A Data-driven approach for process Simulation Optimization: a case study

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ABSTRACT

The paper deals with the development of a data-driven simulation model for the process optimization of an automatic electroplating plant in the fashion industry. Starting from the process mapping of the production process using the Business Process Modelling and Notation (BPMN standard), an object-oriented simulation model has been defined using the commercial software AnyLogic®. Finally, the model has been validated and the plant has been optimized.

INTRODUCTION

The fashion industry is very popular in the literature, many contributions can be found. Despite this, most of the contributions have a brand owners' perspective, whilst labor or raw materials suppliers, mostly composed by micro and small companies, are less analyzed.

Recently, focal companies have faced with an increasing attention to delivery dates, cost reduction, and sustainability issues (May et al., 2015) (Brun et al. 2014) (Caniato et al. 2015) (Brun et al, 2017) (Brun and Castelli, 2008). As a consequence, this attention has moved toward all the Supply Chain (SC) actors, including metal accessories suppliers, that has started a process increasing their performances in terms of quality, time, and costs under the pressure of the brand owners and their increasing attitude toward a performance measurement systems implementation (Cagnazzo et al., 2010).

As widely known, production in the fashion industry is a complex process distributed between different actors operating at different levels. Production scheduling and optimization of a multi-level Supply Chain, composed by several small companies (mostly Small Medium Enterprises - SMEs) coordinated by a big company (which usually is the brand owner in the fashion industry), has been widely discussed in the literature (Fani et al., 2017). Simulation-optimization has been widely recognized as a useful tool to resolve such complex system considering finite capacity (Rahmani et al. 2013) (Ait-Alla et al. 2014).

According to this, this paper presents a data-driven simulation model for the process optimization of an electroplating automatic plant. The electroplating process is the last job of the production process of metal accessories (e.g. buckles, chains, buttons) that have to be assembled in final products as bag, shoes, belts.

The paper is structured as follows. After a brief presentation of the metal accessories industry, the case study is introduced and deeply analyzed. Then some conclusion and future steps are reported.

METAL ACCESSORIES IN THE FASHION INDUSTRY

Metal accessories suppliers have never been deeply analyzed in the literature, despite their relevance from an economical point of view. Only few papers are related to such industry (Fani et al., 2016), even if they cover, looking at the Italian scenario, more than 3.5B€ of revenues in 2020, with more than 250,000 companies and occupying more than 14,000 employees.

One of the main reasons of the lower attention to these suppliers in the literature, compared to that one related to leathers or textile's ones, is that metal accessories do not represent at the costumers' eyes the fashion product, differently from the other components.

Despite this, the performances of these companies and the quality of the products greatly influence all fashion SC. At least a metal accessory has to be added to each bag, shoes or belt, and every delay in the delivery of this item, or a quality problem in a production batch inevitably leads to a delay or the need to reschedule production. This way, it is very important to optimize the production plan of the metal accessories suppliers, and in detail of the electroplating phase, that is the last one of the production processes (Bandinelli et al, 2021).

CASE STUDY

The analyzed company is a metal accessories producer for the fashion industry located in Florence and working for the major fashion brands in Italy. The company is composed of two independent production plants: one for manual electroplating and one for automatic electroplating.

The project carried out focuses exclusively on the production process of the automatic plant. This choice is possible thanks to the assumption of independence between the two plants. A generic representation of the layout, where the automatic plant is reported, can be seen in Figure 1.

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Process Mapping

Before starting with the real modeling on the AnyLogic® software, a conceptual model of the system has been realized, in order to understand the logic of operation, the connections among the different activities carried out within the company and the principal events that characterize them.

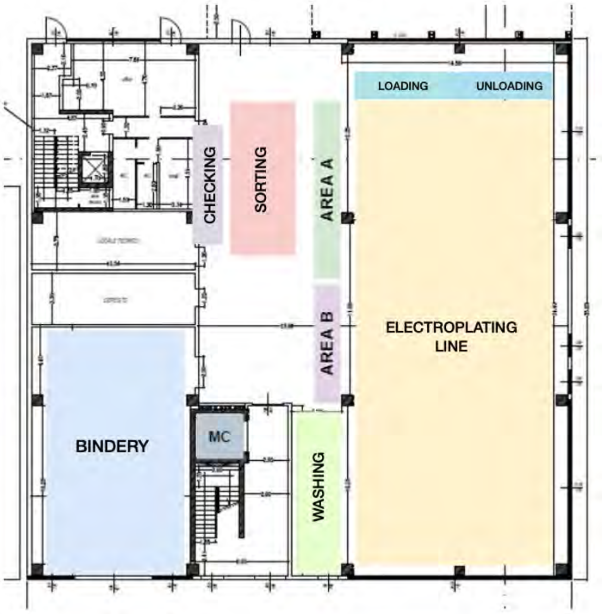

Figure 1: Plant layout

The production process begins at the moment in which the acceptance of the raw product, supplied by the customer (e.g. the brand owner), is carried out following a work order. Therefore, the arrival of raw material can be considered contextual to the order generation. This allows to neglect the operative flows related to the supplying of the material. Subsequently, the work order is transferred to the Binding department, where it is queued on shelves waiting to be taken over. The processing phase related to binding is generally divided into two main operations: the binding together of the individual pieces, using copper wires or rings, and the subsequent assembly of the latter on special frames.

Once prepared, the frames ready to be worked are transported by operators in the warehouse placed in *Area A* shown in Figure 1. From there, items are picked up one at a time by the operator of the electroplating department and transported to the *Loading* area of the plant.
To be placed inside the machinery, the frames are picked up by the trolley and hooked onto bars positioned in a special area, called *Loading*, from which they will be picked up by an overhead crane and moved into the *automatic plant*.
The plant consists of 150 galvanic treatment tanks, arranged according to a "zig-zag" folded line layout, so as to form 4 lines. The production flow is unidirectional and is forced on all four lines.
Unloading from the plant is managed in a similar way to the loading logic: once the last treatment has been completed, it is evaluated whether one of the unloading outlets is empty and therefore available to receive the bar. From this position the bars can be picked up and moved to the *Unloading* area with the same logic.
As soon as they are available in one of the loading inlets, the operator unloads the frames from the bars, places them on a trolley positioned near the unloading area and informs the machine of the unloading by means of a special button. In this way the unloading mouths can be freed from the empty bars, which are then returned to the inlet store in line 1, leaving space free for the next ones.
On exit from the lift, the trolleys are positioned in *Area B* because, before they can be used again for the processing of subsequent work orders, the frames need to be washed. This operation is carried out in a dedicated area to the side of the plant where there are washing tanks. After this operation both the trolleys and the frames can be brought back to the binding department.

Simulation model description

In this section, the simulation model is described, starting from the process mapping described in Figure 2, where the order generation is reported.
The arrival of work orders takes place physically within a designated hub from which, following an acceptance phase represented by a delay, they are transferred to the binding departments where they can be taken over and initiated.

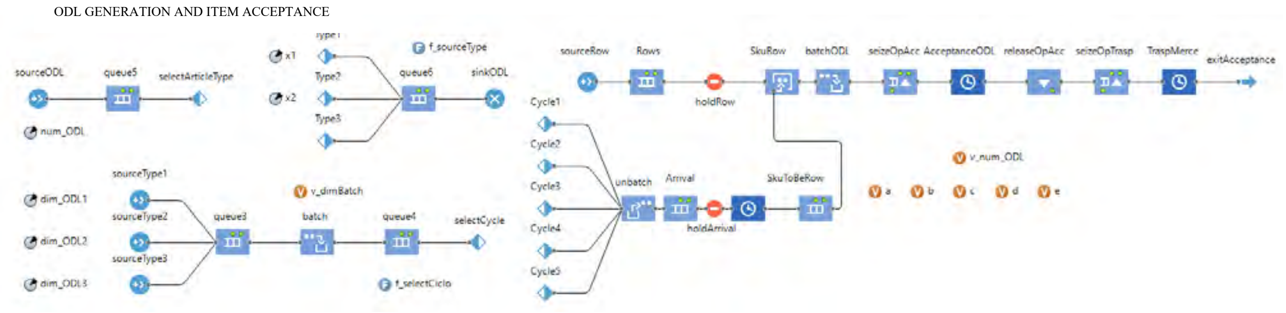

Figure 2: Process chart of the order generation section

Once the work orders have been generated and transferred into the tying department, the goods can be placed in a queue within the appropriate shelves waiting to be processed. The operating logic foresees that the work orders are taken over according to a FIFO (First In First Out) logic, as reported in Figure 2. Moreover, before the binding process can begin, for each work order the presence in the department of the resources needed to advance the goods to the next department is evaluated. In fact, according to the type of article of which the work order is composed, an appropriate type of frame and a certain number of trolleys necessary to transfer the goods towards the galvanic plant are required.

Both of them are generated when the model starts and located into an internal warehouse. They are taken and assigned to an item at the beginning of the production process and then released when the process ends, according to a circular flow.

The operations that are carried out in the bindery include the binding of the wires to the appropriate frames, the scheduling of the RFID devices placed on each frame, the subsequent loading of each of them on the trolley and its transportation to the automatic plant.

The operations of insertion of a specific item inside a container and its subsequent extraction have been managed throughout the process through the functional blocks *PickUp* and *DropOff*.

Since each type of item requires a specific frame and its capacity is variable, it was necessary to create a specific function that appropriately regulates both the release of the required resource and the number of threads to be tied on each of them.

Once the operations of this department have been completed, the looms loaded on the trolleys can be transferred to a dedicated warehouse close to the machinery, queued and waiting to be fed into the plant. In this phase the production flow is divided into two different ways: on one side the frames are picked up to be introduced into the automatic line, on the other side, once the trolley is emptied, it is led inside its dedicated area.

After this phase, the loading phase of the frames into the machinery takes place. The process involves the execution of three consecutive operations. The first involves the transportation of empty bars, initially located inside the inlet store at the beginning of the automatic line, towards the two loading mouths. Subsequently, once the bars are positioned correctly, they are loaded by an operator with the frames ready to be fed into the system. The operator at this time informs the machinery that the operation has been completed by pressing a special button. At this point the bars are once again picked up by the gantries and taken back to the input warehouse, following the movements previously carried out.

The logic of these operations envisages a preference for use of *loading mouth 1* since, through it, the bars can be led more quickly towards their destination, requiring fewer movements. Handling of bars in both directions is carried out by the bridge cranes and shifters located into the line.

A schema of this part of the model is reported in Figure 3, where it is possible to note the use of the Material Handling Library of AnyLogic®.

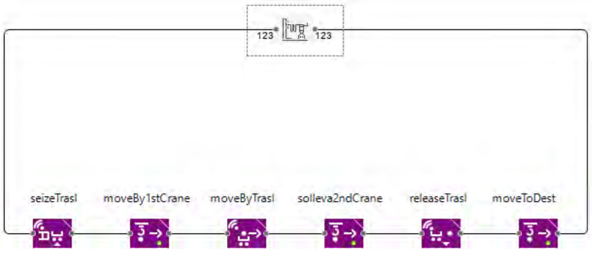

Figure 3: Loading area

The whole working process inside the automatic line has been realized following a different approach compared to the rest of the production process.

In fact, a *data-driven* method was followed, which will be suitably explained later in the paper, in order to increase the flexibility of the model (e.g. different plants configurations, change in the number of cranes, etc.) and the maintainability of the operating parameters by company personnel who do not necessarily have specific skills linked to the AnyLogic® software.

The process ends with the cleaning phase of the frames, which is necessary after the galvanic treatments. The return trolleys are therefore taken from the hoist and positioned in *Area B*. Frames are then washed and transported to the bindery, where they are once again available for use.

Data-driven model definition

Due to the complexity of the model in terms of, the model has been developed using a data-driven approach. Following this approach, the creation of the objects and their interaction between each other is entirely managed through external databases that provide the information for the construction of the model.

The data-driven approach gives the possibility to the user to easily change the characteristics of the plant without entering the model and consequently without the need to have knowledge about coding and simulation. On the other side, the effort needed in order to develop the model from scratch is higher in comparison with a traditional one. Moreover, the rules and the behavior of each element of the model has been described using the Java language, since this approach requires to define with custom action how entities move from one resource to the next one.

In detail, the custom objects that have been created are:

- *Galvanic Tanks*
- *Translator*.

Each of these is characterized by a process chart that describe the behavior of the entities within the object. The data regarding the processing time, transportation speed and how the entities move from one object to another have been parametrized and stored in a database, that is read when the model starts.

Thanks to the functionalities made available by the AnyLogic software, it has been possible to connect the model to a database and parameters are stored within Microsoft Excel®.

Once the database had been defined, java functions able to execute queries which, at each step, determine the destination of the route to be followed and the operating parameters associated with it have been written.

A representation of the two objects is reported in Figure 4 and Figure 5.

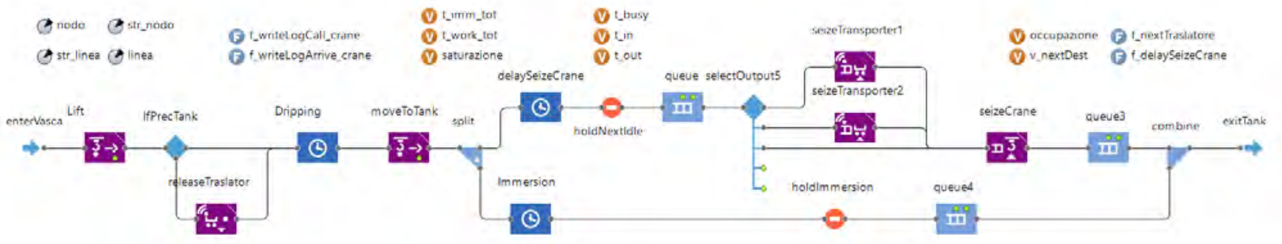

Figure 4: Galvanic Tank Object Process chart

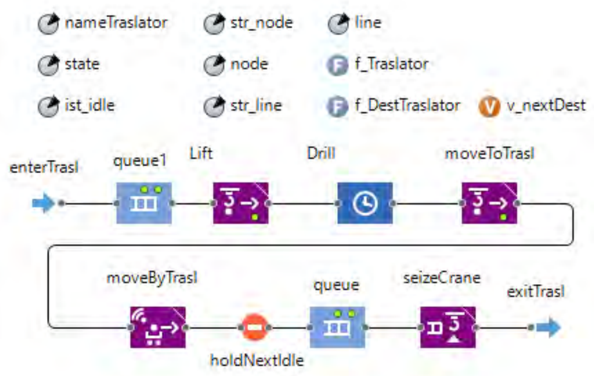

Figure 5: Translator Object Process chart

Due to the presence of cranes, no buffers have been set up between one resource and the following one, so a bar can be extracted and transported to its next step only when the second one is empty.

Moreover, it may happen that several different bars require simultaneously the use of a specific tank, consequently it is required a mechanism that defines the sequence of resources to be assigned to the different bars during the processing phase. The modeling of these aspects has been managed through the joint action of two functions.

The first function, launched every time a bar requires to be moved, executes a query that analyze the production cycles stored in the database and returns the possible next destination or destinations. The list of destinations is recorded, together with other parameters that characterize the bar, in an appropriate array. In each line are recorded the code and the processing cycle of the article, the type of resource and the name of the origin tank and the temporal instant of the movement request. This last parameter is essential for choosing the handling order of the various bars.

The second one is, instead, a *time-driven* function, activated cyclically at constant time intervals. This type of function, in the simulation environment of AnyLogic, is managed through the Event functions.

This mechanism ensures a correct balance in the exploitation of parallel resources and allows a fair ordering mechanism of the movements of the bars that insist on shared resources. Once the appropriate destination has been defined for each of the bars to be handled, a further function executes a new query that reads the operating parameters of the subsequent destinations and assigns them to the entity that will be handled.

Process Charts and Crane Handling

As previously mentioned and reported in Figure 4 and Figure 5, flowcharts can be inserted inside every object, representing the activities that will be performed every time an entity crosses them.

The construction of a *data-driven* model also requires the realization of a mechanism that allows input, output and interfacing between each object. In AnyLogic this aspect is managed through the *Enter* and *Exit* functional blocks thanks to which each entity of allowed type can freely enter and exit each object.

To better clarify these concepts, it is useful to show the process charts of the two objects created (Figure 4 and Figure 5). In both cases functional blocks belonging to two libraries inside the program have been used: the *Process Modeling Library* and the *Material Handling Library*. In the specific case, the entities being handled are the bars to which the frames containing the semi-finished products to be treated are hooked. The means used for their handling along the four lines of the plant are bridge cranes and translators.

Animation of the agents is delegated to special tools known as *Space Markup*, which consist of special forms able to represent paths, movements or operations of the various objects within the system. As far as the realization of gantries is concerned, within the program there are dedicated *Space Markups* in which, with opportune parameters relative to their dimensions, to their shape, to the elevation height and to their displacement speed, they allow to reproduce them graphically. For this reason, in order to faithfully reproduce the operation and movement times of the various gantries within their areas of competence, it a graphical reproduction of the treatment tanks of the entire plant has been developed. Through AnyLogic, it is possible to create both a two-dimensional (2D) and a three-dimensional (3D) graphic representation, that have the double scope of reproducing the movements of the entities and generally constituting an excellent instrument useful for verifying the correct behavior of the model.

To such purpose, it has been realized a graphical reproduction in scale of all the resources inside the plant, as reported in Figure 6. In the figure are represented the tanks of treatment, disposed according to their order and layout, the mouths of loading and unloading, the warehouses of entry and exit, the translators, bound to execute movements exclusively along the lanes of their pertinence and the 12 bridge cranes opportunely distributed on the four lines. In this way, it was possible to realistically reproduce both the movements of the bars processed in the plant and the movements carried out by the *bridge cranes* and *translators*.

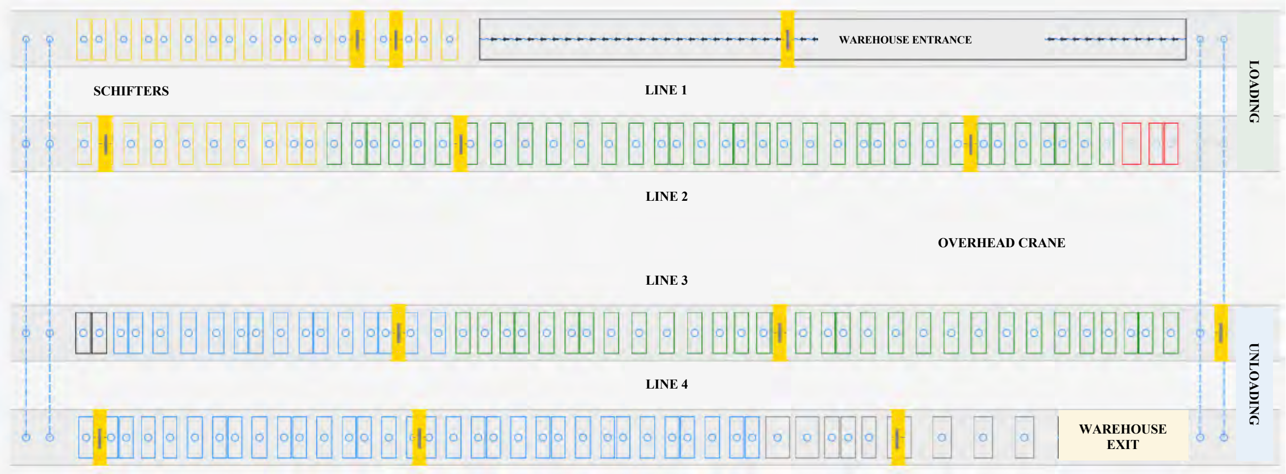

Figure 6: Two-dimensional representation of the automatic line

Once the immersion phase is over, the bar remains waiting for the next destination to be available, following the sorting and calling mechanism previously presented. In order to cope with a construction constraint linked to the process, a critical aspect of the automatic plant representation has been highlighted.

Every time the immersion time relative to a specific treatment end, it is necessary, in fact, that an overhead crane is immediately available to carry out the extraction of the bar from the tank. This constraint is due to requirements linked to the qualitative yield of galvanization, which requires that the treated product should not remain immersed for a longer time than allowed.

Although there are tolerances that allow a delay in the extraction of the bar from the galvanic bath, the permanence of the product inside the tank for too long risks compromising the success of the treatment.

In order to solve this problem, a split block has been added in order to generate a not real entity that, leaving the bath before the end of the treatment, is able to anticipate the request for transport by the bridge crane. With the split block, the *bar* entity is divided a fictitious copy is made. While, on the one hand, the real entity suffers a delay that is defined by the actual immersion time, the copy suffers a shorter delay given by the immersion time from which is subtracted the time that, on average, the bridge crane takes to be physically present above the tank to begin extraction. Doing in this way, the entity copy can execute the seize of the resource with an opportune advance, guaranteeing the immediate availability to the conclusion of the treatment of the real entity. In the case in which the successive destination is, instead, a translator, the fictitious entity will supply to carry out also the seize of this last one, making also it available in advance regarding the conclusion of the galvanic treatment.

The functioning logic of the *Sideshifter* object foresees, instead, an initial lifting by means of a bridge crane and a dripping above the tank of origin, the transport inside the *Sideshifter* and the transfer towards the next line, from which it can subsequently perform the seize of the relevant bridge crane to transfer the bar towards the next treatment tank.

RESULTS

Once the model has been developed, a set of KPIs have been defined according to the company requirements and the model has been validated comparing them with the data coming from the actual physical plant.

Moreover, an optimization of the parameter combination to increase the global saturation have been determined, using the optimization tool OptQuest®.

Validation of the model

In order to validate this model, KPIs related to *productivity*, *immersion time*, *tanks saturations* and *queues* were examined.

The output data were extracted from the log files created by Anylogic®. Simulation has been replicated ten times and the simulation period chosen is three weeks, with five working days each. This time corresponds to the temporal horizon of the real production plan of the company. According to Figure 7, a warm up period of 4 days has been selected.

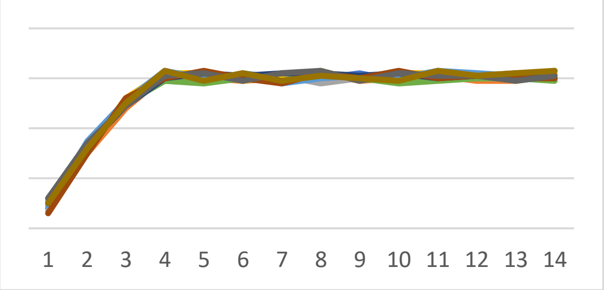

Figure 7: Warm-up

In order to compare simulation data and actual data were used the Minitab software, specifically, the Paried T-test. A graphical comparison between the simulated immersion time and the set tolerance is reported in Figure 8.

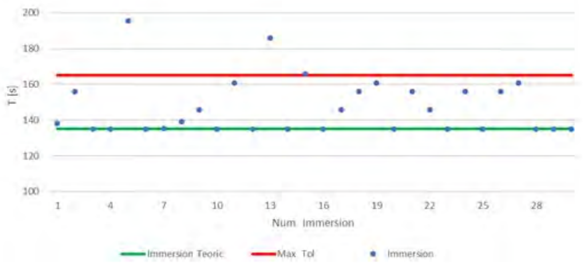

Figure 8: Simulated immersion time comparison

In blue there are the simulated immersions, in green there is the theoretical time and in red there is the max time tolerated. This graphic is related to the gold bath number one. The same graphic has been done for each bath, in order to validate that no bar entities have been stored a longer period than the target one plus the tolerance.

In order to provide a quantitative measure of the effectiveness of the model with respect to production constraints, an error measure was calculated for each tank.

This was obtained through the ratio, reported in terms of percentage, between the number of immersions with excess times and the number of total immersions within the same tank (i), as shown in the equation below:

$$\%\, error_i = \frac{\#\, immersion\ non\ ok_i}{\#\, immersion\ tot_i} \times 100$$

These data were used to determine the KPIs below:

- $\%\, error_{average} = \frac{\sum_i \%\, error_i}{N_{tanks}}$
- $\%\, error_{tot} = \frac{\#\, immersion\ non\ ok}{\#\, immersion\ tot} \times 100$

The first show the average accuracy of each tank, the second show global accuracy of the system. In both cases, a maximum limit of 5% was imposed.

Optimization experiment

A SME does not usually have the technical skills to be able to carry out scenario analyses. Then the optimization tool was used to perform the experiments automatically. In this way, the non-expert user only has to enter the input data, wait for the optimization results and obtain an optimal solution.

The optimization is based on OptQuest®, a proprietary software included into the Anylogic® software. The optimization process consists of repeated simulations of the model using different parameters each time. To do this a graphical user interface to set up and control the optimization process has been adopted. The final result provided by the program is the set of parameters that constitute the optimal solution related to the problem formulated. The interface is showed in the Figure 9.

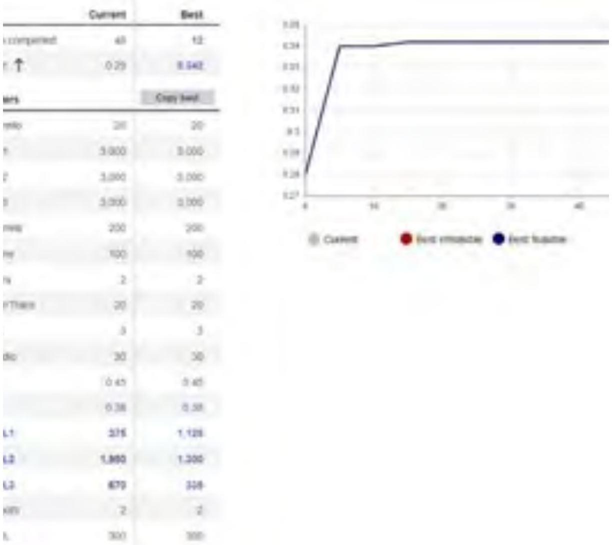

Figure 9: Optimization interface

Two different experiments were conducted: the first concerned the composition of the production mix and the objective function was the saturation of the production lines. The second case concerned the size of the production batches and their sequencing while the objective anointing was always the saturation of the production lines. The latter produced the best results.

In Figure 10 the global saturation of each simulation of the first optimization is reported.

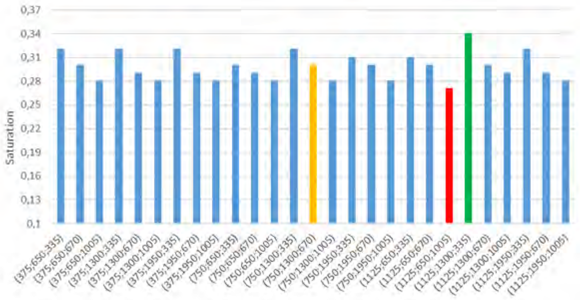

Figure 10: Global Saturation of first optimization

Thanks to this tool it was possible to identify the parameter combination to increase the global saturation of 13,5% (in green).

CONCLUSION

This paper deals with the development of a data-driven simulation model for the process optimization of an automatic electroplating plant of a company belonging to the fashion metal accessories industry.

The main contribution of this paper is related to the development of the simulation model, able to represent a generic automatic electroplating plant and that can be customized without modifying the model itself.

Furthermore, this work provides a framework capable to help non expert users in the field of simulation in the definition and execution of scenario analysis and plant possible optimizations without the necessity to acquire knowledge in the simulation of programming area.

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