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A Bayesian network for recurrent multi-criteria and multi-attribute decision problems: Choosing a manual wheelchair

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ABSTRACT

This paper discusses recurrent multi-criteria, multi-attribute decision problems. Because of the possibility of decision-maker *ignorance* or low decision-maker *involvement* the decision problem structuring is done once for all by a group of experts and does not involve the implication of the decision makers. We propose an original model based on Bayesian networks, which provides a decision process that helps the decision-maker to select an appropriate alternative among a set of alternatives, taking into account multiple criteria that are often conflicting. Our model makes it possible to represent in the same model the decision case (i.e., the decision-maker characteristics, contextual characteristics, their needs and preferences), the set of alternatives with the different attributes, and the choice criteria. The model allows us to compute the value of three essential elements: the importance of each criterion, which is based on the decision-case characteristics; each criterion's evaluation index in terms of the alternative; and each criterion's satisfaction index. The recurrent problem of choosing a manual wheelchair (MWC) illustrates the construction and use of our model.

1. Introduction

A wheelchair is a device designed to replace walking, thus constituting a technical aid for mobility. A manual wheelchair (MWC) is a mechanical device made of hundreds of pieces and includes generally dozens of settings and options. Medical professionals recommend using a MWC to very different people with a physical disability, prescribing for each of them a particular type of MWC and specifying the settings and options that will best suit to this person in terms of the needs and preferences identified.

Choosing a MWC requires clinicians with expertise, both clinical experience and a good knowledge of MWC. Unfortunately, these clinicians are very few compared to the number of cases. For each new MWC choice, their presence – face-to-face or even face-to-screen, as proposed by Kim, Kim, and Schmeler (2012) – is not possible. Choosing a MWC also requires much information about the person who will use the wheelchair, his/her abilities, needs, preferences, environment and constraints. In practice, the expert visits the places where the wheelchair is used.

Making available expertise, knowledge and information needed to select an appropriate MWC is essential to improve the current choice processes. This will reduce the inequalities due to the frequent absence of experts during the choosing process. Since making a poor choice often leads to reduce the mobility of the person (e.g., due to a great lack of maneuverability, or comfort of propulsion, crossing obstacles, transfers, personal care attendants, or loading MWC in the car), making better choice will increase the mobility of people with physical disabilities and reduce health expenses due to negative consequences of choosing an inappropriate. Choosing a MWC need means accessing information about advantages and disadvantages of any MWC. Wheelchair users need help and explanations to simplify what is important in a given case; wheelchair users need to understand why some MWC characteristics of the MWC are especially needed in some situations, and the risks that result if they not follow these characteristics.

This article is one of the results of the research project SACR FRM[1] in France (Lepoutre, 2011). About 50% of the MWC used in France are not well adapted to the person, which may lead to reduced autonomy, inconvenience, pain, bedsores, and musculoskeletal disorders. This project made it possible to collect and formalize knowledge in order to complete a knowledged-based system to support choosing and regulating a MWC. This domain's expert

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[1] Project SACR FRM (Assistance System for Choosing and Regulating a Manual Wheelchair: *Systéme d'Aide au Choix et au Réglage d'un Fauteuil Roulant Manuel*) after the call for projects from the ANR TECSAN (National Research Agency on Health Technologies: *Agence Nationale de la recherche sur les Technologies de la Santé*).

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knowledge concerns specific perspectives, such as propulsion biomechanics (Desroches et al., 2010; Koontz et al., 2007; Mulroy, Farrokhi, Newsam, & Perry, 2004; Yoshimasa, Watelain, Lepoutre, & Thevenon, 2010), transfer biomechanics (Debril, Pudlo, Gorce, & Lepoutre, 2009; Gagnon et al., 2009), quality criteria and general or specific rules for choosing a MWC (Guillon, Bouche, Bernuz, & Pradon, 2009; Tomlinson, 2000) and a CERAH[2] course. In addition, much has been learned from of the Garches Institute's experts,[3] who propose a specific service for choosing and regulating a MWC.

The project allowed us to identify, homogenize and list the characteristics of people, their environment and their life projects that would be likely to influence the choice. The MWC characteristics and the criteria have also been listed. The current available information about MWC in France (Girault, Dias, & Fodé, 2011) allows the user to list the references of MWC responding to a short list of binary conditions over the MWC attributes. This assistance is not enough to give an authoritative recommendation.

We explain the reasons for chosing a Bayesian network model to deal with this kind of recurrent decision problem. We chose a Bayesian network since this model is specialized in representing many sources of uncertainty and in propagating any observed variables on some others. Choosing a MCW is seen as a decision problem with uncertainty. The first level of uncertainty concerns the factors that influence the choice that may be *uncertain*: for example, the data can be incomplete or imprecise, as well as qualitative or quantitative. The second level of uncertainty concerns the way the different factors influence the choice: for example, the ability of the MWC user to stand affects the importance of the stability criterion, but this influence is not deterministic. The MWC evaluation in terms of a given criterion is also not deterministic, since most criteria are not measurable, except for the total cost.

Choosing a MWC is a *recurrent* decision problem. For each decision case, the alternatives set and the reasoning are the same. The problem is to select a MWC alternative that is appropriate for the person concerned by the choice, each one makes his/her choice by taking into account his/her own specificities, constraints and priorities. Since a recurrent problem concerns a wide range of decision-makers, we consider the possibility of decision-maker *ignorance* or low decision-maker *involvement*. The decision is considered to be made by a single decision-maker, even though several people are involved in the choice process. In practice, it is often a general practitioner with a MWC retailer, who may be a pharmacist. In the best cases, the choice is made by a multidisciplinary team, including a rehabilitation specialist, an occupational therapist or a physical therapist, or a social worker. The person who uses the MWC is the first to benefit or to put up with the MWC choice. The personal care attendants are also very concerned by the quality of the choice of the MWC. For example, they push the MWC, they help the person to stand up, or they carry the MWC and put it in the car.

These problem characteristics motivate our choice to use probabilistic graphical models, such as Bayesian networks (Darwiche, 2009; Jensen & Nielsen, 2007), since it brings expert knowledge to the decision-maker. The experts are highly solicited during the model's construction phase in order to provide the list of variables (i.e., attributes of the alternatives, characteristics of the decision case, criteria), the relationships between these variables, and the conditional probability tables. The same model can then be used for each new decision case by non-expert users. Lacking a MWC expert, choosing an appropriate MWC becomes possible. For this reason, the decision-maker is sometimes referred to as the user of the decision support system.

The rest of the paper is organized as follows. Section 2 presents some issues in relation to the problem. Section 3 proposes our model, including a brief presentation of Bayesian networks. Section 4 describes the operations of our decision process. Section 5 discusses about our model in terms of the related works. Section 6 offers our conclusions and presents our future research prospects.

2. The problem position and definition

This section provides the important elements that characterize the MWC problem. These elements concern the MWC attributes, the decision case characteristics, and the criteria. They were elaborated for the SACR-FRM project with the help of our different partners. Capital letters are used to represent the problem variables, and lower-case letters designate their values. Cursive capital letters correspond to sets of variables.

2.1. The set of alternatives

Let $\mathcal{V} = \{V_1, \ldots, V_n\}$ be the set of attributes of the alternatives. The number n of attributes is the same, whatever the decision case. An *alternative* is a n-tuple $(v_1, \ldots, v_n)$ which assigns all the attributes. An attribute V has a domain of definition that can be binary (e.g., the possibility of setting the seat angle), categorical (e.g., the type of frame), and discrete (e.g., the seat width) or continuous (e.g., the angle of the leg rest).

There are several hundreds of MWC references. Each one corresponds to a list of the possible sizes (e.g., seat, back, wheel), settings and options. In the MWC problem, an alternative designates a completely defined MWC (i.e., a reference with the values of any possible sizes, settings, and options).

Fig. 1 illustrates the diversity of MWCs available on the market (Girault et al., 2011). The MWC can be propelled by a personal care attendant or by the person him/herself, either using hands and arm propulsion, or using foot propulsion. Several MWC options make it possible one or several of these propulsion modes, such as the presence and the kind of handrims, one-arm-drive systems, handles (see MWC (a) and (c) on Fig. 1), or braking systems.

There are folding frames or rigid frames. In certain cases, MWCs are designed for a specific sport activity. The frame supports a maximum user weight. It can include a setting device to adjust seat angle, and/or an anti- roll back device to prevent falls. The back and seat are characterized by the kind of structure (e.g., rigid, canvas, cushions), size, and the possibility of adjusting several elements. For example, the MWC (a) in Fig. 1 has a rigid, high back with a headrest. There are many accessories for supporting and positioning body parts and a device to move from sitting down to standing up. The armrests have different forms, sizes and possibilities of adjustment. The footrests can be fixed, retractable or removable, in one or two parts and can be reclined and adjusted in terms of the different axes (see (a) and (c) on Fig. 1).

Several accessories increase the support of legs and feet. For example, as shown in Fig. 1, MWC (a) and MWC (b) have different kinds of support for the legs, while MWC (c) does not have any. The driving wheels and the guiding wheels vary according to their type, size, position, the kinds of covering, the possibility of removing the wheels, and the accessories for propulsion and direction.

2.2. The decision case

The decision case refers to the person who is concerned by the chosen alternative. Let $\mathcal{U} = \{U_1, \ldots, U_p\}$ be the set of variables that characterize a decision case, representing the internal or external

[2] Disability Equipment Research Center: Centre d'étude et de Recherche sur l'Appareillage pour le Handicap.

[3] Wheelchair Test Center: Centre d'essai des fauteuils roulants. http://www.handicap.org/?Centre-d-essai-des-fauteuils.