from the spaghetti chart (figure), which triggers a brainstorming to bring an improvement to the process, taking into account that the path taken by the operators is relevant and that they are forced to make numerous shots of the material manually or by means of manual hoists or trans-pallets. There is a chaotic arrangement and a considerable distance of materials from the workplace in the assembly area.



Spaghetti chart in the assembly area and in warehouse handling

Analysis and construction of a new assembly line for heat exchangers

AS-IS configuration

The Muda analysis is performed following the "5-Whys" allowing to analyze and classify the muda observed during the mapping process, as well as to detect their root causes. The ultimate goal is to discover possible solutions to various problems, which have been organized in order of priority. 6 out of 24 muda (i.e. 25%) are caused by the lack of an adequate production layout, which is why it was decided to give them the highest priority (1). The solution to this root cause is the redesign of the production layout of the final assembly and packaging of the heat exchangers based on the study of the processes. In particular, reference is made to the new plant, in which there is already a main warehouse. This solution eliminates movements and transport between plants and decreases those within the workplace (micro-movements), as well as those within the procurement and unloading processes (macro-movements).

Analysis and construction of a new assembly line for heat exchangers

AS-IS configuration

The second most important cause is the production procedures, which create a production standard based on a "One piece flow" logic (priority 2). This priority makes the procedures and standards more efficient and verifiable only when the production layout has already been designed and implemented. The solution is effective only when operators have learned and understood the difference between power supply and assembler. It is necessary to create standards based on this concept and to ensure that operators respect them, challenging those who have the duty to feed the lines.

Numerical simulation as a tool for optimizing a production system

Analysis and construction of a new assembly line for heat exchangers

AS-IS configuration

Defining an ergonomic and error prevention layout is very important, keeping the process robust and under control (figure before applying the lean techniques).

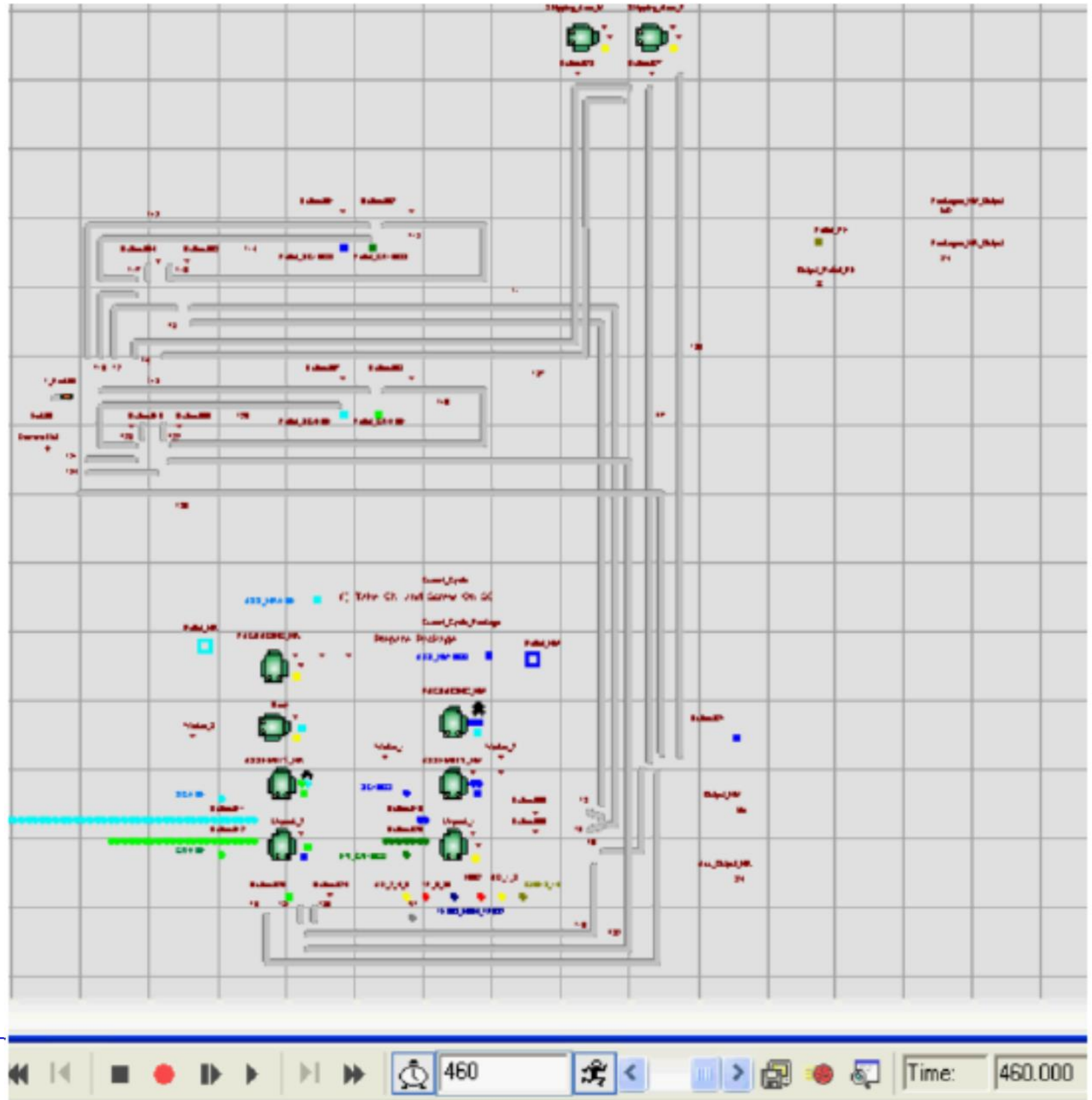
Assembly area before the application of lean techniques

Numerical simulation as a tool for optimizing a production system

<u>Analysis and construction of a new assembly line for heat exchangers</u>

Simulation of the AS-IS state

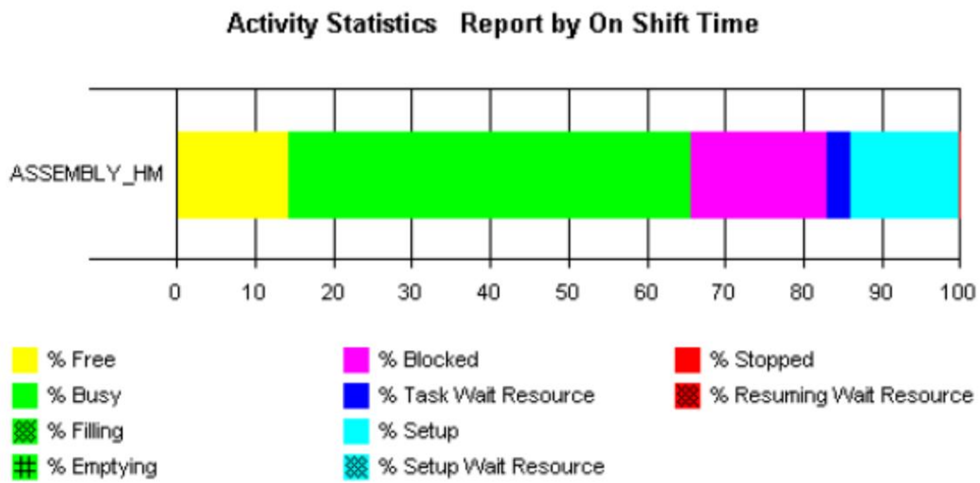
A **Simulation of the AS-IS state model** was designed and executed using an object-oriented software package. The model uses data collected in the field and simulates 460 minutes of operation, which correspond to one shift (figure).



Analysis and construction of a new assembly line for heat exchangers

Simulation of the AS-IS state

There are 50 heat exchangers assembled and packed in one shift (corresponding to 5 pallets). The assembly line capacity used is 65.5% (figure), which includes VA activities (51.5%) and work order (14%).



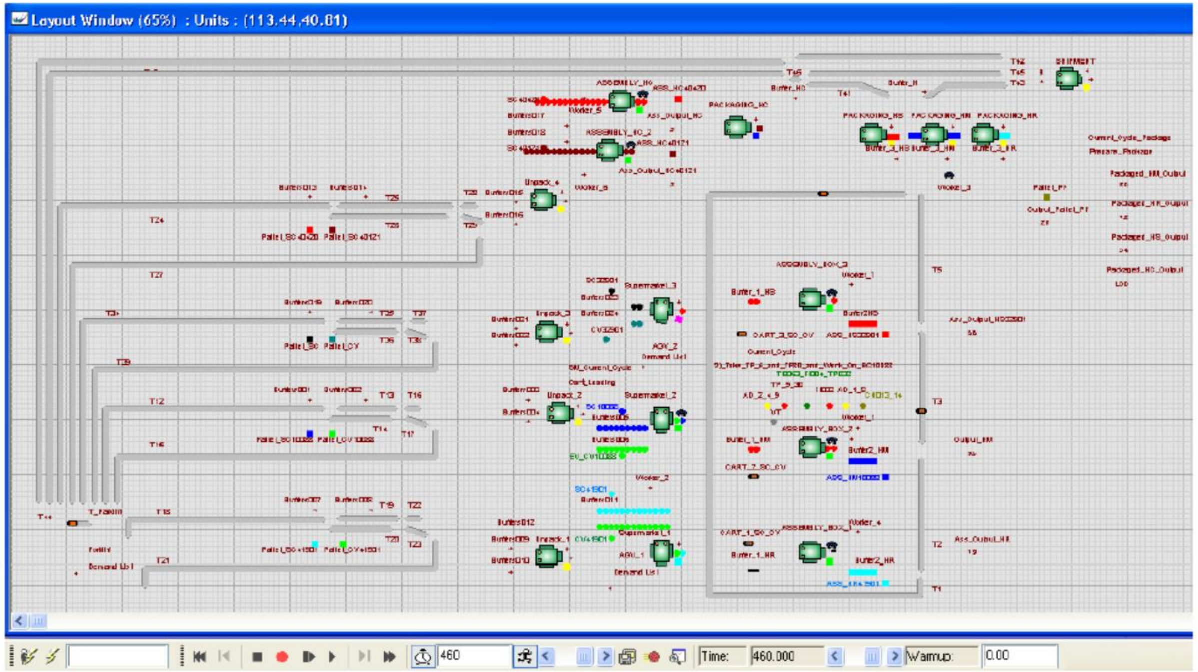
Status of activities during a simulation

Numerical simulation as a tool for optimizing a production system

<u>Analysis and construction of a new assembly line for heat exchangers</u>

Simulation of the TO-BE state

The Simulation of the TO-BE state model reproduces a pilot assembly line that produces class M items: this class includes most of the items produced; the line therefore represents a modular model that can also be used for the other classes. The TO-BE state of the line is characterized by the main aspects (figure):



Numerical simulation as a tool for optimizing a production system

<u>Analysis and construction of a new assembly line for heat exchangers</u>

Simulation of the TO-BE state

The TO-BE state of the line is characterized by the main aspects:

- the assembly line is located in a building with reduced distances between the work centers;
- the flow of the material is based on the pull logic;
- One piece flow;
- the assembly and packaging of different families of items are managed by means of a mixed model;
- the component flow is managed by a kanban system.

Analysis and construction of a new assembly line for heat exchangers

Simulation of the TO-BE state

Several improvements have been made in the new line. A supermarket in kanban decouples the power supply from assembly. A kitting system prevents waste due to lack of material, unnecessary in-line inventory and inefficient assembly operations. Small stocks are available along the line, thus reducing unnecessary movements. Packaging operations are standardized.

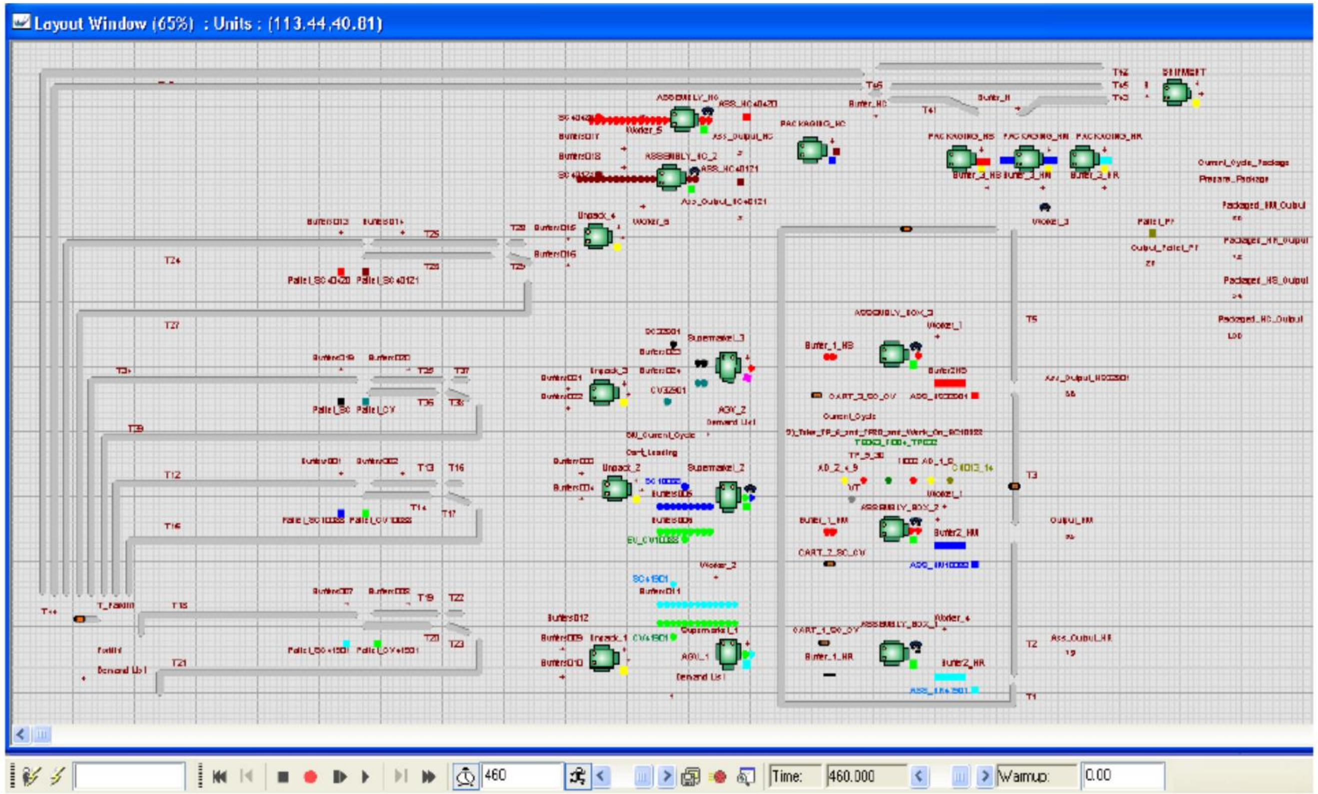
Visual management is applied in the line in such a way that the assembly process is fluid and the manufacturing process minimized. The assembly line is ergonomically improved with benefits for operators and their business. The tasks are clearly assigned and distributed among the line operators, who benefit from a fair work balance; however, the number of line operators has not changed thus making it possible to improve line performance without additional resources.

Numerical simulation as a tool for optimizing a production system

Analysis and construction of a new assembly line for heat exchangers

Simulation of the TO-BE state

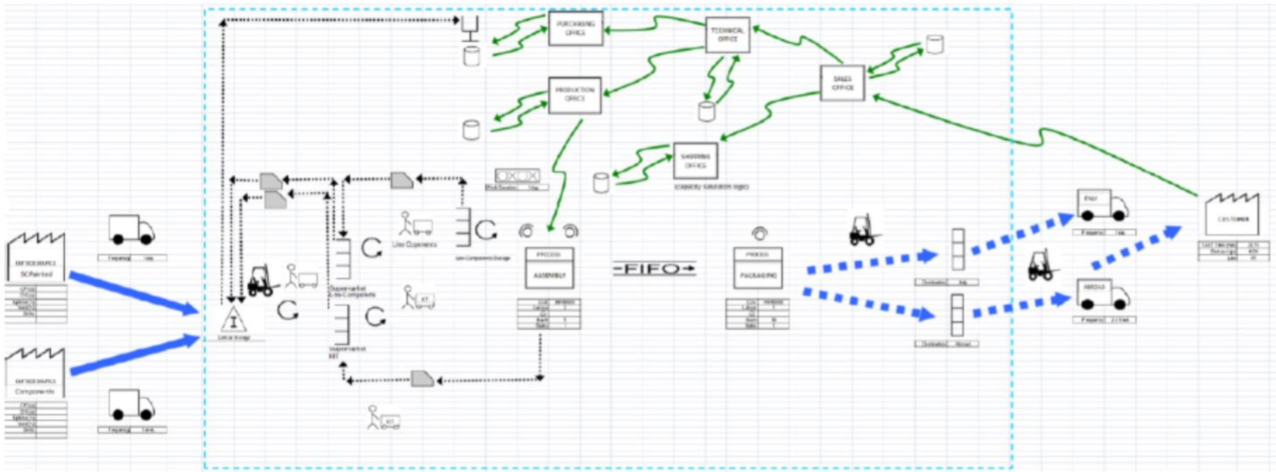
All these solutions have been implemented in the simulation model and then tested.



Analysis and construction of a new assembly line for heat exchangers

Simulation of the TO-BE state

The figure shows the change in the value flow map. First of all, as evidenced by the "5 Whys", that is the analysis of the muda, the top priority of the repositioning of the layout within a single shed has been indicated, which eliminates the movements between the different sheds.



Analysis and construction of a new assembly line for heat exchangers

Simulation of the TO-BE state

A pull flow is used, that is, a flow extracted from downstream requests. Considering that there are no process constraints, because there are no exact and repetitive multiples that force the process to proceed for them, it is possible to have a single flow production, managing the assembly and packaging lines for families in a mixed model process, according to the work orders that must be made.

Borderline materials are supplied with a kanban container. The analysis of the muda also underlines the need for a more standard procedure, in which well-defined and separate roles are assigned with visual management.

The distribution of tasks allows a clear distinction of roles. A forklift driver collects material from the central warehouse and feeds the supermarket; delivery of finished product pallets to the shipping area.

Analysis and construction of a new assembly line for heat exchangers

Simulation of the TO-BE state

The operator of the supermarket supplies, from the latter, the online stocks through a two-tag kanban approach; prepares the assembly kits and loads the basic component of a product onto a forklift truck which is put in a queue at the beginning of the line. Line operators perform assembly activities and line configuration, if necessary. The articles are assembled on the platform trolleys and then moved to the packaging area.

The packaging operator unloads the final items from the platform trolleys at the beginning of the area and puts them in a pre-assembled container. When the package contains all the items listed on its packing list, the operator closes it and the label.

Analysis and construction of a new assembly line for heat exchangers

Simulation of the TO-BE state

Time measurements were made on the pilot line: the results show that the reorganization of the activities positively influenced the production flow time and the cycle time. With regard to class M, the following increases in the production rate were obtained:

- 72.7% per assembly (the average daily production rate increases from 55 pieces to 95 pieces);
- 60% for packaging (the average daily production rate increases from 50 to 80 pieces).

Analysis and construction of a new assembly line for heat exchangers

Simulation of the TO-BE state

The simulation shows a good distribution of work among operators and a 34.5% increase in the use of assembly, which is the stage with the highest added value activity (figures 1 and 2).

WITNESS

Resource Statistics Report by On Shift Time

Name	Worker_2	Worker_1	Worker_3	Worker_4
% Busy	74.37	100.00	81.13	100.00
% Free	25.63	0.00	18.87	0.00
Quantity	1	1	1	1
No. Of Tasks Started	323	671	49	76
No. Of Tasks Ended	322	670	49	75
No. Of Tasks Now	1	1	0	1
No. Of Tasks Pre-empted	0	0	0	0
Avg Task Time	0.89	0.57	6.37	5.19

Figure 1: Summary of simulation results (TO-BE state)

Analysis and construction of a new assembly line for heat exchangers

Simulation of the TO-BE state

The simulation shows a good distribution of work among operators and a 34.5% increase in the use of assembly, which is the stage with the highest added value activity (figures 1 and 2).

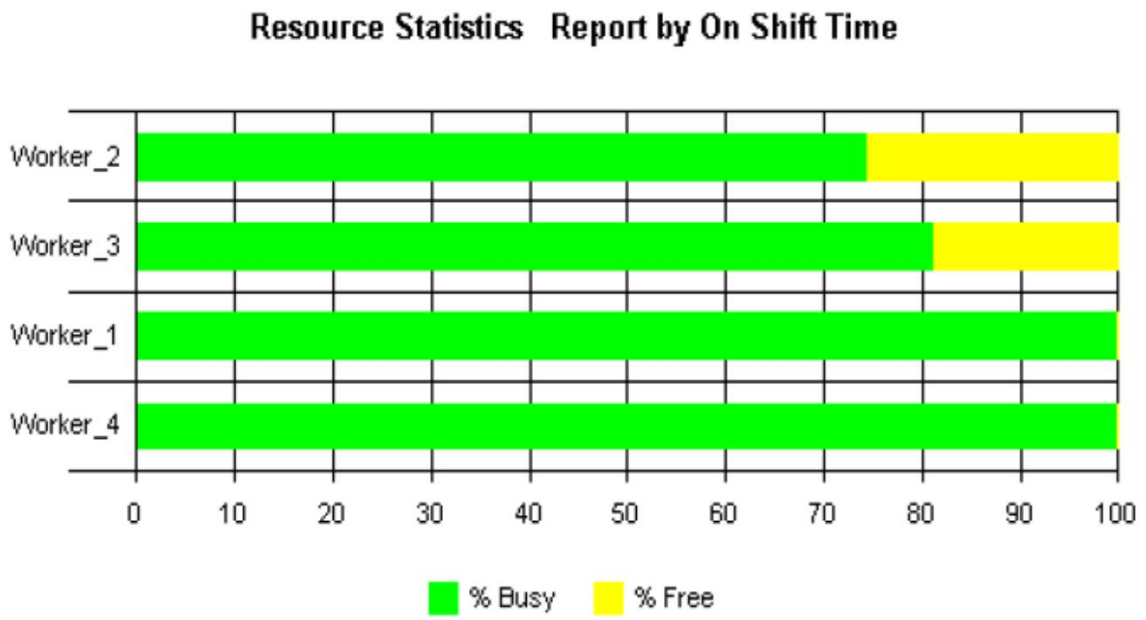
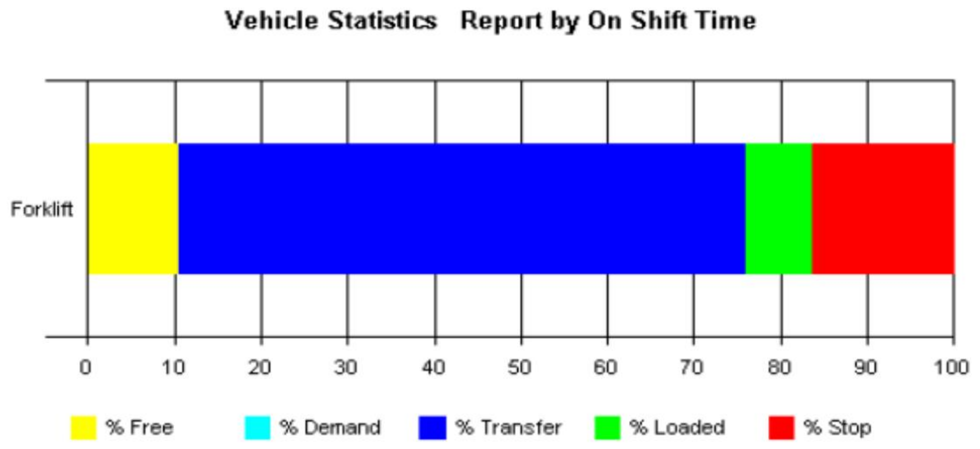


Figure 2: Resource states

Analysis and construction of a new assembly line for heat exchangers

Simulation of the TO-BE state

It is worth noting that the forklift driver, in this balanced configuration, uses 73.1% of the time to power the assembly line (figure).



Forklift driver activity report

The new assembly line layout and layout have been designed to make in-line feed areas available, reducing movement and transportation.

Numerical simulation as a tool for optimizing a production system

Analysis and construction of a new assembly line for heat exchangers

Simulation of the TO-BE state

The reconfiguration of the assembly line, based on lean manufacturing principles and tools, has made significant improvements to the process performance. Simulation played a key role in the study, as it allows you to test possible solutions or changes on a model without the need to implement them on the actual line. The final configuration of the new line, tested in the field, shows production rates that conform to those produced by the model. This opportunity encourages discussion of solutions, which can be immediately verified by the model and their consequences on the system. Using this approach it is possible to prevent possible problems or ineffective changes to an existing line, avoiding the introduction of errors in the design or construction phases.

Numerical simulation as a tool for optimizing a production system

Evaluation of layout solutions for the restructuring of a production process

The improvement of the production process can be obtained by **redeveloping the layout** with the precise positioning of the machinery, the **sizing of the buffers** necessary for the production flow and the **optimization of the forklift paths** used to feed the production lines. To do this, Lean management tools are applied and to validate the goodness of the results obtainable and understand the behavior of the entire production line with the variation of some parameters and the supply system with forklifts, a simulation model is created, which allows to establish the feasibility of the solution conceived.

Numerical simulation as a tool for optimizing a production system

Evaluation of layout solutions for the restructuring of a production process

AS-IS configuration

The analyzed plant in which naval propulsion modules are assembled consists of two warehouses. In the first department, the smaller parts of the engine are prepared and processed (heads, drums and connecting rod heads). In the second department the parts are assembled to build the engine, which is divided into two processes:

a) large mechanical machining on the engine block in which there can be different processing phases, which can last a long time (a few weeks);

b) motor assembly in two phases:
   - Heavy-Preassembly divided into five workstations where the engine stays 2 days and during the night it is moved to the next work station;
   - Main Assembly with island assembly divided into 14 workstations and tests carried out before delivery to the test room.

Evaluation of layout solutions for the restructuring of a production process

AS-IS configuration

The project involves the movement of a series of activities that are carried out in the two warehouses in a single one and the creation in the same of a new warehouse with a capacity lower than the existing one. This warehouse must have internal routes that are not congested in order to supply the materials for production in the right time and with a sufficient number of forklifts to guarantee refueling.

To define the future layout of this shed, an analysis is carried out to identify the current processes and activities, taking the opportunity to make improvements to the machinery and the management of the production flow. It is therefore appropriate to apply the Value Stream Mapping (VSM) methodology, which analyzes the flow of current value and finds waste by eliminating it and defining the flow of future value.

Numerical simulation as a tool for optimizing a production system

Evaluation of layout solutions for the restructuring of a production process

AS-IS configuration

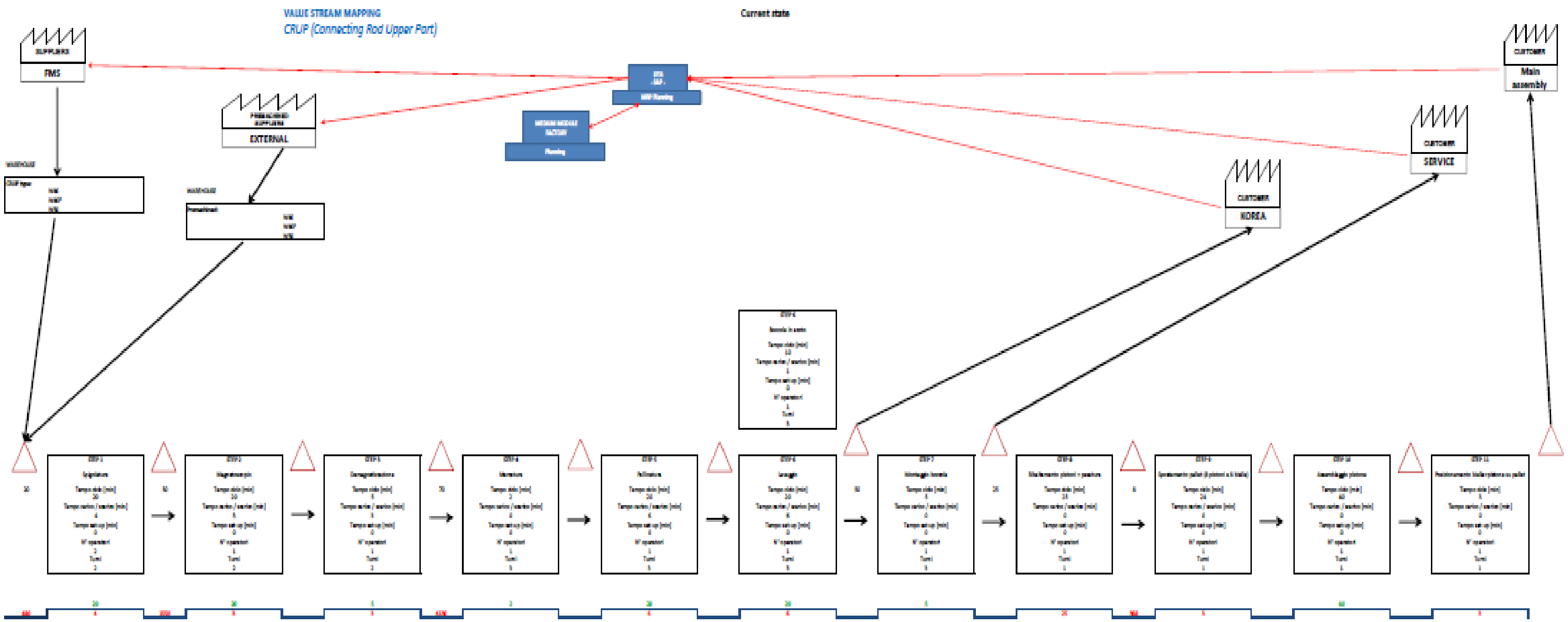
The pre-assembly of the connecting rods for different engines was analyzed, which is divided into two parts: the stem and the connecting rod head. The two products are considered distinct since they are part of two different production lines.

To move from the raw piece to the finished product, the connecting rod requires a series of operations after the Flexible Manufacturing System (FMS): deburring to remove the burrs, magnetoscopy to highlight surface defects and demagnetization, shot peening to improve the distribution of tensions surface, part washing and heating, bushing assembly and piston assembly.

Evaluation of layout solutions for the restructuring of a production process

AS-IS configuration

From the analysis of the process and from the survey of the processing execution times for a significant number of pieces along the production line, the Current State Map is elaborated (figure).



Numerical simulation as a tool for optimizing a production system

Evaluation of layout solutions for the restructuring of a production process

AS-IS configuration

As suppliers we consider both the internal FMS of the company, and the external suppliers, which supply the connecting rods in order to allow an internal activity always constant despite a very fluctuating demand.

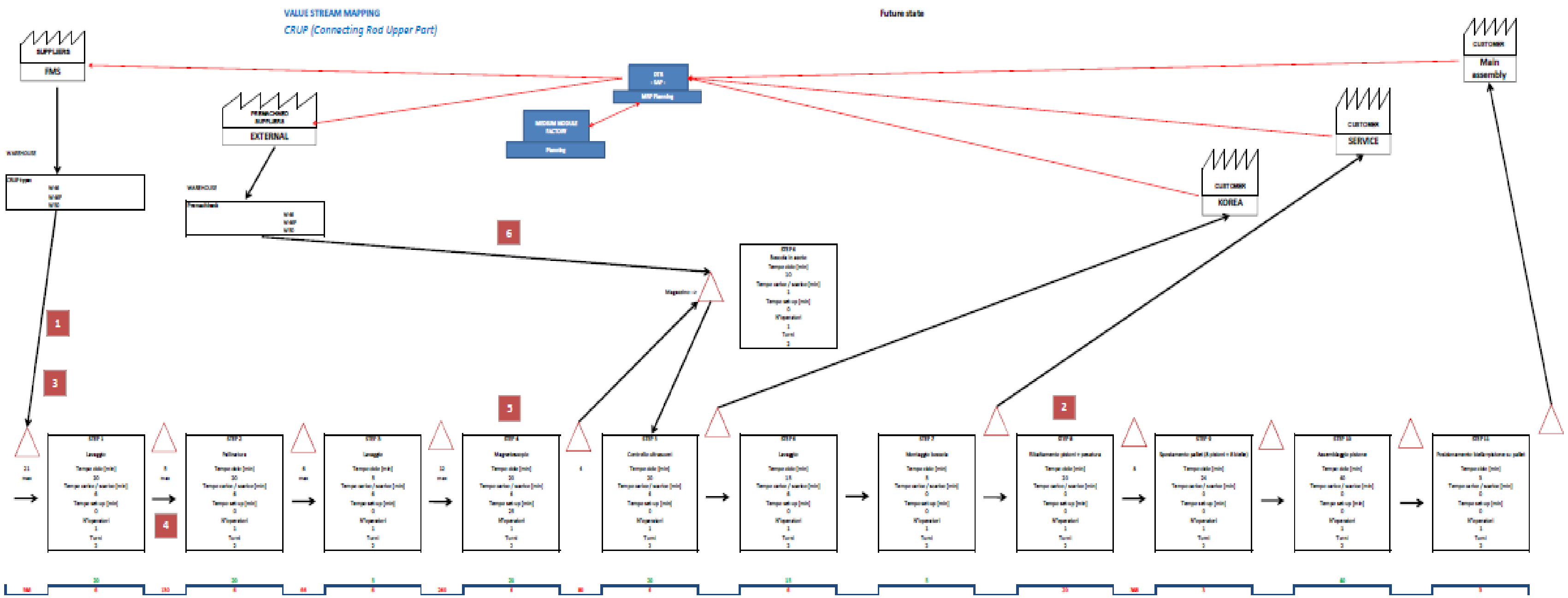
After carefully analyzing the current situation, we proceed with the identification and subsequent elimination of waste. The possible improvements identified are:

- deburring carried out in the FMS;
- reduction of the overturning time of the pistons;
- marking carried out in the FMS;
- buffer size reduction;
- degaussing attached to a new magnetoscope;
- ultrasonic control of components of external suppliers.

Evaluation of layout solutions for the restructuring of a production process

AS-IS configuration

The Future State Map, including the improvements made, is shown in the figure



Evaluation of layout solutions for the restructuring of a production process

AS-IS configuration

The information relating to the two configurations is summarized in the table

Current operations						Future operations					
Operation	Cycle time (min)	Loading-unloading time)	Tempo set-up (minutes)	Number of operators	Number of shifts	Operation	Cycle time (min)	Loading-unloadin g time)	Tempo set-up (minutes)	Number of operators	Number of shift
Deburring	20	4	0	2	2	Wash	20	6	0	1	2
Magnetization	20	3	0	1	2	Shot peening	20	6	0	1	2
Demagnetization	5	3	0	1	2	Wash	5	6	0	1	2
Marking	2	0	0	1	3	Magnetoscope	20	6	25	1	2
Shot peening	20	6	0	1	3	Ultrasound check	20	6	0	1	2
Washing and bushing in nitrogen	20 + 10	6 + 1	0 + 0	1	3	Washing and bushing in nitrogen	15 + 10	6 + 1	0	1	2
Bushing assembly	5	0	0	1	3	Bushing assembly	5	0	0	1	2
Pistons overturning and weighing	25	0	0	1	1	Pistons overturning and weighing	20	0	0	1	2
Pallet movement (pistons and connecting rods)	24	0	0	1	1	Pallet movement (pistons and connecting rods)	24	0	0	1	2
Piston assembly	40	0	0	1	1	Piston assembly	40	0	0	1	2
Connecting rod and piston positioning on pallet	3	0	0	1	1	Connecting rod and piston positioning on pallet	3	0	0	1	2

Evaluation of layout solutions for the restructuring of a production process

AS-IS configuration

The improvement of the production process in terms of elimination of waste is that shown in table. The increase in value-added time is linked to the washing operations before shot peening and one after the shot peening, and the ultrasonic control activity to verify that there are no cracks even in depth. The reduction of time to non-added value lies in achieving a more continuous flow and in the drastic decrease in the size of the buffers.

	Current (h)	Future (h)	Change in hours	Percentage change
Value-added time	2.2	2.4	0.2	10%
Time with no added value	109.7	24.8	-84,8	-77%
Lead time	111.9	27.2	-94.6	-76%
Added value/Lead time	2%	9%	N/A	7%

Characteristics of the production process of the connecting rod heads

Evaluation of layout solutions for the restructuring of a production process

AS-IS configuration

The same procedure has been used for the connecting rod drum where improvements have been made to the operations identified in its head. The Current State Map and the Future State Map are subsequently developed. The improvement of the production process in terms of elimination of waste is that shown in the table

	Current (h)	Future (h)	Change in hours	Percentage change
Value-added time	5.2	3.1	-2.1	-40%
Time with no added value	70.7	43.1	-27.6	-39%
Lead time	75.9	46.2	-29.7	-39%
Added value/Lead time	7%	7%	N/A	0%

Characteristics of the production process of connecting rod drums

Evaluation of layout solutions for the restructuring of a production process

AS-IS configuration

Unlike the connecting rods, there is no increase in the percentage ratio between the value-added time and the lead time due to the decrease in both the value-added time (reduction of the ultrasound control cycle) and the non-value time added (more continuous flow and buffer size reduction). The space available for the production line relating to the connecting rods and the assembly of the pistons was 1500 m^2 and the objective that guided the definition of the new layout is linked to the continuity, homogeneity and linearity of the production flow, compatibly with the production constraints. Different scenarios are developed and the spaghetti chart methodology is applied to reduce the paths between the workstations and improve the fluidity of the path.

Numerical simulation as a tool for optimizing a production system

<u>Evaluation of layout solutions for the restructuring of a production process</u>

AS-IS configuration

Compared to the current situation of the operations on the connecting rods (figure 1) and on the connecting rod heads (figure 2), the solution proposed for the future is that of figure 3.

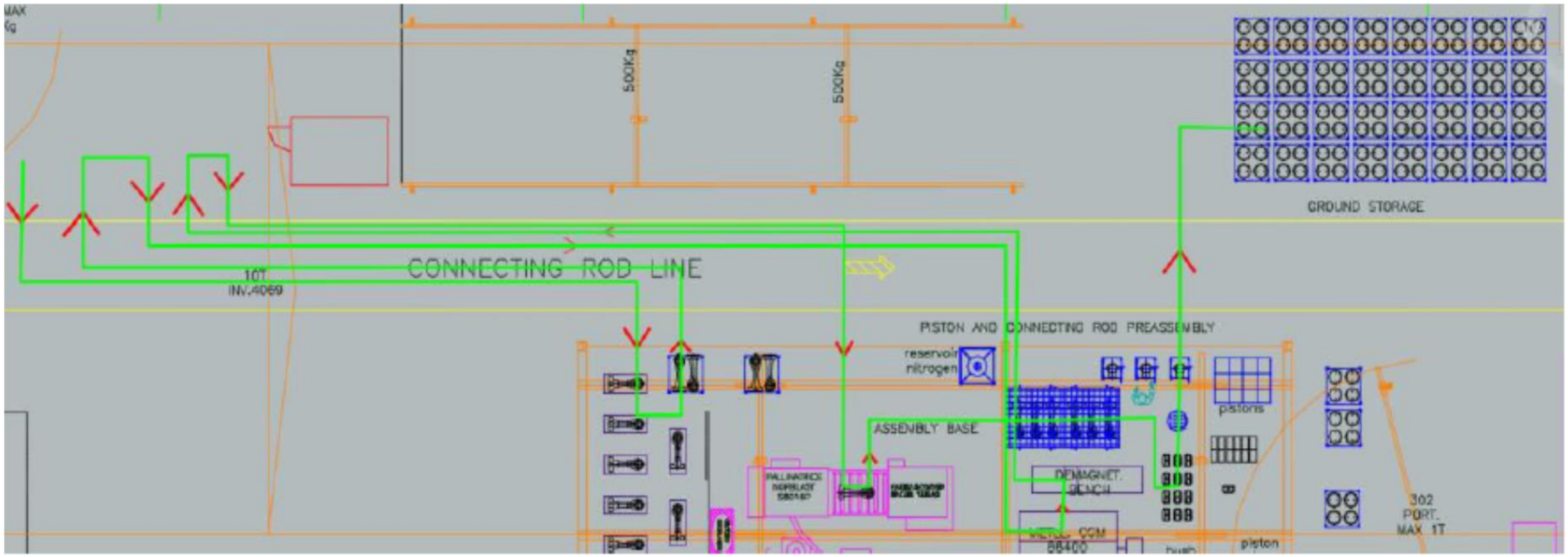


Figure 1: Layout and spaghetti chart of the current configuration for connecting rod drums

Evaluation of layout solutions for the restructuring of a production process

AS-IS configuration

Compared to the current situation of the operations on the connecting rods (figure 1) and on the connecting rod heads (figure 2), the solution proposed for the future is that of figure 3.

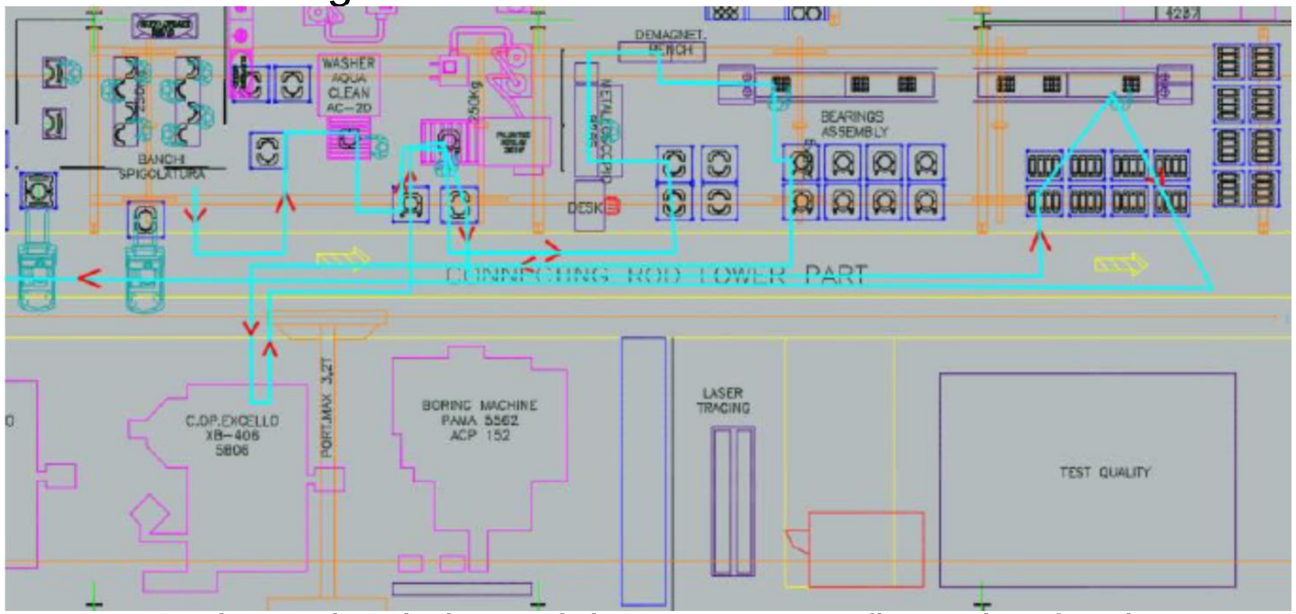


Figure 2: Layout and spaghetti chart of the current configuration for the connecting rod heads

Evaluation of layout solutions for the restructuring of a production process

AS-IS configuration

Compared to the current situation of the operations on the connecting rods (figure 1) and on the connecting rod heads (figure 2), the solution proposed for the future is that of figure 3.

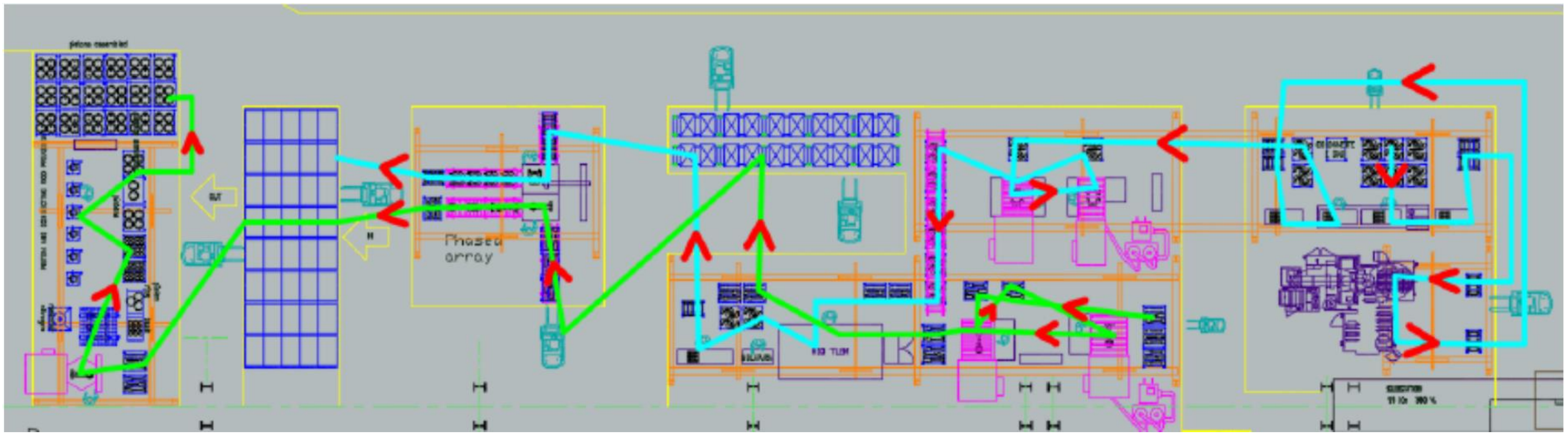


Figure 3: Layout and spaghetti chart of the future configuration

Evaluation of layout solutions for the restructuring of a production process

AS-IS configuration

Considering the current layout, there are significant improvements in terms of quality as the fluidity of the route is significantly increased. The changes made, in addition to making the flow more linear and homogeneous, led to a drastic reduction in displacements (table).

	Current layout	Future layout	Percentage change
Connecting rod drums path length (m)	218	121	-44,5%
Connecting rod heads path length (m)	256	172	-32,8%

Improvements between current and future layout

Evaluation of layout solutions for the restructuring of a production process

AS-IS configuration

The areas of the current and future configurations are very similar. In fact, the available area (total space for arranging machinery, warehouses, passageways etc.) is approximately 1,500 m^2, while the occupied area (space actually occupied by the machinery net of passageways and corridors) is approximately 1,000 m^2 for both scenarios. In the future layout there are warehouses dedicated to housing all the pieces from the outside ready for ultrasound control, in addition to those produced internally.

Numerical simulation as a tool for optimizing a production system

<u>Evaluation of layout solutions for the restructuring of a production process</u>

AS-IS configuration

There is also the Phased array, including the portal and the crane used in this area (figure).

Future layout

Evaluation of layout solutions for the restructuring of a production process

AS-IS configuration

Following the modification of the layout, which produced a decrease in the total area of more than 50%, we analyze what can happen by unifying the two existing warehouses with the future ones consisting of a traditional and an automated one, in order to verify whether the production is supplied on time and constantly with the necessary material, that the routes are not congested and that the number of forklifts is sufficient. To do this, a data collection was carried out, aimed at mapping the factory, analyzing the production plan, identifying the number of pallets needed for production and defining the times for the assembly of the engine taking into account that of delivery of the material.

Numerical simulation as a tool for optimizing a production system

Evaluation of layout solutions for the restructuring of a production process

Simulation of the future production process (TO-BE)

In order to validate the goodness of the results obtainable and understand the behavior of the entire production line by varying some parameters and the supply system, a simulation model was created. The model is often simpler than the system analyzed, often based on incomplete or uncertain data, with a number of simplifications, containing bugs and logical errors: the effort to obtain greater precision is not economically advantageous. Simulating new systems, on the other hand, is sometimes the only feasible possibility, since if the system does not yet exist, nothing in real life can be observed.

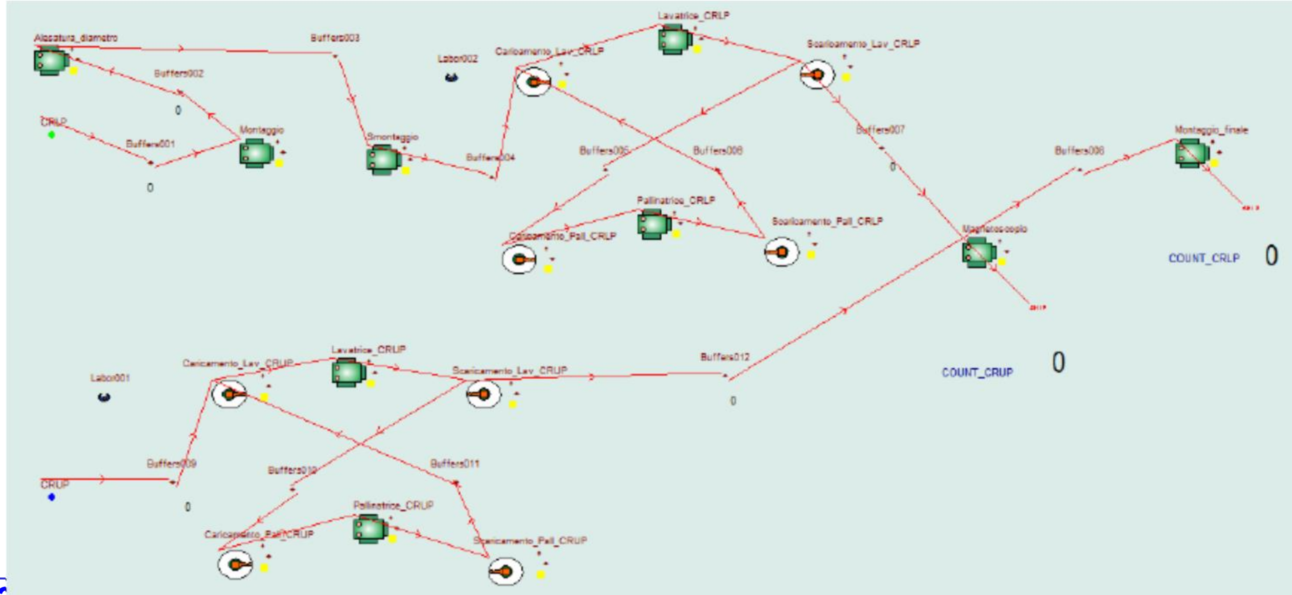
The simplifying hypotheses adopted are:

- represent machines alone without operators and cranes;
- cycle time as the sum of machine time and man time.

Evaluation of layout solutions for the restructuring of a production process

Simulation of the future production process (TO-BE)

The **graphical representation of the model** using the Witness object-oriented software is the one shown in the figure. There are two flows in it: the upper one is relative to the heads of the connecting rods, while the lower one is related to the relative drums. The two flows join to the right near the video recorder which is common to the two components.



Numerical simulation as a tool for optimizing a production system

Evaluation of layout solutions for the restructuring of a production process

Simulation of the future production process (TO-BE)

The incoming pieces are supplied by the FMS with a regular time (works interrupted 24 hours a day) with the exception of Saturdays and Sundays. Between each machine there is a buffer (output for the previous operation and input for the next). Once the last operation is completed, the parts are made to escape from the flow. The connecting rod heads that come from the FMS are 16 halves for a total of 8 pallets (2 connecting rod heads per pallet) with an arrival time of 360 minutes, while for the connecting rods there are 8 for a total of 3 pallets (3 connecting rod drums per pallet) with an arrival time of 540 minutes. The 12 buffers are positioned as decoupling buffers between one machine and the next. Operators are not employed except for a few exceptions: almost in all the workstations there is an operator dedicated to the specific processing, while in the case of the washing machine and shot-peening the operator is unique.

Evaluation of layout solutions for the restructuring of a production process

Simulation of the future production process (TO-BE)

The types of machines used are:

- **batch**: machine with input and output having a number of parts greater than 1;
- **single**: machine with input and output having a number of parts equal to 1;
- **assembly**: machine with multiple parts inlet and one part outlet.

For the input and output actions, two simple rules are considered: the pull rule at the input, while the push rule at the output.

For the cycle times, those that emerged from the VSM are considered and for the input and output commands to the machines it has been established that they are free and that the relative set-up is carried out.

The 8-hour work shift (480 minutes) in the morning and afternoon with which two breaks of 15 and 45 minutes are associated, while in the night shift there are four 15-minute breaks.

Evaluation of layout solutions for the restructuring of a production process

Simulation of the future production process (TO-BE)

To validate the model, two checks are carried out:

- **validation of each individual machine**

  All cycle times are accepted. I accept that of the considered machine, while the incoming pieces are supplied at zero time in order not to slow down the production flow. The production times of 1,000 connecting rod drums and 2,000 half of connecting rod heads are considered. The times obtained from the simulation are compared with those obtained by multiplying the number of parts by the cycle time. The result is an absolute coincidence between the two since the cycle times are exact values and do not follow a probabilistic trend;

Evaluation of layout solutions for the restructuring of a production process

Simulation of the future production process (TO-BE)

To validate the model, two checks are carried out:

- **validation of the production process of each individual part**

  This verification is obtained by setting the cycle time of the machines not involved for the part considered equal to zero. The flow of the connecting rod heads obtained by the simulation differs only 0.7% from the calculated theoretical one; this is due to the fact that in the location where the washing machine and shot-peening are located there is a single operator. The flow of simulated connecting rod drums has a deviation of 8.2% greater than the theoretical calculated one; the motivation is the same as the previous flow in that there is a single operator used to load/unload the washing and shot-peening.

Evaluation of layout solutions for the restructuring of a production process

Simulation of the future production process (TO-BE)

Once verified that the model is reliable, it goes to the testing phase. First of all, an analysis is conducted to look for the saturation of the system obtained by not placing constraints on the number of pieces input, nor by limiting the capacity of the buffers. A two-month warm-up time is introduced and, once fully operational, a one-year production flow is considered. An initial production of 7 pieces/day (7 connecting rods and 14 half connecting rod heads) is taken into consideration, with 2 shifts for 5 working days per week to then increase the pieces produced daily until the line is saturated. Having no limits on the buffers, it is decided to increase the shifts only if the size of the shifts is increased indefinitely.

Numerical simulation as a tool for optimizing a production system

Evaluation of layout solutions for the restructuring of a production process

Simulation of the future production process (TO-BE)

The shifts are set for each individual machine in order to have maximum flexibility: from 2 shifts a day for 5 working days a week, you switch to 3 shifts for the same period and subsequently for 7 working days a week. The maximum number of pieces theoretically produced per day is 18 as the use of the video recorder constitutes the bottleneck of the system even operating in 3 shifts for 7 working days a week. This analysis is theoretical in that the capacity of the FMS is less than that of the drums and connecting rod heads.

Evaluation of layout solutions for the restructuring of a production process

Simulation of the future production process (TO-BE)

From the simulations, it is found that the two lines of the drums and connecting rod heads are well balanced and produce in a year a practically equal number of components. The size assumed by the buffers in the same time period remains almost constant with the increase in the daily pieces produced, in other cases instead it increases significantly. The percentage of occupation of the machines was then analyzed according to the shift and the working days in the weeks considered. It is found that it is never saturated, but the most saturated ones are the use of the video tape recorder and the reamer for the connecting rod diameter.

Evaluation of layout solutions for the restructuring of a production process

Simulation of the future production process (TO-BE)

Subsequently, the simulations are analyzed considering 4 cases:

- 2 cases with the same assumptions seen previously;
- 2 cases with the peculiarity of having limited buffers and introducing preventive maintenance (at regular intervals - 2 hours every 2 months for each machine) or corrective maintenance to the machines (triangular probability distribution: for example for the washing machine the values are those of table).

Time Between Failures				Repair Time			
Units of measure	MINIMUN	MODE	MAXIMUM	Units of measure	MINIMUN	MODE	MAXIMUM
Mounths	5	6	7	Hours	4	6	8
Minutes	89100	106920	124740	Minutes	240	360	480

Triangular probability distribution of the washing machine

Numerical simulation as a tool for optimizing a production system

Evaluation of layout solutions for the restructuring of a production process

Simulation of the future production process (TO-BE)

The situations relating to 8 and 12 pieces/day are considered, with a "target" production for the FMS.

The shifts for each individual machine in the 4 cases coincide (2 shifts on 5 working days a week) except for the use of the video recorder and the reamer for the connecting rod diameter in the case of 12 pieces/day.

A warm-up time of 2 months and an analysis time of 1 year is adopted. Also in this case the number of pieces produced is practically the same for the line of drums and connecting rod heads. There is a perfect correspondence between the number of pieces produced in the 4 cases, this means that the maximum limitation of the buffers and the introduction of maintenance has not led to changes in the flow of the system, given that the machines are not saturated.

Evaluation of layout solutions for the restructuring of a production process

Simulation of the future production process (TO-BE)

The size of the buffers in ideal cases may be larger than in real and borderline cases; the fact that this does not happen is the demonstration that the production lines are well balanced. Finally, the percentage of occupation of the machines was noted, which shows the perfect agreement between the ideal and real cases, which demonstrates the correct choice of the space reserved for the buffers when defining the layout.

Having available the production plan, the number of pallets for each engine and the times for assembling the engine, taking into account that of delivery of the material, the simulation model is created by adopting simplifying hypotheses that neglect the internal handling of the logistics (preparation of pallets and logistic kits), production movements, out-of-shape and overweight pieces, the lifting of the motors that prevent the passage of the forklifts and everything that does not start from the central warehouse.

Evaluation of layout solutions for the restructuring of a production process

Simulation of the future production process (TO-BE)

The initial conditions are:

- single starting point corresponding to the center of the new warehouse area;
- a pallet corresponding to a trip;
- the return journey which can be different from the outward journey;
- all pallets are ready in the morning;
- the operating line used by the various engines;
- the sequential choice of the station;
- the grouping of engines into families;
- the maximum capacity of pallets in the warehouse;
- the capacity of the tracks;
- shifts and collective closing days per year.

Evaluation of layout solutions for the restructuring of a production process

Simulation of the future production process (TO-BE)

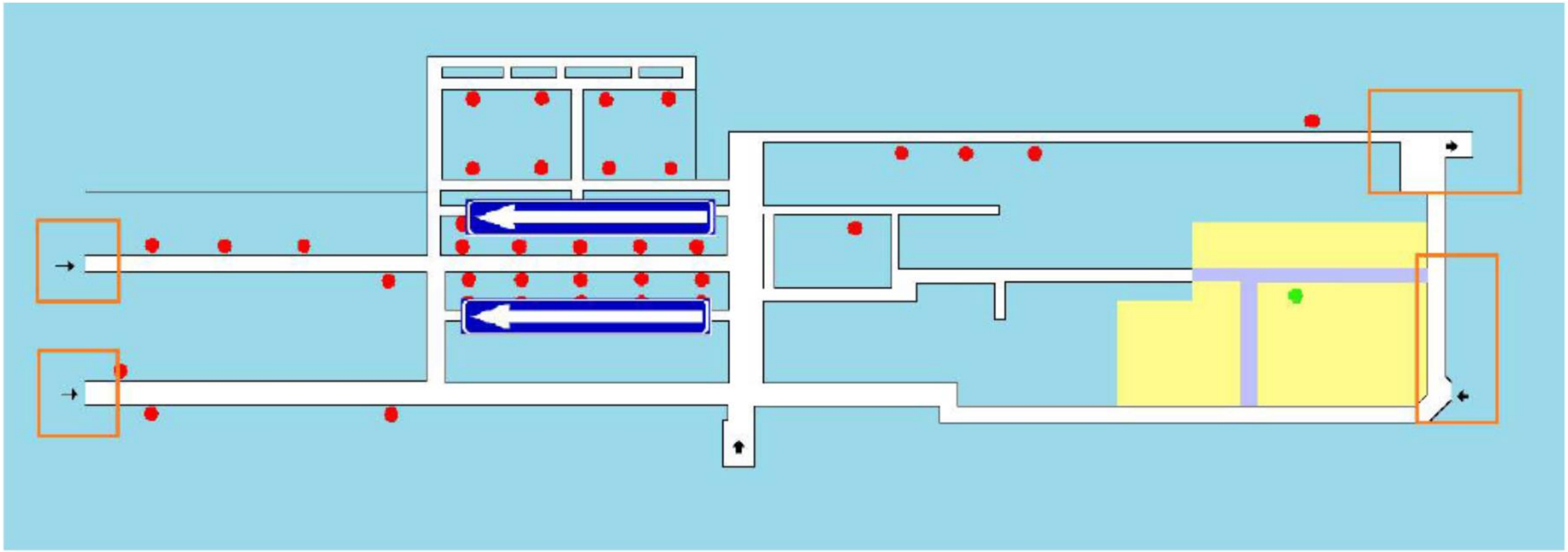
The data relating to forklifts are defined: speed 6 km/h, 1 minute of waiting before leaving the warehouse, 1 minute for loading, 1 minute for unloading, 2 minutes of rest after its arrival in the warehouse, capacity of the forklifts (1 pallet) and variable number of forklifts (3 fixed forklifts and 3 forklift help).

The result to be achieved is: there are no residual pallets in the warehouse at the end of the day, average maximum delivery delay of the pallets of 1 day, 30% of the forklifts loaded, absence of congestion of the routes and leveled daily workload. The variables involved are the number of employees and the time slots dedicated from logistics to the delivery of the material.

Evaluation of layout solutions for the restructuring of a production process

Simulation of the future production process (TO-BE)

Since the space available remains constant, there are characteristics that cannot be changed. The routes remain unchanged compared to the current situation (figure).



Initial situation of one-way streets and unloading areas

Evaluation of layout solutions for the restructuring of a production process

Simulation of the future production process (TO-BE)

There will be areas that will be trafficked by internal production and others used for handling for the acceptance of goods and storage in the warehouse, and different for the handling of finished products.

The validation of the model is made taking into account that the current layout is different from the future one, therefore going to compare the real data with the simulated ones (total annual number of hours of the distance traveled by the forklifts), the substantial differences between the two are taken into account situations (the future one will have a single building and the future warehouse will be in the one made free).

Considering the efficiency of 70% of the operator driving the forklift, the difference between the real situation and the simulated one is 5% (127 working hours), which allows us to say that the model is realistic despite the simplifications made.

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The model is used to evaluate the improvements obtained with the new layout for the same workload.

We try with different scenarios to evaluate the congestion of the roads which is less than 50%, ensuring that the production is supplied in the right times and without delays (time that the pallet spends in the warehouse), that there is a number of forklifts needed through the percentage of uses of carriers and that there are total annual time gains obtained.

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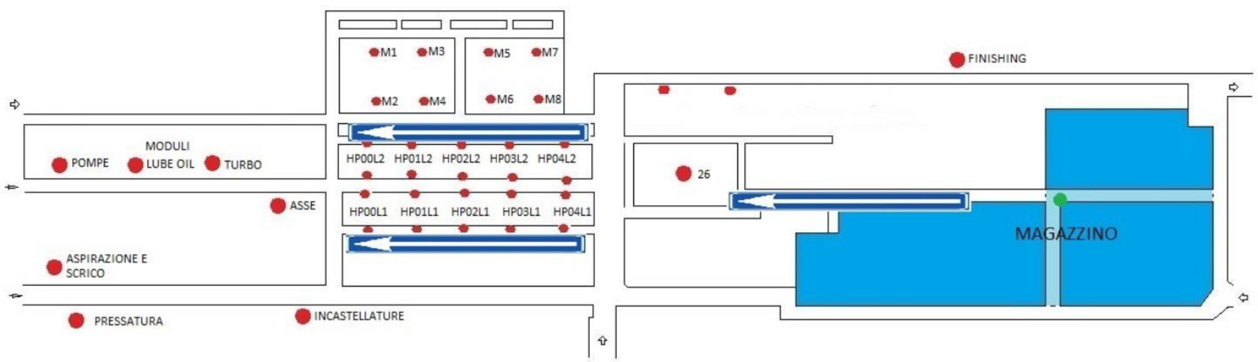
In particular:

a) **scenario 1: travel directions**

In the initial configuration, the way out of the warehouse has a saturation percentage higher than 65% and, in some cases, it is blocked (unacceptable situation). It involves a one-way street (figure).



Unique ways in the new layout

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In particular:

a) **scenario 1: travel directions**

It turns out that for almost 91% of the pallets the delivery is on time, while only 9% is late. However, going to analyze the average (0.53 days) of the storage time in the warehouse and the standard deviation (0.35 days), it is noted that the delay is minimal (only 0.29% of the pallets have a delay greater than two days). Since pallets not shipped on Friday are delivered on the following Monday, this value can be neglected.

With regard to the use of forklifts, three are always available within the time slots for supplying production, while the other three come into play when the warehouse load increases.

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In particular:

a) **scenario 1: travel directions**

They are not always used and in the current situation the forklift can do any task (goods acceptance, warehouse organization, preparation of logistic kits, etc.).

In the future situation, three forklifts are always available and two more that support the first three when the workload is more expensive, while the third forklift can be eliminated;

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In particular:

b) **scenario 2: same as scenario 1, but with forklift speed reduced to 4.5 km/h**

From the simulation analysis, the routes are not congested. The inventory of pallets in the warehouse during the year has an average of 0.66 days and a standard deviation of 0.48 days. Pallets processed late are 14%, a value which is 4% above the limit threshold. One solution is to go to better balance the workload in order to better exploit the forklifts within the time slots to reach saturation. The use of forklifts varies a lot (they are slower) and the pallets are processed from the warehouse with less frequency, while the forklift help are more used. The distance traveled per year is the same and the number of hours of use is 4,130 h with an improvement of 0.65%;

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In particular:

c) **scenario 3: same as scenario 1, but with forklift speed increased to 8 km/h**

From the simulation analysis, the routes are not congested. The inventory of pallets in the warehouse during the year has an average of 0.46 days and a standard deviation of 0.29 days. The pallets processed late are 7.5%, a value that is within the initially established parameters. The use of forklifts varies widely (they are faster) and the pallets are processed more frequently from the warehouse, while forklift help are less used. By homogenizing the workload, only 3 forklifts can be used to make annual deliveries. The distance traveled per year is the same and the number of hours of use is 4,130 h with an improvement of 39.0%;

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Simulation of the future production process (TO-BE)

In particular:

d) **scenario 4: same as scenario 1, but with the difference that for every day every 3 weeks the warehouse does not evade any pallet, thus going to load work the next day**

This scenario simulates several real situations: production delay, breakdown of one or more forklifts, possible errors in logistics or suppliers and blocking of the warehouse. From the analysis of the simulation, the roads are not congested. The inventory of pallets in the warehouse during the year has an average of 0.52 days and a standard deviation of 0.79 days. Pallets processed late are 17.5%, a value that is 7.5% higher than the set limit, so much so that care must be taken to plan the work plan, have reliable suppliers and a quick maintenance service to make it operational both the forklift and the warehouse.

Evaluation of layout solutions for the restructuring of a production process

Simulation of the future production process (TO-BE)

In particular:

d) **scenario 4: same as scenario 1, but with the difference that for every day every 3 weeks the warehouse does not evade any pallet, thus going to load work the next day**

The use of forklifts varies widely (variable workload with peaks due to warehouse blocking) since, being the load unbalanced, there are periods of great use and periods of inactivity, especially of the forklift help. The distance traveled per year is the same and the number of hours of use is 4,130 h with an improvement of 8.0%;

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Simulation of the future production process (TO-BE)

In particular:

e) **scenario 5: same as scenario 1, but with production at maximum capacity (35,500 pallets to be delivered per year)**

From the analysis of the simulation, the roads are not congested. The stock of pallets in the warehouse during the year has an average of 0.83 days and a standard deviation of 0.82 days. Pallets processed late are 17.5%, a value that is 7.5% higher than the set limit, so much so that attention must be paid to planning the work plan, having reliable suppliers and a rapid maintenance service to make it operational both the forklift and the warehouse. The use of forklifts varies widely (variable workload), is intensive and the number is at most 5, of which 3 are always available and 2 on standby. The distance traveled per year is the same and the number of hours of use is 4,130 h with an improvement of 48.2%.

Numerical simulation as a tool for optimizing a production system

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The proposed methodology could be applied to any production reality of redevelopment of the company layout.