DECISION MAKING IN THE RIOJA WINE PRODUCTION SECTOR

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ABSTRACT
The global environment, where many companies compete for their survival, requires a continuous adaptation to changes in the market and to other environment variables. Food industry, agriculture in particular, is a field, where the companies are especially sensitive to modifications in regulations and market requirements. It is very convenient to provide the companies of this sector with a theoretical basis, as well as with practical tools for developing en efficient management that may guarantee not only their survival but also their success. In this area, decision support systems based on the simulation of models, developed by means of the paradigm of the Petri nets, can offer a significant help for improving the efficiency of the farming companies, based on the proper decision making. In this paper, a methodology for decision making, supported by artificial intelligence (and dispatching rules), is applied to the farming field and an application case is analysed for better understanding of the advantages and drawbacks of this approach. In particular, a decision making methodology for improving the management of traditional companies in the farming industry is applied to the wine sector in the region of La Rioja (Spain).

Keywords: workstation design, work measurement, ergonomics, decision support system

1. INTRODUCTION
This section shows the application of the paradigm of the Petri nets to the modelling of business processes in the food industry, performed with success by different authors. The developed methodologies allow modelling and analysing the procedures underlying business processes as a tool for the continuous improvement and even for their complete redesign.

The efficient management of an agricultural corporation constitutes a key strategy for improving farming yield and encourage stable production for small producers. (Shikanai *et al.* 2008) develops an information system to support the management of the cultivation of sugarcane. By applying this system, the small agricultural producers are able to manage their work systematically and efficiently, accomplishing low-cost and highly-efficient cultivation with full mechanization. The system proposed allows the automatic construction of a farm work database, used for simulating the operation of effective farming.

In the field of the wine industry, (Ferrer *et al.* 2008) develops a methodology, not based on a Petri net model, able to provide with an optimized scheduling for the coordinated activities that correspond to the wine grape harvesting and end in the supply of the crop to a couple of wineries.

(Melberg and Davidrajuh 2009) shows that fish farming industry finds in Petri nets a suitable formalism for the modelling and simulation of the different stages and events related to this field. The work examines the atlantic salmon fish farming processes and the different stages are modelled by a scalable hierarchical structure.

(Guan *et al.* 2010) deepens in the decision making process in intensive farming units for improving profits and reducing costs. The efficient management of the small farming business is performed by means of the strategy of intensive agriculture and a structure of farmers' cooperatives or agricultural corporations. For an efficient management of these farming units, appropriate decisions should be made regarding timeliness in all operations, crop rotations, equipment adjustments, and land rent, leading to an increase of yield, profitability, and work efficiency. The authors have applied a methodology for solving the farm work scheduling problem based on modelling by hybrid Petri nets and optimization. It considers nondeterministic events, such as machine breakdown and labour absence. The optimization methodology is completed by a metaheuristic search in the solution space performed by a genetic algorithm.

The application of a decentralized Petri-net execution engine to a workflow for a wine-production process is presented by (Cicirelli *et al*. 2010). The proposed system allows a smooth transition among the various stages of the process lifecycle. It shows as well the coordination of distributed execution of models and a support for dynamic evolution and reconfiguration.

(Léger *et al*. 2011) addresses one specific but very important process for companies in the farming field: the crop protection using the smallest amount of chemical pesticides. In order of providing a decision support system for allowing farmers handling with large amount of available information, the crop protection decision workflow system is presented and applied to the case of wheat.

The issue of the certification of pollution-free agricultural products is considered in (Wang *et al*. 2011). This paper provides with a Petri–net based model for the pollution-free agricultural regulatory system and a subsequent performance analysis of the mentioned workflow model. The presented methodology allows an easier process management than previous existing techniques.

As a traditional sector, wine production has not received much attention from the scientific community for developing efficient management methodologies based on modelling by Petri nets and simulation for decision support system.

La Rioja is a well-known region of Spain for its long tradition in the production of wine and the high quality of the wine with the qualified designation of origin. Several climate features characterizes the grapes harvested in different parts of the region, in addition to the differences related to the growing of diverse varieties of grapes. Moreover, small farming businesses, scattered in the region, produce relatively reduced quantities of high quality grapes and are usually integrated in farmers' cooperatives. These corporations distribute their crop to the different wineries of La Rioja to produce red, white and rosé wines with the highest standards.

The market for high quality products from the food industry requires keeping the highest standards during every single stage of the farming process, transport of the harvested grapes, storage and production of wine and distribution to the final consumer by a worldwide supply chain. These exigent requirements are also encouraged by the increasing pressure from emergent regions that begin producing wines of quality and export them to the rest of the world.

For this reason, the management of small vineyards, cooperatives, wineries and distribution companies should be very effective and the right decisions must be made at the appropriate time. There are, nevertheless, several handicaps to practise an efficient decision making. On the one hand, the small and traditional business and companies are not well adapted to a changing environment and to proceed using the more advanced and sophisticated strategies and tools for decision making. This fact urges the development of specific, effective, and simple tools for these applications. On the other hand, the complexity and diversity of the different processes that participate in the complete production cycle of the wine makes almost impossible to follow successful strategies in every step of the farming, transport and production in this network with a large number of actors, without the help of the appropriate decision support systems.

In this regional production system there is a large number of processes that are developed in parallel, are synchronized at certain stages, and compete for limited resources. Petri nets is a modelling paradigm well suited for the modelling, analysis, simulation and optimization of systems whose behaviour verifies these characteristics (Silva 1993).

The authors of this paper have developed a decision making methodology especially suited for this complex environment, where the networks of commercial relations between farmers, cooperatives, wineries, and distribution companies can be arranged in very different ways, leading to models with alternative structural configurations (Latorre *et al*. 2011).

This methodology is based in the modelling of the system in a compact representation made by means of a formalism that includes all the alternative structural configurations in the so called set of exclusive entities (Latorre *et al*. 2011). Several different formalisms allow representing the system, profiting from the features of the different alternative structural configurations to obtain a compact model of the system. This compact representation alleviates the computer requirements of the algorithm that is applied to solve the optimization problem associated to the original decision making (Latorre *et al*. 2010).

The methodology that has been applied to the wine production sector in La Rioja (Spain) is based on a single-staged search in the solution space. This search is guided by a metaheuristic, which has been implemented by means of a genetic algorithm.

As a consequence of the proposed methodology, a decision making support for the different actors that participate in the growing, and harvesting of the grape, the ones that store and distribute them, those that produce the wine and the companies that distribute the resulting product have a tool for efficient decision making adapted to this sector of the food industry. This tool can be used individually or by organizations that supervise and coordinate the interaction of the different businesses and require a global vision of the sector.

In this paper, the specific and critical stage of winemaking in a small or medium-size winery is afforded by the presentation of the model and the proposed methodology for decision making. The decision problem that is aimed to be solved for the presented methodology comprises not only the scheduling or operational choices but also the design of the business, taking decisions that define the structure of the winemaking process.

The following section introduces the modelling formalism, based on Petri nets, which will be used in the decision support methodology, the section 3 deals with the model of the winery. The fourth section presents the decision problem in detail, while the following section describes the methodology for solving the decision problem. The last section, number six, presents the conclusions and the future research lines.

2. ALTERNATIVES AGGREGATION PETRI NETS

In the previous section, it has been mentioned that the Petri net formalism is suited for the modelling, analysis, simulation, and optimization of discrete event systems. Its graphical representation allows representing, in an explicit and intuitive way, complex behaviours characterized by concurrence and synchronization of subprocesses. Moreover, the matrix-based of a Petri net representation may lead to a very productive structural analysis, as well to the statement and solving of decision problems based on the evaluation of the performance of the system under specific conditions.

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 $\mathbf{m}_0: P \rightarrow \mathbb{N}^*$.

□

This definition 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.

The alternatives aggregation Petri nets consists of a Petri-net-based formalism, which has the ability of representing in a single model, a complete set of alternative Petri nets removing the redundant information that correspond to shared subsystems. Furthermore, 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 can be afforded 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 $S_A = \{ a_i \text{ Boolean} \mid \exists!\ k \in \mathbb{N}^*, k \leq n, \text{ such that } a_k = 1 \wedge \forall\ j \in \mathbb{N}^*, j \leq n, j \neq k \text{ it is verified } a_j = 0 \}$, where $|S_A| = n$, and the assignment $a_k = 1$ is the result of a decision.

□

Definition 3. An alternatives aggregation Petri net can be defined as a 10 tuple $R^A = (P, T, \text{pre}, \text{post}, \mathbf{m}_0, S_\alpha, S_{valnstr\alpha}, S_A , \text{f}_A, R_{val\gamma})$, 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, $S_A \neq \emptyset$ and $|S_A| = n$.
iv) f_A: $T \rightarrow \text{f}(a_1, \ldots, a_n)$ is a function that assigns a function of the choice variables to each transition t such that type[$\text{f}_A(t)$] = 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 $\text{g}_A(t) = a_1 + a_2 + \ldots + a_k$.

□

This formalism, can be used to develop the model of a small or medium-size winery in the region of La Rioja (Spain), with the purpose of its design, improvement or efficient operation.

3. THE MODEL OF THE WINERY

3.1. The winemaking process

La Rioja is a region of Spain, where the wine industry has a long tradition and its influence in the local economy is very important. In fact, La Rioja produces the 6% of all the European wine, being the most important specialty, the red wine.

There exist different methodologies for producing wine, according to the target finished product (red, white rosé, or sparkling wine), with different variants, which depend on the equipment used, the degree of mechanization and automation, the chemical processes, etc.

However, a broadly applied technique for the production of red wine in La Rioja is the traditional Bordeaux method, which has been used in this region since the middle of the XIX century.

According to this winemaking method, the grape clusters can be transported to the winery by different means and in diverse types of containers. At their arrival, the quality of the grapes is measured and they are weighted and transferred to the first stage of destemming, for removing the rachis from the grapes, and of crushing, for liberating their juice.

At this point SO_2 is added to the mixture for antiseptic purposes and the storage of the product for the optional stage of maceration can begin.

The following step is the primary or alcoholic fermentation, where the must is complemented with yeast for the transformation of the contained sugar into alcohol and carbon dioxide. As a result of this stage an amount of free run wine is obtained by decantation, while the rest of the product is pressed for the separation of the so called press wine and the grape skins. The press wine can be mixed with the free-run wine in order to increase the production.

The next step is the secondary or malolactic fermentation, under bacterial action, which can take place in vats or barrels. An optional ageing or maturing of the wine in oak barrels or in stainless steel barrels with oak chips can be afforded at the end of the secondary fermentation. With the clarification and filtration, most of the large particles, yeast, and bacteria present in the wine are removed, improving the appearance of the product and stabilizing it chemically.

The following stage of bottling and sealing with a cork may be followed, optionally, by a wine ageing in bottle. After the end of the previous process, it is possible to add a capsule to the top of the bottle and to label it. The packing can be made in boxes, stored on pallets. From the warehouse, the pallets with wine are prepared to be distributed around the world.

3.2. The marking controllable parameters

Some controllable parameters, which can be considered and specified for the design and operation of a winery, are presented in the following:

- **c_1**. Capacity of the available lorries for the transportation of the grape to the winery.
- **c_2**. Capacity of the available platforms for the transportation of boxes, containing grape clusters, to the winery.
- **c_3**. Capacity of the chutes for receiving the grapes.
- **c_4**. Grape conveying capacity to the destemming machine.
- **c_5**. Processing capacity of the automatic crusher-destemmer.
- **c_6**. Processing capacity of the stemmer machine.
- **c_7**. Processing capacity of the centrifugal crusher.
- **c_8**. Processing capacity of the crusher with rollers.
- **c_9**. Flow rate of the barrelling pump.
- **c_{10}**. Capacity for the cold maceration = number of tanks x capacity of every tank.
- **c_{11}**. Capacity of the winery for the stage of maceration with addition of heat.
- **c_{12}**. Pipeage pump flow rate.
- **c_{13}**. Capacity of the hydraulic press after primary fermentation.
- **c_{14}**. Capacity of the vats for the malolactic fermentation.
- **c_{15}**. Capacity of the barrels for the malolactic or secondary fermentation.
- **c_{16}**. Capacity of the barrels for the wine ageing.
- **c_{17}**. Capacity of the stainless steel tanks with oak chips for wine ageing.
- **c_{18}**. Capacity of the centrifugal clarification machine.
- **c_{19}**. Capacity of the machine for precoating.
- **c_{20}**. Capacity of the clarification filter.
- **c_{21}**. Capacity of the filter for microbial stabilization.
- **c_{22}**. Capacity of the facility for ultrafiltration.

More examples of controllable marking parameters are the stock of empty bottles, the stocks of stoppers of cork, metal or plastic, and the processing capacity of the bottling, labelling and packing machine.

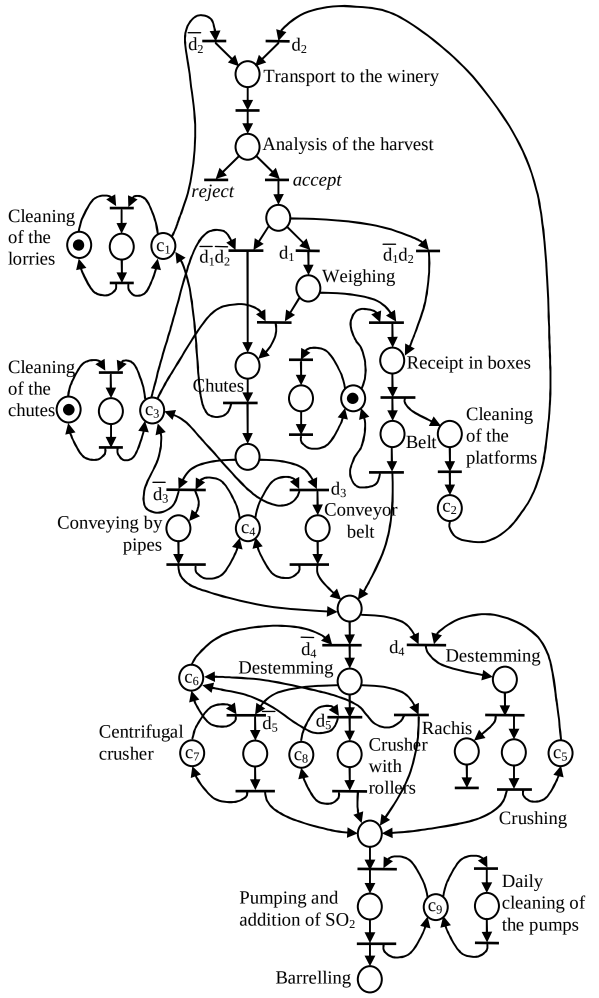

Figure 1: First stages of winemaking

The decision-making methodology, which will be described in the section 5, can afford the choice of the optimal value or a quasi-optimal one for every one of the controllable marking parameters mentioned in this section 3.2, as well as for the structural decisions, which are mentioned in the following section 3.3.

3.3. The structural decisions and choice variables

Some of the stages of winemaking may vary, be combined, or even omitted, according to the quality of the raw materials and the expected finished wine. Furthermore, different equipment and labour force can be used for the diverse winemaking steps. For all these reasons there are many alternative structural configurations for the design of a winery. Hence, there is a large amount of structural decisions that can be made. The most significant ones have been taken into account in the model presented in this paper. They are listed below:

d1. Double or single weighting process of the incoming grape.
d2. Receipt of the grape in boxes or in a chute.
d3. Conveying of the incoming grape by conveyor belts or by pipes.
d4. Combined or separated destemming and crushing.
d5. Centrifugal crusher or crusher with rollers.
d6. Cold maceration.
d7. Maceration with addition of heat.
d8. There is not any stage of maceration.
d9. Secondary fermentation performed in vats or barrels.
d10. Ageing of the wine in oak barrels or in stainless steel tanks with oak chips.
d11. Centrifugal clarification or precoating.
d12. Filtration for clarification.
d13. Filtration for microbial stabilization.
d14. Ultrafiltration.
d15. Normal bottling.
d16. Aseptic bottling.
d17. Bottling with addition of heat.
d18. Ageing of the wine in the bottle.

As a result of these structural decisions, or decisions that condition and specify the structural configuration of the system, 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:

$|S_A| = 2 \cdot 2 \cdot 2 \cdot 2 \cdot 2 \cdot 3 \cdot 2 \cdot 2 \cdot 2 \cdot 3 \cdot 3 \cdot 2 = 2^9 3^3 = 13824.$

As it can be deduced, analysing a set of 13824 alternative structural configurations to choose the best one as solution of a design process is unpractical. The methodology proposed in this paper has been developed to afford such a problem in an efficient single process. Moreover, as it will be seen in the following two sections, the proposed methodology can give a solution for the decision making related to the structural and the non-structural controllable parameters. That is to say, the solution of the decision problem specifies the design of the system, as well as its operation.

3.4. The alternatives aggregation Petri net model

In this section, a model of a typical small or medium-sized winery from the region of La Rioja, in process of being designed, is presented.

With the aim of simplifying the representation, the weights of the arcs that represent the change of interpretation of the tokens in relation with physical items do not appear in the Petri nets.

In figure 1, the model of the winemaking process from the receipt of the harvested grapes to the barreling process is presented. In the alternatives aggregation Petri net model, instead of representing the 13824 choice variables, an abbreviated representation based on the 18 decision variables, d_i, has been considered.

Furthermore, in figure 2, the Petri net model for the subsequent stages of maceration, primary and secondary fermentation, optional aging, clarification, filtering and stabilization is detailed.

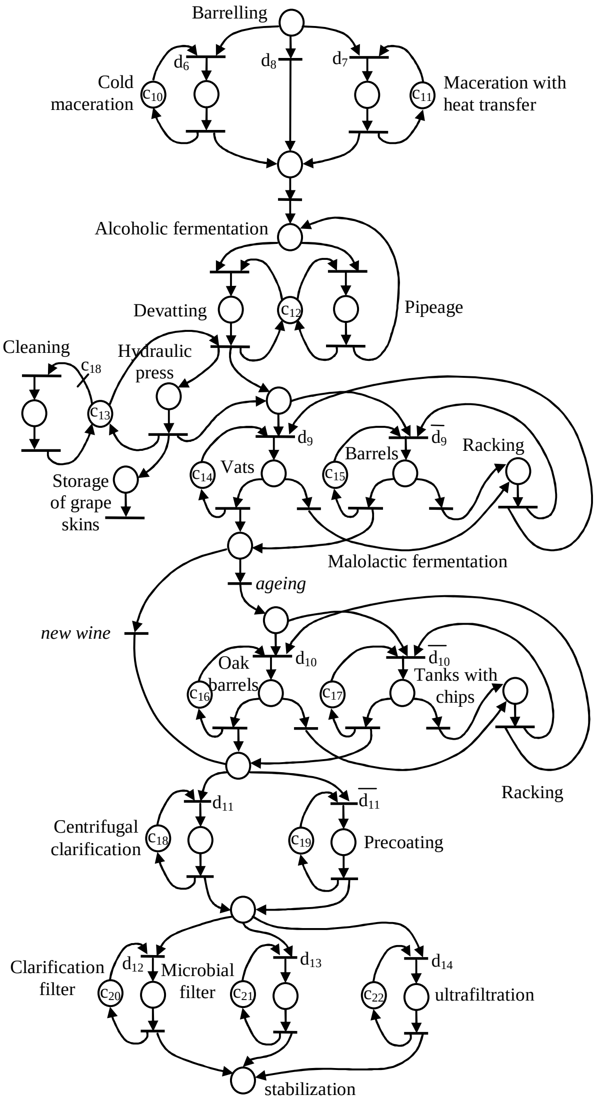

Figure 2: Fermentation and filtration

The Petri net model for the remaining stages of bottling, labelling, and packing, has not been represented in this paper. Nevertheless, as it has been indicated in sections 3.2 and 3.3, this part of the model contains several controllable parameters.

In the next section, the decision problem associated to the model of a winery is presented.

4. THE DECISION PROBLEM

The decision problem stated for the design of the winery aims to optimize the benefit from the facility, hence, it can be written in the form of an optimization problem. This goal implies that a maximal production is expected, with a minimal cost, guaranteeing a high quality standard in the winemaking processes, as well as in the final product.

The solution of the problem is a sequence of optimal values for every controllable marking parameter, as well as a decision, for every structural choices d_i.

The statement of the problem requires an objective function, the consideration of the alternatives aggregation Petri net of the winery as disjunctive constraint and some additional constraints, for example the domain of the controllable parameters.

5. THE SOLVING METHODOLOGY

In order to find the best values for the controllable parameters of the model, a single-staged methodology is proposed (Latorre *et al*. 2010). According to it, a single solution space is constructed, and its exploration can be afforded by means of a metaheuristic, for example a genetic algorithm. Using this search strategy, it is possible to avoid an exhaustive search, usually unfeasible due to the combinatorial explosion and the limited availability of computer resources.

In this exploration, the choice of a given solution to evaluate its quality implies a simulation of the evolution of the Petri net model under the conditions given by the solution and the additional constraints defined in the statement of the optimization problem. This simulation, with the help of the objective function allows characterizing every solution with a performance measurement, which can be used to compare the fitness of the solution as optimal or quasi-optimal solution of the decision problem.

6. CONCLUSIONS AND FURTHER RESEARCH

The traditional but globalized and competitive wine industry may improve by the use of decision support systems, able to improve the design and management of the different business that take part in this sector.

Many actors participate in the winemaking process, from farming and harvesting to conveying the grapes, producing the wine and distributing and commercializing the different type of finished products.

In this paper, a decision-making methodology is described for the efficient design of a small or medium-sized winery. This methodology is aimed to be applied under a more general system, including more alternative items and processes to be considered in the production of wine in the winery, as well as to add more stages of the winemaking, belonging to the external chain supply and farming activities. The goal of this research line consists of developing and proving a general methodology for decision making in the field of wine production, which may help the companies to be more competitive by producing goods and services of higher quality and lower costs.

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