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Decision-Making Support in Stroke Diagnosis Process: An Approach Based on the PROMETHEE Method and Decision Model Notation

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Abstract

Decision-making in the field of healthcare is a very complex activity. Several tools have been developed to support the decision-making process. DMN, a modeling technique focused on decisions, is among these and has been gaining prominence in both, literature and business, as has the multi-criteria method PROMETHEE II that helps decision-makers with multi-criteria in analyses. Thus, this research targets combining these two techniques and analyzing the decision support that these two tools afford together. The diagnostic stage of stroke patients was used to perform this work. The research demonstrated that this proposal can drive major gains in efficiency and assertiveness in decision-making in time-sensitive hospital processes. After all, there is a noticeable dearth of hospitals with specialized teams as well as a shortfall of adequate infrastructure for this treatment.

Keywords:

Decision-making, Stroke, PROMETHEE

Introduction

Currently, stroke is one of the most serious ailments and is the second main cause of death in the world [11]. Strokes occur due to the formation of thrombi in a blood vessel that ends up disrupting the blood flow to part of the brain [5]. It could leave permanent disabilities, such as partial motor paralysis, speech and cognitive impairment, and memory damage, or even death [11,17]. However, with symptoms diagnosed while in their initial stages, and also with the availability of an urgent service with a specialized team, impacts can be drastically minimized. However, not every hospital has the resources and knowledge required and sufficient to deliver care for stroke events. This leads many patients to receive the wrong diagnosis and, as a consequence, to disabilities that could have been avoided.

In this sense, not only the stroke care process but the health area as a whole, are characterized by a high level of complexity. This event involves many aspects, such as clinical guidelines, symptomology, different healthcare systems, availability of resources, etc. [1]. Besides all that, making the right decisions often involves dealing with many conflicts [10]. Therefore, awareness that processes in the healthcare area must be flexible and capable of dealing with changes and conflicts is fundamental [18]. This way, healthcare processes need decision support systems [2].

Thus, the use of several languages and methods for the business processes are observed in the literature, as these are used to efficiently manage organizations [8], such as, for instance, DMN (Decision Model and Notation) that arose to fill the gap in business process models in terms of logical decisions. The system's diagram serves as a model that groups activities by decisions. Furthermore, it also features, internally, tables with the criteria that are evaluated in every step of the decision. This enables it to present, in brief, the logical structure of the process and of each criterion evaluated in its ideal moment [1,21]. And, with this, multi-criteria decision-making methods (MCDM) become really relevant.

MCDM, refers to a field in operational research that cooperates with decision-makers in achieving optimized results in complicated scenarios [15]. Several methodologies that are characterized by their forms of calculation have been developed. So, a methodology based in data form (textual, numeric, etc.) also in the form of decision (single choice, ranking, etc.) is presented herein to decide which would be the best MCDM to apply. [22]. Among the existing methods, the PROMETHEE II method was chosen, because, according to [4], it enables quantitative classification among the different alternatives. Such as [12] who applied this method to help managers reduce overcrowding in the emergency department.

Therefore, the DMN and MCDM approaches becomes extremely relevant when combined. After all, this promotes a gain in speed and assertiveness of decisions. Thus, this research aims to offer a decision-making support framework for the initial stages of the stroke event process, where the primary diagnosis and patient treatment decisions are made. This process is known to be very sensitive to the time, knowledge, and resources available in every healthcare unit [7,9,19] and, not addressing this may lead to very serious disabilities and even death. This suggestion will make it possible, in a simple way, to assist professionals in decision-making in any environment.

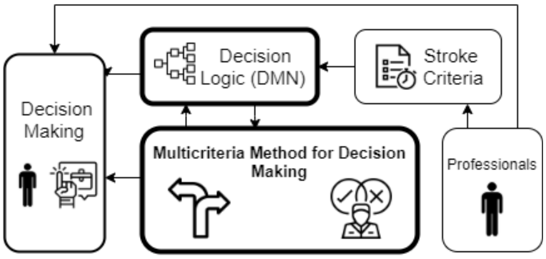
Methods

To elaborate this framework, as shown in figure one, the use of two decision support techniques will be combined: DMN for the decision modelling and MCDM to guide professionals in complex decision-making.

Proposal

To this end, in DMN, for the operation of the framework, according to Figure 1, health professionals (physicians and/or nurses) inputs the answers of a questionnaire into the logical decision-making process model. These answers are the same used to make a manual decision, without the framework

Figure 1 – Framework for decision support in healthcare

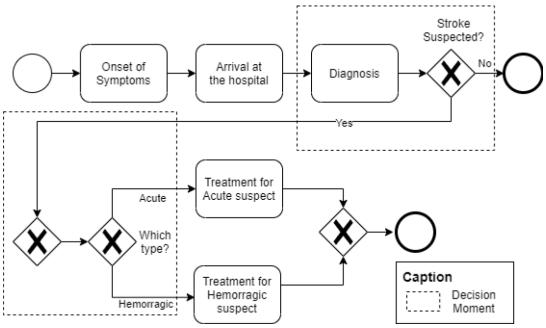


The DMN takes care of automatically guiding process decisions. When the system encounters complex decisions, it goes through a stage of applying MCDM with a view to ensuring professionals that decisions made with greater assertiveness.

Case Study

To explain the development of this paper's proposal, the decision moment will be analyzed, according to the process model developed by [3,14] and shown in Figure 2, referring to the reception of a patient with suspected stroke at the hospital and the correct diagnosis for treatment. After all, most hospitals are not familiar with the full process for stroke care [21]. As well as possibly lacking the proper equipment to assist patients with these conditions. Or even, not having doctors or nurses specialized in this treatment. This leads to the need for querying guidelines that take time, a resource that is precious for this affliction or even to diagnostic errors due to the pressure for an immediate decision.

Figure 2 – Stroke BPMN process



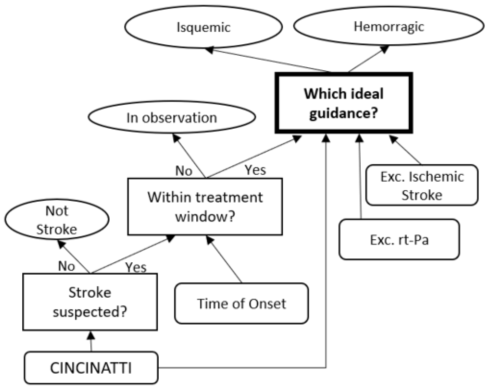
The first step then is in reference to addressing the criteria to be evaluated in the first contact with a patient with suspected stroke, based on the guidance provided by [16,23]. Among them, "Window" evaluates if the patient still has time to go through any treatment, the "CINCINATTI" evaluates the signs of a patient suffering stroke, "Exc. Ischemic Stroke" evaluates whether the patient should be excluded from the suspicion of ischemic stroke and the "Exc. rt-Pa" evaluates if the patient can go through rt-Pa procedure. And, with that, table 1 is constructed.

Table 1 – Questionnaire (Criteria)

Criteria	Question	Answer 1	Answer 2
Window	Symptom start time within 4.5h?	Yes	No
CINCINATTI	Smile	Normal	Altered
	Movement	Normal	Altered
	Speak	Normal	Altered
Exc. ischemic Stroke	Glycemic Level?	< 50 mg/dL	=> 50 mg/dL
	Convulsion?	Had	Did not have
	Dementia?	Has	Does not have
	Previously Bedridden?	Yes	No
Exc. rt-Pa	Recent head trauma?	No	Yes
	Recent extensive surgery?	No	Yes
	Recent bleeding?	No	Yes
	Recent hemorrhagic stroke?	No	Yes

With this systematic configuration, following the logical order of processes and decisions, a decision model must be developed in DMN concerning the process under study of reception/assessment of patients suffering from stroke to establish the correct treatment course, according to figure 3.

Figure 3 – DMN Decision Requirement Diagram with didactic adaptation for diagnosis process in stroke suspects



By looking at the DMN decision model for this process, shown in figure 3, and the questionnaire applied, in table 1, for the decision moment "Stroke suspected?" and for the decision moment "within the treatment window" decisions that evaluate only one criterion happen, respectively, "CINCINATTI" and "time window" can be identified. Therefore, these are simple decisions for immediate guidance. However, when the moment of "Which ideal guidance?", highlighted in bold, is reached if the patient is diagnosed with suspected stroke and is within the treatment window, multiple criteria must be evaluated, in this case, "CINCINATTI", "Exc. Ischemic Stroke" and "Exc, rt-Pa", to target the best possible treatment for the patient. To this end, the relevant criteria for the decision moment in case in point were first consolidated to transform the questionnaire into a mathematical model. See table 2.

Table 2 – Consolidated Criteria

Criteria	Variable	Description
CINCINATTI (C1)	0 to 3	The higher, the stronger the suspicion of a stroke
Exc. ischemic Stroke (C2)	0 to 4	The higher, the stronger the indication for hemorrhagic stroke
Exc. rt-Pa (C3)	0 to 4	The higher, the lower the indication for rt-PA

By analyzing tables 1 and 2 enables identifying that the targeting criteria for patients suspected of ischemic or hemorrhagic stroke are evaluated in conflict with each other. Due to the complexity of decisions and the speed required for the process, integration of the multi-criteria decision methods into this scenario becomes extremely relevant. Thus, a multi-criteria method should be deployed in establishing the correct course of treatment for these patients.

However, prior to applying the MCDM, choosing the ideal method is fundamental. Considering that these cases have no difference in weighting among the criteria, there is an unknown uncertainty and the goal of the application is the diagnosis of the patient's primary suspicion, guided by [14], the PROMETHEE II method was chosen for application of the appropriate MCDM since, in the different versions, different forms of observations are available at the same time, which is something other methods cannot do.

The PROMETHEE II method

This method enables comparing classifications in different scenarios, which is fundamental in this case. The output of the PROMETHEE II method, according to [4], results in a list of patients, on a scale from -1 to 1, regarding how much a patient should be directed to a given diagnostic. Where table 3 shows an example of accumulated points for each criterion *j* based on a table 1 questionnaire, applying the scales from table 2, which will be evaluated by the multicriteria method for three different *i* patients.

Table 3 – Input Values for PROMETHEE

Patient (i)	C1	C2	C3
1	3	0	0
2	2	2	2
3	1	3	1

Using the method's data the calculation is split into four steps. The initial step consists in calculate the preference P(*xi, xk*) that relates patient xi to xk considering criterion *j*. However, not every criterion, for every scenario t, is meant to be maximized. See table 4.

Table 4 – Criteria Objectives per scenario

Criteria (j)	Hemorrhagic (t =1)	Ischemic (t =2)
C1	Max	Max
C2	Max	Min
C3	Max	Min

Thus, PROMETHEE II would have to be applied twice, according to the goals of the criteria for each scenario, according to table 4. In order to calculate this, the first step is normalizing the matrix. In this case, when the goal is maximization, the equation (1) is used:

$$x'_{ij} = \frac{xij\ - (xij)}{(xij) - \ (xij)} \qquad \forall\, i\, \forall\, j\, \forall\, t \tag{1}$$

Otherwise, the equation (2) is used:

$$x'_{ij} = \frac{(xij)\ -\ xij}{(xij) - \ (xij)} \qquad \forall\, i\, \forall\, j\, \forall\, t \tag{2}$$

The results are used to create table 5.

Table 5 – Input values normalized

i	Hemorrhagic (t=1)			Ischemic (t=2)		
	C1	C2	C3	C1	C2	C3
P1	1.00	0.00	0.00	1.00	1.00	1.00
P2	0.50	0.67	1.00	0.50	0.33	0.00
P3	0.00	1.00	0.50	0.00	0.00	0.50

Then, the preference matrix for patients in each scenario is calculated using the equation (3):

$$P\left(x'_{ij}, x'_{kj}\right) = P_j\left(u_j(x'_i) - u_j(x'_k)\right) = P_j(\delta_{ik}\ ) \quad \forall\, j\, \forall\, t \tag{3}$$

In a way that, if $P_j(\delta_{ik}\ ) > 0$ the value is kept, otherwise $P_j(\delta_{ik}\ )$ is substituted with 0. Generating table 6.

Table 6 – Preferences matrix

	Hemorrhagic (t=1)			Ischemic (t=2)		
$P\left(x'_{ij}, x'_{kj}\right)$	C1	C2	C3	C1	C2	C3
P(P1,P2)	0.50	0.00	0.00	0.50	0.67	1.00
P(P1,P3)	1.00	0.00	0.00	1.00	1.00	0.50
P(P2,P1)	0.00	0.67	1.00	0.00	0.00	0.00
P(P2,P3)	0.50	0.00	0.50	0.50	0.33	0.00
P(P3,P1)	0.00	1.00	0.50	0.00	0.00	0.00
P(P3,P2)	0.00	0.33	0.00	0.00	0.00	0.50

In the second step, the preference matrix is included, considering the weightings w_j. In this case, since there are no weightings for the criteria, all criteria are assumed to have equal weightings (33%). Calculated using the equation (4):

$$\pi(\delta_{ik}\ ) = (\textstyle\sum_{j=1}^{k} w_j P_j(\delta_{ik}\ ))/(\sum_{j=1}^{k} w_j) \tag{4}$$

And as a result, generate table 7.

Table 7 – Aggregated matrix

	Hemorrhagic (t=1)			Ischemic (t=2)		
	P1	P2	P3	P1	P2	P3
P1	-	0.17	0.33	-	0.72	0.83
P2	0.56	-	0.33	0	-	0.28
P3	0.5	0.11	-	0	0.17	-

The third part refers to the representation of the superation flows ϕ. The first one is positive, or inflow, which represents the intensity of preference of one alternative over all others. And it is given by the equation (5):

$$\phi^{+}_{it} = \textstyle\sum_{j=1}^{k} \pi\left(\delta_{ij}\ \right) \qquad \forall\, i\ \ \forall\, t \tag{5}$$

The second one is outflow, or negative. This represents the intensity of preference of all alternatives over one of them and is calculated by equation (6):

$$\phi_{it}^{-} = \sum_{i=1}^{k} \pi\left(\delta_{ij}\right) \qquad \forall\ i\ \forall\ t \tag{6}$$

Lastly, in the fourth step, the general selection of the alternatives is performed. To do this, the net flow is used, that is, the balance between the values calculated in the third step and is given by the formula (7):

$$\phi_{it} = \phi_{it}^{+} - \phi_{jt}^{-} \qquad \forall\ i\ \forall\ t \tag{7}$$

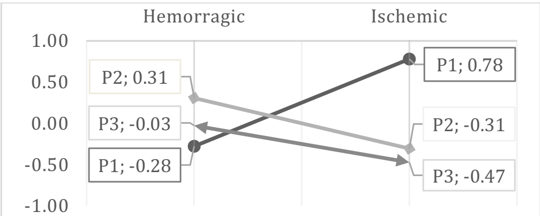
The results of which are shown in table 8:

Table 8 – Inflow, Outflow and Net Flow

	Hemorrhagic			Ischemic		
	ϕ_{i1}^{-}	ϕ_{i1}^{+}	ϕ_{it}	ϕ_{i2}^{-}	ϕ_{i2}^{+}	ϕ_{it}
P1	0.53	0.25	-0.28	0.00	0.78	0.78
P2	0.14	0.44	0.31	0.44	0.14	-0.31
P3	0.33	0.31	-0.03	0.56	0.08	-0.47

After this result, the level of referral to each treatment for a given patient can be established, as shown in figure 4.

Figure 4 –Results



Additionally, considering there are two scenarios, if the target is to refer the patient directly in one direction, the two values obtained in the net flow are compared and the one with the higher value is chosen using the equation (8):

$$Result = max\ (\phi_{it}) \qquad \forall\ i \tag{8}$$

And this would allow the assessment of patients through the evaluation of how much a given patient is indicated or not to specific treatment to be done faster and with more assertiveness. As well as comparing with previous patients, and with control indicators (such as the mean) establish whether the evaluation is coherent given any additional factors that may be perceived at the time.

Results

Our study contributes by presenting the combination of two decision models DMN with MCDM in healthcare environments. This combination enabled a systemization and a formalization of decision support in terms of using the mathematical and formal methods mentioned above. In this way, the paper presents a way of building a mathematical approach to support decisions in hospital systems and, thereby, achieve higher assertiveness and speed in decision-making due to its data-driven orientation.

Due to this, we believe that this proposal can be useful in helping healthcare professionals, during different decision-making processes, whether these be really complex and in need of robust MCDM modeling, or more simple alternatives focused on gaining time and assertiveness in decision making. Besides that, we also realize that such a proposal can be an inspiration and lead to a range of future work combining the MCDM and DMN techniques in the healthcare field and, thereby enhance the mathematical decision potential in complex scenarios like healthcare processes.

Discussion

In the study undertaken, a framework for decision support using MCDM on health processes structured in DMN was organized. In the application, the PROMETHE II method was used to direct and treat the patients suspected of having had a stroke. This formulation is relevant because, a lot of healthcare processes are time-sensitive, such as, for instance, ischemic stroke that should be treated until four or five hours after the event in order not to leave disabilities. This way, the proposal contributes to bringing decision-makers a mechanism capable of speeding, in an assertive way, the decisions that must be made throughout the treatment process.

In the literature, the value in terms of decision support in the health area is remarkable, such as in [12,13] which presents a Dematel application in developing improvements in the urgency and emergency departments of a hospital. Little to no reference exists when talking about the application of DMN in these processes. This is so due to it being a recent approach. In fact, [20] shows that, for the new application, the DMN requires previous knowledge about the technique, which is limited. On the other hand, when combining the two techniques [6] is the only author who presents an approach for this. This approach developed an application of TOPSIS for software selection. And in doing that, this work presents itself as the first one to approach the combination of MCDM with a DMN model in the healthcare processes area.

Therefore, pointing out that a lot of work still needs to be done is fundamental. First, there is value in researching the application of this process in a non-specialized hospital environment. In this sense, also, the continuity of the study exploring other fronts and processes in the healthcare area, such as urgency and emergency or, even, COVID19. Besides these, a research exclusively dedicated to the choice of the MCDM to be applied to different forms of DMN that can be identified in healthcare processes is worth considering. Or even, the construction of an information application system, in the field, of such proposal.

Conclusions

This paper proposed a model that integrates the process of healthcare service modelling in DMN with MCDM to agilely ensure assertive answers to the multicriteria decisions involved. In this case, the deployment was in the diagnosis and course of a treatment process for patients suspected of a stroke. So, from the development from such integration, by using the PROMETHEE II method to explain how much a patient should, or should not, be referred to a given treatment, it was possible to see that this proposal is capable of bringing significant speed to a doctor's decision, as well as ensuring a higher consistency and assertiveness in the decisions for each patient.

Therefore, the model presented is just a simulation, and that is why future work is required to promote a better comprehension of the possibilities offered by this combination. Future research such as on the construction of information systems for application in a real scenario of this method or even an evaluation of which methods are really capable of giving the correct answers for healthcare processes.

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