Group Recommendation Algorithms for Requirements Prioritization

A. Felfernig and G. Ninaus
Institute for Software Technology
Graz University of Technology
Inffeldgasse 16b, 8010 Graz, Austria
e-mail: {firstname.lastname}@ist.tugraz.at

Abstract—Group recommendation is successfully applied in different domains such as Interactive Television, Ambient Intelligence, and e-Tourism. The focus of this paper is to analyze the applicability of group recommendation to requirements prioritization. We provide an overview of relevant group recommendation heuristics and report the results of an empirical study which focused on the analysis of the prediction quality of these heuristics.

Keywords—Requirements Engineering, Requirements Prioritization, Recommender Systems, Group Recommendation

I. INTRODUCTION

Resource limitations in software projects trigger the demand of a prioritization of the defined requirements [9] [14]. Such a prioritization helps managers of software projects to systematically define criteria for subsequent software releases and to resolve existing conflicts in the preferences of stakeholders. An important quality characteristic of requirements is their prioritization. Only systematic prioritization can guarantee that the most essential functionalities of the software system are implemented in-time [14]. Typically, requirements prioritization is a collaborative task where stakeholders in a software project collaborate with the goal to achieve consensus regarding the prioritization of a set of given requirements. The earlier requirements are prioritized, the lower is the effort of implementing irrelevant requirements and the higher is the amount of available resources to implement the most relevant requirements. Establishing consensus between stakeholders regarding the prioritization of a given set of requirements is a challenging task. Prioritizations do not only have to take into account criteria related to business optimization but as well criteria related to aspects of the software architecture. Especially in larger projects, stakeholders need a tool-supported prioritization approach which can help to reduce influences related to psychological and political factors [14].

Requirements engineering processes such as EasyWinWin [3] (which is based on the risk-oriented spiral model [4]) include prioritization operations which are based on the assumption that stakeholders know their preferences. An example technique to the implementation of requirements prioritization assuming such stable stakeholder preferences is based on the concepts of quality function deployment (QFD) [14]. This approach provides a structured way of identifying a prioritization for requirements. All the requirements are enlisted in a table and for each requirement the responsible stakeholders have to define the benefit (business value of the requirements in case it is implemented) and the penalty of not implementing the requirement. Both together form the relative value of the requirement. Beside the value of a requirement we have to estimate the corresponding development risks, for example, the non-availability of the needed expertise and resources and corresponding technological risks. The priority of a specific requirement \( r \) can then be determined on the basis of multi-attribute utility theory [15] with the interest dimensions \( d_i \): value and \( d_i \): risk (see Formula 1) where \( w(d_i) \) denotes the weight of an interest dimension \( d_i \). The result of applying Formula 1 is a recommendation for the prioritization of a given set of requirements.

\[
\text{priority}(r) = \sum_{d=0}^{n} w(d_i) \cdot d_i
\] (1)

Such utility-based approaches rely on the basic assumption of preference stability which means that stakeholders exactly know their preferences, i.e., are able to evaluate requirements with regard to the interest dimensions \( d_i \). In contrast to this assumption, most real-world decisions are based on preference construction [2], i.e., stakeholders are developing their preferences within the scope of a decision making process. Requirements engineering processes not taking into account this fact are running the risk of low-quality requirements prioritizations due to the fact the human decision processes are not taken into account [1].

A mechanism to improve the applicability of requirements negotiation tools is to proactively assist stakeholders in their personal decision making process [1] [6]. In our previous work [6] we showed that group recommendation technologies [10] can significantly improve the usability and decision support quality of requirements engineering environments. Furthermore, group recommendation can stimulate information exchange in requirements negotiation scenarios which results in group decisions of higher quality [8]. Studies in social psychology clearly show that frequent information exchange (of decision relevant information)
between group members can significantly improve the quality of a group decision [8]. The effect of increased information exchange can be explained by the fact that the availability of group recommendations intensifies discussions between group members. The phenomenon is well known and exploited, for example, by critiquing-based recommender systems [5] where the system proposes recommendations and users can provide feedback in terms of critiques. In a group recommendation scenario, such critiques are defined in terms of preference adaptations which are in the following the input for the calculation of new group recommendations. Note that we interpret group recommendation as basic mechanism to support decision processes. However, decisions are still taken by engaged stakeholders and group recommendation should help to improve the overall decision quality and decision efficiency.

The remainder of this paper is organized as follows. In Section II we discuss and exemplify basic group recommendation approaches. In this context we show possibilities of how to apply group recommendation in the context of requirements prioritization. In Section III we report the results of an empirical study in which we compared group recommendation approaches w.r.t. their predictive quality (precision). In Section IV we discuss issues for future work. With Section V we conclude the paper.

II. GROUP RECOMMENDATION HEURISTICS

Group recommendation technologies have been successfully applied in different scenarios where groups of people are in the need of decision support [10]. For example, a group of people is interested in spending the holidays together or celebrating the birthday of a person in a restaurant. In the first scenario, the group has to take a decision regarding the holiday destination, in the second case the group has to develop a consensus regarding the restaurant for the birthday celebration.

The goal of our work is to extend the applicability of group recommendation approaches to requirements prioritization. In the following paragraphs we exemplify basic group recommendation heuristics which are applied in a requirements prioritization scenario. In this simplified example we assume that the requirements $r_1$, $r_2$, and $r_3$ have to be prioritized by the stakeholders Martin, Susan, Peter, and Pauline. Each of the given requirements can be prioritized on a scale $1$=unimportant and $5$=very important. In our example we assume that the stakeholders have already specified their initial preferences and that the group recommender system aggregates the initial user preferences (prioritizations) into a recommendation for a group decision. In the following paragraphs we introduce the basic group recommendation heuristics [10] least distance, majority voting, average value, and random priority selection. In Section III we analyze the predictive quality (precision) of the heuristics on the basis of a real-world dataset collected in software projects at the Graz University of Technology.

Note that these heuristics currently do not take into account importance weights of specific stakeholder votes. For example, if a stakeholder has a very important reason as to why a requirement should be included in a certain release, this information is not taken into account by the discussed decision heuristics. In such a case we assume that the other stakeholders are convinced by the one stakeholder to change their mind. However, the inclusion of the importance of individual votes is within the scope of our future work.

Least Distance. This heuristic determines (recommends) for each requirement $r$, the priority value $p$ with the lowest distance to the other elements in the set of distinct user preferences ($PREF$) where $p \in PREF$. This criteria is formalized in a corresponding evaluation function (see Formula 2).

$$priority(r) = \text{selectmin} \left( p, \sum_{\text{pref} \in \text{PREF}} |\text{pref} - p| \right) \quad (2)$$

A corresponding example is shown in Table 1. In this example, the recommended priority for requirement $r_1$ is 2, since 2 has the lowest distance to all other user preferences (prioritizations) $\text{pref} \in \text{PREF} = \{1,2,3\}$.

<table>
<thead>
<tr>
<th>$r_1$</th>
<th>Martin</th>
<th>Susan</th>
<th>Peter</th>
<th>Pauline</th>
<th>recommended priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>1</td>
<td>3</td>
<td>1</td>
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Majority Voting. This heuristic recommends a priority value which represents the majority of stakeholder votes related to a specific requirement. An example for the application of the majority heuristic is given in Table 2.

<table>
<thead>
<tr>
<th>$r_1$</th>
<th>Martin</th>
<th>Susan</th>
<th>Peter</th>
<th>Pauline</th>
<th>recommended priority</th>
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<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>3</td>
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Average Value. This heuristic determines for each requirement the average value (rounded up) of the declared stakeholder preferences (see Formula 3). This value is then taken as a recommendation of the priority value for the corresponding requirement. An example for the application of the average value heuristic is shown in Table 3.

$$priority(r) = \text{roundup} \left( \frac{\sum_{\text{user}} \text{pref}(lr)}{\#\text{user}} \right) \quad (3)$$

<table>
<thead>
<tr>
<th>$r_1$</th>
<th>Martin</th>
<th>Susan</th>
<th>Peter</th>
<th>Pauline</th>
<th>recommended priority</th>
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</tbody>
</table>
TABLE III. APPLICATION OF THE "AVERAGE VALUE" HEURISTIC.

<table>
<thead>
<tr>
<th></th>
<th>Martin</th>
<th>Susan</th>
<th>Peter</th>
<th>Pauline</th>
<th>recommended priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase 1</td>
<td>r₁</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Phase 2</td>
<td>r₂</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Phase 3</td>
<td>r₃</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>1</td>
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</table>

Random Priority Selection. The random heuristic has been integrated only for evaluation purposes. As will be shown in the next section, the heuristic is – as expected – the weakest one among the investigated recommendation heuristics. Note that the presented set of group recommendation heuristics is an initial set used for our user study. An in-depth analysis of further group decision strategies is within the focus of future work.

III. EMPirical STUDY

In order to evaluate the predictive performance of the group recommendation heuristics presented in Section II, we conducted an empirical study on the basis of a dataset collected in software projects conducted within the scope of a course on object-oriented analysis & design at the Graz University of Technology. This dataset consists of prioritization decisions (prioritization scale of 1—5 where 1=unimportant and 5=very important) of 55 software development teams (team size between 5 and 6 members).

The decision process (see Fig. 1) consisted of three different phases denoted as construction (collection of individual stakeholder preferences), consensus (discussion of prioritization alternatives and adaptation of own preferences), and decision (group decision defined and explained by the project manager). This decision process structure results in ~15.000 stakeholder decisions and 55 corresponding group decisions taken by the team leaders (project managers).

The results of our empirical analysis are depicted in Table 4. The entries of Table 4 represent precision values (see Formula 4) of the analyzed group recommendation heuristics (in Formula 4, \( h \) denotes one specific group recommendation heuristic). For example, using the individual stakeholder preferences (preferences regarding the prioritization of the requirements) of the construction phase for the group recommendation results in a precision value of 0.632 for least distance heuristic (LDIS). Among the currently investigated group decision heuristics the LDIS heuristic has the best predictive quality. It is important to point out that the prediction quality of the decision heuristics increases when we exploit the individual stakeholder preferences of the consensus phase for the determination of the next group recommendation.

IV. FUTURE WORK

Group Decision Heuristics. The heuristics discussed in this paper are basic group recommendation heuristics successfully applied in different application domains such as Interactive Television, Ambient Intelligence, and e-Tourism [10]. Our initial analysis shows the applicability of these heuristics in terms of prediction quality. However, further analyses are required in this context, for example, in terms of performing an in-depth evaluation of the user acceptance of the determined group recommendations – up to now only the user acceptance of majority voting strategies has been analyzed [6]. Furthermore, the basic heuristics discussed in this paper have to be developed further, for example, by combining different basic heuristics to so-called hybrid group recommendation heuristics, for example, by integrating group recommendation heuristics with the concepts of social network analysis. Another example is the integration of measures for personal preference stability which can be taken into account when determining recommendations. For a more in-depth discussion of basic group recommendation heuristics we refer the reader to [10].

Beyond Group Recommendation. The group decision support discussed in this paper is restricted to the application of basic group recommendation heuristics. Our future work in this context will also include knowledge-based recommendation approaches, for example, critiquing-based approaches [5] which will be exploited for supporting a

FIGURE 1. PRIORITIZATION (DECISION) PROCESS OF EMPIRICAL STUDY. CONSTRUCTION: STAKEHOLDERS DEFINE THEIR INITIAL PREFERENCES; CONSENSUS: STAKEHOLDERS ADAPT THEIR PREFERENCES ON THE BASIS OF THE KNOWLEDGE ABOUT PREFERENCES OF OTHER STAKEHOLDERS; DECISION: PROJECT MANAGERS TAKE THE FINAL GROUP DECISION.
navigation-based search in the space of alternative requirement prioritizations.

**Decision Technologies in Software Engineering.** We interpret our work on the application of group recommendation approaches to requirements prioritization as a major step towards the integration of decision technologies into different scenarios in the software engineering context. Our future work will include, for example, the integration of knowledge-based recommendation [7] and diagnosis [11] with existing approaches to release planning [13].

**Psychological Issues.** An important task for future work is the in-depth analysis of the existence of decision biases in software engineering related decision scenarios. As already investigated in [6], misleading recommendations of requirement prioritizations can trigger decision biases which can potentially lead to sub-optimal prioritization decisions. In this context, recommendations can be interpreted as a specific type of default value which has shown to trigger decision biases [12]. Decoy effects trigger a different type of decision anomaly: if a complete inferior decision alternative is included a set of decision alternatives, this new alternative – although completely inferior – can trigger a significant shift in the selection probability of the other decision alternatives. An in-depth investigation of such effects in the context of software engineering scenarios is within the focus of our future work.

V. **CONCLUSIONS**

In this paper we have motivated and shown the application of group decision heuristics in the context of requirements prioritization. Group recommendations have the potential to intensify discussions of stakeholders about alternative requirements prioritizations and – as a consequence – increase the quality of the decision outcome (prioritization of the given set of requirements). The study presented in this paper is the basis for future research on the applicability and impact of recommendation approaches in different types of requirements engineering scenarios.

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**REFERENCES**