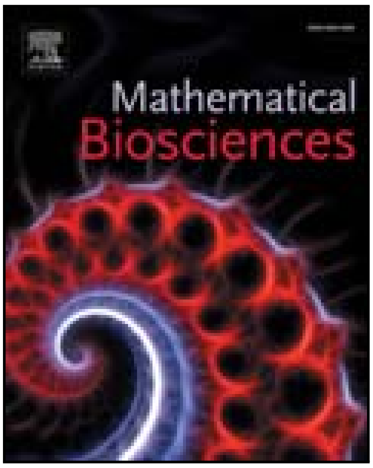

Use of the AHP Methodology in System Dynamics: Modelling and Simulation for Health Technology Assessments to Determine the Correct Prosthesis Choice for Hernia Diseases

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Highlights

- Application of the HTA methodology to a dynamic system for clinical applications.
- Dynamic Evaluation is important to improve the quality and efficacy of treatments.
- The simulation enables the forecasting of results.

Use of the AHP Methodology in System Dynamics: Modelling and Simulation for Health Technology Assessments to Determine the Correct Prosthesis Choice for Hernia Diseases

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Abstract

Health technology assessments (HTAs) are often difficult to conduct because of the decisive procedures of the HTA algorithm, which are often complex and not easy to apply. Thus, their use is not always convenient or possible for the assessment of technical requests requiring a multidisciplinary approach.

This paper aims to address this issue through a multi-criteria analysis focusing on the analytic hierarchy process (AHP). This methodology allows the decision maker to analyse and evaluate different alternatives and monitor their impact on different actors during the decision-making process. However, the multi-criteria analysis is implemented through a simulation model to overcome the limitations of the AHP methodology. Simulations help decision-makers to make an appropriate decision and avoid unnecessary and costly attempts. Finally, a decision problem regarding the evaluation of two health technologies, namely, the evaluation of two biological prostheses for incisional infected hernias, will be analysed to assess the effectiveness of the model.

KEYWORDS: AHP methodology; Decision-making; Health technology assessment; HTA; Simulation.

1. Introduction

Health technology assessment (HTA) is a multi-disciplinary evaluation process that allows the analysis and assessment of health technologies by considering the direct or indirect medical-clinical, organizational, economic, social, legal and ethical implications in the short and long term using the same technologies (Battista & Hodge, 1999; Favaretti, 2007; Favaretti & Cicchetti, 2009; Fernando, 2007; Litsios & Gladstone, 1972). Through this methodology, each alternative is assigned a weight based on the opinion provided by a decision-maker, and then, weight vectors are placed in a final vector that will determine the priority of each alternative. Key application areas in the literature include personal (Tam & Tummala, 2001) social (Liberatore, 1987) and industrial criterion (Fogliatto, 2001); management; manufacturing; engineering (Vaidya & Kumar, 2003; Triantaphyllou & Mann, 1995; Vaidya & Kumar, 2003); education; government (Kuo, Chi, & Kao, 1999) planning, selecting a best alternative; and resource allocation (Saaty, 1990; Saaty, 1980; Melillo, Delle Donne, Improta, Cozzolino, & Bracale, 2011; Masuda, 2003; Vargas, 1990; Zahedi, 1986; Masuda, 1988.

Among the various applications of the HTA, this paper takes advantage of the analytic hierarchy process (AHP) technique and focuses on a specific application of this methodology to a dynamic system in clinical.

However, the AHP uses a hierarchical structure in which linear dependencies between items of different decision-making levels are one way down the hierarchy and there are no dependencies between elements of the same cluster of items belonging to different clusters. For this reason, it cannot be considered suitable for the modelling of complex problems, which are characterized by dependencies, interactions and feedback and especially by the dynamic nature of the decision take (Wong, Johnny, Li, & Heng, 2008). With these premises, in this paper the AHP and HTA methodologies have been implemented through a dynamic simulation model and overcome the main limitations of the single methodologies.

After this introduction, section 2 reports an overview of AHP and HTA-related works. Section 3 discusses the materials and methods of this research. In Section 4, the results of the implemented methodology are presented. Finally, section 5 reports conclusions, implications and limitations of this paper.

2. Related work

The bibliographic review of multiple criteria decision-making (MCDM) tools realized by Steuer (Steuer, 2003; Steuer, 2013) provides an important overview of the decision-making topic. The main research papers on this topic identified by this bibliographic review have been confirmed and updated adopting the well-known systematic literature review approach defined by Centobelli et al. (2016, 2018). The AHP is a multi-criteria decision analysis methodology that was developed in the 1970s by Thomas L. Saaty. AHP evaluates a set of alternatives and creates a final problem by splitting decision making into many sub-problems that are equal and can be solved by summarizing sub-problems in which results of the initial problem are evaluated (Saaty, 1977; Wua & Tsai, 2011).

Among MCDM techniques, the AHP still suffers from some theoretical disputes. One major criticism is that the assumption of independence among the criteria can be considered a limitation of the AHP in certain cases. In fact, one of the main aspects of the AHP is the assumption of independence between the various levels of the hierarchical structure in terms of both the criteria and sub-criteria (Saaty, 1994).

An initial solution to this critique was offered by Saaty, introducing the analytic process network (ANP), a generalization of the AHP with feedback to adjust the weights. However, the decision-maker must answer a considerable number of questions, which can be complex and affect the linear hierarchical structure typical of the AHP. For this purpose, a simplified version of the ANP would be useful for the simplified wider adoption of the method.

Another criticism of the AHP is the inherent static nature of the decision, which means that the method is ineffective in case of the future perpetration of a medium/long-term decision.

The literature review demonstrates that the AHP was initially used alone and that with the increase in researchers' confidence, it is now beginning to be applied in combination with other mathematical techniques or modified versions.

In 2014, Chen et al. (2014) presented a novel framework for the evaluation of teaching performance based on a combination of fuzzy-AHP and fuzzy comprehensive evaluation methods. Specifically, a teaching performance index system was established.

Then, the weights of factors and sub-factors in the index system were estimated using the fuzzy-AHP method (Chena, Hsieha, & Dob, 2014).
Nazam et al. (2015) proposed a fuzzy risk-oriented evaluation model applied to a practical case of the textile manufacturing industry (Nazam, Xu, Tao, Ahmad, & Hashim, 2015). Specifically, the model is a combined fuzzy-AHP methodology used to calculate the weight of each risk criterion and sub-criterion. It also proposed a technique to group performances by similarity (Nazam, Xu, Tao, Ahmad, & Hashim, 2015; Cancela, J., Fico, G., & Waldmeyer, M. T. A., 2015). In the same year, Tyagi et al. proposed an improved fuzzy analytical hierarchy process approach to investigate the influence of effective utilization of socialization, externalization, combination and internalization modes within any product development phase (Tyagi, 2015).

Recently, MCDM tools like AHP and other mathematical algorithms and models have been also applied to assess the impact and the efficacy of treatments, therapies (Rahman, S. A., Vaidya, N. K., & Zou, X., 2016; Hoffmann, A., Scherrer, A., & Küfer, K. H., 2015) and screening procedures (Plevritis, S. K., 2001). Among the MCDM approaches that have been applied to the healthcare from 1990 to 2012, the AHP is the most used technique (Adunlin, G., Diaby, V., & Xiao, H., 2015). MCDM analysis methods have been also used for shared decision making between patients and doctors in the evaluation and selection of therapies, treatments, and health care technologies (Thokala, P., & Duenas, A., 2012). These techniques were said to identify and include the personal preferences of the patient, but the complexity of the proposed models was mentioned as a disadvantage (Thokala, P., & Duenas, A., 2012).

Despite the widespread use of MCDM tools in healthcare, more recently some studies advocate the use of MCDM techniques for HTA (Diaby, V., Goeree, R., Hoch, J., & Siebert, U., 2015; Martelli, N., Hansen, P., van den Brink, H., Boudard, A., Cordonnier, A. L., Devaux, C., & Borget, I., 2016). For example, European Medicines Agency (EMA) proposed MCDM as an approach to support benefit-risk assessment, while the US Institute of Medicine proposed MCDA for its vaccine prioritization framework (Kim, H. J., Kim, Y. J., Park, D. J., Liew, D., & Rhee, Y., 2017). In 2012, the National Institute for Health and Clinical Excellence (NICE) has consulted on the role of MCDA in HTA and, in 2014, International Society for Pharmaceconomics and Health Outcomes (ISPOR) established an Emerging Good Practices Task Force with the aim to provide examples of the use of MCDM in HTA (Kim, H. J., Kim, Y. J., Park, D. J., Liew, D., & Rhee, Y., 2017). In Korea also, there were several research projects associated with assessing AHP in the healthcare sector at a national level, in making decisions for expanding health insurance benefit packages, or priority settings for chronic disease management, and prioritizing nursing services (Kim, H. J., Kim, Y. J., Park, D. J., Liew, D., & Rhee, Y., 2017).

In HTA methodology, the multi-criteria problem is decomposed into a hierarchical structure to evaluate the proposed technologies in different aspects, namely, technical and technological aspects, organizational aspects, economic aspects, legal and ethical aspects, and clinical aspects. Subsequently, each aspect is in turn divided into further sub-criteria. Figure 1 reports a typical HTA structure.

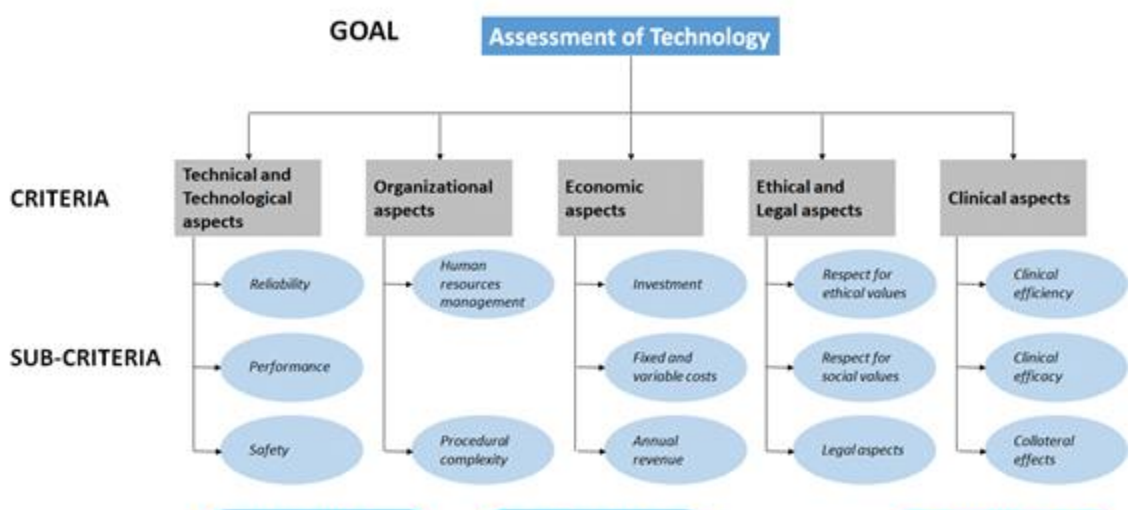

Figure 1: Hierarchical decomposition of an HTA problem.

The literature highlighted that this methodology is one of the most used multi-criteria decision analysis methods and that its use has increased over time, eventually reaching the global level.
The main strengths of this approach are:

- Simplification of the decision problem;
- Opportunity to provide qualitative judgments;
- No requirement for high specialization.

On the other hand, the main limitations of the methodology are:

- Independence of sub-criteria: the problem is decomposed and there is a constraint of independence between the elements. Such an instrument cannot be considered suitable for the modelling of complex problems characterized by dependency between sub-criteria.
- The static nature of the decision: multi-criteria decision making methods like AHP do not offer analyses of decisions in a dynamic environment. Since some decision making problems are not static procedures, it is necessary to adopt a method able to take into account changes and impact of medium- and long-term consequences.

Many previous studies (Converso, Di Giacomo, Murino, & Rea, 2015; Converso, Ascione, Di Nardo, & Natale, 2014) have discussed the innovative contributions of HTAs and other management approaches to healthcare processes (Converso, Improta, & Mignano, 2015; Improta, Simone, & Bracale, 2009; Improta, 2010; Improta, Balato, Romano, Carpentieri, & Bifulco, 2015; Improta, G., Cesarelli, M., Montuori, P., Santillo, L. C., & Triassi, M., 2017; Improta, G., Balato, G., Romano, M., Ponsiglione, A. M., Raiola, E., Russo, M. A., Cuccaro, P., Santillo, L.C., & Cesarelli, M., 2017; Montella, E., Di Cicco, M. V., Ferraro, A., Centobelli, P., Raiola, E., Triassi, M., & Improta, G., 2017; Guarino, F., Russo, M. A., Franzese, M., Righelli, D., Improta, G., Angelini, C., & Triassi, M., 2017; Revetria, R., Catania, A., Cassettari, L., Guizzi, G., Romano, E., Murino, T., Improta, G., & Fujita, H., 2012).

In 2012, Converso et al. (2012) (Converso, De Carlini, Santillo, & Improta, 2012) used the project management methodology to improve the quality of health services. Specifically, they addressed the problem of the optimal allocation of biomedical systems evaluating different issues, such as ethical, legal, social, economic, technical, technological, and organizational issues.

In 2012, Improta et al. (2012) (Improta, et al., 2012) presented an HTA protocol for the classification of hospital and health facility equipment, realized by combining the classical HTA concepts with hierarchic clustering techniques in a multidisciplinary analysis of requirements, costs, logistics, and technology-associated risks.

Several works in literature discuss the use of the AHP in combination with HTA problems (Figueira, Greco, & Ehrgott, 2005; Banta, Behney, & Andrulis, 1978; Felice & Saaty, 2009). These studies demonstrate the ability of the AHP to facilitate an understanding of the criteria and priorities that allow for a successful evaluation of hospital technologies (Danner, et al., 2011; Improta, Fratini, & Triassi, 2012). AHP methodology has been also applied for resolving issues involved in HTA with a system dynamics approach (Vaidya & Kumar, 2004). In 2013, Improta et al. (Improta, et al., 2013) attempted to create a set of indicators that allows for the monitoring of the training service offered by the Biotechnology Centre, referring to the AORN “A. Cardarelli” of Naples, and the evaluation of the level of user satisfaction through an AHP, which allowed for the creation of a hierarchy of user needs. In this paper, HTA is considered because it is a multi-disciplinary evaluation method that lead to consistent results. In addition, there is a widespread interest shown at the top managerial levels in solving decision problem in context characterized by a high multitude of interconnected variables, such as the healthcare system, as well as the need to combine medical needs with management (Naples, 2010).

More recently, specific application oh AHP for HTA problems have been studied. In 2015, Ritrovato et al. (Ritrovato, M., Faggiano, F. C., Tedesco, G., & Derrico, P., 2015) illustrated a detailed new implementation of the EUnetHTA Core Model (a framework for sharing of HTA information) by also describing the main features of the AHP approach in a hospital context. They explained how the integration between AHP and the Core Model as a part of HTA process can closely support healthcare decisions.

In 2016, Mobinizadeh et al. (Mobinizadeh, M., Raeissi, P., Nasiripour, A. A., Olyaeemanesh, A., & Tabibi, S. J., 2016) described a pilot MCDM model for priority setting of HTA in Iran. They combined AHP and TOPSIS (The Technique for Order of Preference by Similarity to Ideal Solution) to design a priority setting model. The proposed model, with nine effective criteria and their relative weights and in combination with TOPSIS approach, proved a suitable applicability by HTA department in deputy of curative affairs and food and drug organization for determination of research priorities in HTA.

3. Materials and Methods

As previously mentioned, to overcome the limitations of the AHP methodology, the problem was implemented through a dynamic simulation model.

The simulation allows to generate hypothetical scenarios and analyse operational situations that may be critical or difficult to forecast or manage in advance. The main advantage of simulations is that experiments can be fully audited and the performance of all experiments can be observed before implement them.

Among the various simulation techniques, this study focuses on the simulation methodology called system dynamics, whose basis is the development of a dynamic simulation model (Andersson & Karlsson, 2001). The strength of the system dynamic simulation model does not lie in its ability to predict precise state details of the system but to understand the logic with which the relevant variables interact with each other, the role played by each variable, the sensitivity of the system to interventions, and the scenarios obtained by varying the criterion used for making decisions or the time horizon (Thacker, Doebling, Hemez, Pepin, & E.A., 2004).

The AHP algorithm remains unchanged in the calculation of weights compared to the criterion goals and of the sub-criteria in relation to the parent criterion to which they belong. This does not violate the principle of linear and hierarchical structure to maintaining dependence between the top-level criteria in that their differences are not directly comparable and are unlikely to create a dynamic system. The system that creates alternatives with sub-criteria, which is the hierarchical level closer to the alternatives, is the dynamic element (Vaidya & Kumar, 2004).

The main innovation of our work compared to previous studies is the application of the HTA methodology to a dynamic system for clinical applications. A decision problem involving companies characterized by numerous interrelations between variables requires the use of simulation techniques for its resolution. These companies must be characterized by greater adaptability and flexibility, which are essential features in a highly dynamic business reality, such as the healthcare system. The application of HTA to a dynamic system is completely different with respect to the same method applied to a static system.

Studying a dynamic system for clinical applications is an important effort to improve the quality and efficacy of patient treatment for both diagnostic and therapeutic applications because it allows us to evaluate different parameters that would not have been considered in other cases.

3.1 Combination of AHP and simulation models

The HTA methodology has been implemented using the simulation. Five simulation models were developed, each one representing a macro-region of the decision problem of HTA according to the AHP methodology. More specifically, it is possible to build a simulation model for each criterion in the hierarchy of the dynamic system; the input of each simulation model is a vector, whose size is equal to the number of alternatives considered in the decision problem. Each row of the vector represents an alternative/preference referred to the decision problem and contains all the data related to the alternative itself. The main goal of the developed simulation models is to support decisions for HTA, an activity that is currently mainly intuitive and based on standardized procedures in hospitals. According to the top-level criteria of the hierarchical structure that divides the decision problem under consideration (Figure 1), we developed:

- a simulation model for technical and technological aspects;
- a simulation model for organizational aspects;
- a simulation model for economic aspects;
- a simulation model for ethical and legal aspects;
- a simulation model for clinical aspects.

The outputs of these models, whose inputs will be different based on the problem under examination, will be vectors containing the local weights of the alternatives considered for each of sub-criterion. These local vectors containing sub-criteria weights will be then normalized and multiplied by the global vectors containing the weights for higher level criteria (parent criteria). This will lead to the final vector of the decision problem.

To summarize, each criterion in the hierarchy will be simulated, taking into consideration not only all the interdependencies between the sub-criteria related to a same parent criterion but also their variability over time.

In this manner, HTA does not alter the decision-maker's perspective but it represents a valuable tool for contextualizing the choice among the alternative solutions that we consider in the decision.

3.2 The simulation model and AHP evaluation

The simulation model was developed according to the System Dynamics method.

In complex systems, objects interact through feedback loops, where a change in one variable affects other variables dynamically, which feeds back the original object, and so on. The interplays among objects determine the different states the system can assume in the course of time, which is known as the dynamic behaviour of the system. Thus, System Dynamics models essentially capture the causal relationships and feedbacks in the system.

System Dynamics models require explicating all time dependent relationships represented by the connecting arrows and involve a set of coupled, non-linear differential equations of the form:

$$\frac{d\boldsymbol{x}}{dt} = f(\boldsymbol{x}(t), \boldsymbol{p})$$

Where:

- $\mathbf{x}$(t) is a vector of levels or state variables,
- f( ) is a vector-valued function and
- $\mathbf{p}$ is a vector of parameters

Such a model is generic and reusable for multiple alternative systems. Furthermore, it can be easily extended and made to evolve into a detailed performance measurement model.

Here, the model was created using Powersim Studio software, which yields a graphical representation of the model. Each graphic symbol represents a specific type of variable. Therefore, the connection between the symbols represents the logical interaction between the different variables of the model.

At first, according to the AHP approach, a hierarchical decomposition of the problem has been done (Figure 1). In general, it defines the overall objective, the criteria to reach, sub-criteria, where the criteria can be specialized, and so on until you get to the alternatives that should be prioritized. The various elements are well organized in different levels which enjoy the dependency property: each level is dependent on the upper level; the elements of a same level are independent of each other.

Then the simulation model has been developed according to the previously defined hierarchical structure. In particular, a network has been developed considering technical, organizational, economic, ethical/legal and clinical factors as high level criteria, each one divided into sub-criteria, which are the state variables of the problem.

For each developed model, we ran simulations to estimate parent criteria-related outcomes under hypothetical scenarios. Results from simulations are used to determine decision makers’ preferences over alternatives, which would be displayed in an exercise environment. After determining decision makers' preferences based on simulation outcomes, AHP can be used to determine ranking of decision makers' preferred strategies.

Therefore, simulation results can be analyzed according to the principles of the AHP in order to integrate, verify and validate the model, as briefly described below:

1. Comparison in pairs between the criteria belonging to the same level: the comparison result is a coefficient a_{ij}, said dominance coefficient, which represents an estimate of the dominance of the first element (i) compared to the second (j). From this comparison one can determine the degree of importance of an element with respect to another, both belonging to the same level. To determine the values of the coefficients aij it is possible to use the semantic scale of Saaty. These coefficients are then used to define the matrix of pairwise comparisons, a square matrix nxn like:

$$A = \begin{pmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{pmatrix}$$

   which enjoys the following properties:
      - Positive (has no element zero): $a_{ij} > 0$
      - $A_{ii} = 1$
      - Mutual: $a_{ji} = 1/a_{ij}$

   So considering the above properties it will need to fill only half of the matrix (the indicators above the main diagonal) performing [n · (n - 1) / 2] assessments; indicators on the main diagonal will have a unit value and those below the main diagonal are the reciprocal of those above.

2. Determine the relative priorities: vector (v) elements are calculated as a product on the row coefficients:
   - $v_1 = a_{11}*a_{12}....*a_{1n}$
   - $v_2 = a_{21}*a_{22}....*a_{2n}$

   Then it is possible to determine the priority (p) dividing the vector element by the sum of them:
   - $p_1 = v_1/\Sigma v_k$ with k=1 to n

3. Determine the local weights: multiplying then the priority for each corresponding coefficient and summing them, it is possible to determine the local weights, which are normalized dividing them be the sum of all the weights.
   - $W_1 = (p_1*a_{11})+(p_2*a_{12})....+(p_n*a_{1n})$
   - $W_{1norm}= W_1/\Sigma w_k$ with k= 1 to n

   Local weights measure the relative importance of the elements.

4. Hierarchical synthesis of weights and final vector of the decision problem: after calculating the local weights of each criterion, we proceed with the calculation of the final vector of the decision problem, multiplying the sub-criterion weight by the weight of the parent criterion.

Finally, based on the criteria weights, rank of the scenarios can be determined, so that a specific decision vector can be obtained at each time step of the simulation process. In this way, the static behaviour of the conventional AHP approach is overcome and a time-varying decision making process can be implemented.

These AHP formulas are applied for every criteria and sub-criteria and compared to the simulations results from the Powersim software model.

As a result of the decision making process, the best scenario i.e. the best parameter combination can be selected.

3.3 Description of the developed simulation models

In the model concerning the technical and technological aspects (Figure 2), the "*patient demand vector*" for each alternative under consideration for each technology represents the input. On the other hand, "*views indicators*" that represent the local weights of alternatives compared to three sub-criteria represent the output. In addition, we obtain two performance indicators, one for reliability and one for the security technology level.

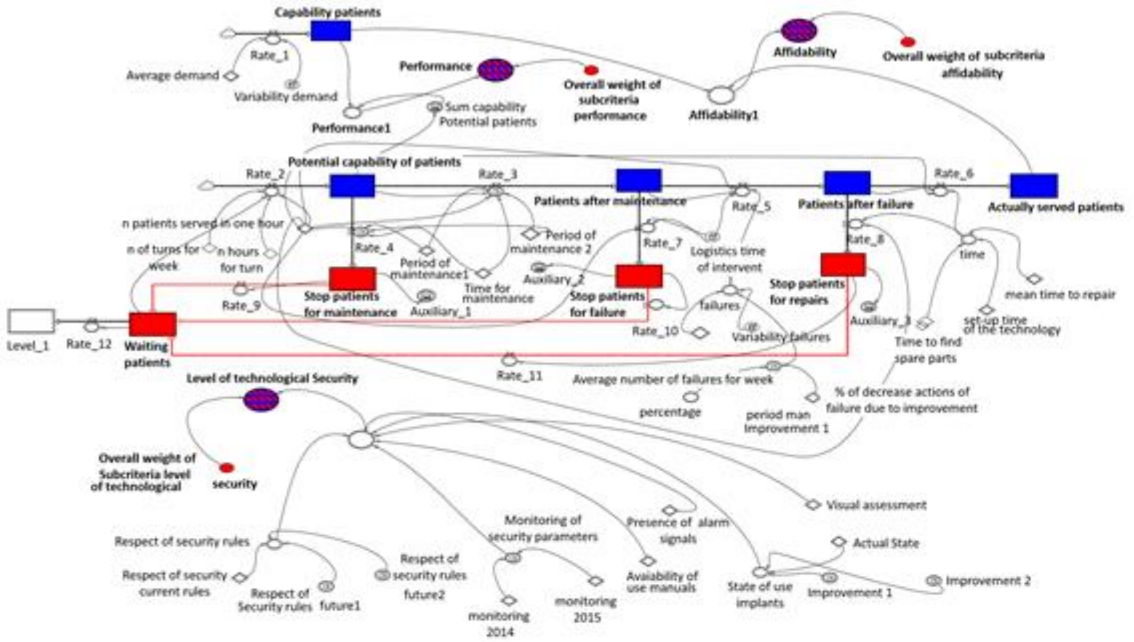

Figure 2: Simulation model of technical and technological aspects.

In the model concerning organisational aspects (Figure 3), the "*patient demand vector*" for each output technology of the sub-criteria indicators acts as the input, whereas "*human resources management*" and "*procedural complexity*" represent the output.

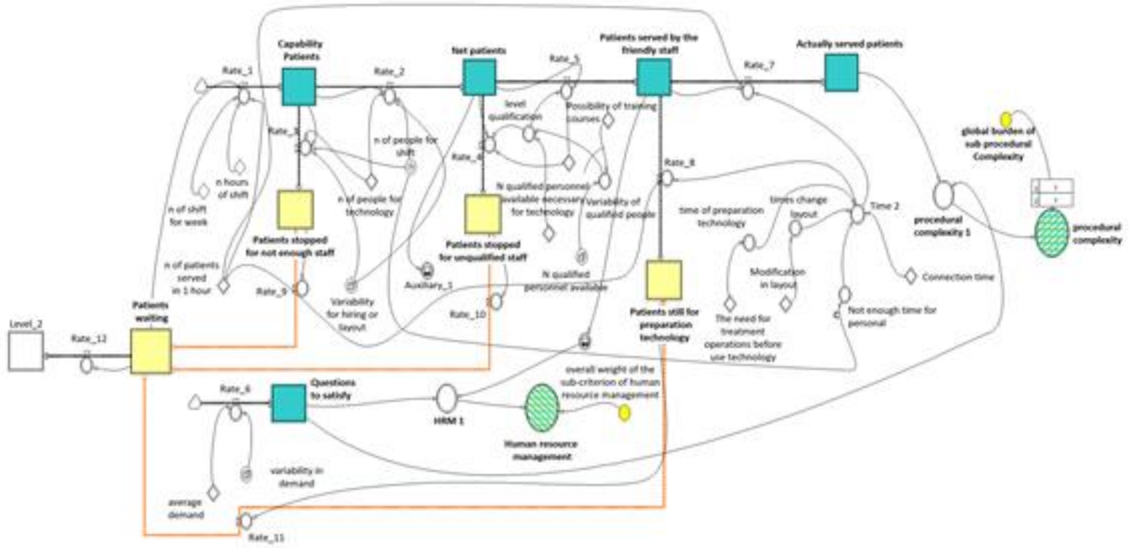

Figure 3: Simulation model of organizational aspects.

In the economic model (Figure 4), the "*amount of investment*" is the input and the value of the three sub-criteria indicators (i.e., *fixed investments*, *variable costs* and *revenues*) represent the output.

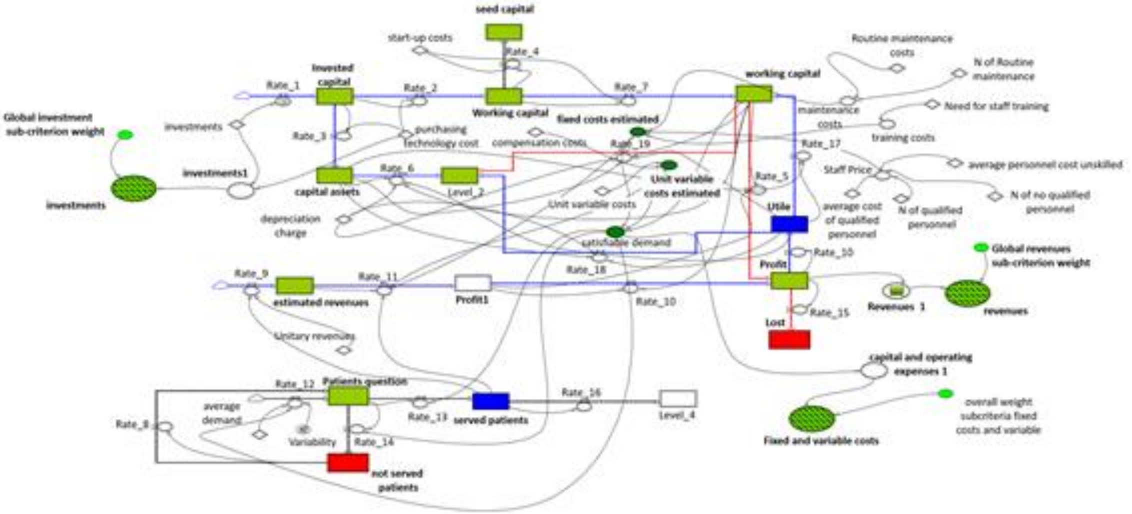

Figure 4: Economic simulation model.

In the model concerning the ethical and legal aspects (Figure 5), the vector of the "*demand for patients*" was used as input and the "*respect for ethical principles*", "*social principles*" and "*legal aspects*" as output.

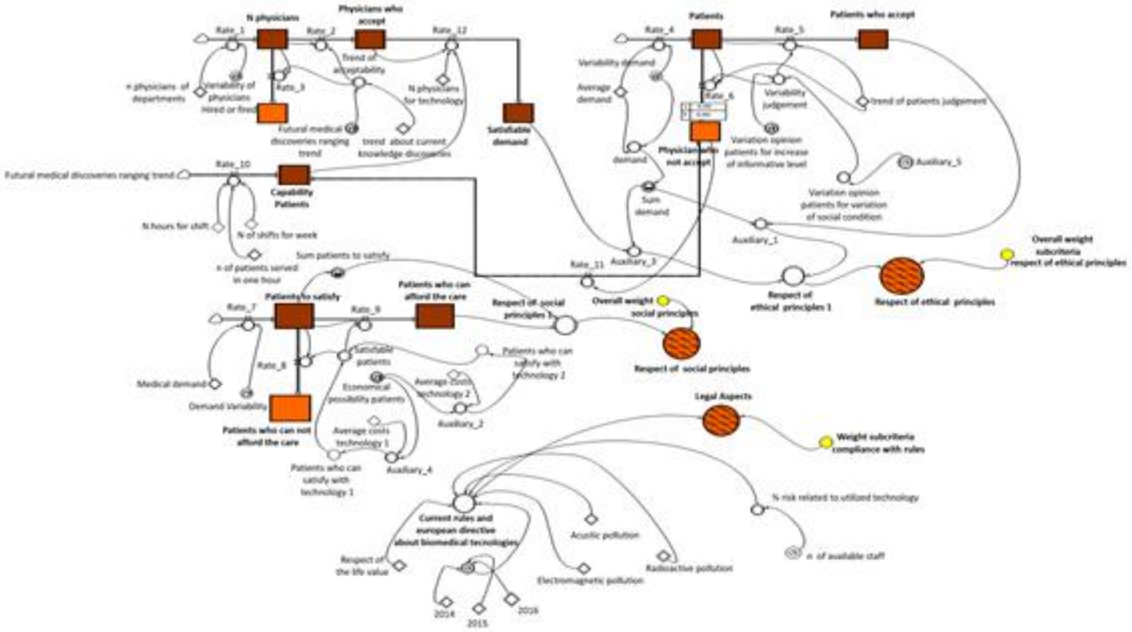

Figure 5: Simulation model of ethical and legal aspects.

Finally, in the model of the clinical aspects (Figure 6) the "*carrier of the request*" represents the input and the "*clinical efficiency*", "*effectiveness*" and "*side effects*" the output.

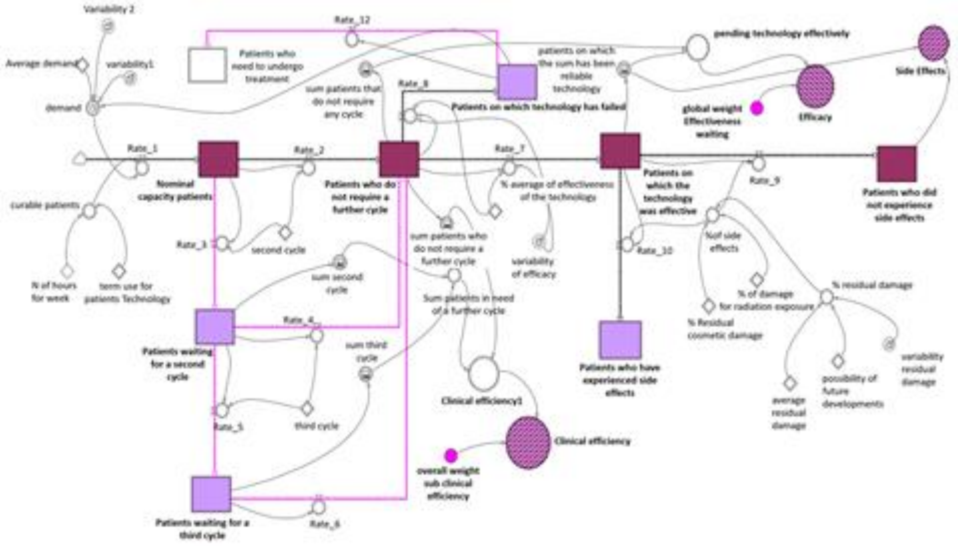

Figure 6: Simulation model of clinical aspects.

By simulating each model, the indicators are properly calculated once the sub-criteria are normalized by the relative weight of the alternatives with respect to the criterion. Each element of the vector was then considered as the ratio of the weight of the alternative, and the alternative building the matrix j such comparisons to couples. Once its properties of reciprocity, positivity and consistency have been calculated in MATLAB, the eigenvectors of these arrays represent the local weight criteria sub-criteria.

Once these weights are multiplied for global weights with respect to criterion goals, which can be kept static, the AHP obtains the final vector alternative sorting for each time step; then, a different carrier and a different decision are obtained for each time step.

3.4 Case study

The proposed model is applied to a case study of the evaluation of biological networks to treat infected incisional hernias to validate the model and assess its effectiveness.

An incisional hernia is a serious post-op complication characterized by the dumping of viscera contents into the abdominal cavity. Parietal biological networks based on collagen are used for the treatment of incisional hernias and infections, particularly the complex task of reinforcing the wall at the site where the collapse occurred (Cooper, 1844). The main biological networks used are implants derived from bovine pericardium, including a sample taken from TUTOMESH, and an implant derived from porcine dermis, such as Permacol (Crovella, Babin, & Fei, 2008; Scardi, 2006; Crovella, Babin, & Fei, 2008).

The case study was initially fixed with the traditional AHP approach. The reviews have been provided by the medical staff of A.O. "A. Cardarelli." Applying the algorithm of hierarchical analysis, a final ordering of the vector of two alternative results, i.e. [0.48; 0.52], where the first position of the vector represents the network and porcine dermis and the second position represents the bovine pericardial network: the weights show a slight preference toward the bovine pericardium.

Once the AHP results are obtained, the traditional results that are global weights of sub-criteria were multiplied by the output of the simulation model, which is the local weight vectors of the alternatives compared to sub-criteria, yielding the final sorting of alternatives. The chosen time horizon for the simulation is three years, and the time step is a week.

3.5 Model validation

After the creation of the model, you must ensure that the developed simulation model reproduces the behaviour of the real system. In particular, it is necessary to check that the measures of actual system are well approximated by the measures generated by the simulation model. The aim of the validation is to compare the results obtained from this simulation model with the real data available. In our case, the model validation was performed by evaluating whether the resolution of the problem with the AHP methodology static coincides with the solution proposed by the simulation model instantly at T_0, which is after the first run. The model is validated because it has been verified that at T_0, the results of every sub-criterion indicator produced by the models correspond with the results provided by the carriers of the local weights of alternatives compared to the calculated sub-criteria with the classical AHP methodology (Figure 7).

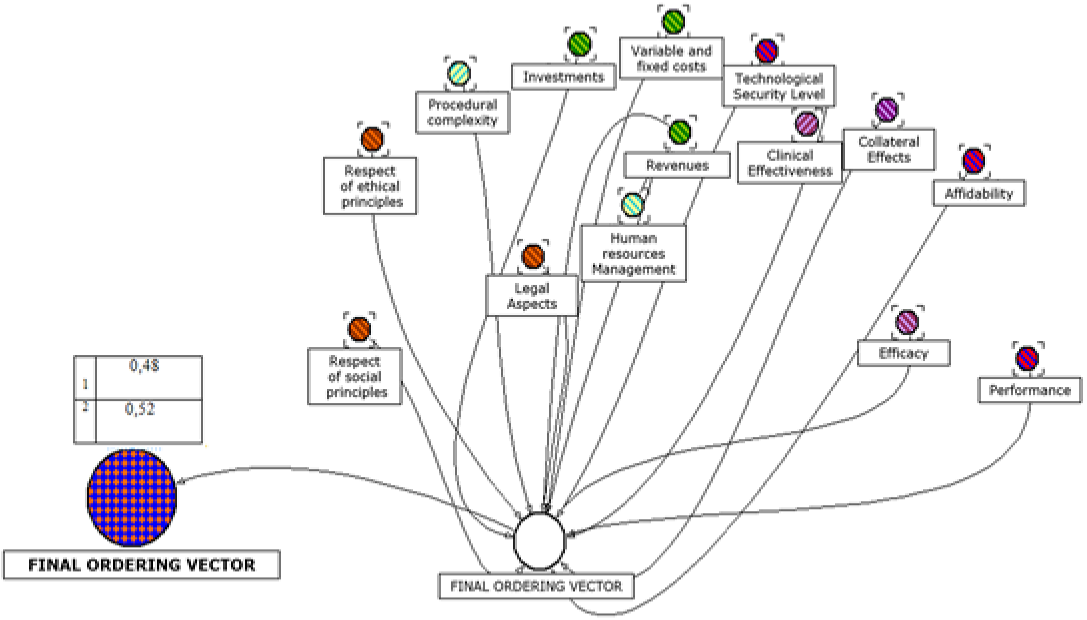

Figure 7: Validation of the simulation models.

4. Results

After comparing the simulation models of carriers' global weights to the various alternatives and adding sub-criteria, the first few lines of each vector are obtained as the overall weight of alternative 1, which is the net sum of all Permacol. The second lines of each carrier represent the global burden of alternative 1, which is the Tutomesh network. This calculation is performed within the variable ' end sequencing vector ' alternatives□ (FOR (i = 1 ... 2 | Reliability [i] + ' legal aspects ' [i] + ' ' procedural Complexities [i] + ' fixed and variable costs [i] + ' side effects ' [i] + Effectiveness [i] + ' Efficiency ' Clinic [i] + ' Human Resources Management ' [i] + gross [i] + ' Technological ' Safety Level [i] [i] + Performance + income [i] + ' social ' principles [i] + ' respect for ethical principles [i])), whose performance is shown in Figure 8.

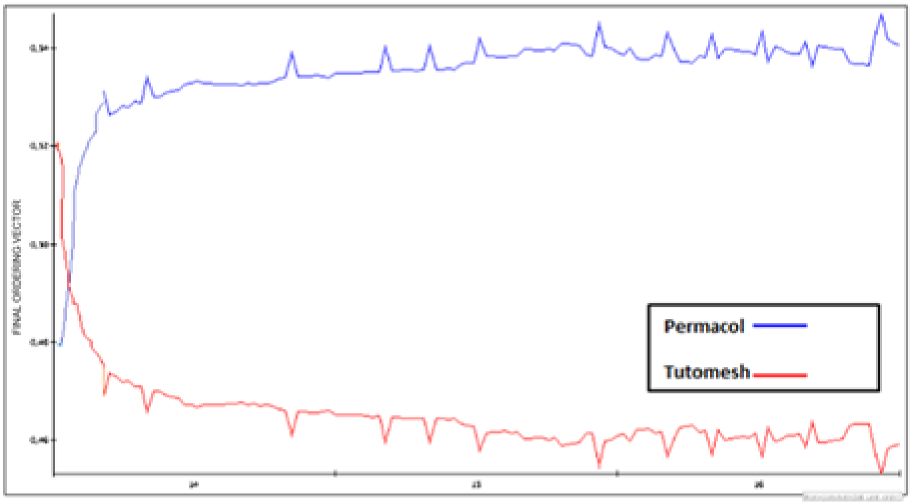

Figure 8: Trend chart vector final sort of alternatives.

The graph shows how the time T_0 has a slight preference for the Tutomesh network, which is assigned a weight of 0.52; during the simulation, this weight varies, becoming 0.48 by the end of the simulation. In contrast, the Permacol network, with a weight of up to 0.48 at T_0, reaches a weight of 0.52 at the end of the simulation. Starting the resolution of the problem through the AHP yields a static tilting of the situation.

5. Conclusions

A particularly strict application was considered as a case study here, as the system was tested on the evaluation of biomedical equipment technology (using a target for this type of method) but for a more complex choice of technologies related to biological prostheses that can look highly similar to each other. However, they are then applied using a simulation model that shows many different aspects that an initial analysis can overlook but which are crucial to the final decision.

The complexity of the case study was demonstrated, especially in terms of the differentiation between different dynamic biomedical systems and operating procedures.

This model was shown to be advantageous in terms of the stability of the results (avoiding the use of calculating average trends in the simulation period).

The most interesting result was the discrepancy in the result obtained by the application of the AHP in a static environment.

Further advancements for the simulation model can also be considered, which will focus on connections, through the use of appropriate feedback, not only between different sub-criteria belonging to a given criterion but between all elements of the hierarchy through analysis of a network structure typical of the ANP and a methodology implemented by Saaty to overcome some gaps of the AHP.

The model was found to be effective, having demonstrated its ability to overturn the results of the static AHP.

However, generally the HTA is context specific. Therefore, the issues addressed in this paper are related to the context under investigation. The results of this application can not be generalized for criterion implications. Other numerous factors (e.g., demographic considerations) should be taken into consideration to generalize the results. Another limitation of this methodology which affects the generalization of the results is represented by the involvement of human in the decision-making process.

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