MANAGEMENT OF RESOURCES AND WASTES IN A NETWORK OF SCHOOLS MODELLED BY PETRI NETS

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ABSTRACT
The management of public resources, such as educative institutions is usually associated to making decisions affecting to a large number of schools, in changing environments, and with large amount of information. In order to ease the management of these complex systems, this paper describes a methodology for modeling a network of schools, simulating the model under a given configuration, and selecting the best decisions for assisting the educative authorities in their managing responsibilities.

Keywords: education, Petri nets, optimization, decision support system.

1. INTRODUCTION
The management of public resources is usually performed under the influence or approach of crisis. Environmental and economic crisis might require the educative authorities to make a special consideration for maximizing the social and educative benefits obtained from invested public resources, as well as minimizing the impact the educative activities might have in the environment.

Giving autonomy of decisions to the educative institutions or centralizing their management is an issue of debate and research, where there still remains a large number of open questions. Among the advantages of autonomous decision making can be found the swiftness in responding to non-expected situations, the possibility to negotiate directly to local suppliers, the detailed knowledge by the managing board of a school of their students, teachers, suppliers, and specificities of the school and its social and economic environment.

Nevertheless, a centralized management of educative centers in a situation of crisis seems to be especially suitable due to the convenience of sharing resources and services. Among the advantages of a centralized management it can be mentioned the economy of scale when negotiating large volumes of products or services or the better utilization rate of resources such as public transport, or communication networks.

A step further in the centralized management of schools can be the formation of clusters with schools of different educative levels, from basic school to secondary education and vocational training. In this case, more services and products can be shared, increasing the efficiency in their use, the reduction in their cost, the improvement in the quality and the satisfaction of members of the educative community with special needs, such as accessibility for handicapped people or special diets for allergic or intolerant students or members of the staff.

Clustering different educative levels into "campuses" may lead to a very efficient use of resources, as well as to better services to society, including not only education but also transportation, counseling, accessibility, catering, long-life learning, or leisure, just to give a few examples.

More examples, this time regarding resources that can be shared are the administrative staff and offices, central heating, catering service, waste management and recycling, communication networks and services, or even central heating.

However, the more centralized the management, the more complex the decision making becomes. This fact arises as a consequence of an increase on the information, as well as on the variability of the schools, which determine that a given decision may derive to different outcomes, depending on the educative level, the location of the school, the social background of the members of the educative community, etc.

As a consequence of the previous considerations, the centralization of the management of educative institutions implies the need of a decision support system for the assistance of the managers in the decision making.

In this paper, the development of a decision support system for the management of a network of schools is discussed.

The following section deals with the characteristics of such a tool, designed for helping in the process of decision making. Section 3 describes briefly the educative institutions, whose assisted management is the objective of the present research. The formalism chosen for developing the model of a network of schools, the Petri nets, is presented in section 4, while a model of a school is shown in the following section. In the same section 5, it is detailed the modeling of the decision making process in a given school, which has been decomposed in three levels: operational, tactical, and strategic one.

The modeling approach bottom-up is used in section 6 for constructing a Petri net model of a network of schools. The following section describes the development of a decision support system, based in the model shown in the previous section. A section of conclusions and another one dedicated to the bibliographical references relevant to the paper conclude the present paper.

2. DECISION SUPPORT SYSTEM

A decision support system assists a human decision maker in complex and difficult decisions. The application field of this kind of tools is very broad and grows every year, ranging from medical diagnosis to manufacturing management.

There are diverse approaches for producing a decision support system. One of them, the one followed in the research presented in this paper, is the one based in the construction of a model of the system of interest (Swanepoel, 2004).

In the field of education, the use of decision support systems has been broadly used for the development of timetables and, in general, for allocating resources, such as classrooms, to students and teachers. Nevertheless, its use in the management of educative institutions is much more limited (Otero et al, 2012b).

As it has been mentioned in the previous section, the more educative institutions in the scope of the management board, the more complicated is the resulting administration of the required resources, the provided services, and the generated wastes.

The management of a network of schools requires dealing with a large number of actors and variables, which are difficult to take into account in an appropriate manner by classic and manual methodologies.

Techniques applied commonly, such as the ones based on spread sheets or even simulation not based on models of the network but on information gathered at the beginning of the academic year or even in the precedent year, may lack of realism and prompt reaction to new variables or non-expected situations, which might arise at any moment of the academic year (Otero et al., 2012a).

In order to overtake the limitations of the mentioned classic approaches for managing a network of schools, while earning the benefit of a centralized administration of resources, services, and wastes, it is possible to consider a methodology of optimization based on simulation, where the simulation is performed by using a Petri net model of the network of educative institutions.

This approach is not new, but has been applied to diverse sectors with success. For example (Jiménez et al, 2006) discusses the application of modeling and simulation in the industry, while (Tuncel, 2007) presents a scheduling heuristic rule that aims to allow choosing the best operating policy and system configuration for a flexible manufacturing system. Also in the manufacturing field (Mušič, 2009) discusses the Petri net based job-shop scheduling by means of a combination of dispatching rules with a local search guided by a metaheuristic.

Furthermore, (Latorre et al., 2012) applies the methodology proposed in this paper to the Rioja wine production sector. On the other hand, (Latorre et al., 2013) presents a refinement of this methodology for the design of a discrete event system, instead of its management.

The mentioned approach, based on the simulation of a model of the system, will provide the human decision makers with predictions for the time to come, which can be adapted on-the-run by adding new variables or modifying the existing ones. This powerful tool may provide with confidence to the decision makers, who will be able to test the outcomes of different decisions.

By means of the information obtained from the analysis of the decisions by simulation, it will be possible that the decision makers choose the most promising option, improving in this way the management of the educative institutions.

3. EDUCATIVE INSTITUTIONS

In Spain, regional authorities have competences in education. Furthermore, there is a department in every regional government devoted to the management of schools, including primary education, secondary education, and vocational training.

There is little autonomy for the educative centers. This practice implies that the approach presented in this paper has a very appropriate application at this regional level of management.

In fact, as it will be described in section 5, operational decisions are made at the level of the educative center, whereas tactical decisions are made usually by regional authorities or by the managing board of the schools with the approval of the regional authorities. The strategic decisions on the management of the educative centers are made by the national or regional authorities.

4. FORMALISM OF THE PETRI NETS

The choice of the Petri nets as the modeling formalism considered in this research has been made because they are especially suited to model and analyze discrete event systems showing parallel evolutions and whose behavior are characterized by concurrency, synchronization and resource sharing.

The behavior of a network of schools falls under this category. In fact, the different schools present parallel evolutions, sometimes with a small contact with other schools. However, they compete for the limited public resources provided by the government, such as money, teachers, spaces for teaching, or courses for teachers.

On the other hand, the graphic nature of the net allows them to be self-documented specifications, which can make easy the communication among designers and users (Silva, 1993).

A definition of a Petri net is presented in the following:

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

□

The marking of the Petri net is an essential element of the model. In fact, the structure of a Petri net is something static, while the behavior of the system can be described in terms of system state and its changes, which is modeled by defining a marking and the marking evolution rule.

A token is represented as a black dot in a place, essentially to indicate the fact that the condition described by that place is satisfied.

In the model of the network of schools that is presented in this paper every actor in the educative community will be represented by an individual token. The mentioned actors include every student, teacher, as well as the members of the managing staff, the administrative staff, and the maintenance staff of every school.

In order to assign at every moment the appropriate activity to every actor, it is convenient that the model of every actor presents some identification to personalize it. In this way, a token representing a teacher will not perform the same activities than a student. Analogously, a student of primary education will not perform the same activities than a student of vocational training.

In order to personalize the tokens representing students, teachers, and other staff, it is possible to assign to them some attributes. There is a special kind of Petri net that is suited to include the mentioned attributes. It is the colored Petri nets, a very well-known formalism, broadly used, and provided with powerful analysis and simulation tools.

A formal definition of a coloured Petri net is given by (Jensen and Kristensen, 2009):

Definition. Coloured Petri net.
A non-hierarchical coloured Petri net is a nine-tuple

$CPN = \langle P, T, F, \Sigma, V, \text{c}, \text{g}, \text{e}, \text{i} \rangle$, where:

1. P is a finite set of places.
2. T is a finite set of transitions T such that $P \cap T = \emptyset$.
3. $F \subseteq P \times T \cup T \times P$ is a set of directed arcs.
4. Σ is a finite set of non-empty colour sets.
5. V is a finite set of typed variables such that type[v] $\in$ Σ for all variables $v \in V$.
6. c : $P \rightarrow \Sigma$ is a colour set function that assigns a colour set to each place.
7. g : $T \rightarrow EXPR_V$ is a guard function that assigns a guard to each transition t such that type[g(t)] = Boolean.
8. e : $F \rightarrow EXPR_V$ is an arc expression function that assigns an arc expression to each arc a such that type[e(a)] = c(p)$_{MS}$, where p is the place connected to the arc a.
9. i : $P \rightarrow EXPR_\emptyset$ is an initialisation function that assigns an initialisation expression to each place p such that type[i(p)] = c(p)$_{MS}$.

□

Notice that MS stand for multiset over S. A multiset is an ordered pair (S,f) where S is a set and f:$S \rightarrow$N is a function, called the frequency or weight function. (Joshi, 1989).

5. MODEL OF THE DECISION-MAKING IN A SCHOOL

The development of a Petri net model for a network of schools can be performed following a variety of methodologies. There are two main groups of methodologies, which are called bottom-up and top-down (Silva, 1993).

The bottom-up approach begins with a detailed model of every subsystem and is followed by a stage, where all the submodels are linked together to obtain a detailed model of the complete system.

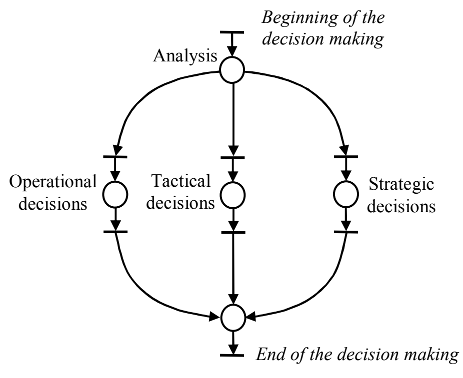

Figure 1: Decision-making by the managing board

On the other hand, the top-down methodology is implemented by constructing a low-detailed model of the complete system, which is refined and expanded by detailing different parts of it. This second approach is the one, which has been considered for the development of the present model. The low-detailed model of the network of schools is shown in the next section, as well as a general model for a school, which corresponds with an intermediate level of detail.

In this section, it has been represented detailed models of the decision making, which has been made correspond to the managing board of every school.

This approach does not prevent the simulation of centralized methodologies. On the contrary, it allows the simulation of both a centralized or a decentralized management for the educative centers.

In figure 1, it can be seen the model of the decision-making that correspond to the managing board. Considering that any set of decisions is made sequentially, a stage of analysis of the information required to make a decision is followed by either an operational decision, a tactical strategic one.

In figure 2, 3, and 4, the different levels of decisions have been modeled by means of Petri nets. In order to develop these models, it has been considered that operational decisions are those, whose influence is extended to a time window of weeks or few months. The tactical decisions are considered to range from few months to a year, while the strategic decisions range from a year to up to a decade.

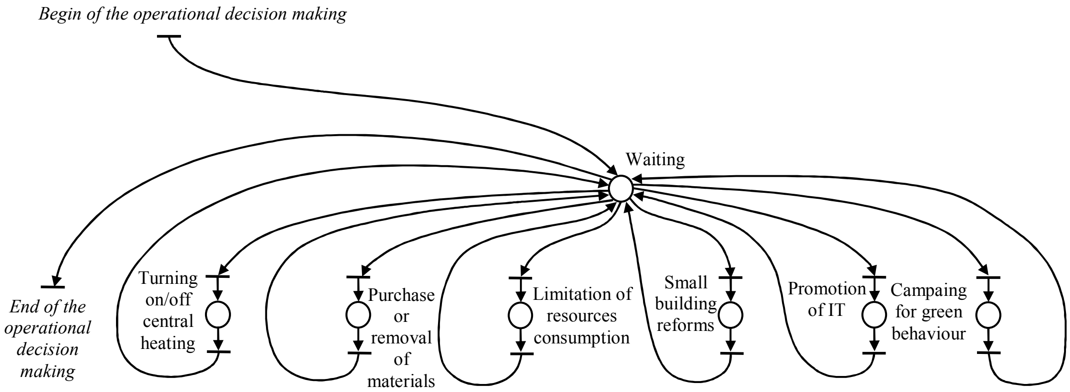

Figure 2: Operational decision making by the managing board

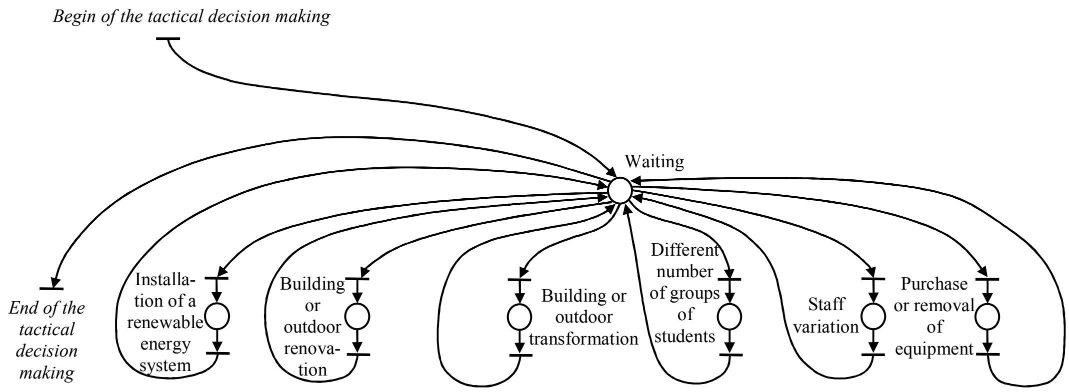

Figure 3: Tactical decision making by the managing board

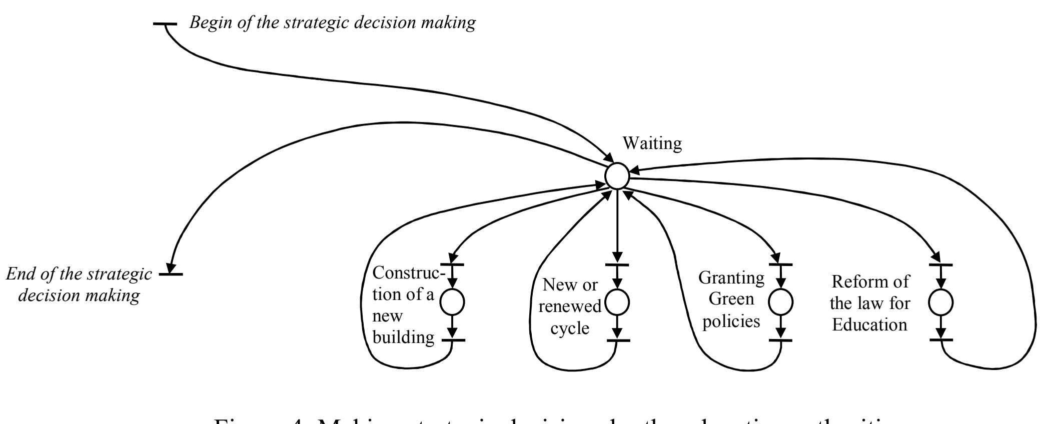

Figure 4: Making strategic decisions by the educative authorities

6. MODEL OF A NETWORK OF SCHOOLS

This section discusses the model of a network of schools to be implemented in a simulation-based decision support system.

Figure 5 represents a model of an individual school, where the school day is divided into three groups of classes interrupted by two breaks.

During the class time, the different actors may perform diverse activities according to their role. This role is represented in the model by means of the attributes of the tokens of the marking. Every token represents an actor of the educative community (student, teacher, member of the managing staff, administration, or maintenance).

The model of the network of educative institutions should take into consideration the natural simultaneous evolution of the different schools, as well as the competition for limited resources or sharing common resources.

Moreover, in such a system, with discrete states distributed into the different educative centers, and with discrete number of actors, such as students, teachers, administrative staff, or external services, a very adequate formalism to develop an accurate model are the Petri nets, as it has been stated in section 4.

This formalism offers a very intuitive and easy to draw graphical representation, yet the underlying mathematical considerations permit a matrix-based representation, very appropriate to implement simulation and optimization algorithms to analysis the evolution of the model.

The development of a Petri net model of a complicated system, such as a network of educative institutions, has been undertaken by means of successive refinements from a low-detailed representation shown in figure 6. The model of the network of schools represents on the top, two places where the staff and students are hired and enrolled respectively, usually for a year. The rest of the model is composed by the schools belonging to the network.

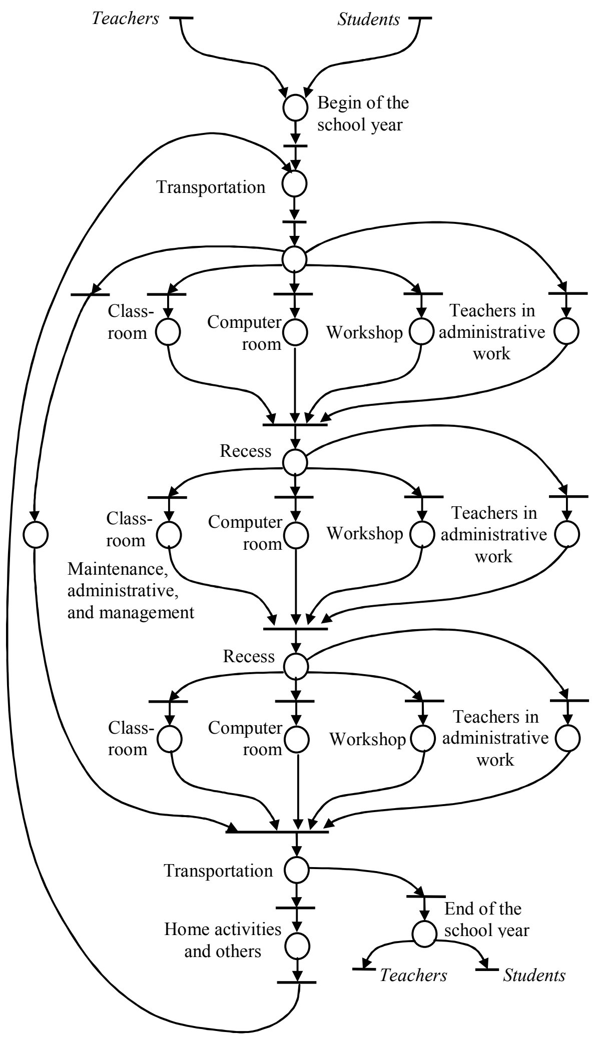

Figure 5: Petri net model of a school to be integrated in a network

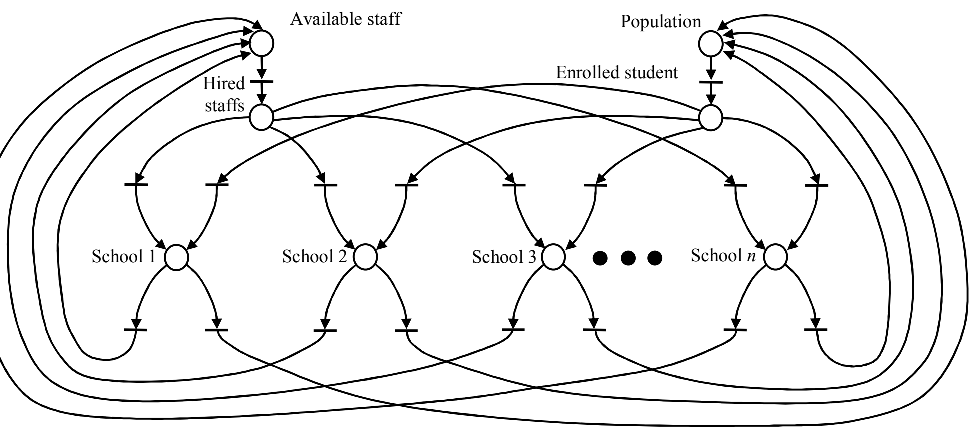

Figure 6: Network of *n* schools

7. OPTIMIZATION METHODOLOGY

Once the Petri net model of the network of educative institutions has been concluded, it is possible to use it for supporting the decisions made by the educative authorities. The methodology proposed to perform this activity is composed by the following stages:

a) Making a decision:

The model of the network of schools has freedom degrees, usually in the form of conflicts, which provide the system with flexibility and the administrative authorities with the possibility to make decisions. For this reason, it is necessary to choose a solution for every decision to be made in the period of the educative process to be analyzed.

The choice of the decisions to specify the freedom degrees of the model of the system can be performed by different ways, ranging from a random choice to the use of metaheuristics.

The selection of a method for choosing a solution for the problem of making decisions is of vital importance and will determine the efficiency of the decision support system, or even its effectiveness, since some problems do not allow an exhaustive search in the solution space of the problem in a reasonable amount of time.

b) Testing the decision:

The decisions made in the previous stage should be tested by simulation of the model to determine its suitability to solve the problem of management. As it can be seen, this approach is an application of the "what-if" analysis.

An important issue in this stage consists in the calculation of a parameter to represent with a numerical value the quality or suitability of the tested solution. In order to perform this task it is necessary to define the criteria that will determine the quality of a solution. In other words, the objectives of the educative authorities should be defined clearly and formally: social impact, invested resources, environmental impact, etc.

Once the objectives to be achieved by the management of the network of schools are clear it is necessary to quantify them, usually in the form of a multiobjective function. The calculation of this function should be done during the simulation. In this form, a tested solution can be "labeled" with a numerical value representing its quality. Steps (a) and (b) should be repeated iteratively.

c) Choosing the best decision:

From the pool of tested solutions, the one with the highest quality can be chosen as solution of the decision making of the educative authorities.

8. CONCLUSIONS

In this paper, a methodology of modeling and simulation of a network of schools has been discussed in order to construct a decision support system for assisting the educative authorities in their duties.

This methodology is based in the use of the paradigm of the Petri nets, which has been shown as a formalism very suitable to model educative institutions integrated in a network. The process of choosing the best decision is complemented by an iterative process of choosing feasible solutions and testing them to measure their quality. This methodology will provide with a quantitative tool for supporting the management of the educative institutions that may be very useful.

The next steps in the research will be to implement the tool and test it on a real network of schools.

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