Visualizing A Dynamic Web-Based Collaborative Idea Selection Algorithm for Increasing Acceptance in Innovation Processes

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***Abstract* – In order to maintain competitiveness, companies must constantly find new and better business ideas. They use innovation processes for managing idea generation and implementation. This process involves the employees that will be responsible for the implementation of these ideas, and the success of an innovation venture depends on their motivation. Especially during the first idea phase there is a high risk of making an evaluation error, which may reduce acceptance of the result and consequently also motivation. The authors have previously developed the so-called threshold group idea selection algorithm, which although fast suffers from a less-than optimal acceptance by the group. In this paper, we assume that acceptance depends on the understanding of how a selection is achieved by the group. We therefore created a dynamic, web-based interaction design for the algorithm that visualizes the effects of decisions made during the collaborative selection process. We applied basic visualization principles and chose appropriate input devices for different types of collaboration phases. Our findings indicate that the acceptance level of the improved threshold algorithm achieved nearly the same acceptance as the commonly used, but significantly more expensive group discussion method.**

Keywords-Innovation; Dynamic Interaction Design; Idea Selection; Acceptance; Group Evaluation; Collaboration.

I. INTRODUCTION

This Section motivates the research work. An important application, a motivation and the requirements for a solution will be given.

A. Background

Business innovations are crucial for companies to survive. They provide companies with a competitive advantage by reinventing their processes, products, services or business models. Increasing market dynamics creates the need especially for faster innovation creation [25].

Companies waste a lot of money in the development of unsuccessful ideas. An IBM study [7] discovered that less than 1% of the company's ideas are economically successful, while 99% of their innovation efforts are lost in the selection and development process of the ideas.

In order to manage ideas, companies use innovation processes. An innovation process is divided into the Front End and the Back End [22]. The Front End defines the development of an idea from its generation up to a business concept ready for implementation, whereas the Back End develops and brings ideas to market that are ready for implementation. The Front End tends to be unstructured and uncontrolled in contrast to the Back End. This makes it difficult for a company to ensure their innovation successes. These processes are designed and managed by an innovation manager. An innovation manager usually has to manage hundreds of ideas, concepts and projects.

A Stage-Gate process [9] is one common model for an innovation process (see Figure 1.). It divides the process into stages and gates. In the stages, innovation projects are developed. Gates are decision points for whether a project should proceed to the next development stage. The Stage-Gate process was originally proposed for the Back End, but it can also be applied to the Front End. The Front End starts directly after the idea generation and ends with the investment or development decision by management. After that, the development of the projects starts in the Back End.

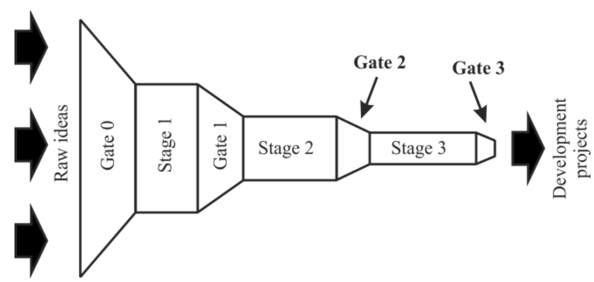

Figure 1. Front End of Innovation Process

For the Back End of the process there are many tools to support the successful development of ideas. The two major differences between the Front End and the Back End are the number and the quality of ideas. The Back Ends needs to deal with few but well defined ideas whereas the Front End needs to deal with hundreds of ideas that are ill defined. Especially gate 0 lacks methods that support innovation managers accordingly to this situation. Decision Maker (DM) need to choose here among hundreds of ideas that are uncertain and ambiguous. They lack time for discussing their opinions in detail [3]. If five engineers had to discuss 100 ideas and each discussion only lasted five minutes, this would cost about 42 man hours, which is too expensive.

The next problem associated with gate 0 is the involvement of the DM. In order to increase the chances of

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developing successful innovation, the innovation manager needs a motivated team [17] that will engage in a challenging development phase after they have made their decision. If – in their individual opinions – promising ideas were declined or bad ideas were selected, the DM will lose motivation. This may significantly decrease the probability of a successful implementation.

B. Motivation

A group selection method for gate 0 would provide a selection result which is both fast and also achieves a high level of acceptance. Two common selection methods lack either speed or acceptance of selection results:

- **Individual selection.** Each DM is assigned a subset of the ideas and independently selects or rejects them. The overall selection result is then simply the union of the results of each individual DM. This method is very quick and easy to understand, but severely lacks group acceptance [14]. This lack of group acceptance is assumed to be due to the lack of transparency in how the group achieves their overall selection: each group member only evaluates their own subset of ideas and is asked to accept the evaluation of the other group members without seeing or discussing important questions. A discussion is often used for clarifying the selection goal and how they should apply to the selection alternatives.
- **Group discussion.** Each idea is discussed face-to-face. The group then votes to select or reject each idea. With this approach, every DM sees every idea and gets the chance to discuss them with the other DM. This process is fully transparent. DM can follow every discussion and are able to observe how the group reaches their overall selection result. This method delivers selection results with a high level of acceptance, but is very slow and exhausting for the group [14].

Goers et al. [14] proposed a collaborative, computer supported threshold algorithm for combining the advantages of the speed of the individual selection method and the high acceptance rate of selection results of the group discussion. The threshold algorithm achieves a selection in three phases. In the first phase, the ideas are divided into subsets and each subset is assigned to a different DM. These then carry out a local selection and identify the idea, which represents the threshold between acceptance and rejection of ideas within their subsets. In the second phase, DM discuss their threshold ideas, make the selection and identify the global threshold idea. In the third phase, each DM compares their decisions for their own subset from phase one to the newly discussed global threshold idea from phase two, and completes the selection. This threshold algorithm is a trade-off between the pure fast individual selection that lacks acceptance in selection results and the expensive group discussion that generates a high acceptance in selection results. The algorithm combines the advantages of both methods while expending a minimal amount of effort to avoid their respective disadvantages.

The threshold algorithm performs twice as fast as the group discussion and generates less cognitive load. However, it produces only a moderate level of acceptance for the selection results. So, although the threshold algorithm appears to be more appropriate for the selection of ideas in gate 0 than the usually used methods, there is still room for improvement, and our research aims at increasing its acceptance without compromising its speed advantage.

The lack of group acceptance may have many influencing factors such as group behavior or psychological factors. An example could be the trust each DM has in the ability to evaluate alternatives. No process would be able to create a high level of group acceptance if the DM did not trust each other's abilities to evaluate alternatives.

This work examines the influence of process understanding for group acceptance. We assume that low acceptance arises from a lack of process understanding. The DMs cannot trace how their individual decisions or group discussion input might have an impact on the overall selection result. The reason lies in the execution of the algorithm:

- **Number of individually considered ideas.** The threshold algorithm parallelises the selection task in order to obtain speed, thus every DM only evaluates a small subset of the ideas. For all other ideas, the DMs are forced to trust in the selection abilities of the other DMs.
- **Decision consequences on overall selection.** DMs make their judgments individually and as a group. Each decision effects the overall selection. But the DMs cannot track and therefore cannot reconstruct how the overall selection result is produced due to the invisible calculations of the algorithm.

It is thus the limited control over the ideas, the limited visibility of ideas and the non-traceability of the selection process that may cause misgivings and therefore result in the lack of acceptance of the overall selection result.

In 1980, Davis developed a technology acceptance model [11]. It states that a user accepts a technology if two attributes are fulfilled: usefulness and ease of use. A user would accept a technology if he perceives the technology is useful. This includes the perceived quality of result and process understanding. If from the user's point of view, the technology is easy to use, the user is more likely to accept it. That requires the low complexity of the technology as well as the usability. The original implementation of the threshold algorithm did not allow the DM to trace individual decisions and see for themselves how the overall result is achieved. The algorithm gathers their evaluations but did not show them the invisible calculations of the selection. The acceptance of selection results suffers when the calculations are invisible, even if the calculation is simple.

Also, Briggs [6] suggests visualising collaboration processes in order to motivate groups, improve a group's performance and to improve the exchange of information. In the threshold algorithm, DM will see their own subset and their decisions as well as the group ideas and decisions, but have no visualization about the subsets of other decisions makers. This might have led to a lack of acceptance in the selection results for the threshold algorithm.

Human Computer Interaction (HCI) approaches could improve the group acceptance of the selection result. This is a discipline that closes the gap between the much higher abilities of computers and the abilities of humans. The threshold algorithm drives the selection process and calculates the overall selection result. It is neither a very complex nor a difficult method, but the distributed and invisible selection task makes it difficult to follow the selection process. HCI is a chance to support the threshold algorithm so that the DMs only need to provide their individual expertise to the evaluation of ideas. The computer then takes care of calculations and transparency issues and saves time of the DMs.

C. Requirements

An improved threshold selection algorithm therefore needs to fulfill the following requirements:

Requirement 1: **Acceptance.** The selection at gate 0 will decide which ideas are worth investing more effort in. The DM will not only be responsible for making a decision but also for developing and even implementing the ideas. A subjectively unacceptable decision in gate 0 will decrease their motivation. However, each DM evaluates only a subset of the ideas and is expected to accept the selection results for the majority of the ideas, which he/she is not even shown. Nevertheless, the process needs to make sure that the group will come to an accepted selection result in order to ensure the motivation for the idea implementation. This acceptance needs to be comparable to the group discussion method.

Requirement 2: **Process understanding.** The original threshold algorithm only allows to trace partial selection as their own decisions and the group decisions. Decisions made by other DM and their influence on the overall selection result are neither traceable nor explained. Even though the selection calculation is simple, the DM cannot follow the effect of their own decision on the overall group selection result and the decisions of other group members contribute to the overall selection result. We assume that a higher process understanding will lead to a higher acceptance of the selection result. The DM need to be able to comprehend how the threshold algorithm comes to an overall selection.

Requirement 3: **Traceability.** The original threshold algorithm does not allow DM to trace the effects of individual and group decisions on the overall selection. But to ensure that the DM understand the selection calculations of the threshold algorithm, they need to trace how their individual decisions or decisions by other DM will influence the overall selection result.

Requirement 4: **Speed.** The threshold algorithm should be able to evaluate hundreds of ideas fast in gate 0 in order to save time of the most valuable resource of a company. So it should keep the speed advantage over the group discussion.

D. Assumptions and hypothesis

We investigated two variants of the threshold algorithm. Both of them are collaborative and web-based computer supported systems. The first variant of the algorithm uses visualization support whereas the second variant works with no visualization support.

The visualization of the threshold algorithm is based on the following assumptions:

Assumption 1: The visualization of the selection process of the threshold algorithm increases the understanding of it.

Assumption 2: A higher level of understanding of the achieved selection results is more likely to make them accepted by the group.

Assumption 3: The visualization support of the threshold algorithm does not take longer than the threshold algorithm without the visualization.

Hypothesis. The threshold algorithm with a visualization of the selection process yields a comparable acceptance to the group discussion. The acceptance level of the threshold algorithm without visualization support is lower.

E. Structure of this study

Our work will be presented in four Sections. The next Section will give an overview of the related work. It will describe our group decision making problem as well as potential solutions in human computer interaction. Little previous work could be found for applying HCI approaches for our specific group decision making problem.

Section III describes the group decision making algorithm and the application of interaction as well as visualization approaches in order to increase the level of group acceptance. Five visualization approaches will be adapted to the specific needs of the selection algorithm as well as appropriate interaction types for different collaboration phases during the algorithm will be developed.

In order to investigate the hypothesis that the new visualization and interaction of the selection algorithm actually increases the group acceptance, Section IV presents the experimental design, findings and their interpretations.

Our conclusions are made in Section V. Here we hope to give some general indicators for which kind of group decision algorithms the applied visualization approaches could increase the level of group acceptance.

II. RELATED WORK

The algorithm delivers a collaborative decision making solution whose performance will be increased by using principles from Human Computer Interaction, Collaboration Interaction and Visualization. This Section describes the link between these disciplines.

A. Characterisation within decision making

The threshold algorithm can be classified in four dimensions of decision analysis methods (TABLE I.) [28]. The first dimension describes the number of DMs that are involved in the decision method. There are decision analysis methods that work for multiple DM. Every DM needs to evaluate at least every idea and provide the method with their judgment. After that the decision method calculates an aggregated result.

The second dimension describes the number of criteria the method is able to work on. The threshold algorithm is a single-criterion method.

The measurement of scale describes the type of judgments the DM uses to evaluate alternatives. The threshold algorithm uses nominal judgments. For a selection of ideas a nominal judgment is sufficient. The nominal judgments are: select or reject idea.

The last dimension describes the decision making result. Either the DM generate a choice, or they are sorting the alternatives according to some qualitative criterion or they are generating a ranking. The threshold algorithm generates a selection, so it generates a choice.

TABLE I. TAXONOMY OF DECISION ANALYSIS METHODS

#DM	Single		**Multi**	
#Criteria	**Single**		Multi	
MoS	**Nominal**	Ordinal	Interval	Ratio
Res.	**Choice**	Sorting		Ranking

B. Characterisation within HCI

In order to make the calculations the threshold algorithm needs individual and group judgments. The requested information cause interaction:

- **Computer-Human interaction**: The algorithm requests individual decisions.
- **Computer-Group interaction:** The algorithm requests group decisions.
- **Facilitator-group interaction:** The selection method is conducted by a facilitator.

Furthermore, the proposed approach will encourage interactions that support process understanding and increase the group acceptance of the selection:

- **Face-to-face Human-Human interaction:** Group decisions need a group discussion about interpretations of the criterion and a consensus where the threshold that distinguishes ideas that are worth putting more effort in and ideas that are dispensable.
- **Human-Computer interaction:** Visualising the individual decision effects on the overall selection result.
- **Group-Computer interaction:** Visualising the group decision effects on the overall selection result as well as the limitations that result from the threshold algorithm rules for the DMs.
- **Facilitator-Computer interaction:** The facilitator conducts the threshold algorithm, supervises the progress and supports the face-to-face group discussion.

Our approach combines a web-based software architecture, dialogue architecture and interface visualizations for the interactions with individuals and a group in order to conduct the threshold algorithm.

C. Approaches for collaboration interaction

Baltes' et al. [2] meta-analysis on computer-mediated communication and group decision making suggests that face-to-face decision making outperforms computer-mediated methods in three key factors (effectiveness, DM satisfaction and time). This analysis investigated only methods that use exclusively face-to-face or exclusively computer-mediated communication (e.g. video conferencing, chat, e-mail). However, our threshold algorithm combines both communication media. Individual phases use computer-mediated interaction and group discussion uses face-to-face communication.

Other findings [24] suggest that especially in situations where a group needs to make a decision under risk, a computer-mediated group discussion performs less well than a face-to-face version. The computer-mediated discussion contained less argumentation than the face-to-face discussion. This emphasises to conduct the group discussion of the threshold algorithm in face-to-face form.

Our approach concentrates on designing a collaboration interaction that involves different individual phases, a group discussion and the collaboration interaction during the whole decision process.

D. Approaches for visualization

Visualization is able to increase the process understanding because it supports the ability to process information quickly, and thus reduces search efforts for information during the process, makes patterns and trends visible and channels the attention of participants.

Gutwin et al. [16] investigated the difference between the visualization of computer systems for single users and for multiple users. The findings suggest that in collaboration systems the effects of the actions of a user needs to be visualized. Applying these findings to the threshold algorithm means to visualize dynamically which actions lead to the current selection state.

Cooper et al. [10] claims that pairwise comparison methods are seldom used in practice because DMs are skeptical about the intransparent calculation of evaluation results. Another finding by Condon et al. [8] supports this claim. Condon's research investigated using visualization for avoiding negative decision behaviour (trying to cheat the algorithm) in the pairwise comparison method AHP. His findings show that a visualized feedback of the effect of the input of DM support the process understanding and by that hopefully the acceptance of evaluation results.

Alonso et al. [1] visualizes consensus by presenting the group a real-time consensus value in order to allow them to follow their level of consensus and build a higher level of consensus. However, the visualization consist exclusively of the presentation of a number and is not focused on creating a higher level of understanding of a decision process.

The aspects of visualization of complex process were investigated by Bobrik [4]. The suggestion is to provide the user with a familiar and recognizable environment, and visualize effects of individual actions on a process-wide level. Different types of HCI during the threshold algorithm could benefit from this. Individual phases could be performed at individual computers (laptop, tablet) while group phases could be performed at a table (multi-touch-monitor, multi-touch-table).

In order to enable quick access to relevant data from a complex, often multidimensional data set, preattentive visualizations [18] are used. Applications are critical systems where a visualization might help to anticipate actions needed before the system gets actually in a critical state. An

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anticipated selection result would support a DM in coming to a decision due to the visibility of the decision effect.

Gonzalez et al. found that dynamic visualization has a significant impact on decision quality [15]. Especially the use of animated visualization of process steps improved the decision quality.

Brath outlines basic visualization parameters [5] for reducing distractions and channeling attention: length, width, light intensity, texture, colour, conditions, affinity, nearness, connectivity, continuity, symmetry, and many more. These visualization parameters could structure the information and dialogue during the threshold algorithm.

Furthermore Preim et al. [27] describes a visualizing effect for directing the attention of users called preattentive perception. Users tend to focus their attention more to a different element in an otherwise homogeneous group of elements. This effect can be activated when using strong saturated colours, different forms or different frames. This visualizing effect can be used for directing the attention of users. This could be used to create a higher level of understanding of a process.

In decision making methods, visualization is often used for information pooling or information structuring of the alternatives [20] [23]. It supports the overview. But alone it is not sufficient for increasing the process understanding of the threshold algorithm.

Visualizations have been used in education for sorting algorithms [29]. Partially the basic visualization parameters were adapted to the visualization of sorting algorithms. An effective visualization of these algorithms then is able to obtain the same level of understanding as a detailed lecture but in less time. Our approach is also an algorithm. By applying these principles, we hope to achieve a similar improvement in process understanding.

In summary, visualization can support understanding of processes or algorithms and the effects of individual actions on a system. By applying these principles to the threshold algorithm, we hope to increase the group acceptance of the selection.

III. DYNAMIC COLLABORATION INTERACTION

This Section describes the dynamic collaboration algorithm and the application of the performance-increasing collaboration and visualization approaches.

A. *The threshold algorithm*

In this Section, the threshold algorithm introduced in [14] will be described. The threshold algorithm processes $\boldsymbol{M}$ ideas with $\boldsymbol{d}$ DMs. The result is a set of selected $\boldsymbol{S}$ and a set of rejected $\boldsymbol{R}$ ideas. In order to achieve this, the threshold algorithm works in three phases.

Phase 1: Individual selection.

- Input is a set of $\boldsymbol{M}$ ideas.
- The set is split into subsets of size five. Each subset is assigned to a DM.
- Each DM selects which ideas are worth putting more effort in and which are not. Ideas are marked as selected $\boldsymbol{S} = \{\boldsymbol{S}_1, \boldsymbol{S}_2, \ldots, \boldsymbol{S}_d\}$ and rejected $\boldsymbol{R} = \{\boldsymbol{R}_1, \boldsymbol{R}_2, \ldots, \boldsymbol{R}_d\}$ where indices refer to the subsets created by each DM.
- Each DM chooses from his or her own selected ideas the idea which is just good enough to put more effort into $\boldsymbol{T} = \{\boldsymbol{t}_1, \boldsymbol{t}_2, \ldots, \boldsymbol{t}_d\}$. This type of idea is called the personal threshold idea.
- <u>Visualization tasks:</u> Initially, each DM only sees five ideas. DMs must be made aware what the others are doing and understand the implications of choosing a personal threshold idea.

Phase 2: Group selection.

- Inputs are the personal threshold ideas from Phase 1 $\boldsymbol{T} = \{\boldsymbol{t}_1, \boldsymbol{t}_2, \ldots, \boldsymbol{t}_i\}$.
- The group comes together in a face-to-face discussion.
- This discussion is important to reach an overall consensus about the threshold that distinguishes the ideas that are worth to put more effort in and those not. Inevitably, this discussion draws out individual interpretations of the criterion. The group then agrees on their interpretation of the criterion.
- The group decides which of the personal threshold ideas are worth putting more effort into or not.
- The group chooses the idea, which is just good enough to put more effort into from the set of selected personal threshold ideas. This idea is called the global threshold idea $\boldsymbol{t}_g$.
- <u>Visualization tasks:</u> DMs need to determine the meaning of the criterion. After that they need to understand the concept of a global threshold idea. The effects of the group decision on individual subsets of ideas needs to be visible.

Phase 3: Individual reselection

- Inputs are the global threshold idea $\boldsymbol{t}_g$ (a symbol for of the threshold that distinguishes the ideas), the mental model of the meaning of the criterion and the already partitioned individual subset of ideas from phase 1.
- According to the global selection or rejection of the personal threshold idea, each DM needs to reconsider their selection of phase 1.
- If DM $\boldsymbol{i}$'s personal threshold idea was rejected in phase 2 then they need to reconsider their selected ideas $\boldsymbol{S}_i$.
- If DM $\boldsymbol{i}$'s personal threshold idea was selected but was not the global threshold idea then they need to reconsider their rejected ideas $\boldsymbol{R}_i$.
- If DM $\boldsymbol{i}$'s personal threshold idea is also the global threshold idea $\boldsymbol{t}_g$ then they do not need to reconsider either rejected or selected ideas.
- <u>Visualization task:</u> Each DM only sees a subset of the ideas. DMs must be made aware what the others are doing. The consequences of the reselection according to the position of the personal threshold idea compared to the global threshold idea must be understood. Transparency of the reason of the reselection rules is needed.

During the whole selection process, the visualization of the current selection state is needed. Therefore the visualization should be dynamic.

B. Applying visualization approaches

In order to solve the interaction and visualization task, four general visualization approaches were adapted.

1: Dynamic application. According to Gonzalez et al. [15], the evaluation quality increases when using a dynamic approach. Since the threshold algorithm needs to process inputs of various DMs, visualising decision effects and the collaboration the application should be distributed and dynamic. All DMs therefore work on a web-based application which is accessible from devices such as laptops, tablets and smartphones.

2: Collaboration. Gutwin et al. [16] claims that in collaboration systems the effects of the actions of users should be made visible. That indicates that each DM needs to understand the decision process and how the threshold algorithm calculates the overall selection result. Furthermore the DM needs to be able to visualize own and other decision effects. Each phase contains an individual view (Figure 2.) that is surrounded by a small representation of the work of the other DMs. At all times, each DM is able to follow the decisions of the other group members (Figure 3.). The current selection result can be identified at all times.

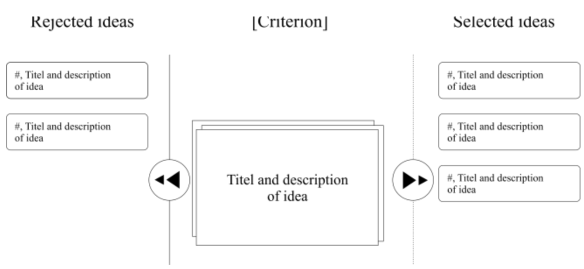

Figure 2. Simulated screenshot of individual view

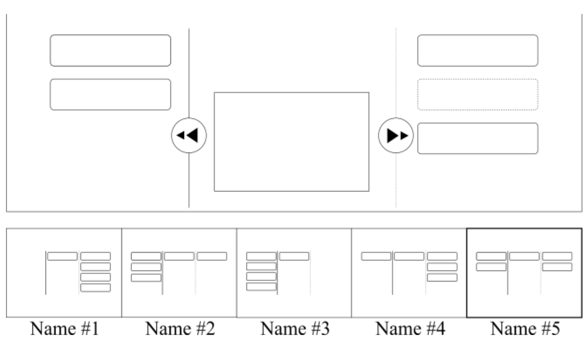

Figure 3. Simulated screenshot of overall view

3: Traceability. The DM should be able to track what the current decision for an idea is. The colours of the container of an idea was used. The colour of the border symbolises the selection information of phase 1. The colour of the filling of the container represents the selection information of the group discussion or the individual reselection. The colour code:

- Green = selected
- Red = rejected
- Orange = threshold

Figure 4. visualizes an example. For the idea in the first container, a decision has not yet been reached. The idea in the second container is a personal threshold idea. The group discussion rejected the idea in the third container, which was a former personal threshold idea in phase 1.

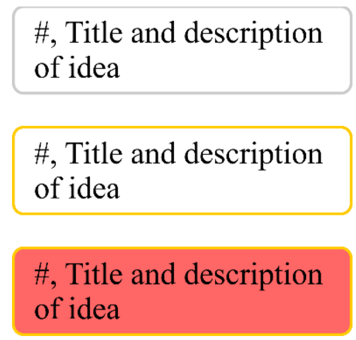

Figure 4. Visualization of decision tracking for ideas

4: Incremental instructions. The three algorithm phases are led by a facilitator. Each phase could only be started on his order. The DMs in individual phases receive their assignments, and in the face-to-face environment the facilitator guides them through the algorithm.

5: Channel attention: Colours and objects were chosen carefully and only according to the interaction and visualization task defined in Section III.A. The decision of an idea is visualized by the colour code described in *3: Traceability*. Every other element is coloured in neutral perceived grey colour tones. This is according to the main rule for preattentive perception [27] (spare use of visualization elements) and therefore allows a targeted direction of the attention of the user.

The colour of elements will change during the process but only piece by piece. This allows the DM to follow slowly the process steps without the need of explanation. For example, in the first phase when each DM makes a decision two parameters visualizes this. At first the position of the element, left for rejected ideas and right for selected ideas. This alone would not allow a preattentive perception, only colours, forms or the change of frames would create a preattentive perception. That is the reason for the second parameter, marking the decision visible by using colours (following the decision colour code, see *3: Traceability*). Every decision the DM creates, the visualization makes the effect visible. So, the DM is able to follow the process steps quickly.

C. Applying interaction approaches

For phase 1 and 3, the DMs work separately on a single computer (see Figure 5.). Due to the web-based application, access to the threshold algorithm is open to every device with a monitor and an Internet connection. The input devices could be a mouse, a keyboard and a touch-sensitive monitor. Each DM is technically capable to fulfill the given selection task but also receives impressions about others, their tasks and their progress.

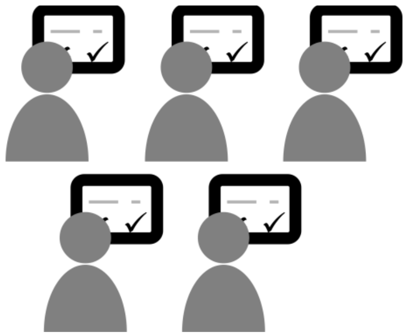

Figure 5. Individual selection computer-support

However, phase 2 of the threshold algorithm is a face-to-face group discussion in contrast to phase 1 and 3 (see Figure 6.), where each DM works individually. But during the group discussion DMs should also be able to monitor group decision effects on their individual subsets. Baltes et al. [2] and Introne [20] suggest conducting group discussions in face-to-face environments. The more familiar the environment for the given task the better for the collaboration result according to Bobrik [4]. So the group discussion takes place in a face-to-face environment but is supported with a multi-touch monitor. This multi-touch monitor presents the DM with the group selection task as well as the overview of the effects of group decisions on their individual subsets. Again due to the web-based application the group immediately receives a response to group decisions.

Figure 6. Group discussion computer-support

IV. EXPERIMENTS

In this Section the results, observations and interpretations of the experiments will be described as well as the limitations of our work.

A. Experimental Design

We designed an experiment to test our assumptions and hypothesis from Section I.D. Our goal was to find out if visualization could be a tool for increasing acceptance of results for the threshold algorithm. Other factors could play an important role in the acceptance of a selection result for a group such as trust in other DM or the influence of a web-based support system. So this experiment should show if further investigation in this matter could be beneficial.

We were also interested in whether the additional visualization meets our requirements from Section I.C.

The following methods were compared:

- **Method M_1: Threshold algorithm without visualization**
- **M_2: Threshold algorithm** with visualization

Furthermore, we compared the results of the experiments for M_1 und M_2 to results of the methods M_3 and M_4 from a previous study [14]. The design of the experiments for M_3 and M_4 were conducted under the same conditions and for the same parameters as the methods M_1 and M_2. One difference of M_3 and M_4 is that they were conducted face-to-face without any computer support:

- **M_3: Group discussion** in which each idea was discussed by the group and reached a consensus whether to select or reject the idea. They pick an idea and discuss whether the idea is worth putting more effort in or not. If they are not in consensus they need to discuss the idea and come to a conclusion.
- **M_4: Parallel individual selection** in which the set of idea was divided into equal subsets. Each DM received one subset and selected and rejected ideas independently. The overall selection result is the unification of all individual selections.

We had 30 participants who were mostly students from the Computer Science department of the University of Magdeburg without any experience in idea selection methods. Inexperienced participants were important, because we will measure the connection between the understanding of a group decision process and the resulted acceptance of the selection. Experience with group decision making method could influence the perception and subsequently our measurements. We divided the 30 participants into six decision-making groups. Three of these carried out M_1 and the other three conducted M_2. M_3 and M_4 were conducted in the previous study with 20 participants. The results were normalized for comparison with M_1 and M_2. This study investigated if an algorithm could be find that enables at the same time an efficient and acceptable selection result in a group.

For the execution of the threshold algorithm we used 25 ideas for attracting new customers to a supermarket. Each decision-making group was instructed by a computer-mediated and face-to-face facilitator. The criterion given to each group was "Could this idea attract new customers to our supermarket?" Students know supermarkets and should be able to make appropriate selection decisions.

Each decision-making group was subsequently asked to fill in an evaluation form and the time needed for the selection was measured.

B. Results and interpretation

In Section I.C, we state the requirement that with the visualization and interaction adaptations the threshold algorithm should not lose its time advantage. The results in 0show that M_2 still performs almost twice as fast as the group discussion. M_1 does not perform quite as well as the threshold algorithm with visualization.

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TABLE II. ACTUAL DURATION

in Minutes	M_1	M_2	M_3	M_4
Mean	15:40	**13:40**	24:30	6:00
Min	13:00	**12:00**	13:00	4:00
Max	19:00	**16:00**	34:00	10:00

Another requirement of Section I.C was that the DM understand the process and could comprehend the overall selection result. In the evaluation form the participants were asked to respond to the statement: "The selection method is understandable." on a five-point Likert scale from 0 to 4 points. For each measurement and method the total achievable sum and actual achieved sum were built and converted into a percentage. The results in TABLE III. show a value of 82% for the question whether M_2 leads subjectively to a higher process understanding, which meets our expectation (see Section I.D, assumption 1).

M_2 almost reached the process understanding of M_3. Surprisingly the process understanding of M_3 is only 90%. It could be assumed that the process understanding of the group discussion should be at the maximum. Nevertheless, M_2 performed better than without the visualization and nearly as well as M_3.

TABLE III. SUBJECTIVE PROCESS UNDERSTANDING

M_1	M_2	M_3	M_4
75%	**82%**	90%	63%

We also wanted to get a more objective way to verify the process understanding results. This is the reason why the evaluation form contained questions in exam-style. Five multiple choice test questions on the functionality of the threshold algorithm were given. The number of correct, wrong and "don't know" answers is shown in TABLE IV. As expected, M_2 reaches a higher number of correct answers. Surprisingly was that M_2 reached twice as many correct answers than M_1. By contrast, M_2 made nearly as many wrong answers as M_1. M_3 and M_4 were not investigated in this manner, because in the former study the objective process understanding was not an issue.

TABLE IV. OBJECTIVE PROCESS UNDERSTANDING

	correct	wrong	don't know
M_1	23	25	27
M_2	**43**	**23**	**9**

The threshold algorithm with the additional visualization reaches both subjectively and objectively a better process understanding than the threshold algorithm without the additions. This meets our assumption in Section I.D.

Another expectation is that the additional visualization of the threshold algorithm increases the group acceptance of the selection. The participants were given three types of questions. We were interested in the assumed group acceptance, the personal view on the acceptance of the overall selection result and if the threshold algorithm would in general lead to accepted group selections.

At first we were interested in the assumed group view of acceptance. The participants were given the statement "I assume that the group accepts the overall selection result." and were asked whether this statement fits (4 points) or does not fit (0 points) their perception on a Likert scale. For each method the total points from all participants were calculated and converted to a percentage. TABLE V. shows the corresponding values. M_2 performed better than M_1 and nearly as well as M_3.

TABLE V. SUBJECTIVE ASSUMED GROUP ACCEPTANCE

M_1	M_2	M_3	M_4
75%	**82%**	86%	74%

Secondly, we were interested in the personal view of the acceptance of the selection result. The participants were asked if the statement "I accept the overall selection result." fits (4 points) or does not fit (0 points) their perception on a Likert scale. For each method the total points from all participants were calculated and converted to a percentage. TABLE VI. shows the results. Surprisingly, M_2 reaches even a higher acceptance than M_3. It is an interesting finding. It seems that the assumed group acceptance of the selection was underestimated by the group members.

TABLE VI. PERSONAL ACCEPTANCE OF SELECTION

M_1	M_2	M_3	M_4
60%	**87%**	84%	60%

Finally, we were interested in the assumptions of the participants whether the threshold algorithm would lead in general to accepted selection results. The statement given in the evaluation form was "I assume that the selection method in general will lead to group accepted selection results." The participants should answer if this statement fits (4 points) or does not fit (0 points) their perception on a Likert scale. For each method, the total points from all participants were calculated and converted to a percentage.

As shown in TABLE VII. a value of 85% is achieved for M_2, whereas a value of only 62% is achieved for M_1. M_3 and M_4 were not tested, because the general ability for group acceptance was not an issue in the former study.

TABLE VII. GENERAL ABILITY FOR GROUP ACCEPTANCE

M_1	M_2
62%	**85%**

It is an interesting finding: although each DM still only sees one-third of the ideas, the opinion is strong that the selection method would provide a group accepted selection result. This was achieved just by adding visualization support to the algorithm.

The additional visualization for the threshold algorithm exceeded our expectations. Our second and third assumptions are fulfilled. The findings support the hypothesis stated in Section I.D.

C. *Other Obserations*

In addition to our planned experimental investigations, participants also gave some voluntary feedback:

1: Relevance of the discussion. The discussion was perceived as very supportive for the decision-making task. It improves perspectives on ideas and the criterion. This results in a new research question: How could the threshold algorithm profit more from the effects of the useful discussion?

2: Multiple phases improve decision quality. The multiple views on ideas during the different phases give the chance to reconsider already made decisions. During the process, helpful information and expertise of others changes the participants' views on criteria and ideas. Given the application area, this is not a surprising comment. But we underestimated the impact on the decision quality in the opinion of the DMs. How could we encourage such a thought?

3: Too restricted in the reselection. In the re-selection phase, the threshold algorithm lets the DMs only reconsider in certain ways. That leads to the possible rejection of ideas that otherwise would have been accepted. This is especially true when new information changed the point of view of the DM. In combination with the observation that multiple views on ideas change, the DMs should be able to reconsider all (and not just some of) their already made decisions in the third phase of the algorithm.

D. *Limitations*

The experiment was carried out using a task that all participants had similar experiences and views. Real-life tasks could be harder because experts may represent different views (such as Marketing, Engineering and Sales), and – in the case of radical innovation projects – have little or no expertise.

The participants were selected for their inexperience in selection methods so that we can obtain an unbiased view on our approach. However, DMs with experience in selection methods might reject the threshold algorithm a priori due to its unfamiliarity.

The experiment was conducted in one room, face-to-face facilitated and in one sitting. By contrast, the threshold algorithm would be able to schedule the three phases on different dates. This change in format could decrease the overall algorithm performance because participants will have forgotten the inputs linking each phase to its successor.

The algorithm was tested with five DMs and 25 ideas. Results may change when these parameters are varied.

The experiments were carried out with a small number of subjects, which limits the statistical basis of the conclusions drawn.

V. CONCLUSIONS

A summary of this work as well as the applicability and open questions for future work are presented in this Section.

A. *Summary*

The selection of ideas supported by the original threshold algorithm lacked group acceptance in comparison to the group discussion of all ideas. Our approach was to increase acceptance by applying approaches from human computer interaction. The visualization and interaction additions to the threshold algorithm performed nearly as well in process understanding and group acceptance of selection as the group discussion. At the same time, the threshold algorithm was able to maintain its speed advantage.

This result was possible because we were able to improve understanding of the basic principles of the threshold algorithm and at the same time make it transparent how the current selection result is generated by each DM and by the group overall. Our approach applied basic visualization rules, a dynamic web-based application, dynamic visualizations and appropriate media for every DM throughout the whole selection process.

B. *Applicability*

The threshold algorithm is a collaboration algorithm with changing types of individual and group involvement. This is needed for the performance of the algorithm but causes also intransparencies and misunderstandings. In order to achieve a higher level of acceptance or process understanding, applying visualization and interaction approaches could be beneficial in other scenarios:

- Many group selection methods deal with acceptance issues.
- Methods that divide (decision) tasks into individual and group phases.
- Methods where invisible individual decisions lead to a lack of process understanding for others.

C. *Open questions and future work*

This investigation demonstrated new perspectives for the threshold algorithm:

- Evaluation errors are dangerous in this selection phase. Especially a false rejection error can lead to high opportunity costs. By making hidden profiles visible in the group discussion of the threshold algorithm the value for applications in business increases. The resulting research question: How could we use the mining of hidden profiles [19] for increasing quality of the group discussion respectively the definition of the global threshold?
- The concept of a threshold is hard to understand for a DM. In the evaluation form, the function of the threshold algorithm was often answered incorrectly. Are there visualization or interaction approaches that are able to support the understanding of this basic element in order to improve group discussion and decisions?
- Each DM still only saw only one-third of the ideas. Making the overall selection during the decision-making process explorable might help to improve the overall group acceptance of the selection. How could

the threshold algorithm benefit by exploring the reasons for others' decisions?

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