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Treatment Planning in Smart Medical: A Sustainable Strategy

Fei Hao*, Doo-Soon Park*, Sang Yeon Woo**, Se Dong Min***, and Sewon Park****

Abstract
With the rapid development of both ubiquitous computing and the mobile internet, big data technology is gradually penetrating into various applications, such as smart traffic, smart city, and smart medical. In particular, smart medical, which is one core part of a smart city, is changing the medical structure. Specifically, it is improving treatment planning for various diseases. Since multiple treatment plans generated from smart medical have their own unique treatment costs, pollution effects, side-effects for patients, and so on, determining a sustainable strategy for treatment planning is becoming very critical in smart medical. From the sustainable point of view, this paper first presents a three-dimensional evaluation model for representing the raw medical data and then proposes a sustainable strategy for treatment planning based on the representation model. Finally, a case study on treatment planning for the group of "computer autism" patients is then presented for demonstrating the feasibility and usability of the proposed strategy.

Keywords
Degree of Membership, Fuzzy Evaluation, Smart Medical, Sustainable, Treatment Plan

1. Introduction

In today's society, healthcare has been upgraded to an important social issue related to people's work and study. This past decade has witnessed the dramatic development of modern medical technologies by virtue of the wireless internet, the Internet of Things, and other ubiquitous technologies. Importantly, smart medical, which is one of the results of this big data era, emphasizes effective treatment planning and processing for various diseases that occur in patients. Generally speaking, the process of treatment planning begins after a doctor has initially diagnosed a disease. The doctor must determine if the patient's health needs are best met by providing potential treatments and maintaining their healthcare. This question is becoming more complex than ever before because of the wide array of treatment modalities available. Particularly, smart medical aims to facilitate economic development, social progress, and environmental protection [1,2]. This is because medical organizations must take the responsibility to value natural resources by complying with regulations, while they also pursue their own maximum profit and work to reduce treatment complexities in this context.

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Corresponding Author: Doo-Soon Park (parkds@sch.ac.kr)
* Dept. of Computer Software Engineering, Soonchunhyang University, Asan, Korea ({fhao, parkds}@sch.ac.kr)
** Dept. of Sport Science, Soonchunhyang University, Asan, Korea (woosangy@gmail.com)
*** Dept. of Medical IT Engineering, Soonchunhyang University, Asan, Korea (medi1223@gmail.com)
**** School of Biological Sciences, Seoul National University, Seoul, Korea (sewon14@gmail.com)

As a result, designing an eco-efficient strategy for treatment planning is becoming a sustainable development issue. Typically, because sustainable treatment planning has multiple and mutually conflicting objectives, it is necessary and important to evaluate all available alternatives and to determine preferable strategies that conform to sustainable development.

1.1 Motivating Example

Fig. 1 shows a motivating example on the selection of treatment plans for a computer autism patient. In this example, suppose patient Joe suffers from 'computer autism' disease [3], which leads to obstacles in regards to communications and creates language barriers between people. First of all, Joe requests for medical treatment from the medical doctor, then, the medical doctor might carefully consider his situation and make selections from historical medical treatment plans. This means that many existing treatment plans might be selected for him—e.g., training intervention (applied behaviors analysis, TEACCH autism program, and interpersonal training methods) and medicine. However, some of these treatment plans cannot satisfy social and economical sustainability (i.e., higher medicine costs, expensive treatments, more pollution). Therefore, how to efficiently select the best treatment plan is a quite complicated problem. After a sustainable treatment plan is selected, it will be given to Joe.

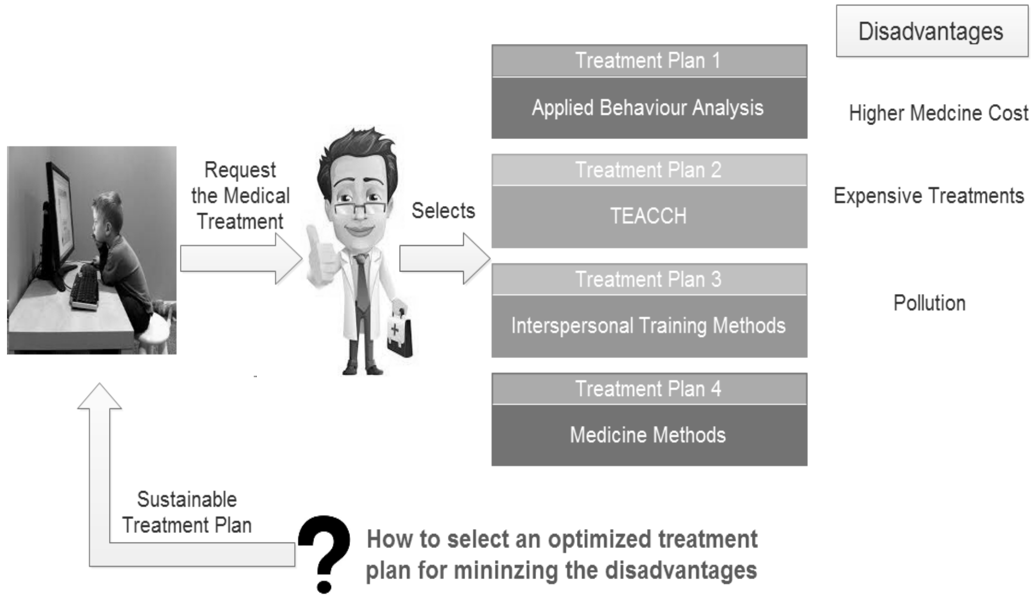

Fig. 1. A motivating example on treatment planning for a computer autism patient.

1.2 Challenges and Contributions

There have been several existing literature attempting to evaluate the level of a hospital with the multi-level fuzzy evaluation approach [4-6]. Zhang et al. [4] built a three-level evaluation model for demonstrating the plow adaptive multi-level fuzzy evaluation analysis system in coalmine industries. Hao et al. [5] adopted the multi-level fuzzy evaluation method for radar anti-jamming effectiveness, which is used to evaluate radar receiver technology levels. Tsaur and his colleagues applied the fuzzy set theory to evaluate the service quality of airlines [10]. Douali et al. [7] studied and evaluated a model framework for diagnostic decisions based on a cognitive process and a semantic web approach. Their work represented a first step towards the development of a methodology for the implementation of dynamic heterogeneous knowledge in medicine for decision support systems. Considering the difficulties that exist in measuring many intangible attributes of service quality, they employed the fuzzy set theory into the measurement of performance. Unfortunately, these studies did not take the lifecycle of the treatment and associated items into account. That is to say, existing works did not consider enough treatment dimensionalities. To overcome these existing disadvantages, this paper attempts to take the objectives, treatment plans, and treatment plan phases into account, and then proposes an efficient and sustainable strategy for selecting a treatment plan that meets the following requirements: low-side effects, low-cost, low-pollution, and sustainability [8].

The major contributions of this paper are summarized below.

- Data Representation: A tensor-based representation of the evaluation of a medical treatment plan is provided. We constructed a 3-order tensor that includes three dimensions of the objective, treatment phase, and treatment plan. Each element in this constructed tensor indicates an evaluation.
- Novel Strategy for Treatment Planning: A three-dimensional fuzzy evaluation model for selecting the sustainable medical treatment plan is devised. In order to obtain a sustainable treatment plan, we first established the membership functions for various evaluation linguistic terms. Then, a vertical aggregation was carried out (i.e., the degrees of membership are aggregated from the dimension of treatment phase), and then the overall degrees of membership were aggregated by a linear aggregation formula (i.e., horizontal aggregation).
- Evaluation: A case study was used for our model and strategy evaluation. The results demonstrate the feasibility and effectiveness of the proposed strategy. Also, the representation model was proven to have a scale extensibility via our case study.

1.3 Paper Organization

The rest of this paper is organized as follows: Section 2 presents the formalism of treatment planning and the proposed solution framework for selecting a sustainable treatment plan. Then, the three-dimensional evaluation model that takes the relevant evaluation criteria of a treatment plan into account is described in Section 3. The proposed sustainable medical treatment plan selection strategy is provided in Section 4. Section 5 provides a case study and Section 6 concludes this paper.

2. Formalism on Treatment Planning and Solution Framework

The treatment plan is the road map that a patient will follow on his/her journey through treatment. The treatment planning system begins as soon as the initial assessments are completed. In fact, the potential treatment plans can vary for the same disease. Hence, it is necessary to have a formal and accurate treatment plan for each particular patient. A sustainable strategy for treatment planning can result in the benefits (http://www.accuray.com/solutions/treatment-planning) listed below.

- Generating the highest quality treatment plans quickly and intuitively.
- Improving clinical workflow with intelligent automation.
- Creating versatile treatment plans for a variety of clinical applications.

We understand that a sustainable treatment plan must be selected quickly and confidently. By taking into account, a formalism of the addressed problem is described as:

$$T_{sustainable} \leftarrow OPT\{f(\cos t, complexity, side-effect, pollution, ...)\} \quad (1)$$

where, $f(*)$ is a comprehensive multi-objectives evaluation function, it might be a nonlinear function. Therefore, the problem of sustainable strategy for treatment planning is transformed into an optimization process upon this multi-objectives evaluation function that is associated with treatment cost, complexity, side effects, pollution, and so forth.

Table 1 lists the important variables and corresponding descriptions used throughout this paper.

Table 1. Important variables used in the paper

Notation	Description
T_n	The n_{th} treatment plan
P_m	The m_{th} phase of treatment
O_l	The l_{th} objective
w_n	The weight for the m_{th} phase of treatment
e_{ij}^k	Evaluation for a treatment plan T_k at the phase of treatment P_m

In smart medical systems or sustainable development medical industries, treatment planning is regarded as a fuzzy multiple criteria decision-making problem in which the fuzziness and uncertainty of subjective perception should be considered [1]. As for the evaluation of treatment plans, users usually employ natural language to express their thinking and subjective preferences. With natural language, the meaning of a word might be well defined, but when using the word as a label for a set, the boundaries within which objects do or do not belong to the set become fuzzy or vague.

Fig. 2 shows a generic solution framework for the problem addressed in this paper. Obviously, this framework contains two modules: Module 1, data preprocessing and representation and Module 2, data optimization and selection. In Module 1, the row medical data (numerical evaluation data) is preprocessed and tensorized as a 3-order tensor where the objective, treatment phase, and treatment plans are regarded as three dimensions. After the tensoriztion of medical data, we obtained the linguistic-represented tensor by establishing the membership functions for the linguistic terms and aggregating the calculated degree of membership on various terms (as shown in Module 2). We are going to elaborate the above-mentioned two modules in Sections 3 and 4, respectively.

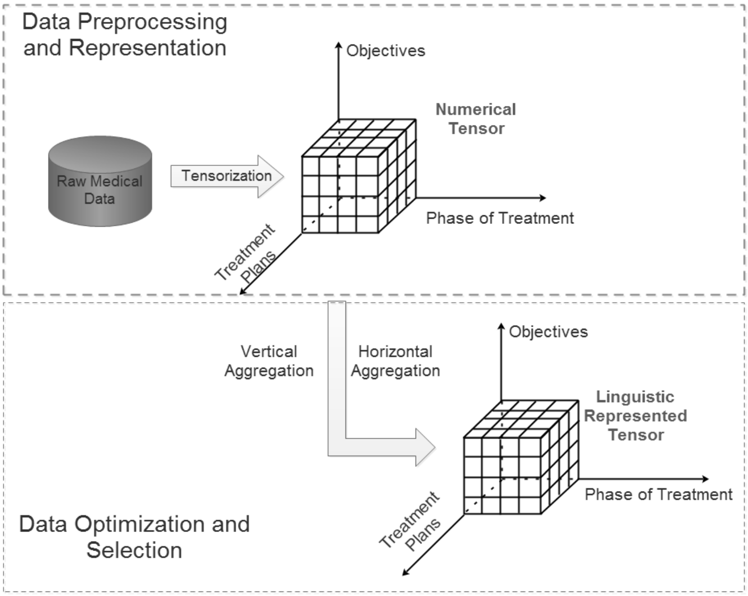

Fig. 2. Solution framework for the problem addressed in this paper.

3. Tensor-Based Representation of the Evaluation of Medical Treatment Plans

This section is devoted to presenting the conceptual structure of the three-dimensional evaluation model. As described in the introduction section, the objectives of the sustainable medical treatment plan are to provide an economical and social sustainable treatment scheme. An efficient treatment plan should save the design cost, reduce medical pollution, and lower the side-effects for patients during the different life cycle of the selected treatment plan, such as medicine selection, diagnosis, and recovery processing. Based on these motivations, a three-dimensional evaluation model for a treatment plan was constructed with a 3-order tensor [9] and is depicted as shown below.

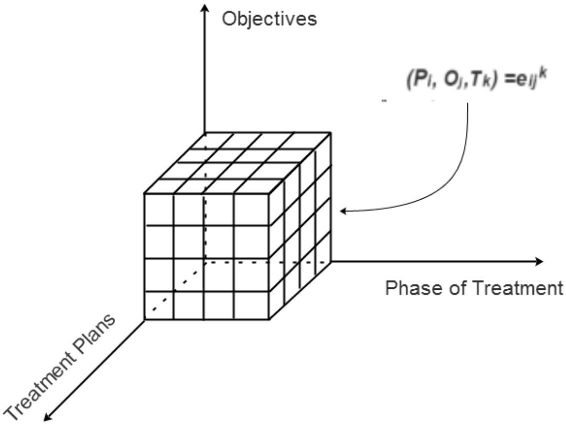

Fig. 3. Representation of evaluation on medical treatment plan with three-dimensional evaluation model.

Fig. 3 shows a 3-order tensor equipped with the 3 dimensions of: objectives, treatment lifecycle (treatment phase), and treatment plans.

Treatment lifecycle dimension: Generally, the completed lifecycle of medical treatment is mainly divided into medicine selection, diagnosis, recovery processing, and so forth, which are formally denoted as $P=\{p_1, p_2,...p_m\}$. During real life treatments, these different lifecycles have different weights, which are denoted as $W=\{w_1, w_2,...w_m\}$. For example, the weight for the diagnosis phase is obviously greater than others.

Treatment plan dimension: A set of treatment plans, $T_1, T_2,...T_k,....T_n$, are all of the possible medical treatment schemes that will be evaluated in this dimension.

Objective dimension: A sustainable treatment plan should be selected according to different objectives $O=\{o_1, o_2,...o_t\}$. For simplicity, this paper only considers 3 attributes (i.e., the lower cost, less pollution, and lower side effects of the potential treatment plans).

If we project this 3-order tensor from the dimension of objective, it has *l* rows, and it has *m* columns when we project the 3-dimensional array from the treatment phase dimension. Regarding the treatment plan T_k at the phase of treatment p_m with an evaluation value e_{ij}^k in terms of evaluation criteria e_{ij}. Therefore, each element in the constructed tensor is interpreted as e_{ij}^k.

4. The Proposed Strategy

Smart medical industries emphasize users' intelligence and experiences, an efficient treatment plan evaluation is facilitating these industries sharply [10,11]. During the evaluation of a treatment plan, users usually describe and evaluate them in natural language [8], such as

T_1 generates a little bit pollution, costs much money, has rare side effects during diagnosis

T_2 generates a lot of pollution, costs a little money, has relatively high side effects during diagnosis

Based on the above observations, the question of, "Which treatment plan is the sustainable one and how should they be evaluated?" naturally arises. To answer this question, this section presents a sustainable strategy for treatment planning based on a three-dimension fuzzy evaluation model. Our proposed strategy is composed of the steps listed below.

Step 1: Establishing the membership functions of the fuzzy linguistic terms expressed for objectives evaluation at different phase

Step 2: Calculating the degrees of membership of Step 1 and obtaining the aggregated degrees of membership in order to characterize the most sustainable one.

Step 3: Ranking the treatment plans in terms of maximum aggregated degrees of membership.

4.1 Establishing the Membership Functions

Fully integrating with users' objective opinions, we investigated the frequently used fuzzy linguistic terms "worst," "worse," "average," "better," and "best," which are normally used to evaluate the treatment plans in terms of different objectives during different phases of it.

Let $L=\{l_1, l_2, \ldots l_5\}$ be the set of fuzzy linguistic terms, $P=\{p_1, p_2, p_3\}$ be the different phases of the treatment plan, and $O=\{o_1, o_2, o_3\}$ be the evaluation objectives. The corresponding numerical evaluation matrix for a given treatment plan T_k is then expressed as $E_{ij}^k=\{e_{ij}^k\}$. Consequently, the membership functions for all possible treatment plans are characterized with triangle membership functions [12-15], as shown in Fig. 4.

1) For the linguistic term "worst," the membership function is as follows:

$$\mu_{ijl_1}(e_{ij}) = \begin{cases} 1 & e_{ij} \le r_1 \\ (r_2 - e_{ij})/(r_2 - r_1) & r_1 < e_{ij} \le r_2 \\ 0 & e_{ij} \ge r_2 \end{cases} \tag{2}$$

2) For the linguistic terms "worse," "average," and "better," the membership functions are unified as follows:

$$\mu_{ijl_{2|3|4}}(e_{ij}) = \begin{cases} (e_{ij} - r_{l-1})/(r_l - r_{l-1}) & r_{l-1} \le e_{ij} \le r_l \\ (r_{l+1} - e_{ij})/(r_{l+1} - r_l) & r_l < e_{ij} \le r_{l+1} \\ 0 & e_{ij} \notin (r_{l-1}, r_{l+1}) \end{cases} \tag{3}$$

3) For the linguistic term "best," the membership function is defined as:

$$\mu_{ijl_5}(e_{ij}) = \begin{cases} 1 & e_{ij} \ge r_5 \\ (e_{ij} - r_4)/(r_5 - r_4) & r_4 < e_{ij} \le r_5 \\ 0 & e_{ij} \le r_4 \end{cases} \tag{4}$$

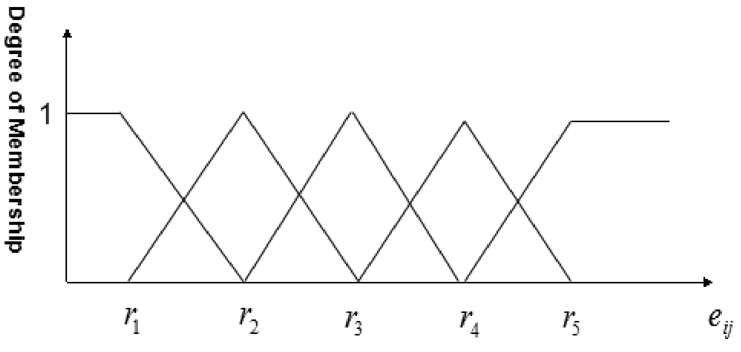

Fig. 4. The membership functions for evaluation of treatment plan.

4.2 Aggregating the Degrees of Membership

As a matter of fact, it is not enough to obtain the overall evaluation of the potential treatment plans due to the multiple dimensions criteria. To aggregate these degrees of membership, it is composed of two types of aggregation: vertical aggregation (VA) and horizontal aggregation (HA). First, VA aggregates the degrees of membership in terms of treatment phase. Second, HA aggregates the overall degrees of membership by a certain linear aggregation formula.

4.2.1 Vertical aggregation

For a given treatment evaluation objective o_i, and a given treatment phase p_i, the VA represented with $A_i^{\{V\}}$ $ at p_i, is defined as follows:

$$A_i^{\{V\}} = \prod_{j=1}^{3} \max_{l_k \in L} \mu_{ijl_k}(e_{ij}) \tag{5}$$

Eq. (5) indicates that the treatment plans at phase p_i adopt the approach of maximum degree of membership multiplication to realize the aggregation and obtain $A_i^{\{V\}}$.

4.2.2 Horizontal aggregation

The purpose of HA focuses on aggregating all the degrees of membership obtained from VA. HA is quite different from VA since HA is carried out from the treatment phase dimension for a completed treatment plan regarding a disease. Due to different weights for the final evaluation at different phases, a linear aggregation formula is constructed as:

$$A_i^{\{H\}} = \sum_{i=1}^{3} w_i A_i^{\{V\}} \tag{6}$$

That is to say, for any given treatment plan T_i, we can easily evaluate the advantages/disadvantages of T_i according to $A_i^{\{H\}}$.

4.3 Ranking the Treatment Plans

As the last important step of our proposed selection strategy, ranking the treatment plans is in charge of re-ranking of treatment plans according to $A_i^{\{H\}}$. The higher $A_i^{\{H\}}$ is, the more sustainable the treatment plan is. Formally, the most sustainable medical treatment plan can be mathematically described as follows:

$$T_{Sustainable} \leftarrow \max\{A_i^{\{H\}} \mid i = 1,2,3\}$$

4.4 Algorithm

Based on the above-proposed strategy, the corresponding algorithm is devised, as shown in Algorithm 1.

Algorithm 1 A Sustainable Algorithm for Treatment Planning in Smart Medical.

Input :

Set of treatment plans: $T=\{T_1, T_2, \cdots, T_k\}$;

Phases of treatment plan: $P=\{p_1,p_2,p_3\}$;

Evaluations for $T_k : e_{ij}^k$

Set of linguistic terms: $L=\{l_1,l_2, \cdots, l_5\}$;

System parameters: $r_1,r_2,r_3,r_4,r_5,w_1,w_2,w_3$;

Output:

The most sustainable medical treatment plan $T_{sustainable}$

1: Initialize $pro=1$, $sum=0$;
2: **for** $j=1$ **to** 3 **do**
3: **begin**
4: $pro := pro * \underset{l_k \in L}{\mathrm{argmax}}(\mu_{ijl_k}(e_{ij}))$;
5: $A_i^{\{V\}} := pro$;
6: **end**
7: **for** $i=1$ **to** 3 **do**
8: **begin**
9: $sum = sum + w_i A_i^{\{V\}}$
10: $A_i^{\{H\}} := sum$;
11: **end**
12: **for** $i=1$ **to** 3 **do**
13: $T_{sustainable} := \mathrm{argmax}(A_i^{\{H\}} | i=1,2,3)$;
14: **end**

In this algorithm, the inputs are a set of treatment plans T, phases of treatment plan P, evaluations for a given treatment plan T_k, termed e_{ij}^k, system parameters r_1, r_2, r_3, r_4, r_5 and weights w_1, w_2, w_3. The output is the most sustainable medical treatment plan $T_{Sustainable}$. Line 1 initializes two variables *pro* and *sum* that are used for storing the results of $A_i^{\{V\}}$ and $A_i^{\{H\}}$. Lines 2–6 are for obtaining the vertical aggregation $A_i^{\{V\}}$. Lines 7−11 are for calculating the horizontal aggregation $A_i^{\{V\}}$. Finally, Lines 12–14 are in charge of re-ranking treatment plans according to the $A_i^{\{H\}}$, that is to say, it will return the maximum $A_i^{\{H\}}$.

5. Case Study

This section presents a case study on a sustainable medical treatment planning service for computer autism in smart medical, which includes the three dimensions of: a treatment plan, treatment phase, and objectives. Similar to Fig. 3, we collected the existing five mainstream treatment plans $T_1, T_2, ...T_5$ and the evaluations for each treatment plan T_i. These numerical evaluation values can be stored with a 3-order tensor, as shown in Fig. 5.

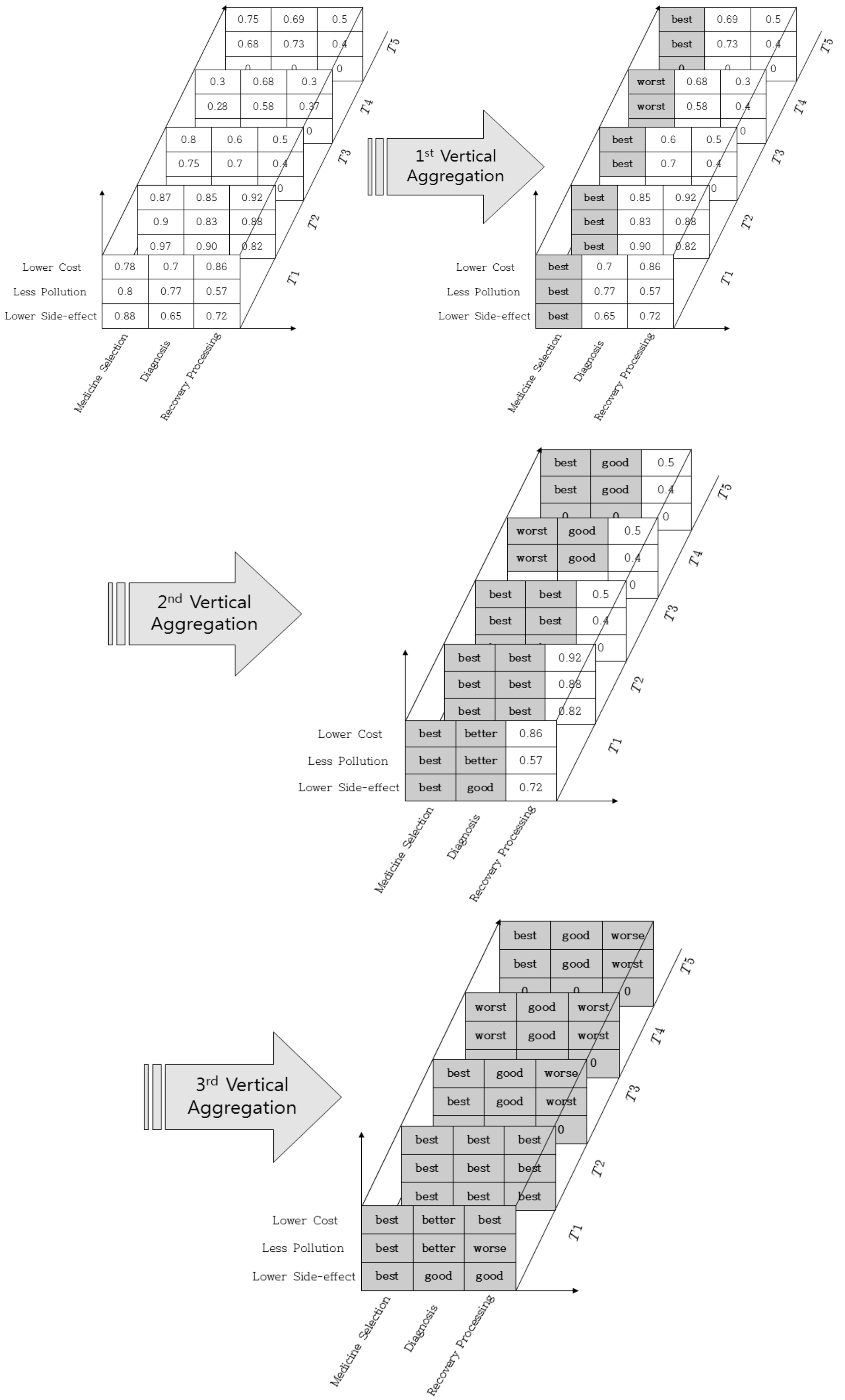

Fig. 5. An illustration for selecting the sustainable treatment plan for patients with computer autism.

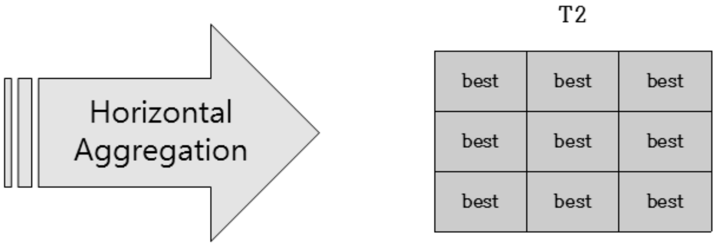

Fig. 5. Continued.

For the sake of better illustration, the parameters r_1, r_2, r_3, r_4, r_5 were set as 0.2, 0.4, 0.6, 0.8, 1 in this case study. After fuzzification, we were able to easily obtain a reasonable linguistic-expressed evaluation, as shown in Fig. 5. As a matter of fact, no matter what we set the weights for the treatment phases, the treatment plan T_2 was selected as the most sustainable one for older acute myocardial infarction patients by using the vertical and horizontal aggregations. This coincides with the user's intuition since the treatment plan T_2 exhibits the best benefits on the aspects of the environment, the economy, and patients' health.

This case study is composed of three main objectives: 1) to represent the evaluation data with a 3-order tensor; 2) to establish the membership functions for various linguistic terms that are used for expressing the evaluations on the treatment plans; and 3) to obtain a sustainable one via aggregations. Overall, it made possible to model the complex medical evaluation data with tensor and to convert it into a linguistic-expressed tensor.

6. Conclusions

Aiming to evaluate and select the most sustainable option from all possible treatment plans for a certain disease, this paper studies a practical issue on treatment planning in smart medical. First, this paper presented a three-dimensional evaluation model and then proposed a sustainable strategy for medical treatment planning based on a three-dimensional fuzzy evaluation model. Furthermore, a concrete case study on the disease 'computer autism' was provided for demonstrating the feasibility of the proposed approach. The results analysis of the case study embodied good consistency with users' intuitions. It is believed that this research can provide good insights for the development of smart medical in the future.

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Fei Hao

He received B.S. and M.S. degrees in School of Mathematics and Computer Engineering from Xihua University, Chengdu, China in 2005 and 2008, respectively. He earned Ph.D. degree from Soonchunhyang University, Asan, Korea on August, 2016. His current research interests include social computing, ubiquitous computing, big data analysis and processing and mobile cloud computing. He is a member of KIPS.

Doo-Soon Park

He received his Ph.D. in Computer Science from Korea University in 1988. Currently, he is a professor in the Department of Computer Software Engineering at Soonchunhyang University, Korea. He is Director of Wellness Service Coaching Center at Soonchunhyang University. He was President of the Korea Information Processing Society (KIPS) in 2015, and Director of Central Library at Soonchunhyang University from 2014 to 2015. He was Editor-in-chief of Journal of Information Processing Systems at KIPS from 2009 to 2012, and Dean of the Engineering College at Soonchunhyang University from 2002 to 2003. He has served as an organizing committee member of international conferences including FutureTech 2016, MUE 2016, WORLDIT 2016, GLOBAL IT 2016, CUTE 2015, CSA 2015. His research interests include data mining, big data processing and parallel processing. He is a member of IEEE, ACM, KIPS, KMS, and KIISE.

Sang Yeon Woo

He is at present working as a professor in the Department of Sport Science of Soonchunhyang University, Korea. His research area includes Sports Biomechanics.

Se Dong Min

He was born in Seoul, Korea, on December 23, 1975. He received M.S. and Ph.D. degree in electrical and electronic engineering from the Department of Electrical and Electronics Engineering, Yonsei University, Seoul, Korea in 2010. He is at present working as an assistant professor in the Department of Medical IT Engineering of Soonchunhyang University, Korea. His research area includes biomedical signal instrumentation and processing, healthcare sensor application and mobile healthcare services and technologies.

Sewon Park

She received her B.S. in biochemical engineering and life science from Sogang University in 2012. Currently, she is a graduate student in Interdisciplinary Program in Neuroscience at Seoul National University, Korea.