Delphi-Neural Approach to Clinical Decision Making: A Preliminary Study

Ki-Young Song\textsuperscript{1} and Madan M. Gupta\textsuperscript{2}

\textsuperscript{1} Department of Mechanical Engineering
The University of Tokyo
Tokyo, Japan
sky8071@gmail.com

\textsuperscript{2} Intelligent Systems Research Laboratory
College of Engineering
University of Saskatchewan
Saskatoon, Canada
Madan.gupta@usask.ca

Abstract. In clinical practice, making diagnostically crisp decisions is critical to successful treatment outcomes. However, there is no agreement on the operational methodology that is best suited to convert imprecise symptomatic information into crisp clinical treatment decision making. In this paper, a new computational decision making tool, Delphi-Neural Decision Making Processor (D-NDMP), is introduced as a preliminary study to apply to clinical practices for more successful and efficient operational decisions. A case study in a dental clinical decision involving a deep decay tooth is presented as an example to perform D-NDMP. The results yield a more reliable and confident opinion on the practical application of treatment decision in uncertain cases in a clinical decision making process.

1 Introduction

In our daily life, we make frequent decisions based on our past experiences which we are consciously or unconsciously subject to. Decision making may solve a problem or make it worse, but that is only revealed once an activity has been applied. In professional fields, however, such as health care, we rely on experts to make the best possible decisions and thereby lessen the chance of an unfortunate outcome following the treatment. Therefore, it is natural to develop a method to capture the best expert knowledge to ensure as much as possible that we have successful and effective clinical practices in diagnosis, monitoring and interventions.

Clinical decision making is conventionally a cognitive heuristic process: assessment (through data gathering, assimilation, and analysis), judgment (through evaluation and choice), and operational decision. Heuristics may result in a feasible solution but may cause a substantial decision error due to bias.\footnote{[1]} Also, clinical decisions involve uncertainties and trade-offs. The uncertainties may be
from the accuracy of diagnostic tests, the natural history of a disease, the effect of treatment in an individual patient, or the effects of an intervention in a group or population as a whole [2]. Considering the complexity, clinical decision making becomes a crucial and difficult procedure.

In this paper, we present a new computational decision making model, named Delphi-Neural Decision Making Processor (D-NDMP), to assist clinicians to make more successful and efficient decisions. In this model, we propose a significant modification to the neural inputs and synaptic weights by employing the Delphi technique. This Delphi-neural approach increases the reliability and the confidentiality of clinical decision making processes by quantitatively adapting opinions of professional clinicians and practitioners. As a preliminary study, a dental decision making process is introduced as an example in this paper. From the result, D-NDMP shows very promising assistance to the clinical decision making process.

2 Methods

In a decision making process, the qualitative (descriptive) terms, such as ‘very’, ‘normal’, ‘so so’, and others, which are common in clinical encounters, should be transformed into numerical scores to reflect the subjective qualitative evaluations of experts (professional clinicians and practitioners). The descriptive terms are rather fuzzy (not crisp) making it difficult to make a crisp decision. It is more precise to use numbers to represent an opinion. In this study, we use scores between $-5$ and $5$ to evaluate clinical factors (categories) for operational decisions. In this way, the limitation of point scales (such as losing information by few points and cognitive overload by too many points [3]) can be overcome. For example, if a clinician has an ‘extremely negative’ opinion on a category for a decision, the clinician would score between $-5$ and $-4$ on the category.

Table 1 describes the starting position in such a basic clinical decision making process. At the top of the table, a problem is defined for an operational decision. Regarding the definition of the problem, $n$ questionnaires are formulated as categories (clinical factors) with $m$ experts (professional clinicians). The clinicians score the categories between $-5$ and $5$ in the shaded area of the table, $C$, considering the definition of the problem. The average, $A$, of each category is calculated as

$$A_{mn} = \frac{1}{m} \left( \sum_{i=1}^{m} C_{in} \right), n \in N$$

Then, D-average, $D$, is computed by adapting the Delphi technique to improve the reliability of the opinions from the experts. $D$ represents the value of agreeing opinions from experts. The Delphi technique (or Delphi method) is a structured communication technique with a panel of experts. It was originally developed in the 1950s by the Rand Corporation, Santa Monica, California, for use in operation research. The schematic diagram of the Delphi technique is shown in Fig. 1. Experts are asked to give their opinions on questionnaires in the first round.
Table 1. Delphi-neural approach to clinical decision making

<table>
<thead>
<tr>
<th>Clinicians</th>
<th>Categories</th>
<th>Category#1</th>
<th>Category#2</th>
<th>Category#n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clinician#1</td>
<td></td>
<td>C₁₁</td>
<td>C₁₂</td>
<td>...</td>
</tr>
<tr>
<td>Clinician#2</td>
<td></td>
<td>C₂₁</td>
<td>C₂₂</td>
<td>...</td>
</tr>
<tr>
<td>...</td>
<td></td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Clinician#m</td>
<td></td>
<td>Cₘ₁</td>
<td>Cₘ₂</td>
<td>...</td>
</tr>
<tr>
<td>Average (A)</td>
<td></td>
<td>A₁</td>
<td>A₂</td>
<td>...</td>
</tr>
<tr>
<td>D-average (D)</td>
<td></td>
<td>D₁</td>
<td>D₂</td>
<td>...</td>
</tr>
</tbody>
</table>

In the next round, the experts receive other opinions anonymously as a feedback and then give new opinions under the influence of their colleagues’ opinions. This expert survey is repeated several times until a consensus occurs. This technique delivers quantitative as well as qualitative results by using explorative, predictive and normative opinions from experts. Thus, this technique is a relatively stronger process for use with naturally unsure and incomplete information [4].

As aforementioned, the core of the Delphi technique is the ‘anonymous’ circulation of the expert opinions with proper reasoning as internal feedbacks. The anonymous circulation can be expressed as

\[ C_{mn}(k + 1) = C_{pn}(k) \]  \hspace{1cm} (2)

Fig. 1. Schematic diagram of Delphi technique
where $k$ is number of round, $p$ is randomly permuted number ($p \in 1, 2, \ldots, m$). Then, average opinions, $D$, can be updated by the feedback as

$$D_n(k + 1) = \frac{1}{m} \left( \sum_{l=1}^{m} \frac{C_l(k) + C_l(k + 1)}{2} \right)$$

(3)

The feedback process can be represented by averaging the opinion from an expert and an anonymously circulated opinion. The reliability of averaged opinions, $R$, can be calculated by using variance of the opinions as

$$R_n(k) = \frac{1}{\text{var}(Cmn(k))}$$

(4)

where $\text{var}(\bullet)$ represents variance function. As the variance of $Cmn$ decreases, the reliability of the average opinion of $Cmn$ increases. The circulation should stop in the condition as

$$\forall R_j > r_d, \quad j = 1, 2, \ldots, n$$

(5)

where $r_d$ is a desired reliability defined by a user. However, it is more convenient to appoint a desired variance as an allowable variance. Thus, a consensus of opinion for each category can be achieved with final value of $D$.

The next process of clinical decision making is to analyze the consensus by a classification method. Neural networks are one of the most powerful tools for classification. Neural networks were inspired by the study of biological neurons. By employing synaptic operation and somatic operation, neural networks provide a superiority of identification and classification and have therefore been widely used in research fields [5]. In this paper, we do not consider the dynamic feedback (such as back-propagation algorithm) in neural networks but apply static neural networks to the clinical decision making process. The schematics of the proposed process is illustrated in Fig. 2.

A neural unit (single artificial neuron) is composed of synaptic operation, $v$, and somatic operation, $y_N$, and they are expressed as

$$v = \sum XW$$

(6)

$$y_N = \Phi[v]$$

(7)

Fig. 2. Schematics of the process flow of D-NDMP
where $X$ is input vector, $W$ is weight vector, and $\Phi[\bullet]$ is a mapping function. Conventionally, a sigmoid function is chosen as a mapping function due to its special characteristics exhibiting a progression from small beginning to accelerated end as natural processes [6]. In clinical decision making, D-average $D$ replaces $X$, and the value of $W$ is assigned by the professional clinicians (experts) between 0 and 1 with agreement. The Delphi technique is applied to evaluate the importance of the clinical factors (categories) for the given problem (the more important, the higher number). Thus, the synaptic operation for the Delphi-neural approach can be rewritten as

$$v = \sum DW$$

(8)

3 Case Study: Operational Decision in a Dental Clinic Practice

Decision making in dental clinics is not easy for dentists or patients. One of the most common complex dilemmas is an operational decision on deep tooth decay. In this case, mainly two choices are available: root canal treatment or implant (see Fig. 3). The former operation saves the natural tooth with a permanent filling after removing the damaged pulp (which includes the nerve and blood vessels) of the tooth. It is necessary to remove all of the pulp in the tooth to avoid further infection. Sometimes, a cap on the treated tooth is necessary to protect the tooth from a heavy load. However, sometimes the removing process cannot be perfectly performed due to the shape of the root canals. The latter operation extracts the damaged tooth and replaces it with an artificial tooth. Dental implants are titanium tooth roots that anchor an artificial tooth to the dental bone. Replacing a tooth takes time and planning. Other factors such as gum disease and bad bite may cause an implant to fail prematurely. Among professional dental clinicians and practitioners, there are no absolutes applicable to this complex decision making process [7,8].

![Fig. 3. Dental treatment for deep tooth decay: (a) root canal treatment and (b) implant](image-url)
Now we apply the proposed Delphi-neural decision making processor (D-NDMP) to this clinical decision making. In order to perform the process by D-NDMP, we first need to define the clinical problem in order to formulate questionnaires (categories). An example is presented for a case study below.

A healthy man had a very sensitive molar. A few days later, he felt pain around the molar and went to see a dentist. The dentist (d1) found that the root of the molar was infected by a virus. The dentist (d1) decided to perform a root canal treatment on the tooth after discussing the situation with the patient. While the dentist (d1) was drilling a hole on the tooth, he found a crack on the tooth. The crack has not shown on the X-Ray picture taken before the process. The dentist (d1) informed the patient about the crack and decided to continue the root canal treatment on the next visit. The patient visited another dentist (d2) for a second opinion on the tooth. The second dentist (d2) examined the tooth carefully and discovered that the crack continued into the gum. The second dentist (d2) then suggested an implant process to the patient since in his opinion the crack probably continued to the deep end of the tooth. The second dentist (d2) explained to the patient that in this case root canal treatment would not be sufficient to treat the tooth permanently. The patient visited a third dentist (d3) who concluded that root canal treatment would be a suitable treatment for the tooth.

The problem in the given example is to select the better treatment for the damaged tooth: root canal treatment or implant. In order to select one alternative using D-NDMP, root canal treatment is scored in positive numbers (1 ∼ 5, the higher number being a stronger recommendation). The implant option is scored in negative numbers (−5 ∼ −1, the lower number being a stronger recommendation). The neutral opinion is scored as 0. Three experts are associated with different opinions on the treatment. The clinical factors (categories, F) for the operational decision and the weights (W) of the factors would be:

- F1: importance of infection in the tooth for the treatments (W1: 1)
- F2: importance of crack on the tooth for the treatments (W2: 1)
- F3: importance of mobility (shakiness) of the tooth for the treatments (W3: 0.1)
- F4: importance of the patients health for the treatments (W4: 0.8)
- F5: predictability of the success of the treatments (W5: 1)
- F6: risk of the infection after the treatments (W6: 0.8)
- F7: finances for the treatments (W7: 0.6)
- F8: aesthetic after the treatments (W8: 0.8)

The clinical factors and weights would vary in a real practical case. The given factors and numbers are reasonably selected for this case study. The weights (W) of the factors vary between 0 and 1 which would be defined after agreement of the experts opinions. F3 has very low weight since the damaged tooth is rarely mobile (shaking). The complete table of decision making for this example is shown in Table 2.
Table 2. D-NDMP to decision making in dental operational decision

<table>
<thead>
<tr>
<th>Clinicians</th>
<th>F1 (W1: 1)</th>
<th>F2 (W1: 1)</th>
<th>F3 (W1: 0.1)</th>
<th>F4 (W1: 0.8)</th>
</tr>
</thead>
<tbody>
<tr>
<td>d1</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>d2</td>
<td>-5</td>
<td>-5</td>
<td>-1</td>
<td>-4</td>
</tr>
<tr>
<td>d3</td>
<td>2</td>
<td>-2</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Average (A)</td>
<td>0.67</td>
<td>-1.67</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>D-average (D)</td>
<td>0.04</td>
<td>-0.42</td>
<td>0</td>
<td>0.06</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Clinicians</th>
<th>F5 (W1: 1)</th>
<th>F6 (W1: 0.8)</th>
<th>F7 (W1: 0.6)</th>
<th>F8 (W1: 0.8)</th>
</tr>
</thead>
<tbody>
<tr>
<td>d1</td>
<td>4.5</td>
<td>3</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>d2</td>
<td>-4</td>
<td>-2</td>
<td>-4</td>
<td>-5</td>
</tr>
<tr>
<td>d3</td>
<td>2</td>
<td>0</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Average (A)</td>
<td>0.67</td>
<td>0.83</td>
<td>0.33</td>
<td>1.33</td>
</tr>
<tr>
<td>D-average (D)</td>
<td>0.05</td>
<td>0.02</td>
<td>0.08</td>
<td>-0.04</td>
</tr>
</tbody>
</table>

3.1 Conventional Approach (Averaging)

Conventionally, the average value, A, would be applied to make a decision. For the calculation, A was applied as neural inputs with given weights and sigmoid function. As the result with A, the root canal treatment is highly recommended for this patient. The result is shown in Fig. 4. The blue line represents the mapping function between -5 and 5. The red dot is the final neural output (yN), and the output represents how the final decision is confident with the two treatment, implant (-1) and root canal treatment (1), respectively. In this example, the value of synaptic operation (v) is 1.17, and yN is 0.82 with average, A, as neural input, which means that it is highly recommended (about 82%) that the patient should take the root canal treatment as operational decision. The decision may be acceptable; however, the reliability of the decision is still questionable.

3.2 D-NDMP Approach

Now we perform D-NDMP to make a decision for the same example. MATLAB was used to develop D-NDMP. In order to increase the reliability of the processor, the tolerance for matrix C was initially set to 0.1. That means that the circulation round for the Delphi technique continues until the variance in each category becomes less than the tolerance. D-average was achieved with little variances (< 0.1) for each category, which yielded v = -0.24 and yN = -0.24. This result recommended that the patient might take the implant operation, which is a different opinion from that of the conventional decision making. Furthermore, the decision may be reconsidered since the value of the neural output
Fig. 4. Result of the decision making by a conventional method, averaging the scores. From the result, the root canal treatment is certainly recommended (82%).

is not convincing (< 0.4). It was also observed that as the tolerance changes, the decision of D-NDMP are altering (see Fig. 5). That indicates that operational decision is still debatable, which indicates that the conventional decision may not be a right choice.

4 Conclusions

In this paper, we propose a new computational decision making method by developing a Delphi-neural decision making processor (D-NDMP) as a preliminary
study. The Delphi technique was adapted to increase the reliability of the decision, and neural networks were employed for classification. D-NDMP provides an adaptive method on consensus opinions to improve quantitative as well as qualitative decision making in clinical decision making processes. An operational decision making in a clinical dental practice was considered as a case study in this paper. The result of the case study shows that as the reliability of the information increased, the decision became more neutral, which indicates that both treatments are still in debate with current experts and categories. The model developed herein will next to be tested with actual clinical data.

References