A Decision Support System for strategic planning in public hospitals[*]

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In this paper we propose a decision support system developed to prioritize the optimization programs of the processes involved in the surgical patient flow in a typical Italian hospital context. The DSS is based on Analytic and Network Process methodologies, which are useful in addressing complex problems whose solution requires choosing among alternatives, taking into account both quantitative and qualitative criteria, also contrasting with one another.
In developing our DSS we have considered four processes of the surgical patient flow and the resources involved in them: indeed, the impact on efficiency and the feasibility represent the fundamental issues in the prioritization of the process optimization programs. The DSS, therefore, prioritizes the resources, in terms of their contribution to processes optimization, so as to reach a higher level of efficiency without improving resource level in the system.

Keywords: Decision Support Systems, Strategic decision making, Analytic Network Process (ANP), Health care

Topic Areas and Methodological Areas: MULTI-CRITERIA DECISION MAKING METHODS and Analytical hierarchy process (AHP)

Unlike private firms, public hospitals are characterized by a set of objectives, which cannot be limited to profit-seeking. In accordance to Italian Government guidelines, they have to reach both health effectiveness, in its different facets, and non-health indicators, such as cost efficiency, appropriateness of use of resources, *etc*. This complex set of objectives makes strategic planning in public hospitals very difficult, because all the actions planned might have a specific impact on each objective.
Besides, in the last years, Italian health policies has increased the importance of cost efficiency, promoting a better use of resources which are already at the disposal of hospitals. These cost efficiency programs, if not correctly realized, might have a negative impact on health effectiveness. Therefore, the hospital General Manager has to develop a strategic planning able to define the best cost efficiency actions to upgrade the global performance of the hospital. The first step of this strategic planning should be the detection of key processes and resources – those which mostly affect global performance and therefore have the maximum priority.
In this paper we propose a Decision Support System (DSS), based on the Analytic Network Process (ANP), that supports the General Managers of hospitals in this first step of the strategic planning. In particular, we focus our attention on one of the most important service provided by hospitals, that is surgical path, analyzing all the processes (pre-hospitalization, pre-operation, operation, and post-operation), and all the resources (surgeons, anesthetists, nurses, operating rooms, internal transport, etc.) involved in this service. Our DSS prioritizes the optimization of these processes and resources, evaluating their contribution to the different activities of the surgical path and their impact on the global performance of the hospital. Our DSS could combine both quantitative data, such as the actual use of resources in each activity, and qualitative ones, obtained through interviews to main actors in the process. We developed our DSS in collaboration with the top management of some hospitals of Tuscany on the occasion of the Ge.Ri.C.O. project, which aims to define new methodologies to manage critical resources in hospitals. We have developed the DSS and we tested it on simulated data, evaluating also the impact of several scenarios on process prioritization.
In section 1 we describe the structure of the Italian Health System, with its control and delegating

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power systems, highlighting the contribution of each tier of decision-making to the attainment of the final goals of the National Health System. In section 2 we describe how to detect critical processes and resources involved in the provision of public health services: this is an important task in order to pursue efficiency in carrying on the activity of public health service provision, i.e. improving the level of service without adding additional resources in the processes. Section 3 describes Analytic Hierarchy and Network Process, two methodologies onto which our DSS model relies, which allow to prioritize processes and resources in order to optimize the services basing on quantitative and qualitative characteristics of both processes and resources. In section 4 we describe our DSS model for the prioritization of the optimization programs for processes and resources, developed addressing to the surgical patient flow in the system. Finally, we analyze some limitations and future developments for our DSS.

1. The governance of the Italian Health System: tiers of decision making, actors and performance indicators

Health Systems have been always characterized by a high level of complexity, as they provide touchy and highly personalized services, which require the procurement of a plurality of expensive resources and the management of heterogeneous and uncertain activities. Moreover, public Health Systems could be considered even more complex, because they have to make their services accessible to as many people as possible.
Starting from 1978, Italian governments developed a National Health System with the principal aim to guarantee homogenous services to the Italian population. In order to make these services as accessible as possible, their tariffs have been maintained lower than those asked by private Health Systems. This political will has required a continuous effort in the improvement of the National Health System efficiency. So, in order to favor a stronger monitoring of the Health System, in the Nineties its governance has been progressively delegated to the Regions, which are responsible for the planning and control of the Health System in their own territory. The governance of the Italian Health System is based on three different tiers of decision making: national, regional and local (Figure 1).

[INSERT HERE FIGURE 1]

The national tier establishes, through the definition of a three-year National Health Plan made by the Government in collaboration with the Standing Conference on the Relations between the State, the Regions and the Autonomous Provinces, the level of public expenditure provided to the National Health System and the essential levels of care (LEAs) that have to be homogenously guaranteed in the whole country. These LEAs encompass the services of community prevention, local health care, and hospital care, and they are defined on the basis of five fundamental principles: the dignity of human being; the health need; the equity in the access to health care; the quality and the appropriateness of treatments, in accordance with the specific needs of the person; the efficiency in the use of resources. The LEAs have been clarified through the definition of a set of qualitative and quantitative standards, related to structural, technological, process and results requirements, whose verification makes it possible to monitor the respect of the LEAs and the public expenditure.
The satisfaction of the LEAs defined in the National Health Plan should be guaranteed by the action of each Region, which is addressed through the Regional Health Plan, a strategic plan that specifies the objectives and the organization of the Regional Health System. Actually, the Regions are the main actors in the Italian Health System, because they have to address, support, monitor, and evaluate the local units which provide health services to the consumers (Centro di ricerca sulle amministrazioni pubbliche “Bachelet V.”, 2008). In particular, each Region funds the public local units, checks *ex ante* their main measures, and carries out an *ex post* control on their performance.
The local units which provide health services to the customers in the Italian Health Service can be classified into two typologies: the Local Health Enterprise, which manages the Health System related to a specific territory, and the Public Hospital Enterprise, which manages only a specific hospital. These typologies have been instituted from 1992, when the public local units of the Health System have been transformed into public enterprises, with financial and organizational autonomy in the

provision of services (Lo Scalzo *et al.*, 2009). Both the Local Health Enterprises and the Public Hospital Enterprises are leaded by a General Manager, who is appointed by the Region and is responsible for the global performance of the public local unit. In particular, the General Manager has to attain the objectives established by the Regional Health Plan, maintaining the economic and financial equilibrium. For this reason, in collaboration with an advisory committee (Hospital board) composed also by the Medical Director, the Head of Administration, the District Directors, the Hospital Center Directors, and the Department Directors, he proposes a three-year Local Health Plan, a strategic plan that analyzes the characteristics of the local health demand and highlights the measures adopted by the local unit. The Local Health Plan, which has to be discussed also with the Mayors of the Municipalities involved in it, is detailed through annual general, district and departmental plans.

The implementation of these plans, carried on by all the personnel involved under the supervision of the District Directors, the Hospital Center Directors, and the Department Directors, should make it possible the attainment of the objectives established by the Regional Health Plan in the area assigned to the local unit.

The complexity of the Italian Health System governance requires a strict alignment among the objectives and the strategies defined and engaged by each actor, at every tiers of decision making. This alignment will be obtained only if each actor is conscious of the final goals of a public Health System and if he is able to set his own objectives and strategies in the light of these goals, also respecting each other's role in this governance system.

So, the first step in governing a public Health System should be the choice of its final goals. This choice depends, first of all, on the identification and the prioritization of its key customers. For example, in a free-of-charge Health System, if we take into consideration only patients in need of care, we have to build a Health System with the maximum level of effectiveness in the illnesses treatments; nevertheless, if we broaden our view to all the population, which funds the Health System through taxes, we have to guarantee also a certain level of efficiency. Besides, this choice has to take into account the evolution of the public Health System, due to scientific and technological progress, to the growth of customers' expectations, and to the economic situation (Durán *et al.*, 2011). The difficulty of this choice is witnessed by the great variety of goals included in the strategic plans made by public Health Systems around the world, and by the long-standing debate in scientific literature. In Italy, the final goals of the National Health System could be extracted by the analysis of the LEAs established in the National Health Plan and of the related set of qualitative and quantitative standards, whose last update dates back to 2002, thanks to a specific Ministerial Decree (No. 34/2002). Nevertheless, these standards have been organized partially according to a general framework of the National Health System, with indicators of process quality, output and outcome, partially according to the different health services provided, with specific indicators of community prevention, local health care, and hospital care. These latter encompass, for each service, various types of indicators related to effectiveness, efficiency, appropriateness, *etc*., without a coherent and systematic approach. This lack may be partially found also in the Health Plans approved in the last years by Italian Governments and Regions, and in many heterogeneous reforms, approved in the last twenty years, which try to reduce the income and geographical inequalities on health services supply, to foster the diffusion of appropriate treatments, so as to improve both customer satisfaction and quality of human resources involved in the health services (Lo Scalzo *et al.*, 2009). At the same time, even if the amount of the Italian public health expenditure is consistent with the European average, Italian Government has spent much effort in the improvement of the Health System efficiency, because of its impact on the Italian fragile deficit (Ministero della Salute, 2011).

The unique pragmatic attempt to systematically identify the final goals of the Italian public Health System has been realized in 2002 by the "Commissione per la Garanzia dell'Informazione Statistica" (CGIS), which tried to define a general framework for the measurement and the monitoring of Health System performances (Rodella *et al.*, 2003). Starting from a deep analysis of the literature, CGIS identifies four dimensions that contribute to the global performance of a public Health System:

- Health problems and health-related results, which could be measured through the evaluation of the level of the Health System effectiveness and safety;
- "Non-health" problems and results, which could be measured through the evaluation of the level of the Health System responsiveness and financial equity;

- Provided services, which could be measured through the evaluation of the level of appropriateness and productive efficiency of the services provided by the Health System;
- Internal organization, which could be measured through the evaluation of the level of accessibility, adequacy, allocative efficiency, integration, and attitude towards innovation and change of the Health System.

Nevertheless, the relationship among these dimensions, the related indicators and the steps of the health production process appears to be a little bit confused, with some elements, for example the financial equity of the Health System, that are considered both among the inputs and among the outcomes of the health production process.

A more systematic framework of the final goals of a public Health System has been proposed by the Health Care Quality Indicators Project of the Organization for Economic Co-operation and Development (OECD) (Kelley & Hurst, 2006). This framework is based on six principal dimensions:

- **accessibility**, that is the availability of the health services required by each consumer, provided in adequate way, time, space and quantity;
- **equity**, that is the availability of the health services to all the consumers, without any exclusions and disparities, especially those related to health needs and economic condition. The analysis of equity could be widened also to the *ex post* evaluation of the distribution of the outcomes of the Health System among the population;
- **safety**, that is the ability to provide the health services without any adverse outcomes or injuries that could damage the patient;
- **effectiveness**, that is the ability to provide the health services that are able to prevent and treat the disease of the patient and, more generally, to improve his quality of life. The analysis of effectiveness has to consider also the level of clinical appropriateness, that is the ability to choose the most relevant clinical procedures for each health need, the level of competence of the human resources involved in the provision of the health services, and the level of innovation and change attitude;
- **responsiveness**, that is the ability to provide the health services that are adequate to the patient legitimate expectations (WHO, 2000). These expectations could be related to health aspects, as those regarding the continuity of the treatments, but, almost always, they are related to non-health ones, such as communication, respect and comfort;
- **efficiency**, that is the ability to provide the desired health services at the lowest cost (Donabedian, 2003). This dimension could be expressed both in macro-terms (the lowest level of total public expenditure able to guarantee the desired health services) and in micro-terms (the maximum feasible level of output with the available amount of resources). The level of efficiency is strictly related to the ability to buy the necessary resources at the minimum price, but also to the ability to organize in the best way the available resources and the related activities.

This framework is able to combine the perspective of the main key customers of a Health System, the single consumer and the entire population, balancing their health needs with the economic sustainability. Besides, the dimensions proposed by the OECD framework are strictly related to the steps moved by each consumer in the health services fruition (Figure 2).

[INSERT HERE FIGURE 2]

Indeed, when a consumer wants to prevent or treat a disease, he should have the ability to access to the health service required, which is guaranteed only if the Health System is characterized by a certain level of *accessibility* and *equity*. Nevertheless, the ability to access to a health service is not sufficient to assure the satisfaction of the health demand, which could be guaranteed only if the Health System is characterized by an adequate level of *safety*, *effectiveness* and *responsiveness*. These three dimensions define, even if with a different impact, the quality of a Health System: an unsafe health service could even determine a negative service level, while the effectiveness and the responsiveness could increase the service level improving respectively the real and perceived service level. Anyway, a consumer, who supports with his taxes the development of the public Health System, is also interested in establishing the correct level of public health expenditure and in defining the correct way

to use this through the achievement of the maximum level of *efficiency*.
The definition of the final goals of a public Health System, as those proposed by the OECD framework, represents the first step for the definition of an adequate Performance Measurement System (PMS) (Porter & Teisberg, 2004). This could be a very huge effort because of some peculiarities of a National Health System, such as the heterogeneity of its goals, the presence of several internal and external stakeholders (Lemieux-Charles *et al.*, 2002), and the interaction between demand and supply, which is very different from other markets (Adair *et al.*, 2006). However, the importance of linking the PMS to the final goals is more and more urgent, due to the current evolution towards decentralization in the Western countries, with a growing separation among different levels of decision-making in the Health Systems, in particular between the institutional level and the managerial/technical one (Rodella *et al.*, 2003). In this sense, the definition of a multi-level PMS, as those used in other businesses, could foster the implementation and the monitoring of the strategic plans developed at the institutional level (Smith *et al.*, 2009), supporting also a more straightforward division of roles among the several actors involved in the Health System governance.
First of all, the definition of such a multi-level PMS has to identify the best set of indicators, reducing as much as possible its size, including both financial and non-financial indicators, choosing meaningful, strategic and evidence-based ones, and taking into consideration also the problem of the availability and the collection of the related data (Adair *et al.*, 2006). Nevertheless, this step has to be carried on together with the definition of a model that defines the indicators related to each decision making level, links them to one another, and, above all, links them to the final goals of the Health System. In literature, such models have been generally defined simply through a table, which assigns each indicator to one or more final goals. Veillard *et al.* (2010) propose a more systematic method, based on the creation of a strategic map, which contains the strategic objectives pursued at each level of decision-making. Nevertheless, this method does not give the possibility to summarize the global performance of a Health System and, consequently, to understand the actual contribution of each actor.

2. Optimization in public hospitals: The problem of the detection of the critical resources

The growing decentralization of the Italian National Health System has reinforced the role of the last levels of decision-making, which are involved in the management of their local units, either Public Hospital Enterprises or Local Health Enterprises. As described in the previous section, these units are leaded by a General Manager who, in collaboration with the Hospital Board, develops the strategies, which are summarized in the Local Health Plan and are necessary for the attainment of the objectives established by the Regional Health Plan. In order to strengthen the General Manager's commitment, the prosecution of his mandate has been subdued to the achievement of some targets, fixed by the Region at the time of his nomination. Although the precision of these targets (and of the related assessment procedures) are extremely variable across the Italian Regions (Lo Scalzo *et al.*, 2009), a General Manager has a strong responsibility for the performance of his assigned local unit and, for his part, for the attainment of the final goals of the Health System, which should inspire the National and the Regional Health Plans. Clearly, not all the final goals of the Health System fall under the responsibility of a General Manager: for example, the level of financial equity is basically due to the regulation of the tariffs of services decided at National and Regional level. However, the General Manager could promote strategic plans that aim to improve accessibility (*e.g.* through the reduction of the services waiting times), the safety (*e.g.* through the diffusion of specific safety protocols), the effectiveness (*e.g.* through the promotion of more appropriate procedures), the responsiveness (*e.g.* through the enhancement of the quality of the catering service) and the efficiency (*e.g.* through a more productive use of the available resources) of the services provided in his assigned local unit. A General Manager should develop the strategic plans aiming to obtain and maintain an adequate level of all these goals, guaranteeing also a constant economic and financial equilibrium. This requires a correct balance in the attainment of these goals, considering their impact on the patients, but also on the other stakeholders, first of all human resources, that are involved in the health services provision.
Unfortunately, in the last years, the General Managers have focused their strategies mainly on

efficiency, because of the health expenditure cuts approved by the Italian Government in response to the economic and financial crisis. These cuts have made the situation of the Health Systems local units, 65 percent of which registered a loss already in 2009, even more critical. The focus on the efficiency improvement of the Health System has been registered also in other Western countries, and it has been even more urgent by the increasing cost of drugs and machineries and by the growing need for continuous training of medical and nursing staff (Lega & De Pietro, 2005).

This focus on efficiency has favored the implementation of several programs that aim to improve the output of the Health System, through the reduction of the wastes related to the utilization of the available resources. In Italy, these wastes often result from a structural overcapacity of some resources – caused by the combination of an uncontrolled health expenditure and the adoption of methods for the resources allocation based more on the power of Department Directors than on the actual health needs (Lega & De Pietro, 2005) – and from a sub-optimal management of the health services, which is caused, among other things, by a scarce propensity of resource sharing among the Departments.

In order to reduce these wastes, the General Managers could address the optimization of the use of a resource, through models based on Operations Research, which aim to detect the most correct capacity level for the resource (planning problem) and the best assignment to each service/patient that asks for it (scheduling problem). First of all, in the application of these models, General Managers have to choose the resource that has to be optimized, in accordance with its relative importance in the Health System. For example, a huge number of scientific contribution focuses on the optimization of operating rooms, proposing several planning and scheduling methods, characterized by different types of patients (*e.g.* elective or non-elective), different decision variables (*e.g.* number of operating rooms or their capacity), and different resolution approaches (*e.g.* stochastic or deterministic) (Cardoen, 2010). The focus on the optimization of operating rooms has been sometimes justified with their costs, because this is the most expensive resource among those involved in the surgical pathway. This justification may be even more valid when the variable costs, which could be reduced through a resource optimization, are predominant on sunk ones; nevertheless, the operating room has, on average, a percentage of variable direct costs equal to 44.4% (Macario *et al.*, 1995). A better economic justification for the choice of focusing on the optimization of operating rooms is given by its potential impact on the hospital revenues that, in the Italian Health System, are principally due to the reimbursement made by the Region in accordance with the number of patients treated, on the basis of their assigned Diagnosis-Related Group (Lo Scalzo *et al.*, 2009). Gupta (2007) reinforces this choice highlighting that more than a half of the hospital admission is due to health services related to operating rooms. This justification may be valid only if the resource optimization could effectively increase the overall capacity of the health services related to this one (Wachtel & Dexter, 2008). A strong evidence of this fact has been provided by the analysis, made by Weinbroum *et al.* (2003), on the causes of wastes related to the utilization of the operating rooms, which amount to a 15% of the scheduled surgery time. This analysis shows that, only in a 32 percent of the cases, the main cause of these wastes is the unavailability of operating rooms; in the other cases, these wastes are due to the unavailability of nurses (20%), of post-anesthesia care unit (9.8%), of surgeons (7.4%), of anesthetists (7%), and of transportation (2.5%), while in a 12.1 percent of the cases to an inappropriate patient preparation.

In general, in order to improve the output of the Health System unit and to reduce the wastes related to the use of the available resources, the General Managers should address their effort, first of all, to those that have a greatest impact in the service provision, the so-called bottleneck resources. The detection of the bottleneck resources could be obtained through the analysis of the services provided. In particular, a bottleneck resource may be characterized by a long queue of work-in-process that demands it, by a high use of process expeditors, or by one of the longest average cycle time. Bottleneck resources determine the performance level of the whole system and, in accordance with the Theory of Constraints (Goldratt, 1984), have to be specifically managed through their exploitation, through the subordination of "non-bottleneck" resources to bottleneck ones, and through the increase of their capacity. So, the application of the Theory of Constraints in healthcare services requires the detection and the optimization of bottleneck resources, while the management of other resources should be directed not to their optimization, but simply to the synchronization with the bottleneck ones (Young *et al.*, 2004). General Managers could obtain such a result through the support of some models that analyze a system with multiple resources characterized by several flows and dependencies among them, in which one or more resources could become bottleneck, in accordance with their available capacity. In particular, in health care literature there are several Operations Research models that deal with similar contexts; for example, Pham and Klinkert (2008) propose a generalized job shop scheduling model that they tested with a limited capacity of operating rooms, beds and staff, while Augusto *et al.* (2010) present a four-stage hybrid flow-shop with a limited capacity of operating rooms, beds and transporters. These models are limited by the growth of the computational effort in accordance with the increase of the number of variables under analysis. Alternatively, other authors have proposed the use of models based on System Dynamics (Brailsford *et al.*, 2009), or on simulation (Ahmed & Alkhamis, 2009).

Through the application of these models, General Managers have the possibility to maximize some performance indicators, such as the utilization rate of one or more resources (Fei *et al.*, 2008), the service throughput (Testi *et al.*, 2007) – that is the services discharge rate, equal to the number of patients that received a health service – , the length of stay (Testi & Tanfani, 2008) – that is equal to the number of days spent by the patient in the hospital – or the service waiting time (Bowers, 2011) – that is equal to the number of days from the service request made by a patient to its fulfillment. The former three indicators are principally related to the level of efficiency of the Heath System unit, because they measure, respectively, the ability to utilize the available resources in the provision of the health services, the ability to produce a level of output from the available resources, and the ability to provide the health services with a limited waste of resources. Some of these indicators could be interpreted also as a measure of the quality of the services; in particular, the services discharge rate could be considered also an indicator of effectiveness, because it measures the ability to provide the health services required by the patients, while the length of stay could be interpreted also as an indicator of responsiveness, because it measures the ability to provide a health service aligned to the patient legitimate expectations on the time of service. Finally, the latter indicator could be considered as an indicator of accessibility, because it measures the availability of the health services requested by a patient and provided in adequate time.

In general, all the models based on quantitative methodologies, such as Operations Research, System Dynamics, and simulation, could help to improve the performance of a Health System unit, but they are not able to completely analyze and tackle all the questions faced by a General Manager. For example, these models deal with the safety problems only by managing the treatment delays experienced by patients, through the maintaining of a continuous flow of the work-in-process among the resources involved in the service provision. These delays could negatively impact on the service safety, even if the main causes of the post-operative and procedural complications are related to clinical practices (Christian *et al.*, 2006). So, these models, rather than tackle the factors that affect the probability of negative outcomes, focus their attention on the potential impact of these events, especially in terms of efficiency, because of the need for further services provision for the same patient, with an increase of the length of stay and a waste of the related resources.

Another important question for the General Managers, which is only partially tackled by the models based on such quantitative methodologies, is the human resource management. The relevance of this question is due to the fact that daily provision of the health services, as well the attainment of the final goals of a Health System, is strictly related to the contribution made by human resources. Each Health System unit is based on the interrelation among physicians', nurses', and administrators' activities, who all together contribute to the correct services provision, even if they are characterized by distinct, and sometimes contrasting, objectives, levels of autonomy and professional culture (Glouberman & Mintzberg, 2001). Besides, in the last years, the role of these professionals is radically changing, with a growing responsibility assigned to nurses, who move towards a supplementary physician role (Mintzberg, 2002), and with a progressive shift of the strategic management from a model based uniquely on physicians to a model based on the share of responsibility between administrators and physicians (Scott, 1993). So, human resource management in Health Systems now requires a strong effort in redesign the role of the different professionals involved in the service provision, aiming to increase the value guaranteed to patients and to the population, also thanks to a greater integration, collaboration and sharing among these professionals (Lega & De Pietro, 2005).

The pursuit of all the final goals of the Health System, together with the implementation of an adequate system of human resource management, represents a difficult challenge for the General

Managers, also because there are very few methodologies that try to deal with all these problems in a holistic way. Among them, Lean thinking is now obtaining a growing success in this context (Mazzocato *et al.*, 2010). This methodology was born in Toyota in the 1950s, has been systematized by Womack and Jones (1996), and has been introduced in Health Systems, starting from UK and USA, in the first years of the third millennium (Radnor *et al.*, 2012). This methodology is based on the admission that not all the activities provided by an organization add a real value for the customer. Starting from this assumption, Lean thinking suggests to map all the processes involved in the services provision and to re-engineer them, reducing to the minimum the level of wastes, which could be classified into “muda”, “muri” and “mura”. The former encompasses all the wastes that could affect the integration among the different resources and activities that made up each process, such as transportation, inventory, motion, waiting, overproduction, over-processing, defects. “Muda” have been adapted to health care context by NHS Institute for Innovation and Improvement (2007), while the other two concepts, “muri” – that is the waste of resources due to the tendency to overload them in the short term, with an increase of injuries and dissatisfaction in the long term – and “mura” – that is the irregular fluctuation of the demand which causes the process variation and also the emergence of “muda” – obtain only a limited application in health care (Radnor *et al.*, 2012). The detection of these wastes should be obtained through the development of the value stream map of each family of services provided, characterized by an adequate number of common activities. After that, the processes could be re-engineered by guaranteeing a continuous flow of the work-in-process, by adopting a pull logic among each activity and its downstream ones, and by improving the processes through a constant effort toward wastes elimination. This focus on wastes is one of the main difference between Lean Thinking and Theory of Constraints, which principally aims, on the other hand, to the maximization of the throughput, and, partially, explains the diffusion of this methodology in health care contexts. In the same way, the potential combination of Lean Thinking and evidence-based medicine – that aims to apply the best available evidence gained from the scientific method to clinical decision making (Timmermans & Mauck, 2005) – gives the possibility to increase the safety of health services and, contextually, to standardize the necessary processes and activities (Bentley *et al.*, 2008). This last objective represents one of the most important condition for a complete application of Lean Thinking, even if in health services it could be only partially attained because of their intrinsic variability (McDonald *et al.*, 2006). Another critical point for the implementation of Lean Thinking is due to the fact that a Health System unit provides different services, which could not be easily grouped in families characterized by an adequate number of common activities. This fact requires the integration of several value stream maps and the definition of an active collaboration among the Departments that utilize the same resources for the provision of their services. Hence, the implementation of Lean Thinking have to face and solve the separation among the professionals involved in the services provision and the scarce propensity of resource sharing among the Departments that, as described above, already characterize the Health System units. Nevertheless, Lean Thinking has been successfully applied in many cases, with an increase of accessibility – thanks to the reduction in waiting times – of service quality – thanks to the reduction of errors and the improvement of customer satisfaction – of efficiency – thanks to the reduction in costs – and also of the employee motivation (Radnor & Boaden, 2008). By now, the main limit of these Lean Thinking implementations in Health Systems is due to the fact that they appear disjointed among them, like the results of small projects that aim to develop ‘pockets of best practices’, rather than the application of a system-wide approach (Brandao de Souza, 2009). This situation points in evidence that the General Managers, who apply Lean Thinking for the re-engineering of some services, have difficulties to integrate these programs with a strategy for the global improvement of their assigned Health System unit (Radnor *et al.*, 2012). This failed strategic alignment may be due to the lack of a clear view of the Health System unit, which could be understood by taking into consideration that the accounting and the information systems are not ever adequate (Carter, 2002). In other cases, the decision to limit Lean Thinking programs to some processes is caused by the costs and the obstacles that, in accordance with the General Managers’ view, could prevent their diffusion to the whole system. Otherwise, only the application of Lean Thinking at organizational, and also at inter-organizational level, could guarantee the full realization of its benefits (Hines *et al.*, 2004). This fact makes more urgent the adoption of specific methods that could develop a successful route for the attainment of the final goals of Health System unit, through an effective prioritization of the optimization programs related to the processes and the resources involved in the provision of the several health services.

3. Two methods for supporting prioritization: Analytic Hierarchy Process and Analytic Network Process

The Analytic Hierarchy/Network Process (AHP/ANP) is a decision making methodology developed by Thomas L. Saaty, which is useful in addressing complex problems under bounded rationality conditions.

The main idea onto which the methodology is based is the consideration that solving a complex problem is a task which is far too hard if we consider the problem as a whole. Instead, we should consider the problem as a system, so made up by several parts, which interacts in various and complex ways to determine an outcome. If we adopt this point of view, we can address our attention on the analysis of each part of the system, which will be, obviously, less complex in its functioning mechanisms than the whole. Therefore, by decomposing the problem in smaller and smaller sub-systems – easier to analyse – we will be able to understand which are the key variables of our decision making process. Nevertheless, in doing so, it is of paramount importance not to lose information on the relations among the various parts in which we are decomposing our system.

The AHP/ANP methodology allows to decompose the whole system in several components without losing information on the relations which occurs among them. The difference between the two specifications of this methodology is the way in which we can decompose the problem.

To this end, the AHP uses a breakdown structure, in which the source node represents the problem as a whole and, therefore, the object of the decision making process. At the lower level the analyst can define various decision making criteria, which will impact on the choice among alternative solutions. The identified criteria – which can be quantitative as well as qualitative and can also conflict with each other – represent as many facets of the main problem, and can therefore be considered as second-order-objectives. It is also possible to decline each criterion into other sub-criteria in a more detailed way. However, it is worth noting that when we split a criterion in a certain number of sub-criteria we are building a cluster in which all the elements – the sub-criteria, precisely – are homogeneous among them, being different specifications of the same facet of the problem.

In breaking down the structure of the system, the functional relations among its components are represented by arrows, which link each node in the hierarchy with its sub-criteria. The aim of breaking down the structure of the problem is to determine which is the contribution of the elements in the lower level of the hierarchy to the satisfaction of the general objective of the decision making process. The hierarchy can therefore be considered as a distribution of priorities among criteria and sub-criteria relating to the goal we want to reach. Given a 100% priority to the goal of our decision, this priority will split on the node beneath the goal basing on the relevance that the decision maker assigns to them in achieving the goal itself. The priority of each criterion will then divide on its sub-criteria until the bottom of the hierarchy has been reached. In this way, the analyst can define a priority for each decision making element at the bottom of the breakdown structure: this priority represents the contribution of that element in achieving the main goal of the decision making process.

Once the hierarchy has been determined we can link all the alternative solutions for the problem to all the elements in its lowest level: indeed, each alternative has to be analysed according to every specific decision making element, in order to determine how well it performs with respect to that element. The choice of which alternative to implement will be a best compromise between the performance of the alternative with respect to each decisional element and the importance of that element in achieving the general goal of the decision.

In many cases, the hierarchy does not describe well decision maker’s opinions about the way in which priorities spreads among elements. Indeed, the hierarchy is based on the assumption that the priority of the goal falls down on the criteria and sub-criteria, following the links, which represent a functional dependence. Therefore, this structure does not allow for dependence among elements belonging to the same level of the hierarchy, nor for feedback cycles from lower levels towards upper criteria. In other words, a criterion belonging to a specific group cannot affect other elements in the same level of the hierarchy, nor can be affected by them; moreover, it cannot spread its priority towards elements belonging to upper levels in the hierarchy.

When these assumptions do not describe accurately the structure of the problem we have at hand, it is possible to fall back upon the ANP. Indeed, this specification of the methodology represents the problem by decomposing it in a network of influences, rather than in a hierarchy. Decision making elements are divided in clusters according to their homogeneity (as well as in AHP), but we can hypothesize a spreading of priorities in which inner dependences and feedback cycles are also allowed. From this point of view, the ANP represents a more general methodology than AHP.
Figure 3 shows an example of ANP network of dependences.

[INSERT HERE FIGURE 3]

In this Figure decision making elements are divided in five clusters according to their homogeneity in representing various features of the problem. If we consider clusters C_i and C_j the following considerations hold:

- There is an arrow from C_i to C_j if at least one element in C_i spreads its priority over at least one element in C_j;
- There is an arrow from C_i to C_i (loop) if at least one element in C_i influences at least one other element in C_i;
- One cluster is made up by the alternative solutions to the problem we have to solve: indeed, once we know which the alternatives are, we could be willing to revise the importance we assign to the decision making elements.

3.1 Pairwise comparisons

Once the breakdown structure (or network) of the problem has been built it is necessary to determine the priority that each decision making element will assume in determining the choice for solving the problem. To this end, we must be able to assign to each arrow in the structure a value (or weight) which quantifies this priority. There are two possible levels of priorities:

- the one that the element assumes within its own group, which is called local priority;
- the one that the element assumes with respect to the structure of the problem as a whole, which is called global priority.

Therefore, the decision maker has to express his opinions on the importance that the different elements in the structure will assume for the goal. Generally, people are able to rate the importance of different objects if they can use a measure of some quantitative variables. Indeed, in this case it will be sufficient to have some measuring device and a reference scale. Then, it is possible to rank the various objects according to the value assumed by the variable.
When we are dealing with elements which are not objectively measurable, it could seem that we will not be able to assign a rank position. But if we assign a relative evaluation to the objects we are dealing with instead of an absolute one, we can still come to a rank. Indeed, if we say that the first object is three times worth the second one, the comparison will be independent of the measuring device, as well as from the reference scale: this is true both if we have at our disposal a quantitative absolute measure or not.
Therefore, this procedure can be applied also to the determination of priorities of decision making elements: the problem of assigning levels of importance to decision making criteria will be solved by the expression of their pairwise comparisons. The conditions we have to respect in making pairwise comparisons are the following:

- first of all, the elements that we are comparing have to be homogeneous. Considering the AHP/ANP, this means that we can only compare elements belonging to the same cluster, therefore having a dependence from the same source node, which is the control criterion upon which the pairwise comparisons are made;
- the characteristic according to which we are comparing two elements has to assume values in the same order of magnitude for the two objects. If it is not the case, we could make an error in judging their relative importance which could be too large to make a good decision;
- the elements we compare must not be too much. Indeed, when we have at our disposal a measuring device, staring from the absolute values of the characteristic we are considering we

are able to determine whichever number of pairwise comparisons we want, simply applying the transitivity property. But when we are directly expressing a pairwise comparison the transitivity is no longer assured. As an example, we could state that the first object is three times worth the second, and the second two times worth the third, but then state that the first object is only five times worth the third. The error we introduce is called inconsistency and it is as much higher and probable as the number of pairwise comparisons we have to make increases. Therefore, to limit this number we have to limit the number of elements we have to compare. The hint is to put less than 7-9 elements in each cluster.

The decision maker can express its judgments both in natural language and using a 9 points scale. Saaty has defined a semantic scale which allows to turn natural language judgments into values.

[INSERT HERE TABLE 1]

When dealing with the AHP, pairwise comparisons are summed up in the pairwise comparison matrix A. In this matrix the generic element a_{ij} represents the relative importance that the decision maker assigns to the criterion i over the criterion j. A is therefore a squared matrix with a number n of rows and columns corresponding to the number of elements which are in the same cluster.

This matrix represents the network of influences between elements belonging to the same cluster: therefore, an element will be as much important for the decision making process as its impact on the other elements increases, not only on direct arcs, but also considering indirect influences over all the possible paths in the network.

It can be proved that the pairwise comparison matrix has a principal eigenvalue, whose eigenvector can be used to represent local priorities for decisional elements within a cluster.

In the AHP global priorities of all decisional elements with respect to the goal can then be obtained simply by combining local priorities in a top-down approach.

In ANP, instead, local priorities of decisional elements in the cluster C_i over decisional elements in the cluster C_j are summed up in a so-called supermatrix W.

The supermatrix has as many rows and columns as the number of decisional elements in the ANP network. Decisional elements shown in this matrix are subdivided by components. Therefore, it is possible to find blocks in the supermatrix, which corresponds to the intersection between cluster C_i and cluster C_j. If there isn't any priority between elements in C_i and elements in C_j the corresponding block of rows and columns in W will be identically null; otherwise, in the block between the two components we will find the local priorities of the elements in C_i over the elements in C_j, determined by the pairwise comparisons of the AHP methodology.

Figure 4 represents a supermatrix W.

[INSERT HERE FIGURE 4]

The supermatrix W represents the priorities among all the decisional elements, divided in components. Nonetheless, it can happen that different components have to assume different importance in reaching the goal of the decision: therefore, the priority of an element in C_i over an element in C_j must be weighted by considering the priority of C_i over C_j. This latter priority can be determined by a control hierarchy, in which all the components in the ANP network are compared making use of the AHP.

The combination of the priorities in the supermatrix W with the priorities among clusters gives a stochastic supermatrix W_S, in which the generic element w_{lk} represents the impact of the element e_l in C_i over the element e_k in C_j, already weighted on the impact of the component C_i over C_j.

Also in this case, the matrix W_S can be thought of as an adjacency matrix of a graph, in which arcs represent the priority network and their values the impact between two elements. Again, an element will be as much important for the decision making process as it impacts on a higher number of decisional elements and as its impact on other elements increases, not only on direct arcs, but also considering indirect influences over all the possible paths in the graph.

Therefore, the limiting impact priorities (LIP) of decisional elements can be found through the determination of W_S^k, with $k \rightarrow +\infty$: this priorities are defined between couple of elements in the network.

On the other hand it is possible to determine a synthetic index for the priority of an element over the whole network: this index is the limiting absolute priority (LAP) of the element and it can be proved that it is represented by the principal eigenvector of W_S^k.
Nonetheless, LIP and LAP depends on the characteristics of primitivity and reducibility of W_S: if W_S is imprimitive and irreducible then LIP does not exist.

4. An ANP/AHP model for the prioritization of the critical processes' and resources' optimization: An application to the surgical patient flow

The development and the diffusion of optimization programs, specifically those based on Lean Thinking, requires a great attention in the detection and the prioritization of the processes and the resources that could be chosen as the object of these programs. An incorrect choice may induce to launch optimization projects which are not very relevant, in term of their impact on the attainment of the final goals of a Health System, very costly and difficultly successful (Rother & Shook, 1998). Besides, a prioritization that does not adequately consider these factors may influence the diffusion of Lean Thinking to the whole Health System unit. In fact, a General Manager may begin the Lean Thinking adoption choosing very feasible programs and implementing them successfully, but their scarce relevance could convince human resources of the uselessness, or of the impossibility, to widen them to more relevant and difficult program. Otherwise, a General Manager may begin choosing very relevant programs, but an unsuccessful implementation could cause the premature stop of the Lean Thinking adoption.
As described in the second paragraph, the detection and the prioritization of the processes and the resources that need to be optimized is already an open problem, especially in organizations, like the Health System units, that are characterized by multiple, and sometimes contrasting, final goals. In fact, in these organizations a prioritization based only on financial criteria, such as the Net Present Value or the Incremental Rate of Return, may induce to overlook an optimization program that could produce relevant results, in term of the attainment of non-financial goals, such as accessibility, or service quality.
In order to support the General Managers in the prioritization of the optimization programs, we develop a Decision Support System (DSS) which makes possible to evaluate the choice of the processes and the resources to optimize, at the light of their impact of all the final goals of a Health System. Our DSS is based on the combination of a ANP and several AHP models:

- the ANP model makes a prioritization of the programs of process optimization, basing on their feasibility and on their impact of all the final goals of a Health System;
- the AHP models prioritize the optimization programs of the resources involved in each process, basing on their feasibility and on their relevance in the process.

Thanks to the use of ANP and AHP, our DSS could be used also in organizations, like the majority of the Italian Health Systems units, characterized by the lack of adequate systems of Business Intelligence. In these cases, the data necessary to the DSS could be obtained, rather than through objective analyses based on the measurement of process and resource indicators, through interviews to the General Managers. Thus, the application of our DSS gives the possibility:

- to understand the General Managers' perception on the optimization programs that could be implemented in their assigned Health System unit;
- to support the General Managers in the prioritization of the optimization programs, highlighting which factors most influence their choices and, eventually, re-addressing them so to guarantee a better alignment with the final goals of the Health System unit;
- to favor an *ex-post* evaluation of the General Managers' perception, at the light of the real results obtained in the implementation of the optimization programs.

Our DSS results from the discussions with several General Managers of Health System units, principally in Tuscany, within the Ge.Ri.C.O. project, which aims to propose new management practices for the optimization of critical resources in health contexts. On the base of these discussions with the General Managers, we decide to test our DSS on one of the most important health service provided by hospitals, that is elective surgery, which differs from emergency surgery because its demand is known several days in advance. In this way, we could illustrate our DSS on a concrete service, even if it could widen to the whole Health System unit and its entire range of health services. Besides, we consider only tactical optimization programs, in which the amount of available resources is fixed and the optimization is therefore based on a better use of the actual resources. This choice is motivated by the economic and financial situation of Health System units and, moreover, is in line with Lean Thinking, which proposes, first of all, a better use of the available resources.

4.1 A general model of the surgical patient flow

We analyze surgery starting from the flow of a typical surgical elective patient, through a generalization of all the possible specific flows related to the several Surgery Specialties (Orthopedic surgery, Plastic surgery, Urology, *etc.*). The focus on patient flow is related to the essence of one of the typical Lean Thinking tools, that is value stream map, and makes possible to analyze the surgery service through to point of view of its principal customer. Starting from a model of surgical patient flow developed by the Local Health Unit of Empoli, we consider a general model of the surgical patient flow that is composed of four processes (Figure 5):

[INSERT HERE FIGURE 5]

1. **pre-hospitalization**, that consists in all the activities from the inclusion of the patient in the operating room schedule until the day before the operation. All the activities that compose this process, and the resources involved, have been detailed in Figure 6:
    a. Operating room scheduling: given the Master Surgical Schedule and the waiting list, a surgeon chooses the patient to operate in the next days.
    b. Phone call to the patient: a nurse, or a secretary, calls to the patient so to inform him about the surgeon decision and verify his willingness.
    c. Reception and assistance: a nurse welcomes the patient in the hospital and assigns him a bed in a ward.
    d. Preliminary anesthesiology examination: an anesthetist checks for eventual problems (*e.g.* allergies) related to anesthesia.
    e. Specialist examinations and further diagnostic confirmations: the surgeon visits the patients and requests some specialist examinations, so to check his suitability to be operated. These specialists examinations often have been provided in ambulatories, separated from the ward, equipped with specific equipment.
    f. Consensus statement: the patient gives several consensuses. Among them, a nurse asks for the consensuses for privacy and blood transfusion, an anesthetist asks for the consensus for the anesthesia risks, while a surgeon asks for the consensus for the operation.
    g. Pre-hospitalization treatments: a surgeon requests to a nurse some preliminary treatments necessary for the operation, such as diet, shaving, enema, *etc*.
    h. Check of pre-hospitalization documents: a surgeon checks the documents related to the examinations provided during the pre-hospitalization.

[INSERT HERE FIGURE 6]

2. **pre-operation**, that consists in all the activities from the end of the pre-hospitalization to the beginning of the operation. All the activities that compose this process, and the resources involved, have been detailed in Figure 7:
    a. Validation of the patient inclusion in the operating room scheduling: a surgeon, with the support of a nurse, prepares the daily schedule of the operating room, eventually inserting the patient, in accordance with the results described in the pre-hospitalization documents.
    b. Check of pre-hospitalization treatments and insertion of medical devices: an anesthetist checks the results of the pre-hospitalization treatments and administers an anesthetic premedication, while an operating nurse inserts some medical devices (*e.g.* a catheter).

c. Marking of the surgical site: a surgeon marks the surgical site on the patient body.
d. Transport to operating room: the patient is transported from the ward bed to the operating room.
e. Check of patient identity and of consensus: a surgeon checks the patient identity and, together with an anesthetist, checks the consensus statements.
f. Pre-induction assessment: an anesthetist checks the effects of the anesthetic premedication on the patient.
g. Placement of surgical devices: an operating nurse places the surgical devices necessary for the operation.

[INSERT HERE FIGURE 7]

3. **operation**, that consists in all the activities specifically related to the surgery intervention. All the activities that compose this process, and the resources involved, have been detailed in Figure 8:
    a. Patient placement: a surgeon requests to a nurse the most effective patient placement for the intervention.
    b. Time out: a final check, before the beginning of the surgery intervention, of the patient identity and of the necessary surgical procedure. This check involves all the members of the surgical team, which is usually composed of one, two or three surgeons, one or two anesthetists, and two operating nurses.
    c. Surgery: the surgical intervention leaded by a surgeon in collaboration with his surgical team.
    d. Count of surgical items: at the end of the surgical intervention, an operating nurse counts the surgical items so to check that nothing has been forgotten in the patient body.
    e. Intraoperative monitoring: an anesthetist checks the patient heartbeat, his blood pressure and his breathing.
    f. Transport to recovery room: after the surgical intervention, an operating nurse transports the patient from the operating room to the recovery room.

[INSERT HERE FIGURE 8]

4. **post-operation**, that consists in all the activities from the end of the operation to the hospital discharge. All the activities that compose this process, and the resources involved, have been detailed in Figure 9:
    a. Post-surgery monitoring, medical prescriptions and discharge from recovery room: an operating nurse monitors the post-surgery situation of the patient, while an anesthetist decides the necessary medical prescriptions and evaluates for his discharging from recovery room to the most convenient ward, choosing between the Post-Anesthesia Care Unit (PACU) and the Intensive Care Unit (ICU).
    b. Transport to ward: the patient is transported from the recovery room to the assigned ward.
    c. Patient placement and post-operative monitoring: a nurse places the patient in the ward and assists him, while the surgeon monitors his post-operative conditions.
    d. Decision about reoperation: if necessary, a surgeon decides to proceed with a reoperation.
    e. Patient re-education: a surgeon prescribes the re-education treatments necessary for the patient, which has been carried out in collaboration with the nurses.
    f. Hospital discharge: a surgeon evaluates the health situation of the patient and, eventually, decides for his hospital discharge, signing the discharge letter.

[INSERT HERE FIGURE 9]

This description gives a detailed picture of the activities and the resources involved in each process of the surgery service, which aims to transform a “sick” person with a need for a surgical operation to a “recovered” person that could be discharged from the hospital. In this sense, each process that compose the surgical patient flow gives a specific value to the patient:

1. pre-hospitalization transforms a “sick” person in a patient that could be operated the next day;
2. pre-operation transforms a patient that could be operated the next day in a patient that has to be operated within few hours;
3. operation transforms a patient that has to be operated within few hours in a patient that has satisfied his need for a surgical operation;
4. post-operation transforms a patient that has satisfied his need for a surgical operation to a “recovered” person that could be discharged from the hospital.

4.2 The structure of our DSS

In accordance to the role of each process, it’s possible to develop specific optimization programs that could influence the optimization of other processes. In particular, because the four processes are in series, the optimization of a process could directly influence also the downstream one. In fact, in accordance with Lean Thinking approach, a process could provide an inadequate demand level for their downstream, in term of too high, too low, or too variable demand. This question has to be considered in the prioritization of the process optimization programs, which represent the **Alternatives** of our ANP model, which is developed as a simple network, without any subnetwork (Figure 10).

[INSERT HERE FIGURE 10]

Nevertheless, the principal critical factors for the prioritization problem remain their feasibility and their impact on all the final goals of a Health System.
In our DSS, we have operationalized the **Feasibility** as the combination of the subsequent nodes:

1. **Economy**, that represents the level of costs produced by the optimization program. In particular, each optimization program requires an analysis of the actual situation of the process (“AS IS”), the design of a more performing configuration of the process (“TO BE”), and the management of the transition from the actual to the desired situation. All these activities could increase the costs of the optimization program, lowering its economy. The analysis of the actual situation of the process requires data, which could not be present in the available information systems and have to be collected *ad hoc*, and, above all, specific skills (*e.g.* process mapping), which could be not sufficiently available among the hospital human resources and to be developed through specific managerial courses. Similar skills are necessary also for the design of a more performing configuration of the process and for the management of the transition from the actual to the desired situation. Besides, these activities require the development of new procedures and managerial systems, which could be used in the transition stages and in the final configuration of the process.
2. **Success probability**, that represents the success probability of the optimization program. In particular, the success of each optimization program could be influenced, first of all, by the level of the commitment guaranteed by the General Manager. Eventually, also the Region could fund specific optimization programs, as the “Net-VisualDEA” project promoted by the Tuscany Region in order to favor the reduction of the waiting time in the Emergency rooms. Another important factor for success probability is the resistant to change that could characterized the human resources involved in the optimization programs. This tendency strongly affects some professionals, as the physician, who traditionally detain much power in hospitals and are less inclined to modify their procedures. Otherwise, the presence of analogous optimization programs that have had success in similar contexts represents a fundamental factor that could favor the vanishing of the resistance to change.

The Feasibility cluster is linked to the Alternatives cluster through a double arrow, that points in evidence that each optimization program is characterized by specific level of Economy and Success probability, but also that these two nodes weight in different way, in accordance with the optimization program under analysis.

The impact of the process optimization programs has been operationalized through the construction of three clusters that contain all the final goals of a Health System, whose attainment is, at least partially, under the responsibility of a General Manager. So, we consider a cluster related to **Accessibility**, another one related to **Efficiency**, and a last one related to **Quality**. This latter is composed by three nodes, **Safety**, **Effectiveness**, and **Responsiveness**, which represent the final goals related to health service quality. The impact of the process optimization programs on some of these final goals have been clarified through the use of some indicators, chosen among those proposed by the OECD (2011), which have been related to one or more final goals. In particular, we consider the subsequent four indicators:

1. **Procedural or post-operative complications**, which measures the number of complications registered in the surgical patient flows. This is considered a node of the cluster Efficiency because of its impact on the extraordinary use of hospital resources;
2. **Average length of stay in hospital**, which measures the number of days, on average, spent by the patient in the hospital. This is considered a node of the cluster Efficiency because the use of several hospital resources (*e.g.* nurses and ward bed) is strictly correlated with this indicator;
3. **Hospital discharge rates**, which measures the number of patients who leave the hospital after receiving care. This is considered a node of the cluster Efficiency because it measures the capacity of the Health System to produce a level of output, given the available resources;
4. **Waiting times**, which measures the number of days from the service request made by a patient to its fulfillment. This is considered a node of the cluster Accessibility because it measures the capacity to provide the health service in adequate time.

All the clusters Accessibility, Efficiency and Quality are linked to the Alternatives cluster through a double arrow, that points in evidence that each optimization program could impact, at different level, to the attainment of these final goals, but also that these final goals could be a lever for the adoption of these optimization programs. Besides, also the clusters Accessibility, Efficiency and Quality are linked among themselves, because some of their nodes are directly related. In particular:

- Procedural or post-operative complications is linked with a double arrow with Safety, because the former could be also considered an indicator of safety of the health service;
- Hospital discharge rates is linked with a double arrow with Effectiveness, because the former could be also considered an indicator of effectiveness of the health service;
- Average length of stay in hospital is linked with a double arrow with Responsiveness, because the former could be also considered an indicator of responsiveness of the health service;
- Waiting times, which is a measure of the queue of health service demand, is linked with an arrow to Hospital discharge rates, which is a measure of the health service throughput. In fact, the management of Waiting times could be a lever for the increase of the Hospital discharge rates;
- Safety is linked with an arrow to Average length of stay in hospital, because the increase of the safety of the service could be obtained also through the reduction of the average length of stay in hospital;
- Effectiveness is linked with an arrow to Safety, because the level of effectiveness of the health service results, among other factors, by the level of safety;
- Responsiveness is linked with an arrow to Safety and with another arrow to Effectiveness, because both these factors affect the level of responsiveness perceived by the patient;
- Hospital discharge rates is linked with an arrow to Average length of stay in hospital, because this latter, which is a measure of the average health service time, influences also the level of the former, which is a measure of the health service throughput.

The ANP model makes a prioritization of the programs of process optimization, but it does not prioritize the optimization programs of the resources involved in each process. At this aim, we develop an AHP model for each of the four processes.

We describe the AHP methodology only for a process. The other three processes involved in our DSS model have been treated in an analogous way.

Figure 11 shows the AHP breakdown structure for the process “pre-hospitalization”.

[INSERT HERE FIGURE 11]

The goal is to rank the resources involved in this process according to their relevance in its optimization. In particular, the prioritization of resources is evaluated taking into account three criteria. The first one is the economy (E) of a resource: from this point of view we are investigating which resource allows to optimize the process in a less expensive way. The second criterion is "success probability" (SP), i.e. the probability of succeeding in optimizing the process addressing the specific resource under investigation. Finally, the higher the "relevance" (R) of the resource in the process the higher its importance in the process under optimization.
These criteria have been used to prioritize of resources in each of the four processes: therefore, the breakdown structure of the AHP is the same for each process, with an exception for the level of resources: indeed, at the bottom of each structure we have linked only the resources involved in the specific process, which can obviously be different moving from a process to another. Table 2 shows the list of resources involved in each process, and, therefore, the sink nodes of each hierarchy.

[INSERT HERE TABLE 2]

According to the AHP methodology, the managers have expressed their judgments on a 9 point scale and on two sets of elements: the first one is the set of criteria, while the second one is that of the alternatives, which, in our case, are the resources involved in the process.
Starting from the pairwise comparison matrices the AHP allows to determine the local and global priorities of criteria and alternatives (the resources involved in the different processes). Also in this case, we will show the matrices only for the pre-hospitalization process and then we will only show the results we came to for the other three processes.

4.3 Results of our simulation

Thanks to the collaboration of General Managers of several General Managers of Health System units, principally in Tuscany, we have the possibility to make realistic comparison among the different nodes and clusters of our ANP model.
The matrix related to the priorities among clusters is presented in Table 3 and shows, for each column, the impact of all the clusters. Not surprisingly, Efficiency cluster has the greatest impact on the other clusters, because General Managers are now under a pressure for reducing the deficit of their assigned Health System units. After the Alternatives cluster, whose effect on the final goals of the Health System is at the base of our model, a great importance has been recognized to the Feasibility cluster. This fact could be explained by taking into consideration that, by now, few optimization programs have just been implemented in the Italian Health System units, and the General Managers appear to be cautious about the beginning of more difficult programs. Quality and Accessibility clusters have a smaller impact on the other clusters: the former because of the general perception of the high quality provided by the Italian Health System, the latter because, even if it's considered a very important problem by the public opinion, it is often managed through not systematic solutions. For example, in some hospital the problems of excessive waiting times, due to a peak of patients that ask for being operated by a well-defined surgeon, are resolved asking for overtime to this surgeon.

[INSERT HERE TABLE 3]

The supermatrix (Table 4) shows the results of the nodes pairwise comparisons, while the stochastic supermatrix (Table 5) is obtained through the integration of the nodes and the clusters pairwise comparison.

[INSERT HERE TABLE 4]
[INSERT HERE TABLE 5]

In accordance with the mechanisms discussed in the third paragraph, using the Super Decisions software, we obtain the limiting impact priorities (Table 6) which is characterized by identical columns, due to the fact that the stochastic matrix is primitive.

[INSERT HERE TABLE 6]

Finally, we obtain the priorities related to the four process optimization programs under analysis (Table 7).

[INSERT HERE TABLE 7]

The application of our DSS shows that the most urgent process optimization program is "Operation". As shown by the analysis of the other matrixes, this result is due to the fact that the optimization of the operation has a higher direct impact on Waiting times – given that the queue of health service demand is often managed in accordance with the availability of the surgical team and of the operating room –, on Hospital discharge rates – which is strictly correlated with the throughput of this process –, on Effectiveness – because of its nexus with Hospital discharge rates –, on Procedural or post-operative complications – because the principal medical errors happen during the operation –, and on Safety – because of its nexus with Procedural or post-operative complications. Otherwise, "Operation" shows a very low level of Success probability, due to the lack of trust in the realization of an optimization program which involves too many resources and requires the strict respect of several procedures.
The scarce level of Success probability obtained by "Operation" draws up the priority obtained by "Pre-hospitalization" and "Post-operation", which have the same direct impact on Average length of stay in hospital and on the related Responsiveness. Besides, "Pre-hospitalization" has a higher level of Economy and Success probability than "Post-operation", and this fact explain its higher priority.
Finally, the low level of priority of "Pre-operation" is due to the fact that this process is very short and strictly regulated by medical procedures, so the impact of its optimization appears to be limited.
It would be interesting to analyze the variation of these priority levels, in accordance to the variation of the comparison among nodes and clusters. Unfortunately, Super Decisions does not give the possibility to make a sensitivity analysis in the case of ANP model built as simple networks. Nevertheless, we test the variation of the comparison between the Efficiency and the Feasibility clusters, so to evaluate the impact of a more cautious approach. Passing from a case where "Efficiency is equally to moderately more important than Feasibility" to a case where "Efficiency is equally as important as Feasibility" we obtain the "Pre-hospitalization" becomes the process optimization program with the highest priority. This could explain why, in several Italian Health System units, the first attempt of optimization has been implemented on this process, rather than on "Operation".
After the evaluation of our model for the prioritization of the process optimization program, we could analyze the results of simulation made on the AHP models, which prioritize the optimization programs of the resources involved in the process chosen through the ANP model.
In the case of the "Pre-hospitalization" process, the AHP matrices for criteria and resources are shown in Figure 12.

[INSERT HERE FIGURE 12]

Starting from these matrices we have applied the AHP procedure and we have found the vectors of local priorities. In this procedure we have assumed to stop the algorithm to find the principal eigenvector of each matrix when its approximation between two consecutive iterations does not improve more than a 0.1%. We have obtained a consistency ratio (CR) well below the 10% limit suggested by Saaty (2006): indeed, the maximum value for CR in this breakdown structure is 2.65%. This means that all pairwise comparisons, upon which the prioritization of resources is based, are consistent, and therefore the judgments expressed by the management can be used to rank resources.
Figure 13 shows local and global weights of the breakdown structure: obviously, for criteria local and global weights are the same, therefore we have shown only the first ones.

[INSERT HERE FIGURE 13]

As the breakdown structure represents benefit criteria, we should rank the resources according to their descending priority. Therefore, "ward bed" results in being the more strategic resource in the optimization of this process with a priority of 27.11%, followed by "surgeons" (22.96%) and by the transportation system (17.59%). Therefore, the management should address first of all these resources when trying to optimize the pre-hospitalization process.
We have applied the same methodology for the other three processes (pre-operation, operation, and post-operation), adopting the same criteria to rank the resources involved in each process (see Table 2).
Results are shown in Figures 14, 15, and 16, respectively.

[INSERT HERE FIGURE 14]

[INSERT HERE FIGURE 15]

[INSERT HERE FIGURE 16]

Looking at the results, we can note that the main resources for the pre-operation process are anesthetists, with a priority of 21.85%, followed by operation rooms (19.47%) and by the transportation system (18.59%). The operation process, instead, relies mainly on operation rooms (25.71%), surgeons (25.49%), and recovery room beds (17.70%). Finally, to optimize the post-operation process managers should address first of all surgeons (21.11%), then recovery room beds (19.68%) and thirdly the transportation system (19.19%).

Limitations and future developments

Our DSS helps the General Managers in the prioritization of the optimization programs related to the processes and the resources involved in the health services provided by their Health System units. This tool makes it possible to prioritize the optimization programs which are more feasible and could have a greater impact on the attainment of the final goals of a Health System.
In this paper, our DSS is tested starting from the discussion with several General Managers of Health System units. This approach presents one main criticality, related to the high number of comparisons that have to be realized.
In the future, we aim to validate the model, through the elaboration of quantitative data from the information systems of the Health System unit. In this way, we could understand the level of alignment between the real situation of the health services and the General Managers' perceptions.

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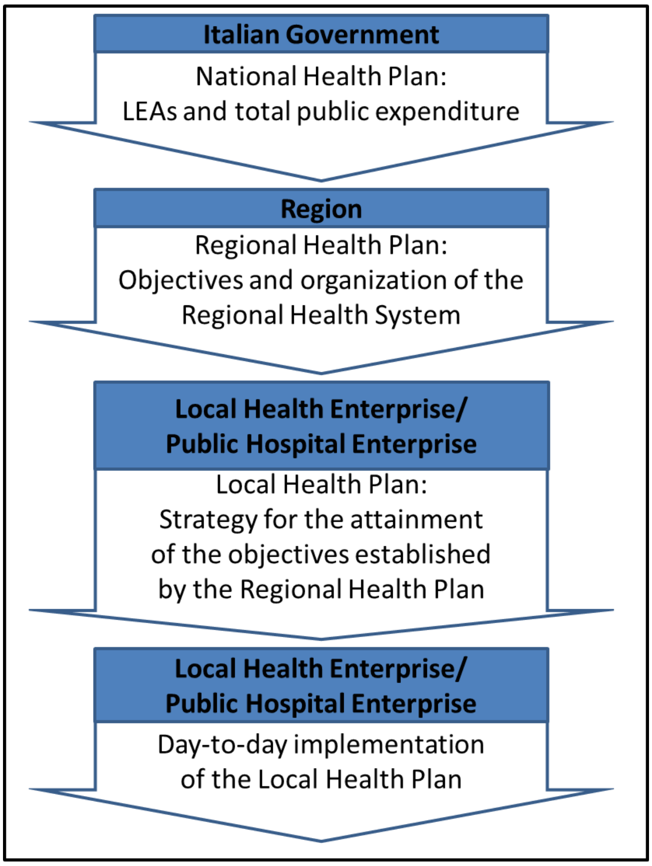

Figure 1. Tiers of decision making in the Italian Health System

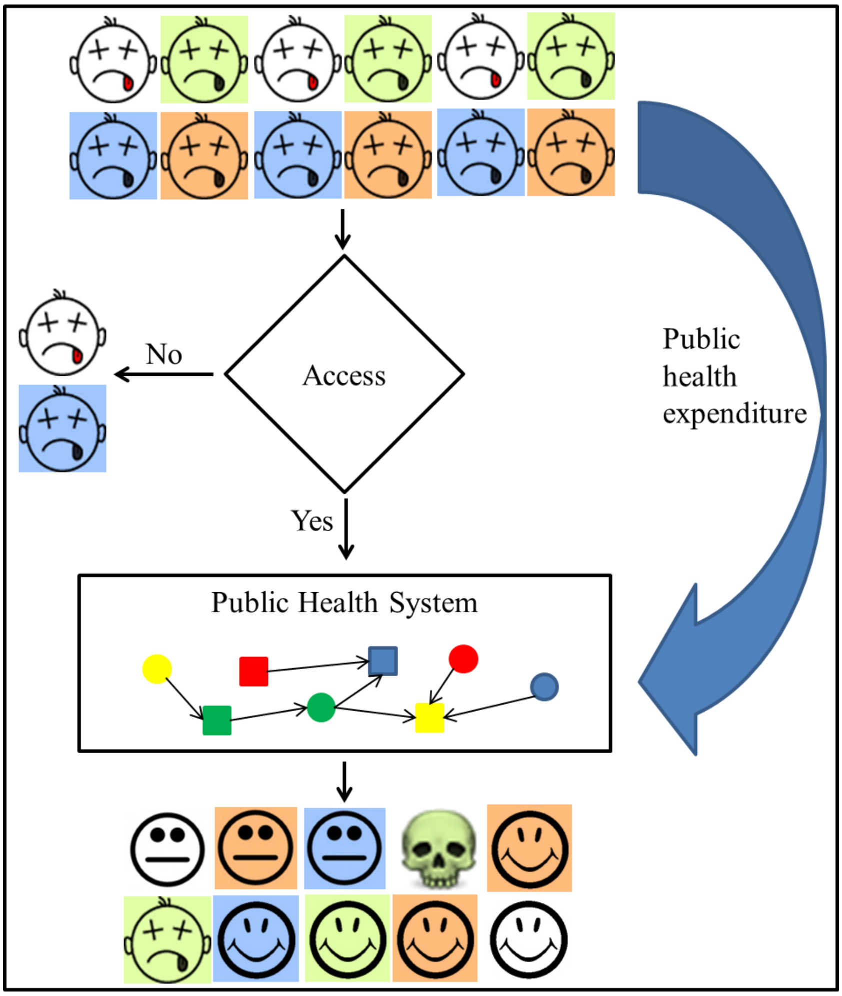

Figure 2. Consumer steps in health services fruition

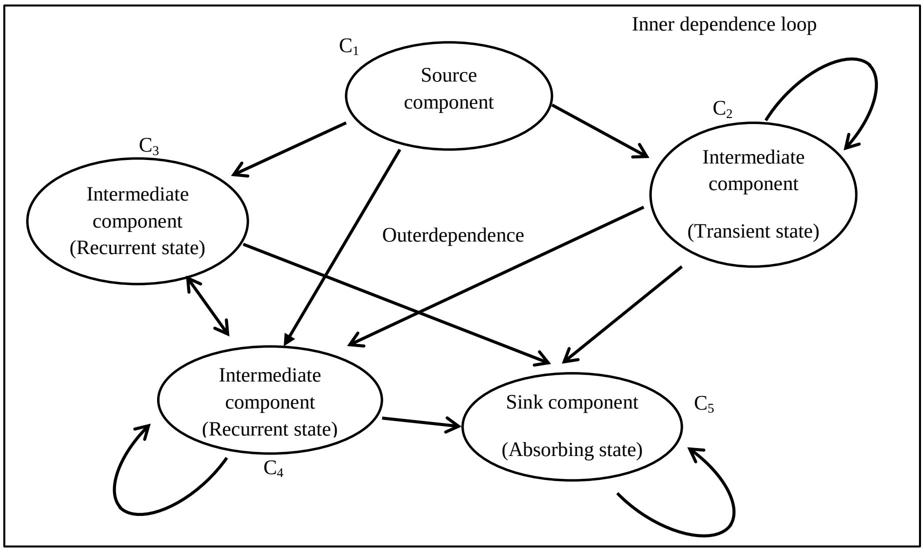

Figure 3. Example of a network of dependences. (Saaty, 2004)

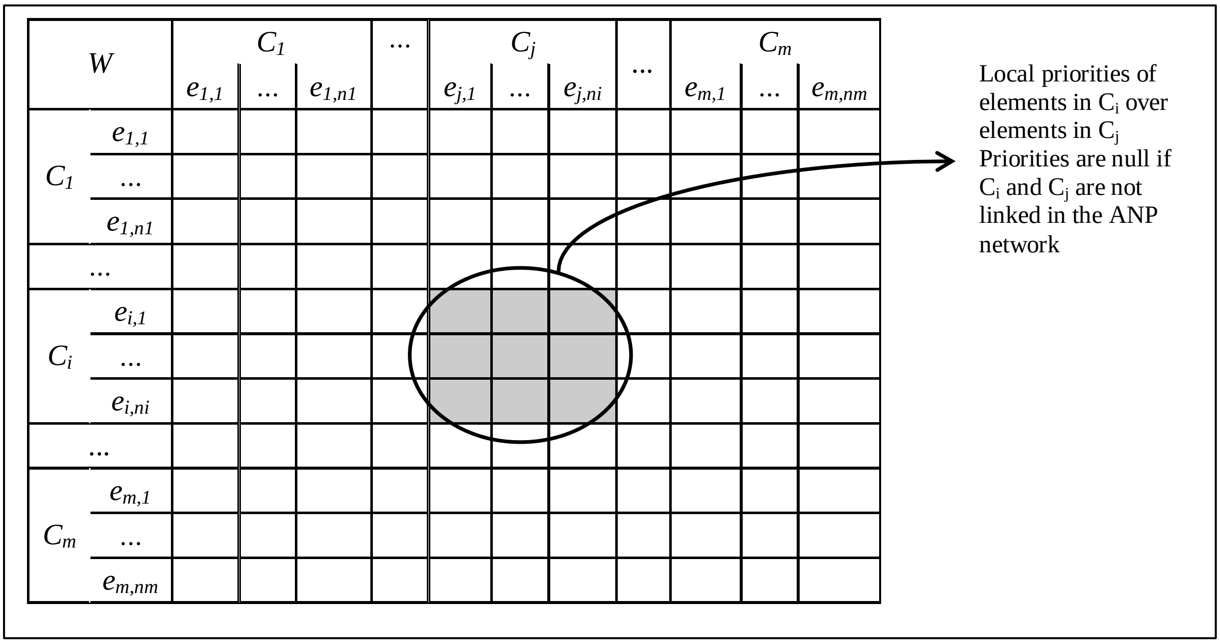

Figure 4. Example of a supermatrix W

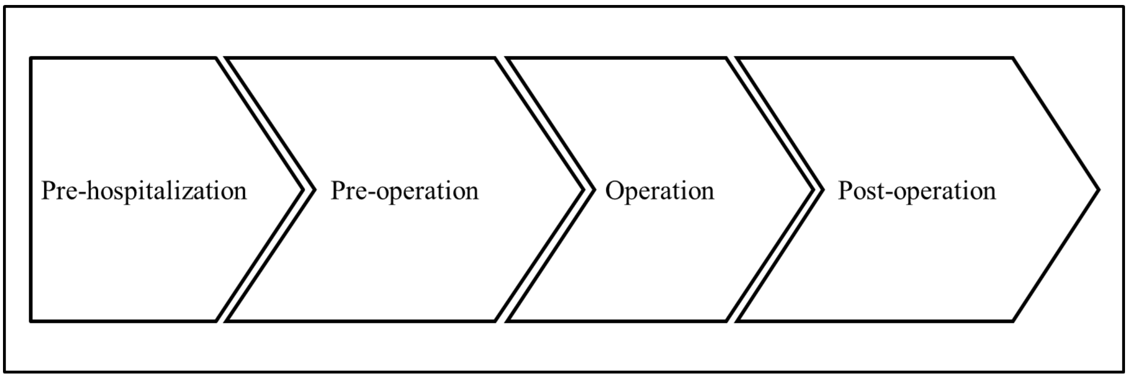

Figure 5. Main processes of the surgical patient flow

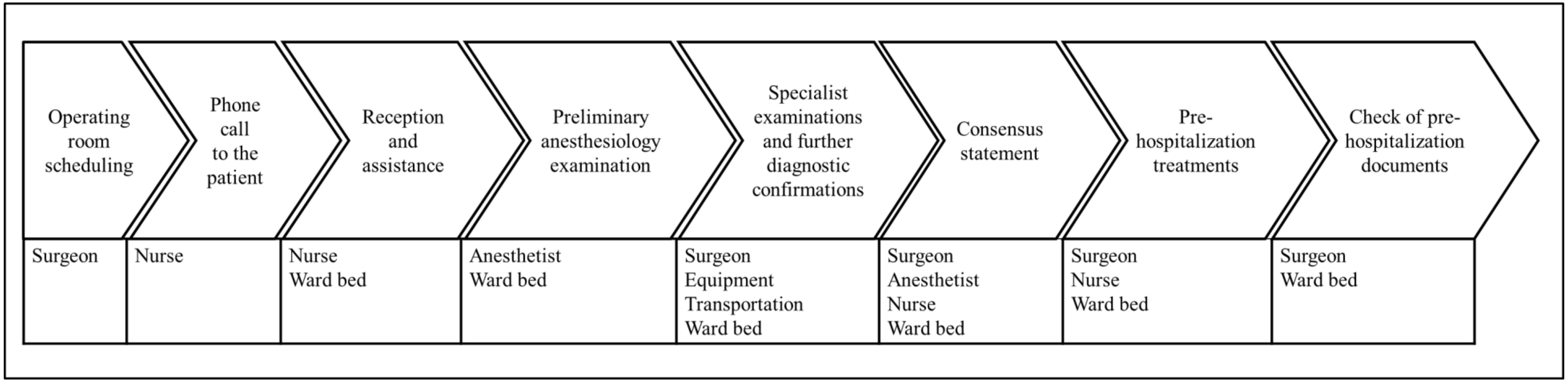

Figure 6. Pre-hospitalization activities and resources involved

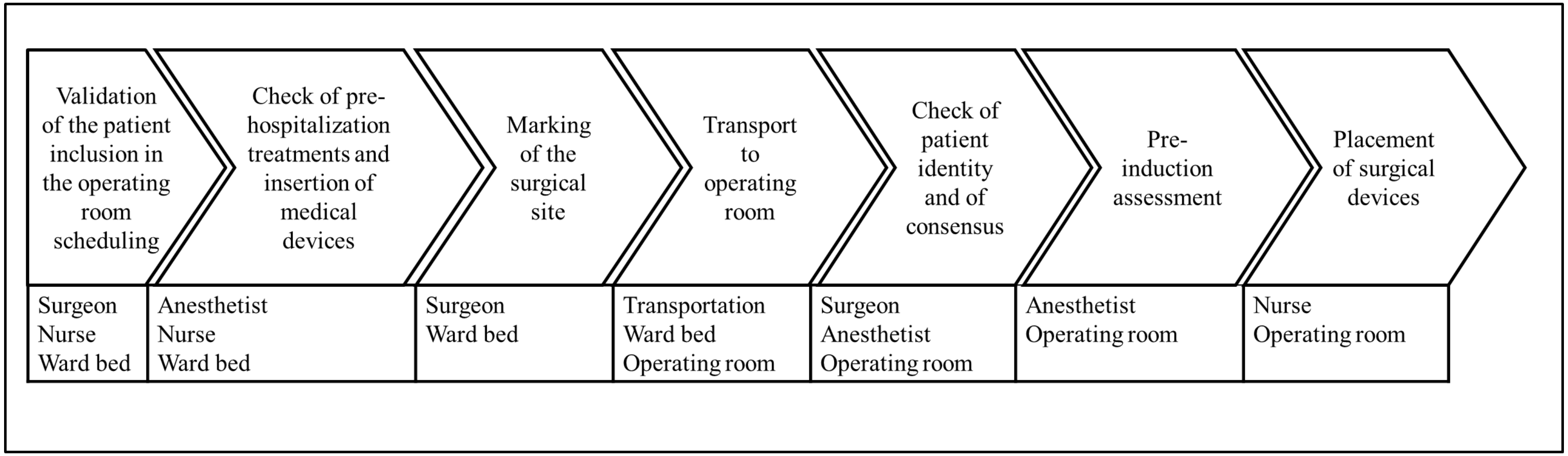

Figure 7. Pre-operation activities and resources involved

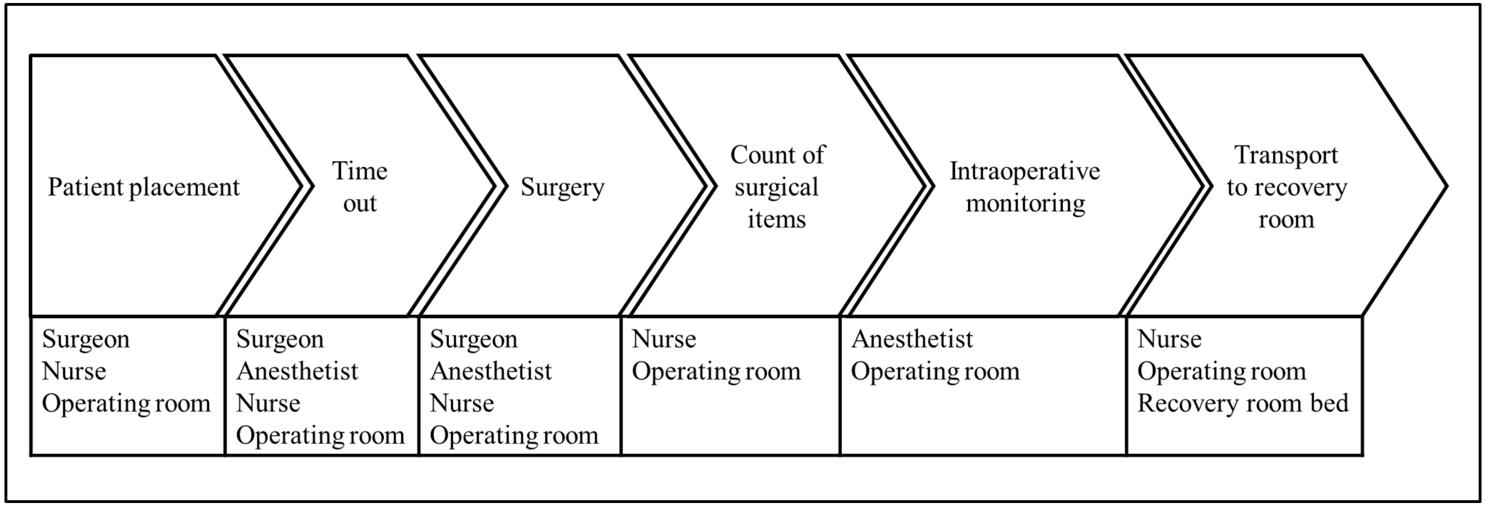

Figure 8. Operation activities and resources involved

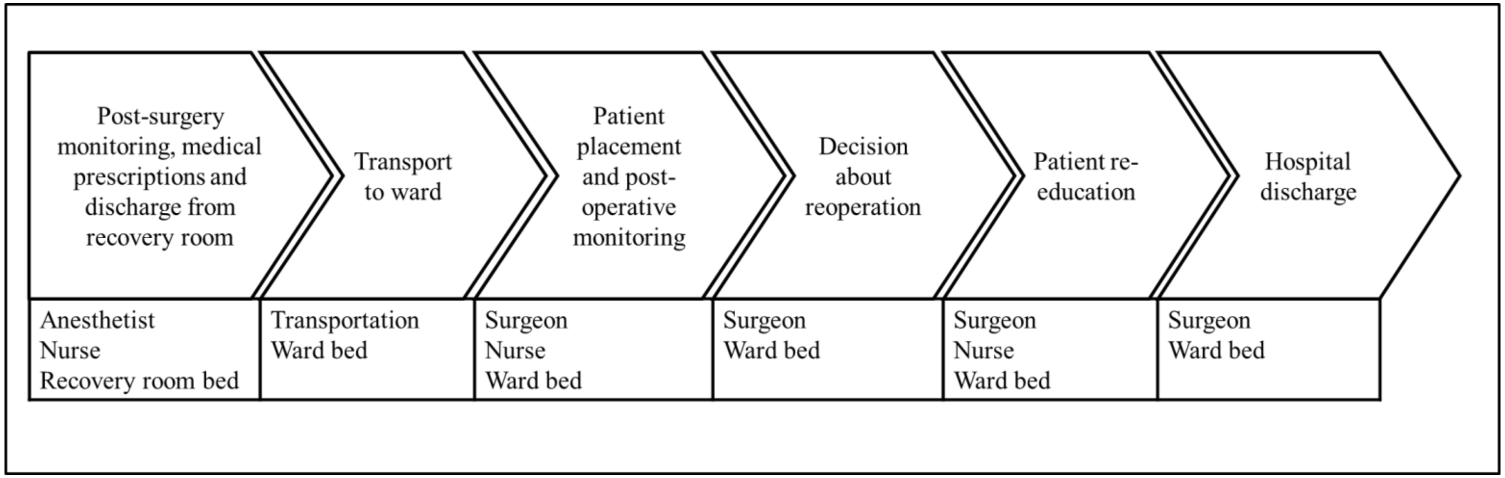

Figure 9. Post-operation activities and resources involved

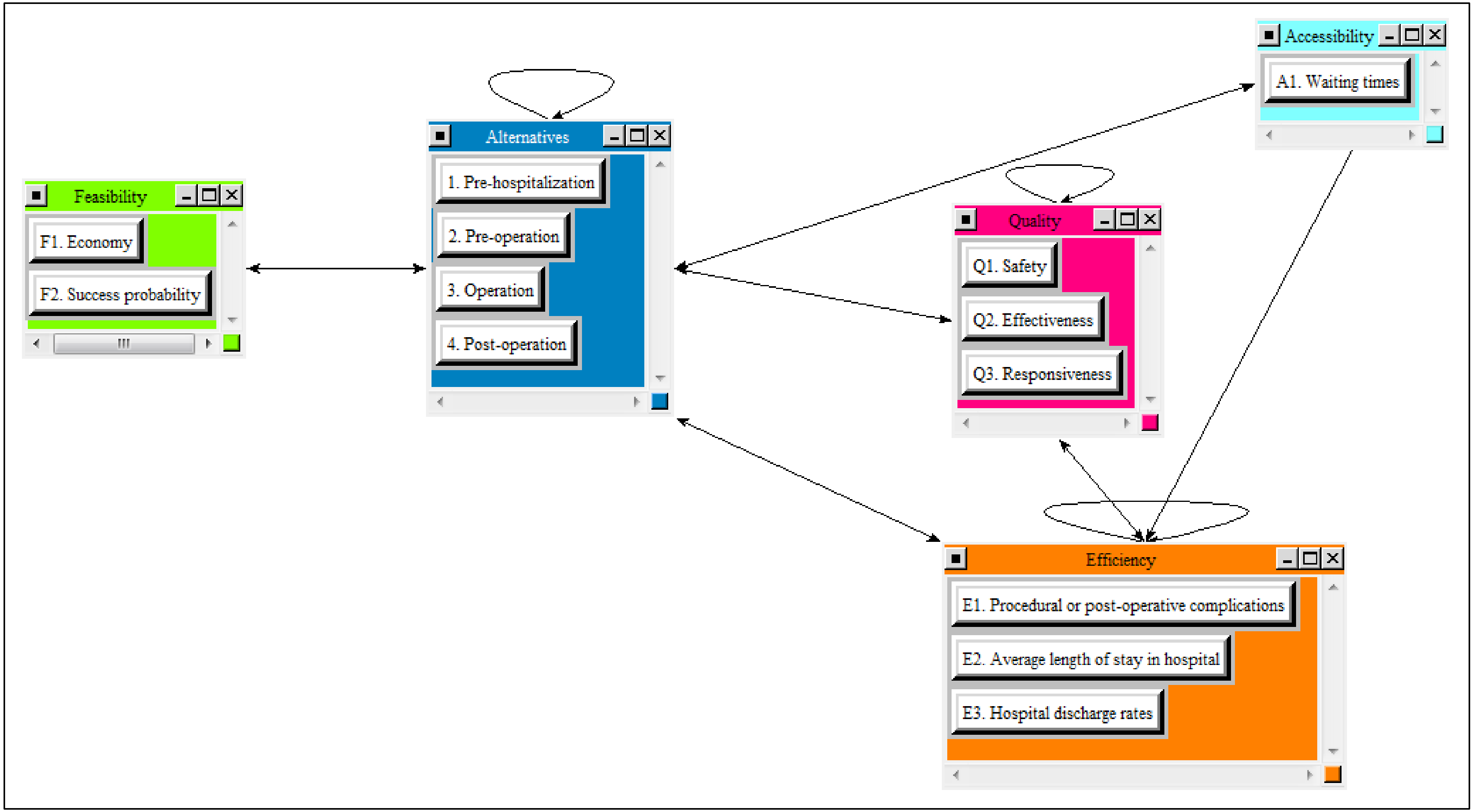

Figure 10. ANP model for the prioritization of the process optimization programs

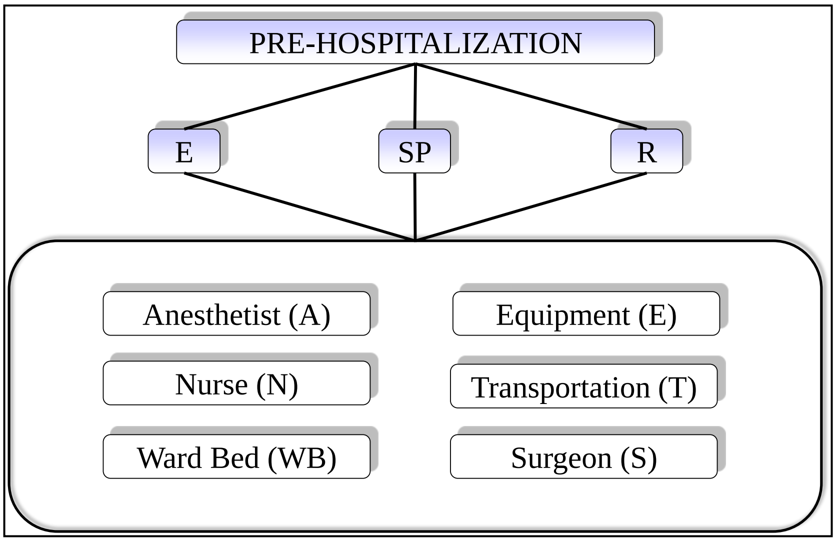

Figure 11. AHP breakdown structure for the “pre-hospitalization” process

A	**E**	**SP**	**R**
E	1	1/3	1/6
SP	3	1	1/2
R	6	2	1

E	**A**	**E**	**N**	**S**	**T**	**WB**
A	1	3	1/2	2	1/4	1/3
E	1/3	1	1/6	2	1/9	1/9
N	2	6	1	6	1/3	1/2
S	1/2	1/2	1/6	1	1/9	1/7
T	4	9	3	9	1	2
WB	3	9	2	7	1/2	1

SP	**A**	**E**	**N**	**S**	**T**	**WB**
A	1	1	1/3	2	1/6	1/7
E	1	1	1/3	2	1/6	1/7
N	3	3	1	5	1/4	1/5
S	1/2	1/2	1/5	1	1/9	1/9
T	6	6	4	9	1	2
WB	7	7	5	9	1/2	1

R	**A**	**E**	**N**	**S**	**T**	**WB**
A	1	1/2	1/2	1/4	3	1/3
E	2	1	1	1/2	6	1/2
N	2	1	1	1/2	6	1/2
S	4	2	2	1	9	3
T	1/3	1/6	1/6	1/9	1	1/9
WB	3	2	2	1/3	9	1

Figure 12. Pairwise comparison matrices for the pre-hospitalization breakdown structure.

Local weights of criteria			
Economy	10.00%		
Success Probability	30.00%		
Relevance	60.00%		
Local weights of resource	***Economy***	***Success Probability***	***Relevance***
A	8.88%	5.17%	7.79%
E	3.87%	5.17%	14.95%
N	17.05%	12.13%	14.95%
S	3.39%	3.05%	36.17%
T	39.86%	39.83%	2.76%
WB	26.95%	34.65%	23.36%
Global weights of resources			
A	7.11%		
E	10.91%		
N	14.32%		
S	22.96%		
T	17.59%		
WB	27.11%		

Figure 13. Local and global weights of the breakdown structure for the “pre-hospitalization” process

Local weights of criteria			
Economy	20.00%		
Success Probability	20.00%		
Relevance	60.00%		
Local weights of resource	***Economy***	***Success Probability***	***Relevance***
A	7.02%	10.06%	30.72%
N	15.22%	17.01%	13.17%
OR	2.39%	2.82%	30.72%
S	3.08%	2.14%	19.49%
T	42.15%	43.35%	2.49%
WB	30.14%	24.63%	3.41%
Global weights of resources			
A	21.85%		
N	14.35%		
OR	19.47%		
S	12.74%		
T	18.59%		
WB	13.00%		

Figure 13. Local and global weights of the breakdown structure for the “pre-operation” process

Local weights of criteria			
Economy	10.61%		
Success Probability	19.29%		
Relevance	70.10%		
Local weights of resource	***Economy***	***Success Probability***	***Relevance***
A	15.77%	17.90%	17.14%
N	23.95%	28.08%	8.57%
OR	3.12%	4.01%	35.10%
RRB	54.04%	47.15%	4.09%
S	3.12%	2.86%	35.10%
Global weights of resources			
A	17.14%		
N	13.97%		
OR	25.71%		
RRB	17.70%		
S	25.49%		

Figure 14. Local and global weights of the breakdown structure for the “operation” process

Local weights of criteria			
Economy	14.29%		
Success Probability	42.86%		
Relevance	42.86%		
Local weights of resource	***Economy***	***Success Probability***	***Relevance***
A	11.35%	6.04%	7.30%
N	11.79%	6.04%	26.86%
RRB	22.26%	32.16%	6.34%
S	2.65%	2.08%	46.30%
T	40.60%	29.14%	2.11%
WB	11.35%	24.53%	11.08%
Global weights of resources			
A	7.34%		
N	15.79%		
RRB	19.68%		
S	21.11%		
T	19.19%		
WB	16.88%		

Figure 15. Local and global weights of the breakdown structure for the “post-operation” process

***a_{ij}* – Intensity of importance**	**Definition**	**Explanation**
1	Equal importance	Two activities contribute equally to the objective
2	Weak	
3	Moderate importance	Experience and judgment slightly favor one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgment strongly favor one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	A activity is favored very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
Reciprocals of above	If activity *i* has one of the above nonzero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*	A reasonable assumption
Rationals	Ratios arising from the scale	If consistency were to be forced by obtaining *n* numerical values to span the matrix

Table 1. Saaty semantic scale (Saaty, 2006)

Process	**Resources**
Pre-hospitalization	Anesthetist Equipment Nurse Surgeon Transportation Ward bed
Pre-operation	Anesthetist Nurse Operating room Surgeon Transportation Ward bed
Operation	Anesthetist Nurse Operating room Recovery room bed Surgeon
Post-operation	Anesthetist Nurse Recovery room bed Surgeon Transportation Ward bed

Table 2. List of resources involved in each process

	Accessibility	Alternatives	Efficiency	Feasibility	Quality
Accessibility	0.000	0.060	0.000	0.000	0.000
Alternatives	0.333	0.201	0.455	1.000	0.253
Efficiency	0.667	0.453	0.455	0.000	0.694
Feasibility	0.000	0.256	0.000	0.000	0.000
Quality	0.000	0.030	0.091	0.000	0.053

Table 3. Cluster matrix

		Accessibility	Alternatives				Efficiency			Feasibility		Quality		
		Waiting times	Pre-hospitalization	Pre-operation	Operation	Post-operation	Procedural or post-operative complications	Average length of stay in hospital	Hospital discharge rates	Economy	Success probability	Safety	Effectiveness	Responsiveness
Accessibility	Waiting times	0.00%	100.0%	100.0%	100.0%	100.0%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Alternatives	Pre-hospitalization	19.19%	0.00%	0.00%	0.00%	0.00%	4.13%	37.05%	9.77%	32.79%	64.12%	4.58%	8.07%	41.59%
	Pre-operation	3.76%	100.0%	0.00%	0.00%	0.00%	10.17%	3.50%	3.64%	17.29%	21.15%	10.06%	4.27%	3.84%
	Operation	68.33%	0.00%	100.0%	0.00%	0.00%	70.04%	22.41%	63.73%	29.43%	3.56%	67.12%	70.60%	12.99%
	Post-operation	8.72%	0.00%	0.00%	100.0%	0.00%	15.66%	37.05%	22.86%	20.49%	11.16%	18.23%	17.05%	41.59%
Efficiency	Procedural or post-operative complications	0.00%	8.42%	30.90%	77.03%	11.30%	0.00%	0.00%	0.00%	0.00%	0.00%	88.89%	0.00%	0.00%
	Average length of stay in hospital	0.00%	70.49%	10.95%	16.18%	65.19%	0.00%	0.00%	100.0%	0.00%	0.00%	11.11%	0.00%	100.0%
	Hospital discharge rates	100.0%	21.09%	58.16%	6.79%	23.51%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	100.0%	0.00%
Feasibility	Economy	0.00%	10.00%	75.00%	10.00%	14.29%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	Success probability	0.00%	90.00%	25.00%	90.00%	85.71%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Quality	Safety	0.00%	22.71%	28.97%	30.86%	68.13%	100.0%	0.00%	0.00%	0.00%	0.00%	0.00%	100.0%	85.71%
	Effectiveness	0.00%	72.19%	65.54%	64.19%	6.88%	0.00%	0.00%	100.0%	0.00%	0.00%	0.00%	0.00%	14.29%
	Responsiveness	0.00%	5.10%	5.49%	4.95%	24.99%	0.00%	100.0%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

Table 4. Supermatrix

		Accessibility	Alternatives				Efficiency			Feasibility		Quality		
		Waiting times	Pre-hospitalization	Pre-operation	Operation	Post-operation	Procedural or post-operative complications	Average length of stay in hospital	Hospital discharge rates	Economy	Success probability	Safety	Effectiveness	Responsiveness
Accessibility	Waiting times	0.00%	6.02%	6.02%	6.02%	7.54%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Alternatives	Pre-hospitalization	6.40%	0.00%	0.00%	0.00%	0.00%	3.44%	30.87%	4.44%	32.79%	64.12%	1.23%	2.04%	10.53%
	Pre-operation	1.25%	20.13%	0.00%	0.00%	0.00%	8.47%	2.92%	1.65%	17.29%	21.15%	2.69%	1.08%	0.97%
	Operation	22.78%	0.00%	20.13%	0.00%	0.00%	58.37%	18.67%	28.97%	29.43%	3.56%	17.95%	17.88%	3.29%
	Post-operation	2.91%	0.00%	0.00%	20.13%	0.00%	13.05%	30.87%	10.39%	20.49%	11.16%	4.88%	4.32%	10.53%
Efficiency	Procedural or post-operative complications	0.00%	3.81%	14.00%	34.89%	6.41%	0.00%	0.00%	0.00%	0.00%	0.00%	65.12%	0.00%	0.00%
	Average length of stay in hospital	0.00%	31.93%	4.96%	7.33%	36.98%	0.00%	0.00%	45.45%	0.00%	0.00%	8.14%	0.00%	69.39%
	Hospital discharge rates	66.66%	9.55%	26.34%	3.08%	13.33%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	69.39%	0.00%
Feasibility	Economy	0.00%	2.56%	19.18%	2.56%	4.58%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	Success probability	0.00%	23.02%	6.39%	23.02%	27.45%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Quality	Safety	0.00%	0.67%	0.86%	0.92%	2.53%	16.67%	0.00%	0.00%	0.00%	0.00%	0.00%	5.28%	4.53%
	Effectiveness	0.00%	2.14%	1.95%	1.91%	0.26%	0.00%	0.00%	9.09%	0.00%	0.00%	0.00%	0.00%	0.75%
	Responsiveness	0.00%	0.15%	0.16%	0.15%	0.93%	0.00%	16.67%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

Table 5. Stochastic supermatrix

		Accessibility	Alternatives				Efficiency			Feasibility		Quality		
		Waiting times	Pre-hospitalization	Pre-operation	Operation	Post-operation	Procedural or post-operative complications	Average length of stay in hospital	Hospital discharge rates	Economy	Success probability	Safety	Effectiveness	Responsiveness
Accessibility	Waiting times	2.94%	2.94%	2.94%	2.94%	2.94%	2.94%	2.94%	2.94%	2.94%	2.94%	2.94%	2.94%	2.94%
Alternatives	Pre-hospitalization	13.26%	13.26%	13.26%	13.26%	13.26%	13.26%	13.26%	13.26%	13.26%	13.26%	13.26%	13.26%	13.26%
	Pre-operation	6.67%	6.67%	6.67%	6.67%	6.67%	6.67%	6.67%	6.67%	6.67%	6.67%	6.67%	6.67%	6.67%
	Operation	14.10%	14.10%	14.10%	14.10%	14.10%	14.10%	14.10%	14.10%	14.10%	14.10%	14.10%	14.10%	14.10%
	Post-operation	11.82%	11.82%	11.82%	11.82%	11.82%	11.82%	11.82%	11.82%	11.82%	11.82%	11.82%	11.82%	11.82%
Efficiency	Procedural or post-operative complications	8.55%	8.55%	8.55%	8.55%	8.55%	8.55%	8.55%	8.55%	8.55%	8.55%	8.55%	8.55%	8.55%
	Average length of stay in hospital	15.72%	15.72%	15.72%	15.72%	15.72%	15.72%	15.72%	15.72%	15.72%	15.72%	15.72%	15.72%	15.72%
	Hospital discharge rates	8.01%	8.01%	8.01%	8.01%	8.01%	8.01%	8.01%	8.01%	8.01%	8.01%	8.01%	8.01%	8.01%
Feasibility	Economy	2.52%	2.52%	2.52%	2.52%	2.52%	2.52%	2.52%	2.52%	2.52%	2.52%	2.52%	2.52%	2.52%
	Success probability	9.97%	9.97%	9.97%	9.97%	9.97%	9.97%	9.97%	9.97%	9.97%	9.97%	9.97%	9.97%	9.97%
Quality	Safety	2.20%	2.20%	2.20%	2.20%	2.20%	2.20%	2.20%	2.20%	2.20%	2.20%	2.20%	2.20%	2.20%
	Effectiveness	1.46%	1.46%	1.46%	1.46%	1.46%	1.46%	1.46%	1.46%	1.46%	1.46%	1.46%	1.46%	1.46%
	Responsiveness	2.78%	2.78%	2.78%	2.78%	2.78%	2.78%	2.78%	2.78%	2.78%	2.78%	2.78%	2.78%	2.78%

Table 6. Limiting impact priorities

Name	Ideals	Normals	Raw
1. Pre-hospitalization	0.940	0.289	0.133
2. Pre-operation	0.473	0.145	0.067
3. Operation	1.000	0.308	0.141
4. Post-operation	0.838	0.258	0.118

Table 7. Priorities of the process optimization programs