OPTIMAL DESIGN, BASED ON SIMULATION, OF AN OLIVE OIL MILL

Juan-Ignacio Latorre-Biel[(a)], Emilio Jiménez-Macías[(b)], Julio Blanco-Fernández[(c)], Juan Carlos Sáenz-Díez[(d)]

[(a)] Public University of Navarre. Deptartment of Mechanical Engineering, Energetics and Materials.
Campus of Tudela, Spain
[(b and d)] University of La Rioja. Industrial Engineering Technical School.
Department of Electrical Engineering. Logroño, Spain
[(c)] University of La Rioja. Industrial Engineering Technical School.
Department of Mechanical Engineering. Logroño, Spain

[(a)]juanignacio.latorre@unavarra.es, [(b)]emilio.jimenez@unirioja.es,
[(c)]julio.blanco@unirioja.es, [(d)]juan-carlos.saenz-diez@unirioja.es

ABSTRACT
Global concurrence is a topic that affects many companies of most of the sectors of the economy. In particular, the improvement in the manufacturing, packing, storage, and transportation of food has allowed farming companies from all over the world to compete for customers of a global market. In order to achieve success in this complex environment it is convenient for the companies to be efficient even before the beginning of their business activity. This paper presents a decision support methodology for improving the design and management of an olive oil manufacturing facility based in the development of a Petri net model of the system, the simulation of its behavior under a selected set of alternative configurations and the choice of the most promising one by means of an optimization algorithm.

Keywords: Petri nets, farming company, alternatives aggregation Petri nets, simulation, olive oil.

1. INTRODUCTION
Global market provides farmers with excellent opportunities for increasing the potential customers of their products. However, the present customers of a given agricultural company can also decide to buy the farming products abroad.

For this reason, it is very convenient for farmers to improve their competitiveness by increasing the quality of their products, and by reducing the cost of their production, while improving their yield.

Key factors to achieve these objectives are the optimal design and management of a farm.

This issue has been researched by different authors, such as (Shikanai *et al*. 2008), where by simulating the operation of small sugar cane producers, an information system is developed to assist the management of agricultural companies.

The modelling and simulation of farming processes to produce atlantic salmon fish farm is discussed by (Melberg and Davidrajuh 2009), showing the suitability of the Petri nets formalism for this purpose.

The scheduling of farm work is analysed by (Guan *et al.* 2010) using a methodology based in the development of a model of the system and the application of an optimization process. Again, the formalism is chosen among the paradigm of the Petri nets. The optimization process is based in the use of the metaheuristic of the genetic algorithms to perform a search in the solution space.

(Cicirelli *et al*. 2010) explores the application of models based on the Petri nets paradigm to the stages of the production process of wine.

The specific issue of crop protection is discussed by (Léger *et al*. 2011) aiming the reduction in the use of chemical pesticides. A decision workflow tool for crop protection in the production of wheat is described.

The formalism of the Petri nets is applied by (Wang *et al*. 2011) for the management of the production of food processes, aimed at obtaining a certification of pollution-free agricultural products.

The development of a decision support system is described in (Latorre et al., 2012) and refined in (Latorre et al., 2013) with an application in the wine-making industry. A Petri net model of a winery in process of being designed is developed with the formalism of the alternatives aggregation Petri nets with the purpose of supporting the design of a winery, as well as its future management.

In particular, the production of olive oil has not received so much attention by the research community than other agricultural sectors. This fact, together with the need of developing tools for the efficient decision support of farmers and producers of olive oil has motivated the present research.

In this paper, a description of the development of a decision support system for the optimal design and management of an olive oil manufacturing company has been presented. This system is based in obtaining a model of the system by using the formalism of the alternatives agregation Petri nets (Latorre et al., 2011) and simulating it under different configurations of the system to select the configuration that bettr fits with the objective of the design and management of the company.

The rest of the paper is organized as follows. Section 2 describes the generalities on the manufacturing of olive oil. The formalism considered to develop the model of the system, the paradigm of the Petri nets, is introduced in section 3. In section 4, the model of the olive oil manufacturing facility in process of being designed is presented and explained. Section 5 deals with the decision-making methodology that can be constructed by the integration of the model of the system, a simulation tool and an optimization algorithm. The following section presents the conclusions and future research lines, while the last section lists the bibliographical references.

2. PRODUCTION OF OLIVE OIL

The olive oil is an important ingredient of the Mediterranean diet, being one of the healthiest vegetable oil from a nutritional point of view. It provides with vitamin A. D, and E, equilibrates the cholesterol, contributes to the development of the bones, as well as of the brain, and the nervous system, among other advantages.

The main producers of olive oil belong to the Mediterranean Basin, being Spain the largest world producer (43% of the world production) and Italy the second (14%) (IOC, 2011).

The production of olive oil began around 5000 years ago in Greece. Since then, a discontinuous method of extraction has been applied for obtaining a product of good quality but in small quantities.

Nowadays, the industrial manufacturing of olive oil is performed usually in a continuous process, which allows obtaining olive oil of different qualities, along with several other products able for feeding cattle, or as combustible in biomass furnaces.

The market of the products obtained from the olive is large and diverse as it is the variety of products themselves. The olive oil of the finest quality should present specific organoleptic characteristics and composition; hence, the production should be performed with a maximum care and precision. Moreover, different qualities of olive oil can be produced for different tastes and with diverse prices.

The three grades of olive oil are extra virgin, virgin, and olive oil, which can be divided into subcategories, such as "premium extra virgin" and "extra virgin" for the first grade, "fine virgin," "virgin," and "semifine virgin" for the second one, and "pure olive oil" and "refined oil" for the third one.

This paper deals mainly with the production of olive oil of the highest quality, for other inferior classes of olive oil, additional stages for processing the pomace and waste waters should be considered.

The process for obtaining olive oil consists basically in the separation of the oil from the rest of the fruit, and it is composed of several stages. There are variations in the manufacturing stages, according to the type of process chosen for producing the olive oil. Nevertheless, the main stages can be found in the following list:

a) Harvesting. This stage begins at the beginning of November and finishes at the end of February in the northern hemisphere. Depending on the month of harvesting the organoleptic properties of the oil may vary.

b) Leaf-removal. This is the first phase of cleaning up the olives.

c) Washing. This stage removes dust, soil, insecticide, and others by the use of a washing machine. The duration of this stage depends on the degree of dirtiness of the olives.

d) Weighing. A scale permits to control the weight of the olives before the production process begins.

e) Storage and measure out. The quantity of olives required by the following stage is provided, the rest of the clean olives are stored in hoppers.

f) Grinding. This stage produces a paste from the original olives.

g) Malaxation. The olive paste is stirred for mixing the small droplets of oil and producing the separation of the water phase and the oil phase.

h) Pumping. The product is pumped into the following machines.

i) Decantation. A screw conveyor introduces the product into the decanter, where by centrifugation three products are obtained: pomace (fragments of the pits of the olives), oil, and vegetation water (water and vegetal substances).

j) Filtering. The solid phase is separated from the liquid one. In the oil, the solid phase is the pulp, whereas in the vegetation water, the solid phase are small fragments of pits called pomace.

k) Centrifugation. A vertical centrifuge removes the impurities from the oil, as well as the last remnants of water.

l) Centrifugation of the vegetation water. The same process applied to the oil is performed on the vegetation water, in order to obtain a fat-free waste water, as well as dirty oil.

m) Storage. The obtained oil is stored until its expedition to the sellers.

n) Drying. The waste water and the pomace may be mixed and dryed for obtaining other useful products from the olives, such as pulp for fodder and pits for combustible.

o) Processing the oil. This processing permits obtaining oil of different qualities for diverse uses and customers and with a diversity of prices.

Several manufacturing processes can be chosen for producing virgin olive oil:

1) Traditional method. This methodology is appropriate for obtaining small quantities of high quality oil. It is a discontinuous process and used by a few small producers.

2) 3-phase decanter centrifugation. In this case, the first separation of the constituents of the olive paste (obtained after crushing and malaxing the raw olives) is performed in a horizontal decanter with three outputs for pomace, vegetation water, and oil.
3) 2-phase decanter centrifugation. The horizontal decanter has only two outputs, in this case for wet pomace and olive oil.
4) 2½-phase decanter centrifugation. The decanter requires a smaller amount of input water, hence the moisture content of the output pomace is not larger than 50%, and the amount of vegetation water is reduced.
5) Sinolea method. In this methodology, the first stage for the extraction of the olive oil from the olive paste is performed by the use of stainless steel discs, where the oil adheres. Scrapers can remove the oil from the discs. The rejected paste can be processed by horizontal decanter centrifugation for obtaining more oil.

The decision making on the design of an olive oil manufacturing facility implies the definition of the type of manufacturing process, as well as its capacity, including the number of machines to be installed in every stage of the process.

Furthermore, the decision making on the management of an olive oil mill, is related to deciding the time and amount of olives to be supplied to the mill, as well as the production rate, the temperature and amount of water to be added to the process, etc.

In the following sections, these decisions will be discussed in the frame of an automatic decision supply system.

3. THE PARADIGM OF THE PETRI NETS

The decision support system to be described in this paper is based in the use of a simulation model. This model has to be represented by an appropriate formalism.

The Petri net paradigm is suited as modeling formalism, as well as for the analysis, simulation, and optimization of discrete event systems.

The Petri nets can be applied by means of a double representation. Their graphical representation shows, in an intuitive and explicit way, complex behaviors, such as combinations of concurrence, synchronization, and competition for limited resources.

Furthermore, a second feasible representation of a Petri net model can be obtained by means of a matrix-based description, which can be obtained directly form the graphical representation and vice-versa.

The matrix-based representation allows the development of a structural analysis of the model, as well as to the performance evaluation required to solve the decision making processes that will be used in this paper to develop a decision support tool.

Definition 1. A Petri net system is a 5-tuple $R = (P, T, \text{pre}, \text{post}, \mathbf{m}_0)$ such that:

i) P is a non-empty set of places.
ii) T is a non-empty set of transitions and $P \cap T = \emptyset$.
iii) pre and post are functions that associate a weight to the directed arcs between the elements of the sets P and T, in the following way:
iv) pre: $P \times T \rightarrow \mathbb{N}^*$ and post: $T \times P \rightarrow \mathbb{N}^*$, where $\mathbb{N}^*$ is the set of natural numbers, excluding zero.
v) $\mathbf{m}_0$ is the initial marking, such that $\mathbf{m}_0 : P \rightarrow \mathbb{N}^*$.

□

A discrete event system in process of being designed contains a set of freedom degrees. As the decisions are made, the freedom degrees in the system are converted into specific numerical values.

The freedom degrees of the system can be represented in the model of the system by means of controllable parameters. These controllable parameters can play different roles in the model of the system. For example they can be marking, structural, or transition-firing parameters.

A marking parameter can represent a freedom degree related to the number of resources, such as number of crushers, industrial decanters, or pumps. Moreover, a structural freedom degree may represent the feasible decision of choosing a methodology of olive oil manufacturing, such as traditional or 2-phase decanter centrifugation.

The definition 1 does not specify explicitly the mechanisms of the Petri net formalism to represent the controllable parameters, which have a significant influence in the behaviour and performance of the system, and the possibility of making a choice for them among their feasible set of combinations of values.

The design process of a system, modelled by the formalism of the Petri nets, usually requires the development of so many models as alternative structures can be selected for representing different solutions for the structure of the system. These models can be called alternative Petri nets (Latorre *et al.* 2011).

Nevertheless, this approach uses to be ineffective, since the whole set of alternative Petri nets usually shows large amounts of redundant information among the models (Recalde *et al.*, 2004). This redundant information corresponds to shared subsystems.

This paper presents a methodology to develop a decision support system based on a formalism belonging to the paradigm of the Petri nets, called the alternatives aggregation Petri nets. This formalism has the ability of describing in a single model, a complete set of alternative Petri nets removing the redundant information, which correspond to shared subsystems.

The mechanism for the decision making associated to the choice of one of these alternative structural configurations is represented explicitly by means of the so called choice variables.

A definition of a set of choice variables for a certain Petri net model can be given once it is known the number of the alternative structural configurations for the system to be modelled.

Definition 2. Given a discrete event system with n alternative structural configurations, a set of choice variables can be defined as $S_A = \{ a_i \text{ Boolean} \mid \exists!\, k \in \mathbb{N}^*, k \leq n$, such that $a_k = 1 \wedge \forall j \in \mathbb{N}^*, j \leq n, j \neq k$ it is verified $a_j = 0 \}$, where $|S_A| = n$, and the assignment $a_k = 1$ is the result of a decision.

□

Based on the previous considerations, it is possible to state a definition for the formalism to be used in the decision support tool presented in this paper: the alternatives aggregation Petri nets.

Definition 3. An alternatives aggregation Petri net can be defined as a 10 tuple $R^A = (P, T, \text{pre}, \text{post}, \mathbf{m}_0, S_\alpha, S_{valnstr\alpha}, S_A , f_A, R_{val\gamma})$, where

i) S_α is a set of undefined parameters.

ii) $S_{valnstr\alpha}$ is the set of feasible combination of values for the undefined parameters in S_α.

iii) S_A is a set of choice variables, $S_A \neq \varnothing$ and $|S_A| = n$.

iv) f_A: $T \rightarrow f(a_1, \ldots, a_n)$ is a function that assigns a function of the choice variables to each transition t such that type$[f_A(t)]$ = boolean.

v) $R_{val\gamma}$ is a binary relation between $S_{val\gamma}$ and R_A.

On the other hand, f_A: $S_A \rightarrow T$, assigns a choice variable to a single or several transitions of the Petri net, and if $S_A' = \{ a_1 , a_2 , \ldots , a_k \}$ is the set of every choice variables associated to the transition t, then the guard function of the mentioned transition is $g_A(t) = a_1 + a_2 + \ldots + a_k$.

□

This formalism, can be used to develop the model of an olive oil mill in process of being designed, that is to say before a decision on the methodology for manufacturing the olive oil is made.

4. MODEL OF AN OLIVE OIL MILL

The process of constructing a Petri net model of a system, in this case an olive oil mill, can be tackled by means of different approaches. These approaches can be classified into two main methodologies, broadly used in the field of modeling discrete even systems by means of Petri nets (Silva, 1993).

The first one is called top-bottom modelling and consists of defining a simple and global model with a reduced level of detail. In a second stage, the subsystems present in the model are expanded to incorporate a larger amount of information.

The second methodology is the bottom-up modelling, which requires the development of independent models for the subsystems of the discrete event system and the subsequent link of the different submodels with the purpose of obtaining the final and complete model.

In the model presented in this paper, a bottom-up modelling has been considered, in several stages.

A first stage in the modelling has been carried out by constructing the models of the different methodologies for manufacturing olive oil. As it has been seen in section 2, a number of five different methodologies have been taken into account.

However, as a result of this phase of modelling, more than five Petri net models have been constructed, since there are different decisions, called structural decisions, which may lead to different configurations of the models that correspond to a given manufacturing technology.

Before entering into detail, it is convenient to take into account the structural decisions that have been considered in the model of the olive oil mill in process of being designed:

d_1. Traditional method.
d_2. Configuration alternative to the traditional method for obtaining high quality olive oil.
d_3. Decantation for separating the oil and the vegetation water.
d_4. Vertical centrifuge for separating the oil and the vegetation water.
d_5. Hammer crusher.
d_6. Disc crusher.
d_7. Depitting machine.
d_8. Knife crusher.
d_9. Three phase decanter centrifugator.
d_{10}. Two phase decanter centrifugator.
d_{11}. Sinolea method.
d_{12}. Two and a half phase decanter centrifugator.

As it has been seen, a sixth methodology for manufacturing olive oil can be considered. It is an alternative configuration to the traditional method. Where the last stages of the process are substituted by the use of modern separation technologies.

Moreover, some of the manufacturing methodologies can be implemented by using four different types of crushers and the sinolea method requires the addition of a horizontal decanter characteristic of others of the production methods.

As a result of these structural decisions, it is possible to define a set of choice variables, one for every alternative system that can be built up from the mentioned decisions.

The size of the set of choice variables S_A can be calculated in the following way:

$|S_A| = 1 + 6 + 24 = 31$.

In the previous calculation, the addend "1" comes from the traditional method, the value "6" of the six configurations for the alternative method, which can be complemented with other manufacturing technologies. Finally, the value "24" is related to the other 4 methodologies with decanter centrifugators, including the sinolea method, since every one of them can be implemented with different crushers.

In fact, easily, it is possible to develop more alternative configurations, which will not complicate largely the decision making process thanks to the use of the formalism of the alternatives aggregation Petri nets to construct the model of the system.

In addition of the previous considerations, it is possible to take into account other controllable parameters, such as the marking parameters that are listed below, in this same section.

The consideration of both the choice variables and the marking parameters increases largely the number of feasible solutions for the construction of an efficient olive oil mill based in the decision support tool.

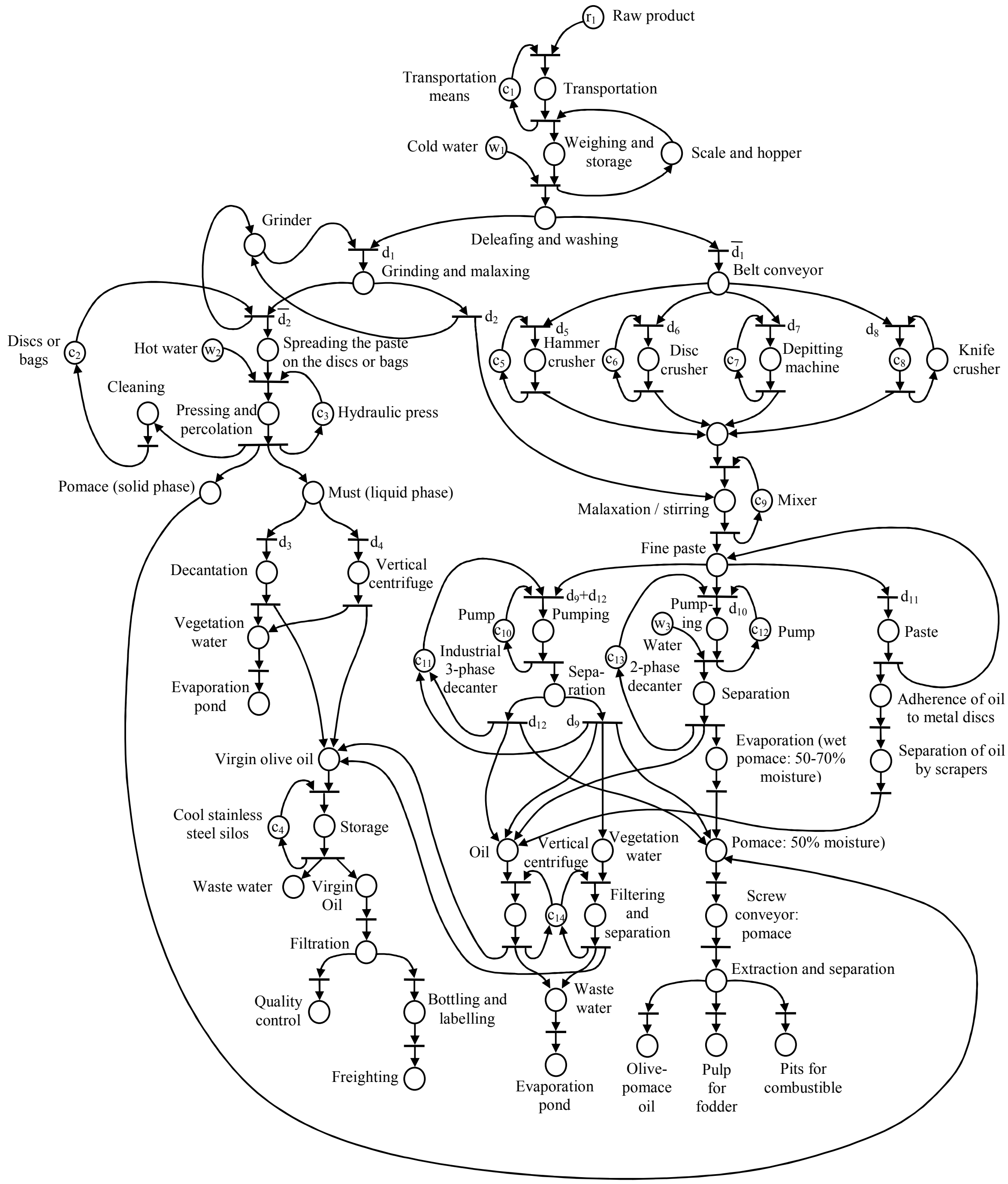

Figure 1. Model of an olive oil mill based on the formalism of the Petri nets

c_1. Number of available lorries, or equivalent transportation means, for supplying the raw olives to the olive oil mill.

c_2. Number of discs or bags for pressing the olive paste in the traditional method.

c_3. Number of hydraulic presses available in the traditional method.

c_4. Number of cool stainless steel silos for storing the resulting virgin olive oil.

c_5. Number of hammer crushers.

c_6. Number of disc crushers.

c_7. Number of depitting machines.

c_8. Number of knife crushers.

c_9. Number of mixers for malaxation.

c_{10}. Number of pumps for conveying the olive paste to the horizontal decanter (3-phase decanter centrifugator).

c_{11}. Number of 3-phase decanter centrifugators.

c_{12}. Number of pumps for conveying the olive paste to the horizontal decanter (2-phase decanter centrifugator).

c_{13}. Number of 2-phase decanter centrifugators.

c_{14}. Number of vertical centrifuges.

Depending on the feasible value considered for the mentioned marking parameters, the size of the solution space may increase considerably, increasing subsequently the optimization time required to make a decision or, in the same way, reducing the quality of the best solution found in the search.

5. DECISION MAKING METHODOLOGY

A methodology for designing a facility for producing olive oil is presented in this section. This methodology requires the development of a Petri net model of the system to be designed, which has been depicted in figure 1.

The methodology is based in the statement of an optimization problem. The goals of the optimization are quantified in the so called objective function and the model is simulated under different promising scenarios with the purpose of choosing the best one.

This best solution will be provided to the designer in order to support the decisions to be made in the process with a forecast of the behavior of the system, thanks to the described optimization methodology (Latorre et al., 2010).

The choice of the best scenarios to be considered in the optimization process may be performed by means of a metaheuristic, such as the genetic algorithms, due to the large amount of feasible configurations that an industrial olive oil meal can have.

As a consequence of all these configurations, the exhaustive exploration of the complete set of feasible solutions is not practical; hence a non-deterministic methodology to guide the search is chosen.

6. CONCLUSIONS

As a conclusion, it can be stated that the application of a mathematical methodology for designing an olive oil mill, based on the simulation of a model of the system, can lead to a useful tool for the support of the decisions performed during the different stages of the design and the management of an olive oil mill.

The future research effort will be focused in the application of the presented methodology to a large pool of practical cases to improve the decision support tool.

REFERENCES

Cicirelli F.D., Furfaro A. and Nigro L., 2010. A Service-Based Architecture for Dynamically Reconfigurable Workflows. Journal of Systems and Software , Vol. 83, n. 7, pp. 1148-1164.

Guan, S., Nakamura, M., and Shikanai, T. 2010. Hybrid Petri Nets and Metaheuristic Approach to Farm Work Scheduling. In Aized, T. (Ed.) Advances in Petri Net Theory and Applications. Chapter 8. Sciyo.

IOC, 2011. *2011/2012 Forecast Reports*. The International Olive Council (IOC).

Latorre, J.I., Jiménez, E., Blanco, J., Sáenz, J.C. 2013. Integrated Methodology for Efficient Decision Support in the Rioja Wine Production Sector. International Journal of Food Engineering. (In press).

Latorre, J.I., Jiménez, E., Blanco, J., Sáenz, J.C. 2012. Decision making in the Rioja wine production sector. In Proceedings of the 24nd European Modelling and Simulation Symposium (EMSS 12). Vienna, Austria, pp. 452-457.

Latorre, J.I., Jiménez, E., Pérez, M., 2011. Petri nets with exclusive entities for decision making. International Journal of Simulation and Process Modeling, Special Issue on the I3M 2011 Multiconference.

Latorre, J.I., Jiménez, E., Pérez, M., 2010. On the Solution of Optimization Problems with Disjunctive Constraints Based on Petri Nets. In Proceedings of the 22nd European Modelling and Simulation Symposium (EMSS 10). Fez, Moroco, pp. 259-264.

Léger, B., Naud, O., Gouache, D., 2011. Specifying a strategy for deciding tactical adjustment of crop protection using CPN tools. Congress of the European Federation for Information Technology in Agriculture, Food and the Environment Efita 2011. Pages 1 – 6.

Melberg, R., Davidrajuh, R. 2009. Modeling Atlantic salmon fish farming industry. In Proceedings of the IEEE International Conference on Industrial Technology. ICIT 2009. Pages 1-6.

Recalde, L.; Silva, M.; Ezpeleta, J.; and Teruel, E. 2004. Petri Nets and Manufacturing Systems: An Examples-Driven Tour. In Desel, J.; Reisig, W.; and Rozenberg, G. (Eds.), Lectures on Concurrency and Petri Nets: Advances in Petri Nets, Lecture Notes in Computer Science / Springer-Verlag. Volume 3098, pp. 742-788.

Shikanai, T.; Nakamura, M.; Guan S.; Tamaki, M. 2008. Supporting system for management of agricultural corporation of sugarcane farming in Okinawa Islands. World conference on agricultural information and IT, IAALD AFITA WCCA 2008, Tokyo University of Agriculture, Tokyo, Japan, 24 - 27, pp. 1101-110.

Silva, M. 1993. Introducing Petri nets. In Practice of Petri Nets in Manufacturing, Di Cesare, F., (editor), pp. 1-62. Ed. Chapman&Hall.

Wang, F., Duan, Q., Zhang, L., and Li,G. 2011. Modeling and Analysis of Pollution-Free Agricultural Regulatory Based on Petri-Net. Computer and Computing Technologies in Agriculture IV. IFIP Advances in Information and Communication Technology, Volume 347/2011, 691-700.Agutter, A.J., 1995. *The linguistic significance of current British slang*. Thesis (PhD). Edinburgh University.