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ASSESSING INFORMATION REQUIREMENTS FOR COMPLEX DECISION MAKING IN HEALTHCARE

Research in Progress

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Abstract

User assistance systems can help practitioners making decision for logistical problems, for example those arising in healthcare. Optimisation approaches included in such a system to determine an (optimal) solution often need to address more than one and often conflicting objectives leading to a number of alternative solutions of similar quality. The study proposed in this paper investigates how many alternative solutions should be proposed to a decision maker, which characteristics they should have, and which level of detail the presentation of solutions should have in order to enable the user in making the best decisions for the individual problem.

Keywords: Decision making, Assistance systems, Healthcare, Empirical study.

1 Introduction

Decision making in healthcare is a complex process. To aid in understanding how much information is useful to decision makers the following study protocol is proposed. Decision making happens on different levels, for s time horizons, by people with various backgrounds, and with either a medical or a logistics focus. Examples include the scheduling of doctor's appointments, planning the locations of ambulances or determining routes for nurses visiting patients regularly at their homes (Brandeau et al., 2004). User assistance systems can help decision makers in practice, especially by offering potential solutions to these planning problems when they are based on analytics and optimisation approaches (Reuter-Oppermann et al., 2017a). For example, it can assist a dispatcher by proposing which ambulance to assign to an emergency or patient transport.

Many real-world decision problems include multiple objectives, often due to the non-uniform interests of different parties. To define a ranking of those objectives is often very difficult for decision makers. Therefore, a suitable approach is to determine so-called Pareto-optimal solutions (or non-dominated solutions) for the multi-criteria problem and let the decision makers choose one of those as the solution to be implemented in practice (Ehrgott, 2006). Often, a large number of Pareto-optimal solutions exist making it necessary to consider a preselection part for the user assistance system.

Supporting complex decisions with modelling approaches (such as optimisation) often generates large amounts of information that complicates the decision making as the information needs to be adequately processed. Multi-criteria decision analysis (MCDA) is one example that leads to large complex data outputs when not only one but several equally good alternative solutions are determined (Ehrgott and Gandibleux, 2003). In addition, presenting all the information for only one solution can already be challenging while it is unclear if all the information is really necessary or helpful for making a decision in practice.

Our goal is to study information complexity in the context of MCDA using experiments and physiologically derived models of decision making. In particular, the research presented herein, contributes to the exiting literature by addressing the following issues:

1. We demonstrate how understanding the dynamics of decision making improves communication and encourage effective implementation.
2. We discuss whether large amounts of information should be presented succinctly in order to facilitate decision making.
3. We investigate whether the *amount* of information or the *type* of information being presented are more important to help (or hinder) decision making.

Besides, we will acknowledge the trade-off between speed and accuracy within complex decisions. Making a decision fast often neglects valuable information, but it is not clear whether this trade-off is exponential or linear over time. We will focus on examples from decision making arising in healthcare management.

2 Foundations and Related Work

2.1 User Assistance Literature

User assistance systems support individuals to perform their tasks better when using information technology (Maedche et al., 2016). The actual instantiation of the assistance can vary and can compromise for example, the support for decision making, task execution, or problem solving also referred to as guidance (Morana et al., 2017). Researchers investigated assistance in the form of guidance for decision making and related decision support systems (DSS) for decades. DSS aim to provide decisional advice to enable fast, better, and easier decision making (Turban and Aronson, 2005) and have been applied, for example, for medical diagnosis (Buchanan and Shortliffe, 1984) or supervising a nuclear power plant (Geldermann et al., 2009).

When designing guidance or assistance systems for decision support there are several characteristics of the guidance to be considered. Morana et al. (2017) propose a taxonomy of guidance design features to describe the provided guidance along ten dimensions. Out of these ten dimensions, the directivity, timing, and format of the guidance are of special interest for our research context.

The *directivity* of the provided guidance influences the individuals' decision making. Suggestive guidance makes judgmental recommendations while informative guidance provides pertinent information that enlightens the users' judgment without suggestions on how to act (Morana et al., 2017). Depending on the actual decision making context and task complexity, both types of directivity have advantages and disadvantages. Research shows that suggestive guidance has a positive effect on individuals' performance (Montazemi et al., 1996) and satisfaction (Huguenard and Frolick, 2001) in contrast to informative guidance. The effectiveness of suggestive or informative guidance depends on the task complexity. According to Montazemi et al. (1996), users benefit from suggestive guidance in less complex tasks, while informative guidance better supports complex tasks.

The *timing* of guidance specifies when the guidance will be provided to the user and is classified into concurrently, during the actual activity, prospectively, before the actual activity, or retrospectively, after the actual activity (Morana et al., 2017). Researchers studied the effects of a prospective timing in the context of emergency management (Shen et al., 2012). Within their laboratory experiment, Shen et al. (2012) could demonstrate that prospective guidance has a significantly positive effect on individuals' decisional accuracy and speed.

The guidance *format* is classified into the four types: text, when using primarily written words, images, when using pictures and depictions, animation, when using videos and moving pictures, or audio, when using speech and verbal instructions (Morana et al., 2017). Within the vast amount of guidance research, there is a strong tendency to use text as a format to provide guidance, e.g. in the form of information or explanations. Researchers often combine text-based guidance with tables or graphs to support individuals' decision making (Limayem and Chelbi, 1997). Depending on the task type, image-based guidance is found to be superior over text-based guidance, for example, for spatial tasks (Mahoney et al., 2003). Moreover, researchers could demonstrate a reduced processing time by 50% when using animated guidance in contrast to text-based guidance (Drews et al., 2007).

2.2 Psychology Literature

From a psychological perspective decision making occurs as a series of 1.5 second events (Logan, 2009). Humans are constantly making decisions and then revising these decisions as new information becomes available until the point that they have sufficient information or circumstances force a final decision to be made (Jersild, 1927). At this point, the decision is enacted, the outcome of the action is observed to determine if the goal of the behaviour has been achieved and whether the outcome was favourable or adverse. This process represents simple decision making and a key constituent of human action (Schneider and Shanteau, 2003). In this way human behaviour can be seen as being mediated by time and information with a trade-off between speed where time is the greatest limiting factor and accuracy where information is the limiting factor (Heitz, 2014).

The limits of time and information can be thought of as naturally occurring limits on our decision making (Henmon, 1911). People often do not have even weeks, months or years to wait for all of the necessary information and processing of that information to make the most accurate decision possible to become available. Conversely, without waiting for any information to become available or to process that information at all a quick but possibly inaccurate decision would be made. It appears to be useful to wait for some information to become available to inform a decision but not to wait for an extended period of time for perhaps an unnecessary amount of information to become available.

Circumstances often require people to make a decision within a certain time period and with limited information. In the context of decision support tools and multi-criteria decision analysis, large or small amounts of information can be provided to the decision maker and they can take a long or short time to reflect on that information. Not having sufficient time has been shown to be detrimental to decision making (Kerstholt, 1994) as is having too much information (Jacoby et al., 1974). Understanding how effective decision making can be facilitated for operational decision making from the outputs of decision support tools requires understanding the speed accuracy trade-off for decision making in this context.

2.3. Operations Research Literature

Planning problems in healthcare regularly face multiple and often conflicting objectives. When locating medical facilities, for example, driving times for patients should be minimised while minimising the installation costs at the same time. Multi-criteria decision analysis is a sub-discipline of Operations Research that explicitly considers multiple criteria instead of only one in mathematical models and approaches. Example references for multi-criteria problems in health care are operating room planning (Rachuba and Werners, 2017) where competing interests of stakeholders need to be met or locating ambulances (Reuter-Oppermann et al., 2017b) where legal standards and cost issues need to be considered simultaneously.

Good solutions for multi-criteria decision problems can be identified in one of two ways: Firstly, in case weights for the objectives are known or can be estimated (and the scales can be combined), so-called weighted sum approaches can be used (Ehrgott, 2006). These approaches reduce the number of objectives to one and aim at only one solution, which is the best possible option, given the weights for the goals. Secondly, assuming that weights cannot be specified, a set of Pareto-optimal or non-dominated solutions can be identified which are equally good with respect to the goals (Ehrgott, 2006). In either case, the evaluation of these solutions is done with respect to objective function values, i.e. comparing costs for an intervention with the Quality-Adjusted Life Years (QALY) to expect. Multi-criteria problems usually lead to a set of non-dominated solutions, the so-called Pareto-optimal solutions (indicated by black filling in Figure 1, all others are dominated, or not optimal, solutions). Any of the Pareto-optimal solutions dominates the remaining (white filling) solutions, but with assumed equal importance for the two goals, the non-dominated solutions are equally good.

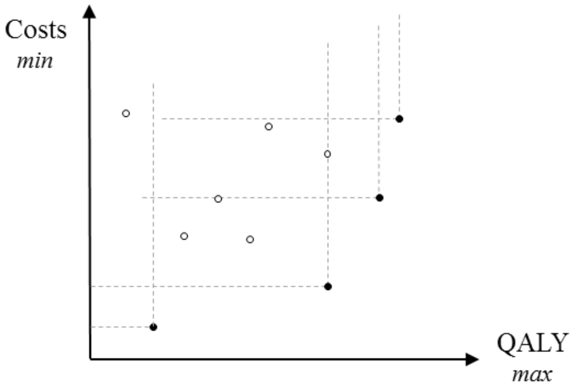

Figure 1. Example for Pareto-optimal solutions (black dots).

While we would prefer one single solution that dominates all others, this does not exist in general due to conflicting objectives. If weights either are known or can be estimated, the quality of a solution increases non-linearly over time. Often, very good solutions are discovered in only a short time. Improving those solutions, however, up to a final optimum, can take significantly more time than finding a good, yet not optimal, solution. Depending on the complexity of the decision problem, determining all efficient solutions in itself can be a challenging problem (Ehrgott, 2006). Pareto-optimal solutions can be determined using dedicated algorithms such as NSGA-II (Deb et al., 2002).

3 Research Questions and Objectives

The context for this project is making decisions from information produced by operational research (OR) techniques. To ensure that the content of the project reflects this context it is necessary to understand what type of information produced by OR modelling techniques is currently available and used for decision making in the real world. A pre-study is being undertaken to identify the types of information used by decision makers across a range of healthcare applications. However to understand how decision makers use modelling outputs the first research question and objectives this project will need to answer are:

1. What information is most useful for making decisions based on MCDA model outputs?
    a. To explore what information types decision makers use in real-world decision making scenarios.
    b. To study how different information types are used to make decisions in real scenarios.

This project will focus on the impact that the amount of information provided to an individual has on their ability to make a decision. Information quantity is a way to manipulate complexity along the two dimensions of the number of different information types and the amount of information of each type. The following research question and research objectives will enable us to understand the role of information quantity on decision making:

2. How does varying the amount of information and information types from MCDA model outputs impact on decision making?

Decision making does not take place in isolation from the world around the individual making the decision, context has a role in mediating the decision making process (Zsambok, 2014). The length of time over which the decision to be made will have an impact (the time horizon) is one possible determinant of the decision to be made. If the decision is perceived to have a very short-term impact then speed may be more important than accuracy however if it will have longer term ramifications then accuracy may be more important to the individual.

Another factor, which might influence the decision, might be the amount of time available for the individual to make the decision. Decision making under time constraints has been shown to impact on the decision strategy used by the decision maker (Ordóñez and Benson, 1997) and reverse the risk preferences of the decision maker (Saqib and Chan, 2015) which have been associated with differences in neural activation to unconstrained decision making (Forstmann et al., 2008).

Task difficulty as represented by the time horizon of a decision and the decision strategy being used as manipulated by the introduction of time constraints have been identified by Hwang (1994) as intervention points for the use of information systems for decision support. However, it is uncertain which factors relating to the individual decision maker might mediate performance but as highlighted by Schneider and Shanteau (2003) it is important to account for possible individual differences in decision performance. To facilitate this we will ask:

3. How is decision making mediated by:
    a. The time horizon of the implications of the decision?
    b. The time available to make the decision?
    c. The background of the person making the decision?

4 Study Designs and Protocols

This project is comprised of three studies. Studies 1 and 2 will be used to answer research question one by understanding how decision makers appraise the data modelling outputs and how they then use that data to inform their decision. Study 3 will be used to investigate research questions 2 and 3. The primary manipulation in this study will be the quantity of data along the dimensions, data types and amount of data within a type. Research question 3 will be studied using secondary manipulations of the time horizon of the decision implications, the time available to make a decision and the background of the individual making the decision.

4.1 Study 1

This study will aim to explore which types of information people use during the decision making process and how they construct an argument to rationalise the decision they have undertaken. The study will use vignettes to present a situation where the participant must make a decision using only the information contained within the vignette text and the modelling outputs. The participant will be asked to verbalise their decision making process as they are processing the information contained within the vignette. The resulting qualitative data from the verbalised decision making processes of the participants will be analysed in terms of the order in which information is used, how that information is interpreted and the level of difficulty the participants have with the each information type.

The method for this study will be the "think aloud" technique originally described by Duncker and Lees (1945) and which has since been used extensively in experimental psychology (Nielsen et al., 2002), clinical decision making (Lundgrén-Laine and Salanterä, 2010, Offredy and Meerabeau, 2005) and human-computer interaction research (Jaspers et al., 2004).

A minimum of 24 participants will be required for this study to ensure that the presentation order of the vignettes can be counterbalanced with all permutations (4! = 24). Each participant will be presented with a total of five vignettes, the first vignette will be a standard practice vignette to allow them to adapt to the technique of verbalising their stream of consciousness. Following the practice vignette, the four experimental vignettes will be presented one at a time. To control for order effects, the order in which the four experimental vignettes are presented will be counterbalanced so that all possible permutations of the vignette presentation order are used and each participant will be randomly allocated a particular permutation. The participant will then be asked to use the "think aloud" technique, which asks them to verbalise their thought processes without reflection on the cognitive process they are undertaking. The verbalised thought processes will be recorded using a digital recording device so they can be transcribed for analysis.

The vignettes for this study will contain an example scenario with a description of the problem situation, which has been modelled, a description of the type of model used to produce the results, the results of the modelling and a specific question, which the participant is to answer about the problem situation. The practice vignette and four experimental vignettes will represent a cross-section of operational research simulation modelling techniques, which produce large amounts of data.

4.2 Study 2

To further aid in understanding how people appraise modelling outputs and use them to rationalise their decision, eye tracking will be employed in conjunction with vignettes to follow their gaze and fixations during the decision making process as they assess the information available to them. The quantitative data from this study will be used to determine if there are any patterns in the way that people read modelling information. The data will be analysed in terms of the path that participants make and the number of fixations to see overall how the information is appraised, how different pieces of information are linked together, how long people spend processing different information types and how the most useful information for informing a decision is narrowed down. The findings from studies 1 and 2 will also be analysed together to understand how the visual processing of information is linked to the internal decision making process.

This study is interested in how much attention participants give to different information types and a technique which has been validated across multiple research areas (e.g. user assistance, human-computer interaction (Jacob and Karn, 2003), psychophysics (Harris and Wolpert, 1998) and information processing (Rayner, 1998) is eye tracking. Eye tracking enables the researcher to quantify the amount of visual attention an individual gives to a target in their environment and the order in which attention is paid to the visual scene. For this study, the use of eye tracking will enable the researchers to examine patterns in information processing relating to the decision making strategy used by the participant.

A minimum of 24 participants will be required for this study to ensure that the presentation order of the vignettes can be counterbalanced with all permutations (4! = 24). The same procedure and vignettes as used in study 1 will again be replicated here in study 2. The only difference from study 1 is that the participants' eye movements will be tracked. The participants will still be asked to "think aloud" because by replicating the procedure from study 1 the influence of the eye tracking technology on the participants' decision making can be assessed for interference. If the participant responses are not significantly different from those collected in study 1 the data can be amalgamated or compared in differing analyses as appropriate.

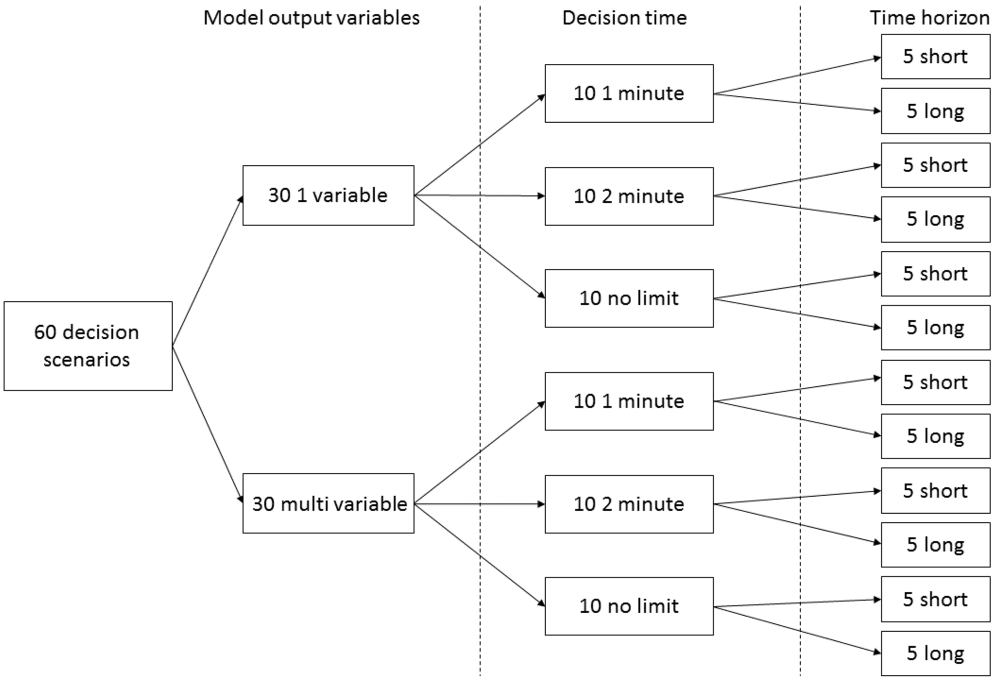

Figure 2. Sixty scenario tree diagram for the primary experimental manipulation of the number of model output variables. The manipulation of the amount of data in a model output variable will conform to the same tree diagram.

4.3 Study 3

Building on the types of information that the study participants find most useful from studies 1 and 2, study 3 will look at the impact of the complexity of the information as determined by the quantity of information being presented. There are other variations on this theme, which could also be studied such as information quality and decision making involving more than one person. Focusing on the quantity of information provided to the decision maker will enable greater control of the experimental scenarios and a more complete study of the impact the quantity of information has on decision speed and accuracy. This study will be a computer based decision making task which will require participants to agree or disagree with a decision based on the model output data presented to them on the screen. In this study, the main experimental manipulation will be the amount of information supplied to the participant along a single output variable and across multiple variables. Within the study, the time horizon and the time available to make the decision will also be manipulated as secondary independent variables. A sub group analysis will be undertaken to determine the impact of the participant's professional background on their decision making.

To study the speed accuracy trade-off for information complexity a standard choice reaction time study design will be used (Harris et al., 2014). Feedback will be used to inform the participant of their accuracy level. Reaction times will be measured from the display of the scenario information and participants will be asked whether they agree with the answer given in the scenario to provide a binary outcome measure. The primary experimental manipulations will be information quantity dimension with 1 outcome variable (10 data points and 50 data points scenarios) and multiple outcome variables with 50 data points (2 variables and 5 variables scenarios). The secondary manipulation will be decision time (1 minute, 2 minutes, no pressure) and time horizon (short term and long-term scenarios). In total, each participant will view a total of 120 decision scenarios (Figure 2).

A minimum of 20 participants will be required for this study. The order in which the information quality dimensions are presented will be counterbalanced and the scenarios for secondary manipulations of time horizon and time pressure will be presented in random order. Participants will be presented with a decision scenario and two possible answers, they will have to appraise the scenario information and choose the answer they believe to be correct. The scenarios will be presented electronically on a computer and response times will be measured using from the commencement off the scenario until the keyboard key indicating the participant's decision is pressed. A reminder will preface each set of scenarios corresponding to the different primary and secondary experimental manipulations for the participant of the task that they must complete, how long they will have to make each decision and the type of information they will be supplied with in each scenario. The decision scenarios will be designed to represent a variety of healthcare applications of operational modelling and they will be standardised for difficulty by subject matter experts. All of the scenarios will be presented electronically with computer controlled presentation timings.

4.4 Preliminary Results

We have conducted a pre-study with decision makers and dispatchers of The German Emergency Medical Service (EMS) system on two planning problems, i.e. locating ambulances and assigning patient transports. The pre-study was implemented as a survey consisting of two parts, one for each planning problem. Participants could decide at the beginning of the survey if they wanted to answer only one or both parts of the survey, depending also on their expertise. 14 participants have answered the survey. While the results validate our research idea and research questions, we could also make the following preliminary conclusions:

1. Costs and travel times with respect to fulfilling the response time target are the key criteria for decision making while the participants gave different rankings for the criteria.
2. Operations Research approaches are applicable to decision making in practice.
3. While they use software in general, they do not use computer-based planning approaches, but they would value computer-based planning support.

5 Conclusion and Outlook

This paper contributes to theory as well as practice by discussing an important challenge, i.e. the necessary amount of information to assist decision making. A set of research questions is defined and the protocol for a 3-stage research study is presented. Healthcare is chosen as the application area.

Part of the outcome will be an insight on the number of desired alternative solutions and the appropriate representation, e.g. for EMS logistics like the location planning of ambulances.

The described research project will focus on decision makers from the healthcare area. Nevertheless, multi-criteria problems also exist in many other areas, as for example production planning or logistics. The presented study outline itself is independent of the actual application area, therefore, future research could analyse if studies with decision makers from different areas besides healthcare lead to similar results, or if insights differ depending on the area of application. If it does, resulting research would include to study how they differ and to find reasons why.

Finally, based on the results, it is of interest to bring the results of the studies into practice, i.e. when actually designing a user assistance system for decision making. In healthcare, this could mean adapting a multi-criteria approach to determine the desired number of Pareto-optimal solutions and editing the solutions with the adequate level of information and detail, for example.

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