PRODUCTION SYSTEMS DESIGN AND MANAGEMENT: A CASE STUDY ON A HAZELNUTS INDUSTRIAL PLANT

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ABSTRACT

The focus of this paper is an hazelnuts industrial plant located in Calabria (Italy). The objective is to implement a support tool (a simulator) to be used for carrying out specific analyses in order to test system performance under different operative scenarios improving and/or optimizing, if required, system design. After the modeling phase, the simulation model has been verified and validated. Four different performance parameters are introduced to evaluate system behavior in correspondence of different operative scenarios.

Keywords: industrial plant, Modeling & Simulation, performance analysis

1. INTRODUCTION

During the last years several research works in the area of Modeling and Simulation (*M&S*) applied to production systems and industrial plants design and management have been proposed (Callahan *et al.* 2006).

The M&S approach generally does not provide exact or optimal solutions to problems but allows the users to analyze the behavior of complex systems, to perform what-if analysis and correctly choose among alternative scenarios (Karacal 1998; Banks 1998). In fact, oppositely to analytical approaches, the main advantage of M&S when studying and analyzing manufacturing and logistic systems is the possibility to take into consideration multiple aspects without introducing restrictive assumptions. Other advantages of M&S include (Banks 1998):

- understanding why certain phenomena occur in real systems;
- diagnosing problems considering all the interactions which take place in a given moment;
- identifying constraints, e.g. performing bottleneck analysis, it is possible to discover the causes of delays;
- building consensus by presenting design changes and their impact on the real system;
- specifying requirements during the system design.

A state of art overview highlights a great number of research works in the field of M&S for production systems and industrial plants design and management, see Berry (1972), Nunnikhoven and Emmons (1977), Stenger (1996), Mullarkey *et al.* (2000), Longo *et al.* (2005). According to Banks (1998), simulation plays an important role above all for its main property to provide what-if analysis and to evaluate all the benefits and issues related to the environment where it is applied.

As a consequence simulation models are decision support tools adopted by company managers to solve problems. In fact, a simulation model is able to reproduce the evolution of the system taking into consideration several operative scenarios. Simulation models are classified in function of decisions they support. Strategic decisions typically concern production systems and industrial plants design and resources allocation in the medium/long period. Tactical decisions are related to planning and control of production systems and industrial plants in the medium period (weeks or months). Finally, operative decisions concern production systems and industrial plants management in the short period.

The main objective of this paper is to present a simulation model used as decision support tool for investigating the behavior/performance of an industrial plant devoted to produce hazelnuts. Simulation Model development, verification and validation and preliminary analysis are presented. The paper is organized as follows: Section 2 reports a description of the hazelnuts industrial plant; section 3 presents the simulation model as well as verification and validation results while section 4 describes the preliminary analysis and simulation results. Finally, conclusions summarise critical issues and main results of the study.

2. THE HAZELNUTS INDUSTRIAL PLANT

As before mentioned, the production system considered in this research work is located in Calabria, south part of Italy, and manufactures hazelnuts for satisfying the demand of the Pizzo Handmade Ice Cream Consortium, see Cimino *et al.* (2009).

The industrial plant has a rectangular shape with a surface of about 2000 m^2. Figure 1 shows the industrial plant layout (red arrows show the material flow through the different work stations).

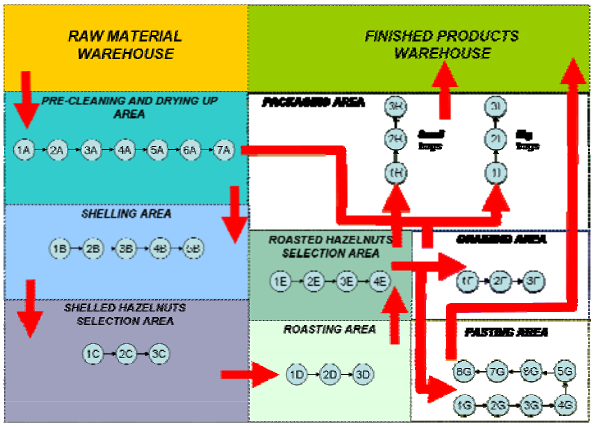

Figure 1: The Layout of the Manufacturing System

According to Figure 1, the plant layout is subdivided in 8 different areas/departments each one including different workstations carrying out the following main operations:

- pre-cleaning;
- drying;
- calibration;
- shelling;
- selection;
- roasting;
- graining;
- pasting;
- packaging (large and small bags).

Figure 2 shows the flow chart of the production process including all the main operations and highlighting the amount of product at the end of each operation.

3. THE SIMULATION MODEL

Based on authors experience (simulation is the most effective tool for designing and analyzing manufacturing systems, industrial plants and supply chain as well (Bruzzone and Longo, 2010; Castilla and Longo, 2010; Cimino et al., 2009; Longo and Mirabelli, 2009; Longo and Mirabelli, 2008). In fact, one of the most important advantages of simulation is to explore and experiment possibilities for evaluating system behavior under internal/external changes.

As a consequence, for a complete scenarios analysis based on a well defined experimental design (i.e. full or fractional factorial experimental design), a specific feature of the simulation model is flexibility. Consider as example Bocca *et al.* (2008); the authors implement a simulation model of a real warehouse highlighting the importance of building flexible simulation models for carrying out experimental analysis. Cimino et *al.* (2009), Longo and Mirabelli (2008) use flexible simulation model to analyze the performance of real manufacturing systems and supply chains by monitoring multiple performance measures under multiple system configurations and constraints. In the next section the implementation of the simulation model is briefly described.

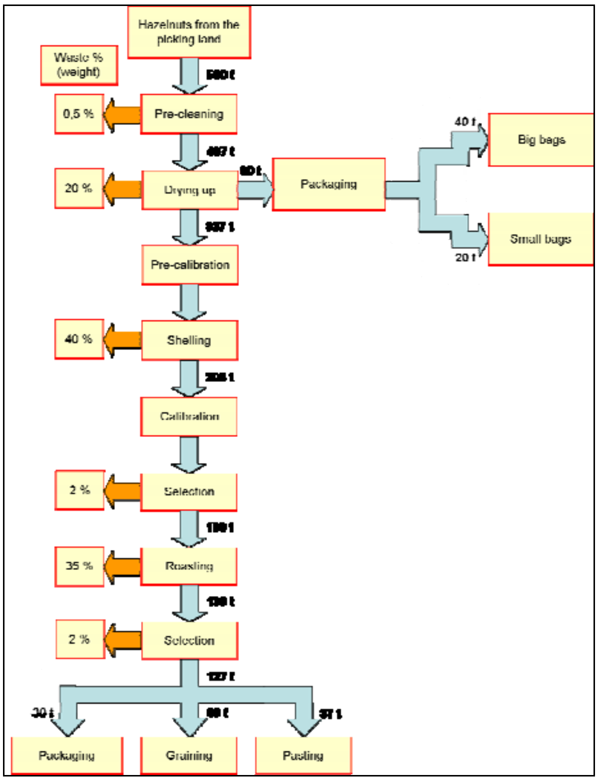

Figure 2: The production process flow chart

3.1. The production system processes modeling

The simulation model presented in this research work reproduces all the most important processes and operations of the hazelnuts industrial plant. The software tool adopted for the simulation model implementation is the commercial package Anylogic™ by *XJ Technologies*.

In particular, for reproducing all the logics and rules used within the industrial plant and for increasing model flexibility, different classes are implemented by using software libraries objects and ad-hoc Java routines. The simulation model is in two parts: the flow chart (or structure diagram) and the animation.

The flow chart displayed in Figure 3 recreates system structure and contains software libraries objects opportunely connected and integrated in order to reproduce with high accuracy the flow of entities (raw material, semi-finished or finished products and workers) through the model.

More in detail, entities defined in the simulation model can be classified into *static* and *dynamic* entities.

Static entities (or resources) belong to specific areas of the model supporting dynamic entities that pass through. From the other side, dynamic entities represent the objects flowing through different classes of the simulation model (workstations of the real manufacturing system). As a consequence, in the simulation model implemented static entities are represented by workers while hazelnuts are the dynamic entities.

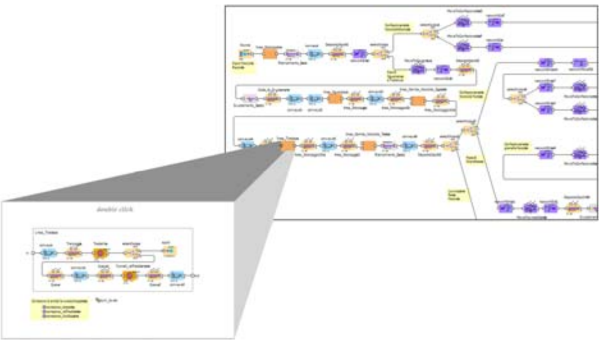

Figure 3: The Simulation Model Structure Diagram

Figure 4 shows the simulation model animation which faithfully reproduces the hazelnuts flow in the real system.

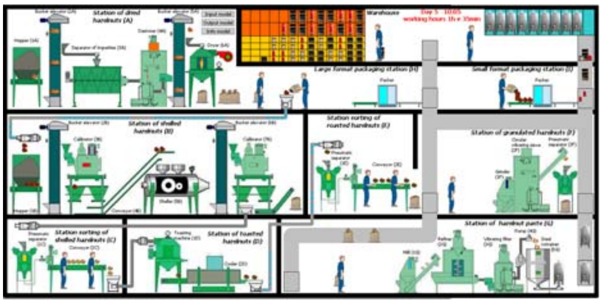

Figure 4: The Simulation Model Animation

3.2. The Graphic User Interface

The main variables of the simulation model are completely parameterized in order to reproduce different operative scenarios. To this end the authors developed a dedicated Graphic User Interface (*GUI*) with a twofold functionality:

- to increase the simulation model flexibility changing its input parameters both at the beginning of the simulation run and at runtime (by using sliding bars, buttons and check boxes) observing the effect on the system behaviour (*Input Section*);
- to provide the user with all simulation outputs for evaluating and monitoring system performances (*Output Section*).

The *Input Section* reported in Figure 5 is subdivided in five different subsections:

- the *Industrial Plant parameters* section in which, for each department, the productive capacity of machines and intermediate buffers capacity can be modified;
- the *Consumption of raw material* section which contains the parameters related to the quantity of hazelnuts to be processed and their arrivals frequency;
- the *Workers* section in which the number of workers to be allocated in each department can be easily selected;
- the *Work shifts* section in which the user can decide for each production line/department the work shifts (up to three work shifts per day);
- the *Products mix* section in which the production mix can be defined.

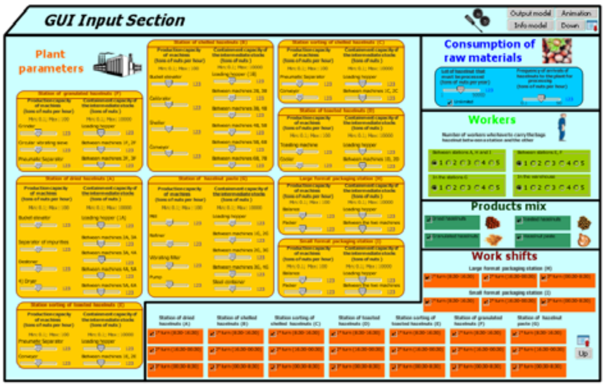

Figure 5: The GUI Input Section

The *Output Section* provides the user with the simulation outputs to evaluate and monitor the industrial plant performances. According to Figure 6 the output section is subdivided in three different subsections:

- the *Plant production* section in which the quantity of dried, roasted, grained hazelnuts and hazelnuts paste is displayed;
- the *Packages* section in which the number of packages for each product is reported;
- the *Plant performance* section in which the performance of the whole industrial plant is monitored. Furthermore, for each department, output data related to machines average utilization level and buffers saturation level can be collected.

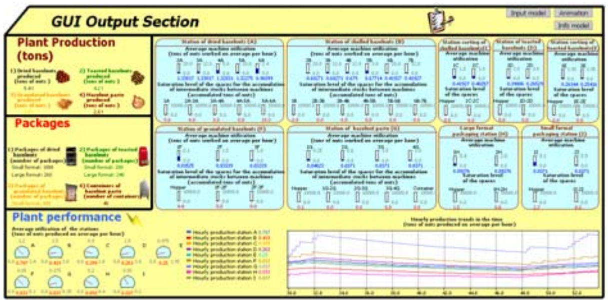

Figure 6: The GUI Output Section

4. MODEL VERIFICATION AND VALIDATION

Verification is the process of determining that a model implementation accurately represents developer conceptual description and specifications (Balci 1998).

The simulation model verification has been made using the debugging technique. As explained in Dunn (1987), debugging is an iterative process that aims at finding and eliminating all the bugs due to model translation. The model is opportunely modified and tested (once again) for ensuring errors elimination as well as for detecting new errors. All the methods (routines written in Java) have been iteratively debugged line by line, detecting and correcting all the errors.

4.1. The Validation

Validation is the process of determining the degree to which a model is an accurate representation of the real world from the perspective of the intended use of the model (Balci 1998). Data used for simulation model validation regard an historical period of 5 years, from January 2005 to December 2009.

In order to evaluate simulation data accuracy, four different statistical indexes are introduced: the Root Mean Squared Error (*RMSE*), the Mean Absolute Error (*MAE*), the Modeling Efficiency (*EF*) and the Coefficient of Residual Mass (*CRM*).

In particular, the RMSE and MAE indexes are calculated according to Fox (1981):

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(P_i - O_i)^2}{n}} \tag{1}$$

$$MAE = \frac{\sum_{i=1}^{n}| P_i - O_i |}{n} \tag{2}$$

in which P_i represents values estimated by the model and O_i are values observed on the real system. MAE is less sensitive to extreme values than RMSE. The lower are these indexes, the higher is the model accuracy.

The other two indexes, the EF and CRM, are calculated using the following formulas (Loague and Green 1991):

$$EF = \frac{\sum_{i=1}^{n}(O_i - \overline{O})^2 - \sum_{i=1}^{n}(P_i - O_i)^2}{\sum_{i=1}^{n}(O_i - \overline{O})^2} \tag{3}$$

$$CRM = \frac{\sum_{i=1}^{n} O_i - \sum_{i=1}^{n} P_i}{\sum_{i=1}^{n} O_i} \tag{4}$$

in which $\bar{O}$ is the average value of observations on the real system. The optimal value for EF is 1; values greater than 0 indicate that model estimated values are better than the average of the observations while negative values confirm that the average of observations is a better estimator of model accuracy. The optimal value for CRM is 0; positive values indicate that model underestimates measured data while negative values indicate the opposite.

In order to assure the goodness of simulation model statistic results each simulation run has been replicated 5 times so P_i are the average values of each run.

Let us consider results of the validation on dried hazelnuts annual production.

Table 1: Validation on Dried Hazelnuts Annual Production

year	***P_i (t/year)***	***O_i (t/year)***	***RMSE***	***MAE***	***EF***	***CRM***
1	66	63,04	29,71	17,72	0,99	0,03
2	415,4	420,29				
3	220	210,14				
4	700,4	765,60				
5	512,6	506,88				

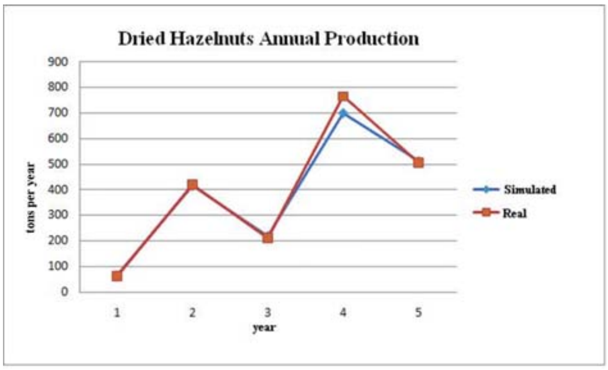

Figure 7: Dried Hazelnuts Annual Production (real and simulated)

According to Table 1, RMSE, MAE, EF, CRM values are good estimators of simulation data accuracy. Moreover, Figure 7 shows real and simulated curves of dried hazelnuts annual production (with different industrial plant setting and production mix every year): these curves are nearly similar so the simulation model is an accurate representation of the real system. Figures 8–9–10 report validation results for roasted, grained hazelnuts and hazelnuts paste (again each year the production mix is different in order to test simulator capability in different operative scenarios).

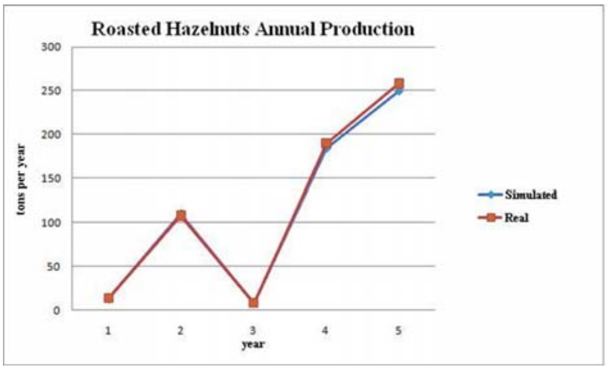

Figure 8: Roasted Hazelnuts Annual Production (real and simulated)

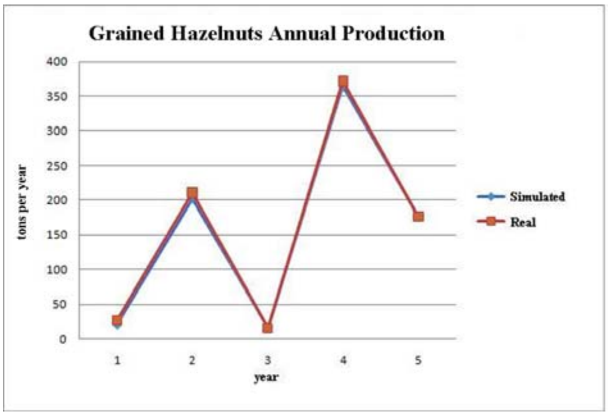

Figure 9: Grained Hazelnuts Annual Production (real and simulated)

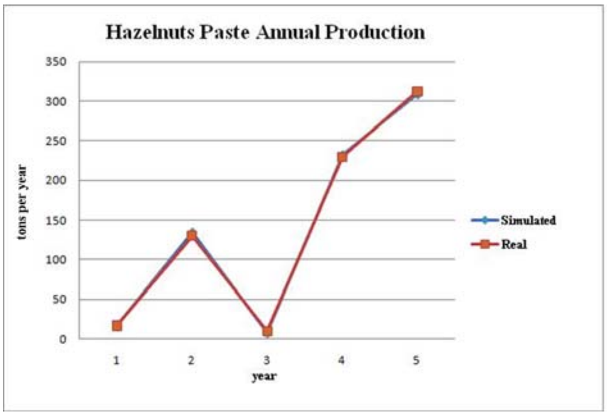

Figure 10: Hazelnuts Paste Annual Production (real and simulated)

5. DESIGN OF EXPERIMENTS AND SIMULATION RESULTS ANALYSIS

As before mentioned, the objective of this research work is to implement a simulation model to be used for carrying out specific analyses in order to test system performance under different operative scenarios improving and/or optimizing, if required, its design.

More in detail, the authors analyze system performance through four different performance parameters and by changing the pre-cleaning, roasting and roasted hazelnuts selection departments productive capacity keeping constant all the remaining parameters/variables. As reported in Table 2, each productive capacity is expressed as percentage of the actual value.

Table 2: Factors and Levels

Factors	**L1**	**L2**	**L3**
Pre-cleaning productive capacity	90%	100%	110%
Roasting productive capacity	90%	100%	110%
Roasted Hazelnuts Selection productive capacity	90%	100%	110%

The four different performance parameters introduced are:

- P_1 related to machines average utilization level (UL_i), see Equation 5;
- P_2 evaluated as the ratio between the intermediate stocks of hazelnuts in tons (*WH*) and the tons of hazelnuts to be processed (*WIP*) as reported in Equation 6;
- P_3 calculated as the ratio between tons of raw hazelnuts (*IN*) and tons of dried, roasted, grained hazelnuts and hazelnuts paste produced (*OUT*) as showed in Equation 7;
- P_4 which is a global system performance estimator, see Equation 8.

$$P_1 = \frac{\sum_{i=1}^{n} UL_i}{n} \tag{5}$$

$$P_2 = \frac{WH}{WIP} \tag{6}$$

$$P_3 = \frac{IN}{OUT} \tag{7}$$

$$P_4 = \frac{P_1 + (1 - P_2) + P_3}{3} \tag{8}$$

Simulation results, for each factors levels combination, are reported in Tables 3–4–5. In particular, the following scenarios have been analyzed:

- comparison of the 90%, 100% and 110% scenarios in terms of pre-cleaning productive capacity;
- comparison of the 90%, 100% and 110% scenarios in terms of roasting productive capacity;
- comparison of the 90%, 100% and 110% scenarios in terms of roasted hazelnuts selection productive capacity.

For each scenario the four different performance parameters have been monitored. Table 3 reports the simulation results under different pre-cleaning productive capacity.

Table 3: Simulation results under different pre-cleaning productive capacity

Scenarios	**P_1**	**P_2**	**P_3**	**P_4**
90% Pre-cleaning productive capacity	0,539	0,997	0,020	0,187
100% Pre-cleaning productive capacity	0,516	0,995	0,207	0,243
110% Pre-cleaning productive capacity	0,926	0,373	0,980	0,844

Considering the P_1 and P_2 parameters, the first and the second scenarios shows a similar behavior while the third scenario provides a better behavior for these parameters and for the global system performance. In fact, the increase of pre-cleaning productive capacity means the increase of the machines utilization level for this production line and, as a consequence, the addition of raw hazelnuts in input.

Table 4 reports the simulation results under different roasting productive capacity. Also in this case, the P_1 and P_2 parameters have a similar value in the first and second scenarios while the third scenario provides the worst behavior for the P_2 parameter.

Table 4: Simulation results under different roasting productive capacity

Scenarios	**P_1**	**P_2**	**P_3**	**P_4**
90% Roasting productive capacity	0,377	0,798	0,016	0,199
100% Roasting productive capacity	0,413	0,796	0,165	0,261
110% Roasting productive capacity	0,833	0,336	0,882	0,793

Table 5 shows the simulation results for the roasted hazelnuts selection productive capacity.

Table 5: Simulation results under different roasted hazelnuts selection productive capacity

Scenarios	**P_1**	**P_2**	**P_3**	**P_4**
90% Roasted Hazelnuts Selection productive capacity	0,647	0,897	0,022	0,257
100% Roasted Hazelnuts Selection productive capacity	0,677	0,896	0,165	0,316
110% Roasted Hazelnuts Selection productive capacity	0,787	0,186	0,735	0,779

Such scenario investigates how system performance changes under different roasted hazelnuts selection productive capacity. In this case the global system performance increase passing from 90% to 100% roasted hazelnuts selection productive capacity is about 30% while the best results in terms of global system performance is related to 110% roasted hazelnuts selection productive capacity.

6. CONCLUSIONS

A simulation model of a hazelnuts industrial Plant, its implementation, verification and validation are presented. Preliminary analysis to investigate system behavior under different factors levels combinations are carried out. In particular, four different performance measures are introduced in order to evaluate system performances under different operative scenarios. Changes in factors levels highlights the tendency of the system to over-react with major changes in some of the performance measures therefore stressing the importance to use the simulator to tune the system correctly to improve system efficiency.

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