A DESCRIPTIVE DECISION-MAKING MODEL OF PATIENTS' TREATMENT DECISION USING DEMPSTER-SHAFER THEORY AND PROSPECT THEORY

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ABSTRACT

This paper explains our proposed descriptive decision-making model under uncertainty elucidating different decision attitudes of humans. In this decision-making model, Dempster-Shafer Theory (DST) is used to represent uncertainty of the problem and the uncertainty is approximated by a probability distribution depending on the decision-makers' attitude towards uncertainty. Prospect theory is then applied to accomplish a descriptive decision-making model. We use the proposed model to illustrate and explain how patients make decisions in case of elective treatment and how their decisions vary with their attitudes towards uncertainty. We have also experimentally determined reliable values of the coefficient of loss aversion and risk attitude. This application area holds great importance in health related decision-making.

INTRODUCTION

Medical science involves decision-making either under certainty or uncertainty. Traditionally, medical practitioners played a paternalistic role in treatment decisions and the patients mostly abided by the decisions. But there has been revolutionary change in medical fields since few decades and the patients are being more and more encouraged to get involved in treatment decisions. The patient's preference is especially more important when there are several alternatives of treatment and each alternative has its own trade-offs and each patient has his/her own viewpoint of judging the trade-offs [2]. For example: a patient with rheumatoid arthritis may face three anti-tumor necrosis factor-alpha (TNF-alpha) therapy options: etanercept (Enbrel), adalimumab (Humira) and infliximab (Remicade). Ref [3] expresses how the therapy decisions vary depending on various factors. Researches on patient decision-making have an extensive history. In early 1980s, researchers started experiments in the field of urology involving advanced technology. Multiple studies have shown that the combination of physicians' knowledge and patient's participation improved patient satisfaction and physician's time [12]. Although the traditional school of thought argued that involving patients in choosing treatment can make them burdened or can be unfavorable for them, yet no such evidence exists to support this issue [5]. In fact there have been evidences that patients feel more active when being included in health-care decisions [7]. Decision-making (DM) is critical to human life in case of treatment and other aspects as well. Decision-making models can be classified into two groups: Normative or prescriptive and Descriptive decision models. This paper describes a descriptive decision-making model under uncertainty in brief and elucidates its application in patients' decision-making. At first we have modeled a DM problem under uncertainty as the Evidential DM Problem (EDMP) and converted it into DM problem under risk. We approximate probabilities using the basic belief assignment (bba) of Dempster-Shafer Theory (DST) [10] associated to the subsets of the states of nature taking into account, the decision-makers' attitude towards uncertainty. Prospect Theory (PT) [4] is then used to explain how a decision maker formulates decision in different attitudes. The goal of this paper is to: 1) illustrate decision trends across patients of varying financial backgrounds, 2) find appropriate coefficient values that support natural behavior based on our model.

PROPOSED DESCRIPTIVE DECISION-MAKING MODEL

Our proposed model initiates with an *Evidential Decision Making Problem (EDMP)*. EDMP has similarity to the conventional definition of decision making in different literature where $A=\{a_i| i=1\ldots N\}$ is the set of alternatives, $S=\{ s_j \mid j = 1,\ldots,M\}$ is the states of nature and the outcome set $O=\{o_{ij} \left| o_{ij} = f(a_i, s_j)\right.\}$ and the utility function $u_{ij}=u(o_{ij})$. The uncertainty is defined on the states of nature $S: m(B)$ where $B\subset S$. $m(B)$ represents the basic belief assignment *(bba)*. We chose the Dempster-Shafer Theory (DST) of Evidence due to its capability of expressing more than one type of uncertainty. Decision-making is practically performed under the realm of certainty, risk, uncertainty and/or ignorance [6]. Our definition of EDMP satisfies all of these realms. A normative model with generalized expected utility (GEU) was proposed [14], [16] to deal with DM under uncertainty with incomplete knowledge of probabilities. GEU of any alternative can be explained by the multiplicative sum of $m(S_k)$ and $V(a_i, S_k)$ where $m(S_k)$ is a basic belief assignment and S_k is a focal element representing a subset of states of nature. It is to be noted that S_k ($k=1...K$) does not have to partition S necessarily unlike rank-dependent utility models [11] or Cumulative prospect theory [1]. $V(a_i, S_k)$ is a utility evaluation depending on a_i and S_k, and is obtained by a parametric function called Ordered Weighted Averaging (OWA) operator[13][15], whose parameters are determined by the attitude of the decision-maker. The weights of the OWA operator are associated with the position in an ordered argument. In an Equative approach, the OWA weight is equally distributed among all states in the subset of the states of nature. In pessimistic approach, the OWA weight is assigned to the state having the smallest utility value and for optimistic approach the weight is assigned to the state with the largest value. A seemingly standard way of approximation from *bba* to probability is the one by equidistribution where the mass is equally distributed over the states of the focal element. When the mass function is defined on a total ordered set, or a set whose elements have a numerical attribute as in this case, we could assign probability distributions of the worst case and the best case which are consistent with the mass function; the best case assigns the whole mass of S_k namely $m(S_k)$, to the largest/best element $s_{best}^{(k)} \in S_k$, and the worst case to the smallest/worst element $s_{worst}^{(k)} \in S_k$. Note that $s_{best}^{(k)}$ and $s_{worst}^{(k)}$ depend on alternative a_i, because utility is a function of a pair of a_i and s_j. Therefore, $P_{pes}(s_j \left| a_i\right.)$, $(P_{opt}(s_j \left| a_i\right.))$ is the probability distribution in the case where we assume that $s_{worst}^{(k)}$ ($s_{best}^{(k)}$) happens with a probability equal to $m(S_k)$, when the decision-maker chooses a_i and thus the name Pessimistic (Optimistic) probability distribution respectively. Moreover, it is also possible to show that any solution with OWA operator can be transformed into a DM under risk. This fact lets us discuss descriptive model of DM under uncertainty in the framework of DM under risk. (Please refer to [8] for detail explanation and derivation). By approximating uncertainty to probability, we have converted the EDMP into three different problems of DM under risk. At this point, applying PT will lead us to a descriptive model of DM under risk corresponding to DM under uncertainty with OWA operator. In PT, the choice of alternatives are determined by the combination of two very important functions: the value function and the weighting function [4]. In value function $v(x)$, x is either gain or loss. For $\alpha < 1$, the value function exhibits risk aversion over gains and risk seeking over losses. Furthermore, if λ, the loss-aversion coefficient is greater than one, individuals are more sensitive to losses than gains. Our proposed model is a mathematical expression representing partly the human cognitive process. Moreover, it has the advantage of deriving the 2nd optimistic/pessimistic, half-/semi-/quarter optimistic and pessimistic attitudes and median approaches [8], [9] which were unexplained by the previous researches. Furthermore, this model removes the problem of considering the difference between weighting function of probability and the one of bba since we have converted the EDMP into a probabilistic decision-making problem.

HOW A PATIENT TAKES DECISION REGARDING TYPE OF TREATMENT

Human life encompasses a wide variety of diseases from minor health problems to life-threatening or terminal diseases. With the advent of new technologies, medical field has gone through major metamorphosis and consequently has come up with several alternatives of treatment for almost any known disease. Studies show that several factors such as external recommendation, intrinsic treatment characteristics, patients' and their supporters' own impressions and economic considerations are the most common factors of treatment decisions for non-malignant diseases whereas treatment efficiency (from the viewpoint of physician as well as patient) gets the top-most priority in case of life threatening diseases. The treatment decisions vary from one patient to another depending on their viewpoint of judging uncertainty. We assume that the patients are not sure about the acuteness of the disease thereby indicating the uncertainty of the problem which is represented in our constructed EDMP.

Problem Formulation

An EDMP includes the set of states of nature *S*, set of alternatives *A* and the set of outcomes *O* for each state and alternative pair (a_i, s_j) and utility values for each outcome. The DM problem of patients' treatment decision can also be considered as an EDMP with ailment/disease severity as states of nature and treatment options as alternatives. Apart from the disease/ailment type, another factor that plays an important role in medical decision-making or choice of treatment is the financial status of the patient. Patients belonging to different financial conditions might have different perspective towards the decision of treatment. Therefore, we have examined the whole problem from perspectives of four different financial statuses: *Poor*, *Lower-middle*, *Upper-middle*, *Rich* and the uncertainty lies in the type/severity of diseases.

States of Nature: In this DM problem the states of nature is considered according to the severity of any disease from a minor to an acute one. Therefore, the set of states includes $S=\{s_1, s_2, s_3, s_4\}$ where s_1 =Type1, s_2 =Type2, s_3 =Type3, s_4 =Type4. Type 1 is a minor ailment and Type4 is the most acute one. There may not always be distinct lines among the states of the diseases while the diagnosis has just been started. Moreover, we are viewing the problem from the patient's side and it is quite natural for him to be uncertain of the severity of the ailment. The levels of disease severity can easily be extended while needed.

Degrees of Belief: We assume that the state of disease/illness is uncertain to the patient and they are always anxious to expand their understanding of their disorder. The availability of evidence as well as consciousness of diseases may not be the same for the patients from different financial conditions. We suppose that the quality of evidence about any disease as well as awareness is higher in case of the rich and the upper middle rather than the lower middle and the poor. Therefore, bba values vary according to their financial background as shown in Table 1.

Alternatives: The set of alternatives consists of various treatment options from which the patient and/or his/her supporters can choose according to their perception of uncertainty as well as their financial ability. Therefore, *A= {Medicine, Minor Surgery, Minor Surgery and Medicine, Major Surgery, Major Surgery and Medicine}* and each of these have levels from one to four. The levels of the outcomes imply the quality, efficacy as well as cost of that particular treatment option. Thus, Level 1, Level 2, Level 3, Level 4 implies moderate, good, very good and best, respectively. Efficacy and quality of treatment are two major considerations of a patient which are closely related to the cost which is also important to the patients with financial difficulties. We believe that the reflection of cost and efficacy in the decision of treatment have made the problem formulation robust and effective.

Outcomes and Utility Values: The consideration of outcome set for a treatment decision mostly depends on *cost or expense of the treatment (X), treatment success rate (S), comfort level (C) caused by the treatment* and also *side effects(E).* Therefore, in this problem we consider four issues and the outcome set can be given by a quadruplet of *O*. The outcomes can be defined by the Cartesian product of the following sets: $O=O_X$ x O_S x O_C x O_E where O_X = *{Very Expensive:0, Expensive:1, Moderately Expensive:2, Inexpensive:3}*, O_S = *{Very Low Success Rate:0, Low Success Rate:1, Moderate Success Rate:2, High Success rate:3}*, O_C = *{Unbearable pain:0, Severe Pain:1, Moderate pain:2, Mild or no pain:3}*, O_E =*{No Side Effect:3, Minor Side Effect:2, Moderate Side Effect:1, Severe Side Effect:0}.* Therefore, the set *O* has 256 outcomes in total. Table 2 partly shows the outcome table with corresponding utility.

Table 1: Belief Table

BBA	Poor	Lower middle	Upper middle	Rich
$m(B_1)$ $=m(\{s_1,s_2\})$	0.35	0.25	0.2	0.2
$m(B_2)$ $=m(\{s_2,s_3\})$	0.25	0.3	0.3	0.25
$m(B_3)$ $=m(\{s_3,s_4\})$	0.2	0.3	0.3	0.25
$m(B_4)$ $=m(\{s_1,s_2,s_3,s_4\})$	0.2	0.15	0.2	0.3

Table 2: Outcome Table

Outcome	Outcome Description	Poor	Lower-middle	Upper-middle	Rich
O_1	Very Expensive, Very Low Success Rate, Unbearable Pain, No Side Effect	4	4	4	13
O_2	Very Expensive, Very Low Success Rate, Unbearable Pain, Minor Side Effect	3	3	3	9
O_{255}	Inexpensive ,High Success Rate, Mild or no Pain, Moderate Side Effect	254	254	254	248
O_{256}	Inexpensive, High Success Rate, Mild or no Pain, Severe Side Effect	253	253	253	244

This is to be carefully noticed that the weights of each outcome criteria vary from one status to another. These criteria have been weighted according to the importance level to the patients. For all patients, irrespective of their financial condition, the highest values of *X, S, C* and the lowest value of *E* represent the highest utility and the lowest values of *X, S, C* with the highest value of *E* represent the lowest utility. Furthermore, it is evident in real life that power of choice increases with financial ability. The poor can maximize the utility firstly by expense, the lower-middle by success rate and expense together, the upper-middle by success rate, comfort and expense together and the rich by all variables. As a result, we have the following formulae for the four financial categories keeping in line with the order of importance of variables for each case. The utility formulae for the Poor, Lower-middle, Upper-middle and Rich are: ($X*64+S*16+C*4+(4-E)$), ($S*64+X*16+C*4+(4-E)$), ($S*64+C*16+X*4+(4-E)$) and (($S*64+C*16+4*(4-(E+1))+X+1$)). According to this, the utility value of outcome $o_1$for the poor can be calculated as (0*64+0*16+0*4+(4-0))=4 as shown in Table 1.

From the belief structure, we can now approximate the probabilities in three different attitudes of a decision-maker: Equative, Pessimistic and Optimistic and proceed to apply PT for overall value of each outcome for the mentioned economic statuses. In PT, the choice of reference point determines the perception of an outcome. In this paper we use 4 different reference points due to the qualitative nature of outcomes and the variation of outcome perception across financial states. As an example, any outcome for poor with utility more than the outcome corresponding to (inexpensive, very low success rate, unbearable pain, and severe side effect) will be a gain. So this outcome can be treated as the reference outcome. Thus, all of the utility values and reference points (required for PT) are derived keeping the power of choice in view. The next important part is to apply value function and weighting function to acquire and analyze decisions in different attitudes. The value function $v(x)$ uses α, explaining risk attitude and λ, called the loss aversion coefficient. It is widely known in different literature that α to be less than 1 whereas $\lambda>1$ resembles loss aversion. To the best of our knowledge, there is no agreed upon value combination for these two very important coefficients apart from the empirical examples performed in the literature. Moreover, the loss aversion and risk attitudes obviously vary from domain to domain. For example, we can in no way state that the loss aversion and risk attitude of money/ finance domain match with those of health. In our research, we have taken this important issue into account and used 48 combinations of (λ, α, γ) for evaluating the alternatives and at last explained the values of λ, α, γ that closely resemble natural behavior pattern of patients.

Natural Behavior: Many surveys have supported the fact that patients of the non-malignant diseases have stronger preferences for pharmacotherapy (medicines or drugs) over invasive procedures [7]. Therefore, we can reasonably assume that the patients with any decision attitude discussed in this work are less likely to adopt an alternative of treatment that involves serious or major invasive procedure (major surgery). A pessimistic attitude can have two fold interpretations in real world. On one hand, a pessimist always thinks that he possesses the most acute ailment and on the other hand he feels that a higher degree of treatment may not be very successful for his cure and can possibly do more harm to his condition. His natural tendency is to lower the degree of treatment to the bare minimum requirement whereas for an optimistic patient, exploring higher degree of treatment does not raise an alarm. An optimist wants to get complete recovery and so, he adopts higher stages of treatment fitting to his financial capacity. But still, he tends to be averse towards higher extremes of treatment. Furthermore, a patient with equative attitude may show similarity to the pessimistic attitude in case of weak financial conditions yet his tendency is to get cured with moderate medical exertion suiting his financial background and therefore he tends to adopt some sort of minimal invasive treatment which differs him from a pessimist with strong financial condition.

RESULT AND DISCUSSION

Financially restrained patients (poor, lower middle and upper middle) for all types of diseases try to minimize their expenses as a first priority. So, for both equative and pessimistic attitudes, their choices are similar and ranges between minor medicinal treatments to moderate medicinal treatment. In the same scenario a rich patient in an equative approach opts for moderate levels of minor surgery whereas in pessimistic approach the treatment choice is similar to the financially restrained patients. For optimistic attitude, all patients intend to choose minor surgery at different levels with an optimistic thinking of getting completely cured. The combination of parameters that closely resembles the natural behavior in decision-making regarding treatment alternatives according to our experiment are given in Table 3.

The value of 3.06 and 4.8 of λ are the higher values whereas the values of α are lower range values and γ values include 2nd and 3rd quarter values within its range. Thus, through our descriptive DM model, we have represented distinguished decision attitudes of patients from different financial background and derived a reasonable combination of coefficients used in Prospect Theory for the health domain that represents natural behavior.

Table 3: Patient's Decision of Treatment

λ	α	γ
3.06	0.32	0.25-0.75
4.8	0.1	0.25-0.75

	Equative	Pessimistic	Optimistic
Poor	Medicine: Level 1	Medicine: Level 1	Minor Surgery: Level 1
Lower Middle	Medicine: Level 2	Medicine: Level 2	Minor Surgery: Level 2
Upper Middle	Medicine: Level 2	Medicine: Level 2	Minor Surgery: Level 2
Rich	Minor Surgery: level 2	Medicine: Level 2	Minor Surgery: Level 2

This might be helpful for future research of the similar domain and characteristics. The proposed structure of DM problem that we used in this research is scalable and applicable to generalized problems of similar nature. It is possible to use this formulation for any specific disease and its corresponding stages of acuteness. Therefore, this research might also be helpful to the management personnel of health care organizations and medical centers. In conjunction with statistics of occurring diseases and/or epidemics in a locality, this research will find its use in efficiently mitigating the supply chain demands of medicinal resources.

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