Social Choice Aggregation Methods for Multiple Attribute Business Information System Selection

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Abstract

This paper targets the area of business Information System (IS) decision making, where accountable and understandable decision support is needed for all involved stakeholders. When information systems investments are evaluated based on applying different dimensions or attributes to the available alternatives the results have to be consolidated into a single ranking to provide a base for the investment decision. This consolidation itself is a multiple attribute decision problem. In this work the situation is perceived from a social choice point of view; a number of voting rules are described that can be applied to this task. The properties of the results they deliver are analyzed in an ex post case study, and are thereafter explored for typical business IS decisions in simulation analysis. From the latter, results include distance information based on the aggregation results for the set of considered voting rules, which, e.g, can be used to select a method mix for validating ranking outcomes. For the case study, results include rankings of the voting rules being contrasted to the outcome of the standard ranking and scoring technique applied in practice.

1. Introduction

This article focuses on decision making for Information System (IS) selection, in particular in the context of business applications. This area has been recognized as important research topic for the last decades producing a variety of decision making methodologies and methods to aid the decision maker in this often business critical task. An important stream of research can be assigned to the concept of multiple attribute decision making (MADM), where problems are represented by several (conflicting) attributes or criteria. It was described as the most well known branch of decision making [Triantaphyllou 2000]. These methods appeal to management due to their intuitive, simple and cost effective application. They are relatively transparent, allowing others to see the logic of the results and enabling the inclusion of the full range of intangible consequences in terms of considered attributes. Nevertheless, many difficulties in MADM exist that lead to application errors in business practice. Model extensions proposed to avoid these errors are in general coupled with increased complexity that in turn hinders their acceptance. In this article, we seek to increase the awareness and test the applicability of well researched selection rules used in social choice theory for their inclusion in popular MADM techniques used in the IS field.

The remainder of this article is structured as follows. Next, the research background and objectives are clarified. Next, social choice methods are shortly described and thereafter applied in a case study showing the selection of an Enterprise Resource Planning System in an Austrian company. Next, results of a simulation comparison of methods is supplied. The last section concludes the article.

2. Research background and objectives

MADM refers to making preference decisions over a finite number of alternatives that are characterized by multiple, usually conflicting, attributes. A MADM problem can be expressed by a matrix, where columns indicate the attributes considered and rows denote the competing alternatives. Each MADM problem needs to be solved by one of the numerous MADM methods available. It is essential for many compensatory MADM methods to obtain comparable scales by normalization of attribute ratings. Solving the MADM problem can imply the aggregation of utilities into an overall evaluation for each alternative leading to a final ranking. In many applications a weight vector describing the relative importance values of each attribute is used to aggregate the alternative evaluations.

In this paper we focus on MADM in a finite IS selection problem, where usually the number of alternatives is limited and a wide choice of selection attributes are considered. In the field of IS evaluation the MADM approach 'Information Economics' received considerable attention [Parker 1988]. The model gives the decision makers the means to identify and assess a comprehensive set of evaluation attributes in the IS evaluation problem setting, therefore it primarily assists in the important generation of attributes. Other more general concepts provide assistance to identify places where important criteria, especially benefits, might be found, e.g. [Farbey 1994].

The common frameworks used in systematic IS selection for MADM are based on additive value models, usually either the Analytic Hierarchic Process [Saaty 1980] (AHP) or some kind of utility ranking models (based on the so-called "Nutzwertanalyse" - NWA) [Zangemeister 1976]. In both cases the decision maker tries to maximize a quantity called utility or value. This postulates that all alternatives may be evaluated on a single scale that reflects the value system of the decision maker and his preferences. To generate this super scale, multiple single-attribute value functions are consolidated, most regularly by a simple additive procedure. In the mentioned methodologies (AHP and NWA) the assessment of attribute weights and single-attribute value functions is supported. The value aggregation per alternative is in the case of AHP, undertaken by a weighted sum of those single-attribute value functions. In terms of NWA, the decision maker is allowed to choose among a set of methods and typically relies on the standard recommendation, again formally a weighted sum approach. In the weighted sum method, the overall suitability of each alternative is thereby calculated by averaging the score of each alternative with respect to every attribute with the corresponding importance weighting. In business practice, important pre-conditions of the NWA (and the AHP) are violated. Regularly, scale types are mis-used or scale transformations made are invalid, e.g., ordinally scaled values are used as if they were cardinally scaled. Another major problem lies in the necessity of defining attribute weights, which is known as major challenge for decision makers.

Another, more general, nevertheless major criticism of MADM is that different methods may yield different results when applied to the same problem. This phenomenon is known as the inconsistent ranking problem caused by the use of different MADM methods [Yeh 2003]. The availability of a wide selection of methods for solving IS decision problems generates the paradox that the selection of a MADM method for a given problem leads to a MADM problem itself [Triantaphyllou 2000].

In this article we seek to simplify the systematic methodologies used in the NWA and the AHP by incorporating popular social choice methods in the selection process. These methods should appeal to business practices since they demand less rigorous information from the decision maker. No single-attribute value functions need to be derived and no weighting of attributes is needed. The analogy between voting and multiple criteria decision support is easily found. If attributes are replaced by voters, and alternatives by candidates, a social choice problem is designed. In other words, the preferences of an individual in social choice problems play the same role as the preferences gained along a single dimension or attribute in MADM [Bouyssou 2000]. A major motivation for this analogy lies in the fact that voting theory has developed since the original works by Borda, Condorcet and Arrow [Borda 1781, Condorcet 1985, Arrow 1963] to a large amount of results at disposal for use in MADM.

It remains to be asked if these social choice selection rules can be transformed into the IS selection domain with its distinctive characterization. For this purpose, we first explore popular selection rules in a case study before undertaking a comparison through simulation analysis. For the latter, we refer to the typical setting found in complex IS decisions as will be motivated. The case study describes an Enterprise Resource Planning (ERP) Software selection, which can be seen as a well suited example for a complex Business Information

System selection problem. The next section gives a short overview of the social choice rules considered in this paper.

3. Methods of rank aggregation

Consider a set of n voters who apply different criteria to a set of m alternatives, resulting in a profile consisting of n rankings, e.g., alternatives a,b,c and rankings $a \succ b \succ c$, $b \succ c \succ a$, $c \succ a \succ b$, $b \succ c \succ a$. The problem of preference aggregation in social choice consists of finding an aggregate ranking $x \geq y \geq z$ such that the preferences stated by the voters are expressed in the aggregate ranking. We assume that the profile does not contain indifferences; however, the resulting aggregation may contain them. As already stated, in the MADM context the voters can be replaced by the dimensions or attributes considered. The evaluation of the alternatives is reduced to finding the n rankings of alternatives for the n dimensions or attributes, instead of defining n single-attribute value functions.

In order to express all possible outcomes from preference aggregation the pairwise comparisons of the m alternatives are stated in $m \times m$ matrix notation, e.g., a possible aggregation from the example above is $(0,0,0),(1,0,1),(1,0,0)$, stating that $b \geq a$, $b \geq c$, and $c \geq a$.

While the social choice aggregation rules are aimed at generating an ordering over all alternatives, special emphasis is on selecting the winner. If an alternative x exists that beats all other alternatives in pairwise comparisons, x is a Condorcet winner [Fishburn 1977]. An obvious demand on an aggregation rule is that it select x as a winner.

The following description gives a short overview of popular methods of rank aggregation from social choice theory, which will be forwarded into case study and simulation analysis. A more detailed definition is supplied by existing literature [Fishburn 1977, Saari 2001].

Simple Majority (SM)

A well-known voting procedure is the simple majority rule which counts the number of rankings where alternative x is preferred to y versus the number of rankings where y is preferred to x; a positive margin means that x wins against y in pairwise comparison and results in $x \succ y$ in the result, a negative margins leads to $x \prec y$, and a zero margin means indifference. This rule can easily result in cycles, such that $x \succ y$, $y \succ z$, $z \succ x$ (drop the fourth voter from the example given above to arrive at a cycle). In addition, transitivity is not guaranteed, i.e. $x \succ y$ and $y \succ z$ does not necessarily entail $x \succ z$. These disadvantages limit the use of the SM rule in practical applications; therefore, a number of extensions and improvements have been introduced, as well as altogether different approaches to the rank aggregation problem.

Transitive Closure (TC)
The transitive closure applies repeated matrix multiplication of the SM rule relation with itself until no more change occurs, in order to arrive at a transitive relation.

Maximin (MM)
The Maximin rule scores the alternatives with the worst margin they each achieve and ranks them according to those scores.

Copeland (CO)
The Copeland rule scores the alternatives with the sum over the signs of the margins they achieve and ranks them according to these scores.

Plurality (PL)
The plurality voting rule is often used in political elections; it ranks the alternatives according to the number of times they received top place. While easily understood and applied, it often fails the put the Condorcet winner in the winning set.

Antiplurality (AP)
A similar rule known as antiplurality ranks the alternatives according to the number of times they did not received last place. This rule tends to create a large winner set.

Borda (BO)
The Borda rule assigns decreasing points to consecutive positions, such as 2 points for first place, 1 point for second and zero for third. The alternatives are then ranked according to their total score.

Kemeny (KE)
The Kemeny rule chooses the ordering with minimal distance to all rankings in the profile, where distance is defined as the number of different pairwise relations.

Slater (SL)
The Slater rule chooses the ordering with minimal distance to the outcome of the simple majority rule, where distance is defined as the number of different entries.

Nanson (NA)
The Nanson rule repeatedly calculates the Borda scores and drops the alternatives with the minimal scores, using the iteration number for the final ranking, i.e. alternatives which survive the dropping process longer are ranked higher.

Young (YO)
The Young rule ranks alternative x by the minimum number of voters which must be dropped to make x an SM winner.

Dodgson (DO)
The Dodgson rule ranks alternative x by the minimum number of switches of adjacent alternatives in the voters' rankings it takes to make x an SMR winner.

4. Case study application of voting rules

This case analysis is based on the situation found at Primagaz Austria, an international wholesaler of liquid and gaseous fuels and related products (SHV Holdings N.V.). In this article we limit the case study semantics to a minimum, since we would like to keep the article focused. For a more detailed description about the company and the undertaken ERP adoption process see (reference suppressed) [Bernroider 2004].

The company's ERP decision making methodology was based on the NWA complemented with vendor related perceptions and a separate financial analysis. Through the NWA, they wanted the desired system to achieve a high ERP utility score through simple additive weighting based on a number of pre-selected attributes reflecting their specific range of targeted software specific functionalities and benefits. The requirements comprised the categories (1) controlling and reporting, (2) accounting, (3) logistics, (4) purchasing, (5) needs of local divisions, (6) services and engineering, (7) sales, and (8) business management. The weighted utility scores for the three pre-selected alternatives (we will refer to them as A, B and C) were 253, 288 and 252 respectively. Alternative B outranks its opponents whereas A and C seem to have a tie, i.e. they can be considered as equally good. This situation demonstrates shortcomings of the NWA: The resulting utility scores are hardly interpretable and do not provide a clear-cut ranking. Furthermore, the common mistake of using ordinally scaled utility values in a simple additive weighting model was observed.

The application of social choice rules would limit the demands placed on the data considerably. No value judgments and no weighting of attributes would be needed. Removing weights from the analysis has the implicit assumption that every attribute is of equal importance. Therefore, analyzing the robustness of the winner becomes even more important. Preference information must be gathered in terms of the alternatives for each dimension/attribute, which were derived for our ex post analysis from the supplied case study data. The aggregation rules described above were applied to the preferences resulting from the application of 8 criteria to 3 alternatives in the case study. The result is shown in Table 1.

In terms of alternative B, the application of all methods validates B as the winner, i.e. as the best alternative. This remains unchanged even if the tie in the second from last criterion is resolved differently. In terms of the remaining alternatives, C seems to be slightly preferable in comparison to A. The results suggest to further investigate the ratings of A compared to C in order to achieve a more stable ranking outcome. Similar interpretations were achieved in the far more complicated NWA, where A was valued higher by one value unit in comparison with C.

Table 1. Application of the voting rules to the case study data.

Rule	Relation	Ranking
SM	((1 0 0),(1 1 1),(1 0 1))	$b \succ c \succ a$
BO	((1 0 0),(1 1 1),(1 0 1))	$b \succ c \succ a$
CO	((1 0 0),(1 1 1),(1 0 1))	$b \succ c \succ a$
TC	((1 0 0),(1 1 1),(1 0 1))	$b \succ c \succ a$
NA	((1 0 0),(1 1 1),(1 0 1))	$b \succ c \succ a$
MM	((1 0 1),(1 1 1),(1 0 1))	$b \succ c \geq a$
KE	((1 0 0),(1 1 1),(1 0 1))	$b \succ c \succ a$
SL	((1 0 0),(1 1 1),(1 0 1))	$b \succ c \succ a$
YO	((1 0 1),(1 1 1),(1 0 1))	$b \succ c \geq a$
DO	((1 0 0),(1 1 1),(1 0 1))	$b \succ c \succ a$
PL	((1 0 1),(1 1 1),(0 0 1))	$b \succ a \succ c$
AP	((1 0 0),(1 1 1),(1 0 1))	$b \succ c \succ a$

Source: Case study

5. Simulation comparison of voting rules

All voting procedures described have been applied to randomly generated linear orderings[1]. As typical setting in IS selection problems, the number of alternatives was set to $m=3$. This count was identified as the (rounded) mean number of alternatives considered in ERP selection problems in an empirical study of Austrian medium and large scale enterprises [Bernroider 2005]. Furthermore, the number of voters (attributes) was set to $n=25$, and the sample size was $s=1000$[2]. The aggregate relations resulting from the random profiles have been compared by using a distance measure on the $m \times m$ bit-wise comparisons in the relation generated by the voting rules [Eckert 2005]. The distances divided by $m(m-1)$ for normalization are tabulated in Table 2. For instance, the very small distance value for Dodgson and Nanson of 0.02 signifies that those rules have generated very similar relations from the random profiles. Note that for 3 alternatives the ranking outcome for Young and Maximin are identical.

We visualized the relationship between the different rules using a method commonly used in phylogenetics, a biological research discipline which investigates the relationships of groups of organisms [Felsenstein 2004]. Pairwise distances were converted into a tree structure by the use of the Neighbor Joining algorithm, a clustering method developed by [Saitou 1987]. Branch lengths are drawn proportional to distance. The neighbor tree resulting

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[1] The simulation has been programmed in the Python language and is available for download at http://prefrule.sourceforge.net.

[2] Rankings are independent from each other and distributed uniformly over the 3! permutations; this is referred to as impartial culture in social choice literature.

from the distance matrix above is shown in Figure 1. It is immediately visible that the Plurality and Antiplurality are distinctly separated from the other rules, while Borda and Copeland are arranged close to each other.

Table 2. Distances of the relations generated by the voting rules on the random rankings.

	SM	BO	CO	TC	NA	MM	KE	SL	YO	DO	PL	AP
SM	.000	.116	.050	.050	.066	.140	.033	.033	.140	.085	.211	.209
BO	.116	.000	.105	.105	.051	.107	.086	.121	.107	.052	.173	.173
CO	.050	.105	.000	.000	.074	.123	.050	.050	.123	.069	.201	.198
TC	.050	.105	.000	.000	.074	.123	.050	.050	.123	.069	.201	.198
NA	.066	.051	.074	.074	.000	.074	.051	.079	.074	.020	.179	.198
MM	.140	.107	.123	.123	.074	.000	.116	.147	.000	.054	.176	.221
KE	.033	.086	.050	.050	.051	.116	.000	.036	.116	.062	.195	.199
SL	.033	.121	.050	.050	.079	.147	.036	.000	.147	.093	.215	.206
YO	.140	.107	.123	.123	.074	.000	.116	.147	.000	.054	.176	.221
DO	.085	.052	.069	.069	.020	.054	.062	.093	.054	.000	.173	.197
PL	.211	.173	.201	.201	.179	.176	.195	.215	.176	.173	.000	.346
AP	.209	.173	.198	.198	.198	.221	.199	.206	.221	.197	.346	.000

Source: Simulation study

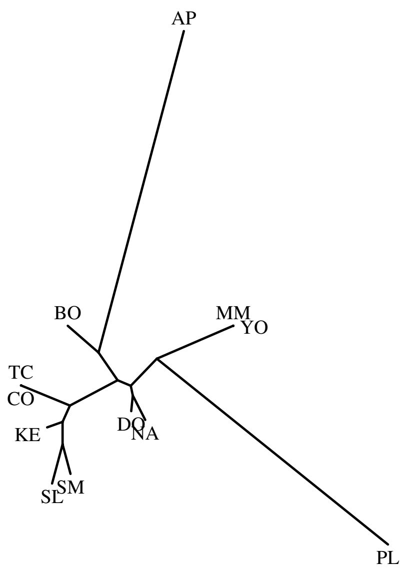

Figure 1. Nearest neighbor tree of the relation distances.

These findings are consistent with other results [Eckert 2005] in identifying Borda and Copeland as a core set of voting rules, with the remaining rules being placed apart in the neighbor tree.

6. Conclusion

Especially in critical decisions, such as large scale IS investments, an understandable and accountable decision support is needed for all involved stakeholders. In the application of selection process frameworks, e.g., the mentioned AHP and NWA, common challenges are the definition of attribute weights, the multi-dimensional valuation of alternatives on appropriate scales and the selection of an aggregation rule. These tasks, often connected with major mistakes, can be simplified by using social choice selection rules. The case study has shown that very similar results were achieved in comparison with the classic NWA chosen in practice - the distinctive winner of the NWA was ranked first in all social choice rules and a tie between the two other alternatives was identified. The interesting observation was the handling of the two almost equally good alternatives by the various selection rules. The simulation results, especially the graphical representation, gives an intuitive impression of the effect of rule choice on the outcome of the aggregation process. Borda and Copeland will generate more similar results than Plurality and Antiplurality. A possible application of this figure is to determine a choice of methods based on their disparity in these result, which can be used to validate ranking outcomes. If strongly differential rules produce the same ranking outcomes, then the validity of the results is supported, otherwise questioned. The usage of a set of methods and comparison of ranking outcomes can supply the kind of easy and applicable MADM validation called for in academic research.

Future work will further analyze characteristics of voting rules and consequence for MADM in IS selection, such as manipulability, Condorcet criterion, and computational feasibility. Based on the achieved results, a modified NWA based procedural model will be developed to supply business practice with the possibility of selecting a suitable aggregation rule portfolio including diverse social choice selection rules. The main goal is apply less information demanding MADM selection approaches and also to support validation, since this requirement is often neglected in practice.

7. References

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