PETRI NET MODELLING AND OPERATIONAL OPTIMIZATION OF A FACILITY FOR THE PREPARATION, CULTIVATION AND PRODUCTION OF COMMON MUSHROOM (AGARICUS BISPORUS)

Latorre-Biel JI [(a)], Jiménez-Macías E[(b)], Pérez de la Parte M[(c)], Leiva-Lázaro FJ[(d)], Martínez-Cámara E[(e)], Blanco-Fernández J[(f)]

[(a)] Public University of Navarre, Tudela, Navarre, Spain
[(b,d,e)] University of La Rioja, Logroño, Spain

[(a)] juanignacio.latorre@unavarra.es , [(b)] emilio.jimenez@unirioja.es , [(c)] mercedes.perez@unirioja.es, [(d)] francisco.leiva@unirioja.es , [(e)] mercedes.perez@unirioja.es, [(f)] julio.blanco@unirioja.es

ABSTRACT
A Petri net model of a facility for cultivating common mushroom (Agaricus Bisporus) is presented and implemented in the development of a decision support system for the operation of the facility. The formalism of the compound Petri net has been chosen for its ability for including parameters in the incidence matrices of the model. The decision support system is based in the solution of an optimization problem by means of a metaheuristics combined con simulations of the model of the system. The implementation of the system may lead to an improvement in the performance of the facility, while reducing the required resources, the produced wastes and the costs involved in the procurement of raw materials.

Keywords: Petri nets, farming company, decision support system, optimization, modelling, simulation, Agaricus Bisporus, common mushroom.

1. INTRODUCTION

Simulation and simulation-based optimization constitute nowadays approaches that find many applications in decision support systems (Longo et al. 2014), (Latorre et.al 2011), and (Latorre et al. 2010).
Decision support systems applied to companies that face a globalized competence has been proven to be very successful. They ease the hard task of making decisions that may affect the profitability of a company, which can be the difference between the success and the failure.
Petri net based modelling for decision making in food industry has been addressed by diverse authors. As examples, it can be considered the sector of wine production (Cicirelli et al. 2010), (Latorre et al. 2013), and (Latorre et al. 2012), sugarcane cultivation and harvesting (Guan et al. 2010), (Shinakai et al. 2008), olive oil extraction (Latorre et al. 2014), salmon fish farming (Melberg and Davidrajuh, 2009), dairy products manufacturing (Latorre et al. 2015), or wheat crop protection (Leger et al. 2010).
The world commercialization of common mushrooms (Agaricus bisporus) reaches every year a few million tons produced by around 70 countries (Leiva et al. 2015a). However, production of common mushroom (Agaricus bisporus) has not received so much attention by the research community than other agricultural sectors. An overview of the process, from the point of view of sustainability and life cycle assessment can be found in Leiva et al. (2016), Leiva et al. (2015a), and Leiva et al. (2015b).
This fact, together with the need of developing tools for the efficient decision support of farmers and producers of mushrooms has motivated the present research.
In this paper, a description of the development of a decision support system for the optimal management of a facility for composting and producing mushrooms is presented.
This system is based in obtaining a model of the system by using the formalism of the generalized Petri nets (Silva 1993) and simulating it under different configurations of the decision variables to select the configuration that better fits with the objective of the management of the company.
The rest of the paper is organized as follows. Sections 2 and 3 describe the generalities on the facilities and processes for composting and mushroom cultivation. The formalism considered to develop the model of the system, the paradigm of the Petri nets, is introduced in section 4. In sections 5 and 6 the models of the production facilities is presented and explained. Section 7 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. PREPARATION OF MUSHROOM CULTIVATION: COMPOST PRODUCTION.

The process of production of compost for mushroom cultivation can be carried out by the development of the following stages (Leiva et al. 2016):

a) Composting batch preparation. This first stage starts by soaking an amount of wheat straw and continues by homogenously mixing the rest of raw materials: poultry manure, gypsum, calcium carbonate, urea, and sulfate. The process ends by building up a compost pile in an appropriate place: a tunnel.

b) Tunnel composting. This stage consists of a wind-row composting process of piles of mixture of around 3m high, 5m wide, and 100m long. The process lasts around 3 days after turning the piles to keep homogeneous the compost temperature. During the process many parameters, such as moisture content, temperature, pH, and aeration are controlled.
c) Pasteurization. This process is carried out in a closed chamber and reduces the content of ammonia in the compost. Aeration is controlled by air recirculating and the temperature is kept in safe limits, reaching up to 60ºC.
d) Packaging. Planting packages are manufactured and stored for the cultivation of the mushroom.

3. CULTIVATION PROCESS

The second facility, whose model is presented in this paper, carries out the cultivation of common mushroom. The different stages that compose this process of cultivation are described in the following paragraphs (Leiva et al. 2015a).

a) Preparation of the soil. This stage starts with the disinfection of the work area, where peat, water, and fungicides are mixed and placed in a container.
b) Preparation of the growing chambers. At this stage the growing chambers are disinfected, the seed packages are placed in cages and the previously prepared soil is poured covering the seed packages. Eventually, water is added to start the following stage.
c) Growing process. In order to favor the development of this stage fungicides and pesticides are applied. Once the fruition is completed, the product is harvested manually and placed into boxes for its expedition.

4. THE PETRI NETS PARADIGM

As it has been mentioned before, the modeling formalism considered in this document is the Petri nets. For a formal definition of the generalized Petri nets and more information about the fundamentals of this formalism it may be consulted Silva (1993).

The decision making methodology to be presented in this paper, requires the integration in the model of the system of some freedom degrees belonging to the original discrete event system. These freedom degrees, represented in the Petri net model by controllable parameters, determine a particular configuration of the model of the system. Solving a decision making problem, under this approach, consists of finding the configuration of the controllable parameters that allow the system to achieve best the goals of the discrete event system.

The controllable parameters can play different formal roles in the Petri net model of the system. In particular they may belong to the initial marking of certain places, to the incidence matrices, the delays associated to transitions in T-timed Petri nets, or the priorities of the transitions involved in actual conflicts, just to give some examples.

5. MODEL OF THE COMPOSTING SYSTEM

The process of constructing a Petri net model of a system, in this case a facility devoted to the production of compost for the preparation of mushroom cultivation, can be carried out by means of two different approaches. Following Silva (1993), it is possible to classify the modeling approaches into two methodologies with wide application into the development of Petri net models for discrete event systems.

a) Top-bottom modelling.

This approach starts with the development of a global model with low level of detail. Its number of places and transitions is reduced.

A second step in the application of this modelling approach is the development of the subsystems expanded from the high level model. These new model, with more details, provide with a larger amount of information.

b) Bottom-up modelling.

This second approach is applied by the development of independent models for the different subsystems that compose the discrete event system of interest.

A subsequent step consists of detailing the links between the models that allow integrating them in the constitution of a complete model, with high degree of detail, describing the structure and the state of the discrete event system.

The models developed in this paper have been built up following the approach of bottom-up modelling.

The construction of the Petri net model of the composting facility has been developed with the purpose of elaborating a decision support tool that may ease the management tasks of such a facility. For this reason, the constructed models present a series of controllable parameters or decision variables, whose values will define the solution to a decision making problem.

These controllable parameters are mainly defined as the initial marking of several places of the model. Even though it has not been considered explicitly in these models, other controllable parameters can be associated to the delay times of a T-timed Petri net model. Some tasks might present a duration that can be changed depending on the equipment acquired, on the way the operations are performed, on the layout of operators and machines, etc. Hence, they may also be considered as decision variables, depending upon the type of decision problem stated.

The model of the system for producing the compost that has been developed is depicted in figure 1. Some parameters are presented in the model, which represent the freedom degrees of the model and require a decision-making process for achieving an optimal or

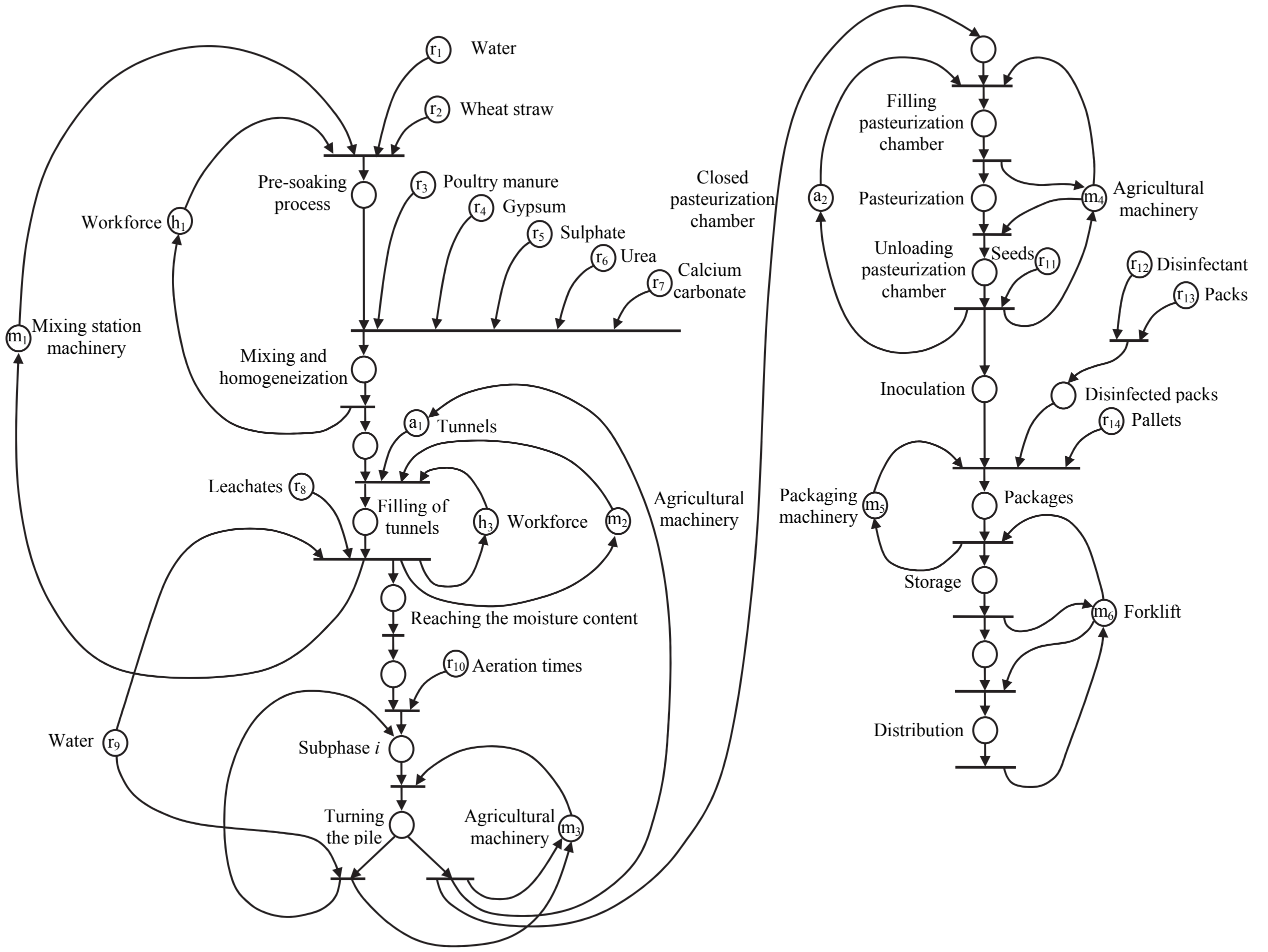

Figure 1. Model of the mushroom compost production.

quasi-optimal configuration of the system. As it has been said, some of the parameters of the model are related to the initial marking, while others are associated to the elements of the incidence matrices (structural ones).

The marking parameters are classified in four groups:

- $\mathbf{a}_i$. Production areas.
- $\mathbf{h}_i$. Human resources.
- $\mathbf{m}_i$. Production machinery, including the operators required to handle the industrial equipment.
- $\mathbf{r}_i$. Raw materials.

More in detail, where the data between brackets represent the units of the item associated with each token present in the place:

- $\mathbf{a}_1$. Tunnels (m^3 of raw materials).
- $\mathbf{a}_2$. Closed pasteurization chamber (m^3 of compost).
- $\mathbf{h}_1$. Operators for mixing the raw materials (person).
- $\mathbf{h}_2$. Operators for filling the tunnels (person).
- $\mathbf{m}_1$. Machinery of the mixing station (kg of wheat straw).
- $\mathbf{m}_2$. Farm tractor with implement for filling the tunnels (tractor and driver).
- $\mathbf{m}_3$. Farm tractor with implement for turning the pile of compost (tractor and driver).
- $\mathbf{m}_4$. Farm tractor with filling and unloading the pasteurization chamber (tractor and driver).
- $\mathbf{m}_5$. Packaging machinery (19 kg of compost, which conforms a package of compost inoculated with mycelium).
- $\mathbf{m}_6$. Forklift for storage and loading the trucks for distributing the compost (forklift and operator).
- $\mathbf{r}_1$. Water for the pre-soaking process (litres).
- $\mathbf{r}_2$. Wheat straw (kg).
- $\mathbf{r}_3$. Poultry manure (kg).
- $\mathbf{r}_4$. Gypsum (kg).
- $\mathbf{r}_5$. Sulphate (kg).
- $\mathbf{r}_6$. Urea (kg).
- $\mathbf{r}_7$. Calcium carbonate (kg).
- $\mathbf{r}_8$. Leachates for increasing the moisture content of the compost in the tunnel (kg).
- $\mathbf{r}_9$. Water for increasing the moisture content of the compost in the tunnel (kg).
- $\mathbf{r}_{10}$. Aeration times (times of aeration of the same duration).
- $\mathbf{r}_{11}$. Seeds of mycelium for the inoculation of the compost (g).
- $\mathbf{r}_{12}$. Disinfectant for the packages (litres).
- $\mathbf{r}_{13}$. Packages for the compost (units).
- $\mathbf{r}_{14}$. Pallets for transporting the compost packages (units).

It may be possible to incorporate structural parameters to the model of the system, in the form of weights associated to the different arcs. Since many arcs represent the flow of raw materials, as well as semifinished and finished products, some weights would represent the size of the production of conveying lot, a parameter that might have a direct impact in the yield of the production system. Despite the fact that structural controllable parameters have not been included in the model of the system, it is ease to introduce them if at a given facility it is found relevant to count on them as decision variables.

Other freedom degrees that may appear in the model are related to conflicts. In particular, structural conflicts are present in all the places with more than one output arcs. These structural conflicts are transformed into actual conflicts, real freedom degrees of the model, if the number of tokens in the place is smaller than the addition of the weights of all the output arcs. If this is the case, it is not possible to fire all the output arcs simultaneously and it might be necessary to assign priorities to the output transitions in order to solve the indeterminism that may arise in this situation.

Structural conflicts are present in the model depicted in figure 1. In particular it is possible to see the following ones:

a) Place labeled “Water”. If water is not a scarce resource, it is possible to say that it will not be necessary to choose the operation that will receive water to the detriment of other production operations. As a consequence, it is not expected that this structural conflict would be transformed into an actual conflict.
b) Place labeled “Turning the pile”. In this case, the process may be repeated several times until proceeding with the following step of the production process in the pasteurization chamber. In particular, one of the output arcs proceeds with a new turning of the pile, while the other starts the pasteurization. There is an actual conflict that should be solved with a variable priority, since a fixed one would prevent a complete process of several turnings and the subsequent pasteurization. This controllable parameter should be part of a solution for the decision problem. In particular it should be decided the number of times the pile is turned over.
c) Place labeled “Forklift”. This conveying resource may be used in different production operations. Every one of these operations would be associated to a different output arc of the place that represents this resource in idle state. At a given moment, it might happen that, the forklift is required in several operations simultaneously and then a decision must be made to solve the actual conflict. The decision on the assignment of this shared resource to the different production tasks should be a part of the solution of a decision problem stated on this system.

6. MODEL OF THE FACILITY TO PRODUCE MUSHROOMS

The model of this second system, a facility for cultivating mushrooms, has been also developed by means of a bottom-up approach. This model has been depicted in figure 2.

The decision variables of this model, may belong to several categories. Some of them have been already implemented in the model, the initial marking of some places and the actual conflicts, but others have not. However, they can be implemented easily. They are the delay times associated to certain transitions of a T-timed Petri net, and the structural parameters or weight of certain arcs.

Analogously to the model of the composting facility, the initial marking parameters can be classified into four categories: production areas ($\mathbf{a}_i$), human resources ($\mathbf{h}_i$), Production machinery, including the operators required to handle the industrial equipment ($\mathbf{m}_i$), and raw materials ($\mathbf{r}_i$).

More in detail, the following list of parameters can be stated:

- $\mathbf{a_3}$. Area for soil preparation (m^2).
- $\mathbf{a_4}$. Growing chambers (m^2).
- $\mathbf{h_4}$. Farm labourers for the manual harvesting of the mushroom fruits (persons).
- $\mathbf{m_7}$. Forklift for handling raw materials, containers, or finished mushroom packages (forklift and driver).
- $\mathbf{m_8}$. Farm tractor with implement for loading soil on containers (tractor and driver).
- $\mathbf{m_9}$. Farm tractor with implement for waste removal (tractor and driver).
- $\mathbf{m_{10}}$. Machinery for packing the final product containing mushroom fruits (packages inside the machine).
- $\mathbf{r_{15}}$. Disinfectant for the area for soil preparation and the growing chamber (litres).
- $\mathbf{r_{16}}$. Bags of peat for soil preparation (units).
- $\mathbf{r_{17}}$. Water for soil preparation and irrigation (litres).
- $\mathbf{r_{18}}$. Fungicide for soil preparation (litres).
- $\mathbf{r_{19}}$. Containers for transporting the prepared soil (litres).
- $\mathbf{r_{20}}$. Cages for placing the inoculated compost (units).
- $\mathbf{r_{21}}$. Packages that include compost and seeds (units).
- $\mathbf{r_{22}}$. Insecticide for disinfecting the crop (litres).
- $\mathbf{r_{23}}$. Labels for the packages of finished product (units).
- $\mathbf{r_{24}}$. Boxes for the packages of finished products (units).

With regard to the category of decision variables related to the actual conflicts, a review of structural conflicts of the model can be done. Figure 2, eases the process of identifying the places associated to the structural conflicts.

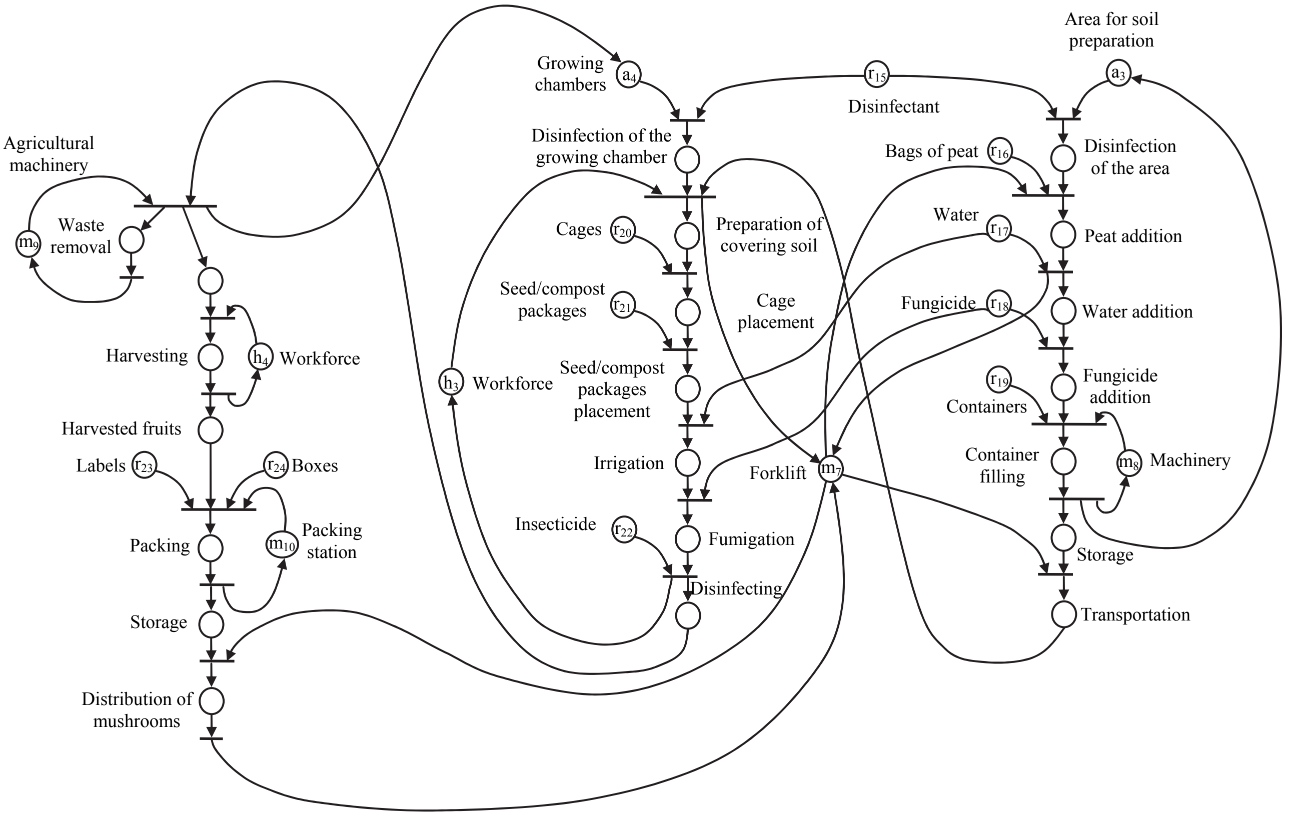

Figure 2. Model of the cultivation facility of common mushroom

As it can be seen in the model of the facility, the cultivation process of mushroom is quite sequential. However, there are some structural conflicts that can be pointed out:

a) Place labeled “disinfectant”. This product should not be in such a restriction that it would be necessary to decide in which operation it is used and in which operation cannot be used. In food industry, it is imperative proceed with enough degree of hygiene in the production operations. For this reason, it is not convenient for this structural conflict to be transformed into an actual conflict. This fact would imply shortages in disinfectant products and it may compromise the quality and even the commercialization of the final production.
b) Place labeled “forklift”. This place has already been explained in the previous section, since there are also this kind of shared resources, which are expensive and for that reason they are not usually overestimated. The optimal management of this kind of shared resources may have a significant impact in production yield.

7. DECISION MAKING METHODOLOGY

Once a model with freedom degrees has been constructed, as described in the previous sections, an optimization methodology can carry out in an automatic manner the search for the best configuration of the freedom degrees or, at least, for one configuration that works reasonably well if it is found in a short period of time.

The optimization problem requires a cost or objective function that quantifies the consecution of the objectives of the system from certain parameters produced during the evolution of the system. Simulation is a convenient methodology, which allows obtaining these performance parameters.

The statement of this optimization problem also requires a model of the system, a pool of feasible solutions or solution space and certain additional constraints.

The solving methodology should include a process to explore the solution space, since usually the exhaustive exploration would consume an amount of computer resources not available to be applied to the decision problem. An effective choice for this process consists of a metaheuristics, such as genetic algorithms, ant colony, particle swarm, or simulated annealing.

8. CONCLUSIONS

This document has presented a Petri net model of a facility for producing compost and for cultivating common mushroom.

The model includes explicitly several type of common controllable parameters and allows easily the addition of more types of freedom degrees. This is a key feature for testing different configurations and finding out the one that best leads the system to the main objectives of the system.

In addition, the description of an optimization methodology would allow to apply the mentioned model to a decision making support tool.

This tool would alleviate the complexity of making decisions related to the operation of a facility for the production of compost and cultivation of common mushroom. Making appropriate decisions can state the difference between success and failure in a competitive food global market.

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.

Latorre, J.I., Jiménez, E., Blanco, J., Sáenz, J.C. 2015. Decision Support System, Based on The Paradigm of the Petri Nets, for the Design and Operation of a Dairy Plant. International Journal of Food Engineering, 11(6): 767-776.

Latorre, J.I., Jiménez, E., Blanco, J., Sáenz, J.C. 2014. Optimal Design of an Olive Oil Mill by Means of the Simulation of a Petri Net Model. International Journal of Food Engineering, 10(4): 573-582.

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.

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.

Leiva, F.J., Saenz-Díez, J.C., Martínez E., Jiménez E., Blanco J. "Environmental impact of mushroom compost production". Journal of the Science of Food and Agriculture. In press. 2016

Leiva, F.J., Saenz-Díez, J.C., Martínez E., Jiménez E., Blanco J. "Environmental impact of Agaricus bisporus cultivation process". European Journal of Agronomy, 71: 141–148. 2015.

Leiva-Lázaro, F.J., Blanco-Fernández, J., Martínez-Cámara, E., Latorre-Biel, J.I., Jiménez-Macías, E. "Mushroom cultivation process, agaricus bisporus variety: comparison between traditional and climate controlled cultivation and identification of environmental impacts of the production processes". Proc. of the Int. Workshop on Simulation for Energy, Sustainable Development & Environment 2015. Bruzzone, Janosy, Longo, Zacharewicz Eds.

Longo, F., De Bonis, F., Spadafora, F., and Nicoletti, L. 2014. Training in car terminals: A modular architecture based on distributed and interoperable simulation. European Modeling and Simulation Simposium. EMSS 2014. Bordeaux, France.

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.

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.