A Model-Based Clinical Decision Support Approach Using DEMATEL, ANP and TOPSIS

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***Abstract*—For many complex diseases, finding the best treatment alternative is a non-trivial task. Clinical decisions are often multiple criteria decision-making (MCDM) problems, involve more than one decision maker and have many, possibly inter-related or conflicting criteria. Clinical decision support systems (CDSS) can integrate MCDM methods to assist physicians in decision making and improve outcomes of care from the perspective of patients. We propose a hybrid analytic approach based on strengths of 3 MCDA methods (DEMATEL, ANP and TOPSIS) applied in a fuzzy setting to assist in medical treatment decisions. The result is a model-based system that has the potential to overcome some of the shortcomings of earlier generations of CDSS.**

I. INTRODUCTION

For some medical treatment decisions, there is one clearly superior path (e.g., acute bacterial meningitis needs antibiotics). But sometimes the scientific evidence about options is limited and a clear solution doesn't immediately stand out. To analyse and interpret the available data for diagnosis and treatment of a patient in these situations, time consuming meetings of physicians from different medical domains (e.g., oncology, radiotherapy, surgery, radiology) is conducted. Each physician creates a mental model of the patient based on their expertise, and reasons for different courses of action based on that model. Including patients in decisions is an additional challenge. Different points of view can make arriving at a unanimous decision difficult. Complex cancer treatment decisions are a good example.

A. Clinical decision support systems

Clinical decision support systems aim at integrating clinical and demographic patient information to provide support for decision making by clinicians [1]. CDSS were first introduced into clinical care in 1950s and since then gained increasing levels of sophistication with regards to inputs (patient-specific data), knowledge bases, logic, and outputs. These systems are expected to improve the quality and safety of health care and reduce patient mortality and complications, but systematic evaluations, have not demonstrated reliable results [2], [3] .

Most CDSS rely on large sets of patient data and supervised machine learning [4] for predictions and prompts. Employing these methods is not easy due to the magnitude of required data which is difficult to attain for complex medical cases. Other systems follow rule-based or fuzzy logic approaches [4] but the weakness of these approaches is the lack of a presentation of causality [5].

To overcome the shortcomings of earlier generations of CDSS, the idea of model-based decision support [4] gained popularity [6],[7]. Andreessen et al. [4] proposed a model-based approach as an appropriate methodology for construction of CDSS. In their approach a structural model of the relevant physiology or pathophysiology is used to predict responses to treatment, and decision theory is used to determine which treatment gives the best expected outcome.

A. Hybrid Decision Making Methods

To increase precision in decision making, various hybrid MCDM methods were proposed and applied in different fields, from performance evaluation of aviation firms [8], wind farm location planning [9], portfolio selection [10], to evaluation of investment projects [11] among others. However, application of hybrid MCDM methods in healthcare, is few and far between. Most studies we found, focus on shared decision making, and on involving patients in treatment selection. We have not found any research for decision support systems that assist physicians in diagnosis and treatment option selection while including patients in decision making in an integrated manner.

Thereby, this study proposes a new integrated approach that could cope with the interdependencies among various criteria in medical decisions.

The objective of this paper is to present a hybrid analytic model-based decision support based on DEMATEL, ANP and TOPSIS methods to assist in medical treatment decisions. The general view of the proposed approach is shown in Fig. 1.

We start by a review of the incorporated MCDM methods, and then the main components of the model are presented to structure a framework for patient-specific treatment evaluation. The next section includes the illustration of the proposed model. The paper concludes with future directions.

II. MODEL-BASED DECISION FRAMEWORK

For evaluating and selecting treatment options for a patient, both qualitative and quantitative factors must be considered. Use of MCDM methods are appropriate in these situations to facilitate decision making in diagnosis and evaluation of treatment options, include patient's preferences in the decision, and reduce bias and possible errors.

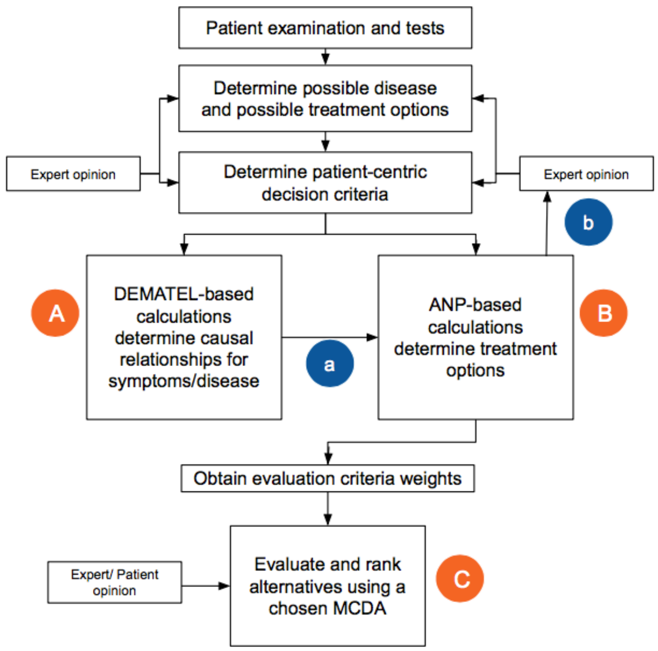

Fig. 1. General model

A. MCDM Methods

A large and growing number of MCDM methods are available [12][13]. MCDM methods vary with respect to the core decision rules that they implement, the required data and parameters of the method, the modelling effort, their outcomes and their granularity. We selected the following methods:

1.*ANP*: Analytic Hierarchy Process (AHP) [14] is a theory of relative measurement based on paired comparisons used to derive normalised absolute scales of numbers whose elements are then used as priorities.

The Analytic Network Process (ANP) [15] is a special variation of AHP that can handle dependence and feedback in-between factors and criteria. Both the AHP and the ANP derive ratio scale priorities by making paired comparisons of elements on a common property or criterion.

A network has clusters of elements, with the elements being connected to elements in another cluster (outer dependence) or the same cluster (inner dependence).

The priorities derived from pairwise comparison matrices are entered as parts of the columns of a supermatrix. Beside local priorities, we can also introduce cluster priorities with respect to the goal. So this raises the question of whether another method is required for analysing interdependencies. This point is addressed in the next section.

2.*DEMATEL:* The Decision Making Trial and Evaluation Laboratory (DEMATEL) [16], is a method for building and analysing a structural model involving causal relationships between the decision elements. Same as ANP, it uses pairwise comparisons to create a contextual relation among the elements of the system. Numerical scales represent the strength of influence.

After a thorough survey of literature, we employed DEMATEL method to analyse the causal relationships and then to build a network relation map (NRM) between factors and criteria and also to obtain the influence levels of each element over others for treatment evaluation. The weights of each factor of MCDM problem for selecting the best treatment will then be derived by using ANP based on the NRM.

Various studies (e.g. [17],[18]) mentioned a problem with handling of interdependencies among elements or clusters in an ANP method, however a careful read of Saaty's explanation [15] clarified that this method can be used when interdependencies exist among criteria, and weights can be applied to clusters.

Since our aim is to introduce a model-based methodology, the different parts of the model are separated even with respect to the MCDA method they employ. The DEMATEL method is used to separate the creation of the causal relationship map of the disease and symptom clusters and to determine the degrees of influence of these factors so that we can apply these to the normalise the unweighted supermatrix in the ANP at a later stage.

3.*TOPSIS:* The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) [18] is based on the idea that the most preferred alternative should be the shortest distance from the ideal solution and the longest distance from the negative ideal solution. The weights required for evaluation of alternative in our proposed model will be derived from the previous two steps (DEMATEL and ANP evaluations). At this step, shared decision making on the course of treatment can be conducted with the patient when possible.

Since decision-making in real world problems needs to take into account the possible uncertainty and ambiguity in linguistic reasoning, fuzzy logic [19] will be used in judgement evaluations.

III. COMPONENTS OF THE MODEL

The model can incorporate both statistical data in construction of treatment options and expert (physician) judgment about the particular patient based on his or her history. When statistical data are present, they can be used in the system instead of expert judgements. When expert judgment is present, it should be possible to combine judgment with statistical data to build models for identifying a course of action that suits the patient best.

The first three steps of the method are based on a patient's examination results and physician's expert judgement. Patient-specific factors that need to be considered in (such as life expectancy, insurance coverage, etc) should be included in the ANP step of the model. A physician needs to derive an initial symptom-disease-treatment network model. A general diagram of the Disease/Treatment Network is shown in Fig. 2. This diagram shows interrelations between symptoms, diseases and alternative treatments.

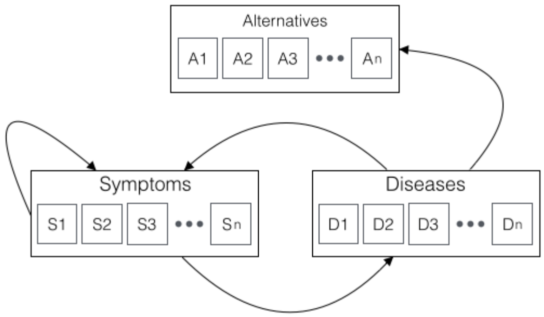

Fig. 2. Disease/Treatment Network

The following steps demonstrate the core methods of the model-based system.

A. Construct causal relations of symptoms/disease using DEMATEL

In this step physicians are asked to indicate the degree of direct influence each symptom/disease experts on each of the other symptom/disease. Statistical data should be used when available, but in absence of reliable data, expert judgements can be applied. A fuzzy scale can be used to elicit expert judgements.

DEMATEL determines factors of order, direction and level, in the complex causal relationship, in a general format, without prioritisation of the important factors to the specific patient case. These "biological models" can be developed for different conditions and be kept in the system for application to different patients.

Fig. 3. shows the inner working of this model.

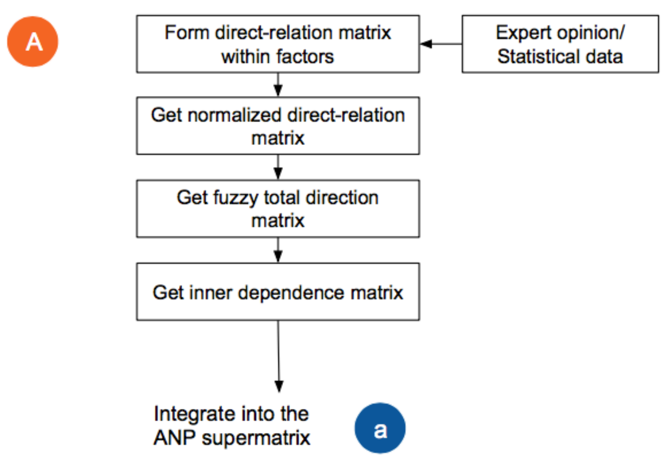

Fig. 3. Application of DEMATEL

The mathematical equations for calculating the inner dependence matrix can be obtained from [20].

Following these step, the network-relation map can be obtained and used for visualisation. The inner dependence matrix, which is the outcome of our calculations at this step will be put in the unweighted supermatrix of ANP for disease/ treatment calculations.

B. Using ANP, rank treatment alternative based on diagnosis

A complete feedback system must factor in the importance and the relationships among underlying factors. An ANP model takes into account the causal relationships derived from DEMATEL as weights for clusters of disease/symptoms.

Priorities of alternative treatments with respect to disease needs to be given at this step. These priorities suggest which alternative treatment would be most appropriate given the disease in question. Patient differences in life expectancy (age), risks, side-effects and other important factor should be included in this step to tailor the available alternatives. Fig. 4. shows the steps in this process.

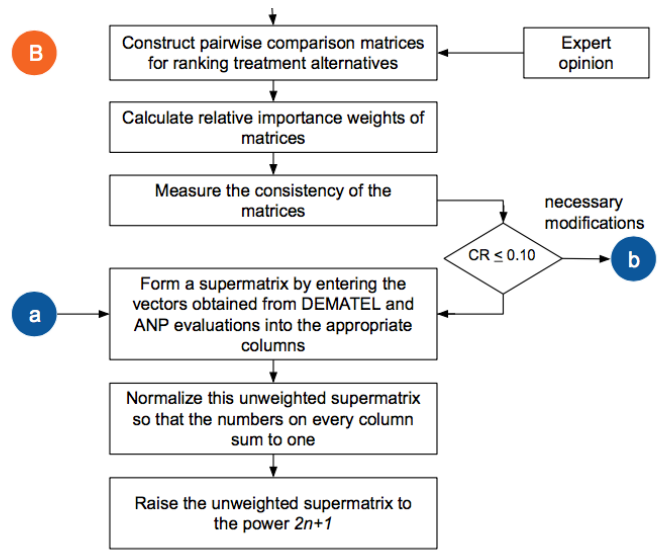

Fig. 4. Application of AHP

Mathematical consistency of judgements need to be validated through inconsistency ratio analysis.

Calculations within the ANP step are in [21].

Finally, sensitivity analysis needs to be performed to identify specific factors that contributed treatment option ranks.

C. Use TOPSIS for shared decision making on treatment alternative

When many suitable treatment options are available, patient's subjective preferences can be included at this step. If the patient can't or does not want to be involved in decision making, the physician can make the final choice.

For the third part of this system, since the weightings of alternatives is already derived from the previous steps, TOPSIS is used because it only requires ideal and anti-ideal parameters.

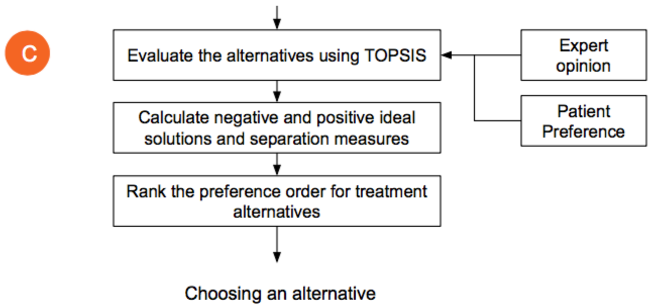

Fig. 5. Application of TOPSIS

Since human judgment about preferences are often unclear and hard to estimate, in both DEMATEL and AHP steps fuzzy scales in Table I are used.

TABLE I
FUZZY NUMBERS RELATED TO LINGUISTIC TERMS

Linguistic Scale	**Abriviation**	**Fuzzy Scale**
Very High Effect	VH	(0.75, 1, 1)
High Effect	H	(0.5, 0.75, 1)
Low Effect	L	(0.25, 0.5, 0.75)
Very Low Effect	VL	(0, 0.25, 0.5)
No Effect	N	(0, 0, 0.25)

IV. DISCUSSION AND CONCLUSION

MCDM techniques have the potential to serve as the foundation for a new generation of CDSS designed to deliver the modern health care system's ideal of patient-centered, evidence-based care. The current literature on MCDM in healthcare offers little guidance to users and developers on application of hybrid models. In this paper we proposed a concept of a model-based decision support approach that integrates three different MCDA methods.

The interrelations between the models were then discussed. By separating evaluations on biological data based on symptoms present in one patient, we create reusable components (matrices) that can be used for other patients in the future. A patient model is constructed in the second stage and includes all patient-specific requirements to rank treatment alternatives. The final decision can include the patient for shared decision making.

The next step for us is to test the validity and usability of the proposed hybrid method in a clinical settings and evaluate it's performance against the methods currently in use.

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