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Validating an innovative real-time Delphi approach - A methodological comparison between real-time and conventional Delphi studies

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ABSTRACT

A novel and innovative real-time Delphi technique is introduced in order to address previously identified weaknesses of the conventional Delphi method, such as complicated facilitator tasks, lack of real-time presentation of results, and difficulties in tracking progress over time. We demonstrate how the real-time (computer-based) method increases the efficiency of the process, accommodates expert availability, and reduces drop-out-rates. Modifications in the Delphi procedure (e.g. change of iteration principle) not only increase efficiency but also change the nature and process of the survey technique itself. By identifying and analysing three individual effects (initial condition effect, feedback effect, and iteration effect) we examine whether the modifications in the survey process cause deviations to the survey results. Empirical data obtained from both conventional as well as real-time Delphi studies is analysed based on multiple statistical analyses. The research findings indicate that significant differences between the two Delphi survey formats do not exist and final survey results are not affected by changes in the survey procedure.

1. Introduction

Since its first application in the 1950s by the US RAND Corporation, Delphi has become a widely accepted and frequently used research method, especially for futures oriented research. The conventional Delphi can be defined as a method that aims at a consensus on a particular topic among a group of experts [1], while the procedure (paper-and-pencil version) follows an anonymous, multistage communication process based on several survey rounds. Previous publications prove that the technique is an established method for foresight activities and that Delphi outperforms other group formats such as statistical groups or standard interacting groups in terms of effectiveness [2,3]. Whilst the method itself has become more prevalent and mature, a number of researchers have focused on improving the procedure and tasks of Delphi [2,4–13] due to critique on the method in the past.

Related to the process and task characteristics of a conventional Delphi survey, Tapio [14] and Gordon and Pease [5] identify several major areas of improvement. They address the challenge of increasing efficiency in order to shorten the time to perform a Delphi survey. Moreover, the availability of experts and the drop-out-rate are identified as major methodological challenges: the repetitive and multiple feedback character of Delphi studies demands considerable time until such studies are completed, which can increase the likelihood of drop-outs [6,15].

In line with other researchers [e.g. 6,16,17], Gordon and Pease [5] therefore attempted to increase the efficiency of the Delphi survey procedure. By omitting sequential rounds and thereby shortening the time frame needed to perform such studies, Gordon and Pease improved the traditional Delphi survey process by calculating experts' responses online in "real-time". Furthermore, they addressed the issues of expert participation and simplifying the process by providing experts the opportunity to participate in the survey via the Internet. Although Gordon and Pease describe their innovative survey method and its benefits as successful, they

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also concluded that their online, real-time survey method exhibits some weaknesses such as the ease-of-use for the facilitator of the Delphi survey, the real-time presentation of results, and the tracking of progress over time, which all require further research and development. Moreover, modifications to the Delphi technique (e.g. round-less, real-time approach) not only increase efficiency in terms of procedure and questionnaire handling, they also change the nature and process of the survey technique itself. Delphi's principle of iteration is affected by immediate provision of feedback and by experts' ability to reassess and adjust their responses as often as they want to. Consequently, the results of a real-time Delphi study could deviate from those of a conventional Delphi study. However, these possible effects have not been studied yet.

This paper contributes to research on Delphi techniques in two ways. First, we introduce a novel real-time Delphi technique that overcomes the shortfalls identified by Gordon and Pease. This real-time Delphi method increases efficiency more than other online-based Delphi surveys and is more convenient for participants. Even though the use of the Internet may help to reduce the time required to conduct a Delphi survey in general, the conventional idea of having several survey rounds is still present. Consequently, experts have to be available and willing to participate in the conventional survey process for at least two survey rounds (assuming that the survey is based on only two survey rounds) and thus dedicate considerable resources into the survey process. If experts do not participate in a later survey round, the facilitator of the Delphi survey would register drop-out rates.

In order to improve and simplify the process of conducting a Delphi study, we developed an internet-based, real-time Delphi survey format which operates without the necessity of having sequential rounds. Once an expert provides his/her initial assessment (which would correspond to survey round number 1 in a conventional Delphi study), he/she receives immediate feedback and is able to reassess the initial estimate (which would correspond to any later survey round in a conventional Delphi study). Consequently, experts need to dedicate fewer resources for participating in the Delphi survey process.

In addition, we specifically illustrate how an internet-based, real-time Delphi survey tool can be equipped with innovative features such as *easy-to-use facilitator portal*, *consensus portal*, and *graphical real-time feedback* to make it easier for experts to participate and for survey moderators to facilitate.

Second, we investigate whether modifying the survey procedure of a real-time Delphi study causes differences in study results. We identify three individual effects that may impact the results of the Delphi study: *initial condition effect, feedback effect,* and *iteration effect*.

In the preparation phase of conducting real-time Delphi studies, it is necessary to provide a set of initial conditions so that even early respondents can receive feedback [5]. We examine whether these initial conditions adversely affect experts' behaviour in the survey process. While experts participating in conventional Delphi surveys do not receive feedback until a certain amount of peers have finished the survey, real-time Delphi participants receive immediate feedback after their responses. Therefore, we compare the effect of feedback provided real-time versus the effect of feedback provided in sequential survey rounds on responses. Furthermore, we analyse whether the convergence processes (i.e. how consensus is achieved) between conventional, round-based Delphi surveys differ (significantly) from real-time Delphi formats. We conduct multiple statistical analyses based on data obtained from a Delphi study that utilizes our new real time Delphi technique and data from a conventional Delphi study to analyse the impact of the 'initial condition effect', 'feedback effect', and 'iteration effect'.

The remainder of the paper is organized as follows: Section 2 outlines the process and task characteristics of the newly developed real-time Delphi survey tool. By referring to two concrete Delphi studies, Section 3 compares the differences of the real-time Delphi technique with the conventional Delphi technique and the potential consequences on final results. The final section summarizes the methodological contribution of the paper and addresses limitations as well as future research areas.

2. Elements of the real-time Delphi survey tool

In order to address the major shortcomings of Delphi studies, several approaches have been followed in the past to increase the efficiency of the process. Researchers provided downloadable questionnaires from the Internet or asked participants to assess questionnaires directly online [11,12,18]. In an interesting study regarding future information technologies in the health care sector, Cuhls et al. for instance performed a two-round based Delphi survey by exclusively using an online platform [12]. However, to the best of our knowledge, no immediate feedback was provided in these studies. Rather, feedback was compiled in an offline modus, leading to a time delay between initial assessment and the provision of feedback. In their attempt to address this time delay, Gordon and Pease developed a "real-time Delphi" platform that provides immediate feedback [5]. Consequently, immediate feedback is the main difference between the real-time Delphi format and general online future surveys where experts can judge as often as they wish.

In line with Gordon and Pease [5] we approach the major shortcomings of Delphi by developing an extended real-time Delphi survey tool, which we applied for futures research. We developed additional functions to further improve the Delphi survey process and task characteristics. An online survey tool allows experts to participate in the study regardless of their physical location. Our real-time Delphi survey tool was additionally equipped with innovative features such as *easy-to-use facilitator portal*, *consensus portal*, and *graphical real-time feedback* for better process efficiency and convenience. In addition, our real-time Delphi survey tool was developed to be easily adaptable for further studies. Furthermore, a tutorial, which is accessible during the entire survey process, explains to experts how to use the tool and answers questions which might arise during the survey process in order to ensure adequate validity and reliability. These innovative features will be dealt with later in the paper.

According to Rowe et al. [9], four main characteristics of the Delphi method can be identified: (1) anonymity in the process, (2) controlled feedback, (3) statistical aggregation of group response, and (4) iteration. In the following discussion, the elements of our real-time Delphi survey tool will be illustrated with respect to these characteristics.

2.1. Anonymity in the process

Anonymity ensures that experts can express their opinion without perceived social pressure of other survey participants [19]. To ensure anonymity throughout the real-time Delphi method, experts are randomly sent hyperlinks via electronic mail in order to access the Delphi portal. All entries and procedures are kept anonymous. Each participant is only represented by a number at random in the database.

Once participants follow the personal hyperlink, they are transferred to the welcome page of the survey, where the purpose, average survey time, and organisers are explained. To assure that participating experts feel confident in using the real-time tool, an optional online tutorial (flash movie) is accessible on the welcome screen. The tutorial explains in detail how to approach the questionnaire and to use the features of the Delphi tool. The tutorial can be accessed at any stage of the survey, thereby enabling experts to receive support in case of survey-related questions or problems (e.g. understanding statistically aggregated group opinion).

After viewing the online-tutorial or activating the start button, a blank questionnaire screen appears, as shown in Fig. 1.

The blank questionnaire screen exhibits four major elements (see numbers 1 to 4 in Fig. 1). First, orientation is given on the progress of the study (number 1). This is done by a text line (1a) indicating question number and Delphi "round" as well as a progress bar (1b). Second, the Delphi question is displayed. In our case, the question represents a projection that describes possible future developments (number 2). For validity purposes, each projection is introduced by the future horizon, i.e. "2025". Thus, with every new projection the experts are mentally taken further into the future. On the left side of the screen, three different evaluation categories of the projection are shown (number 3). The evaluation categories of each projection are: the expected probability of occurrence (EP), the impact on the unit of analysis under review (I), and the desirability of occurrence of the projection (D). In addition, textboxes are provided to allow experts to state qualitative arguments, which back up their assessment on the particular evaluation category (number 4).

Regarding the first evaluation category, experts are asked to assess the expected probability of the projection to occur on a metric scale ranging from 0 to 100 percent. In addition, experts can voluntarily provide qualitative arguments to strengthen their assessment of the expected probability. Regarding the second evaluation category, experts are asked to rate the impact of the projection on the unit of analysis on a 5-point Likert scale ranging from 1 (very low) to 5 (very high). Again, experts can optionally provide qualitative arguments for low or high values of impact. Both the expected probability of occurrence and the impact on the unit of analysis were integral parts of previously conducted Delphi surveys [e.g. 20]. Several authors have argued that clustering along these two dimensions is reasonable to derive appropriate actions and strategies [e.g. 21–23]. The last dimension, desirability of occurrence, is included in the Delphi tool to shed light on the projections' "character" with respect to a negative or a positive specification [1]. Similar to the dimension of impact, the desirability of occurrence is rated on a 5-point Likert scale ranging from 1 (very low) to 5 (very high).

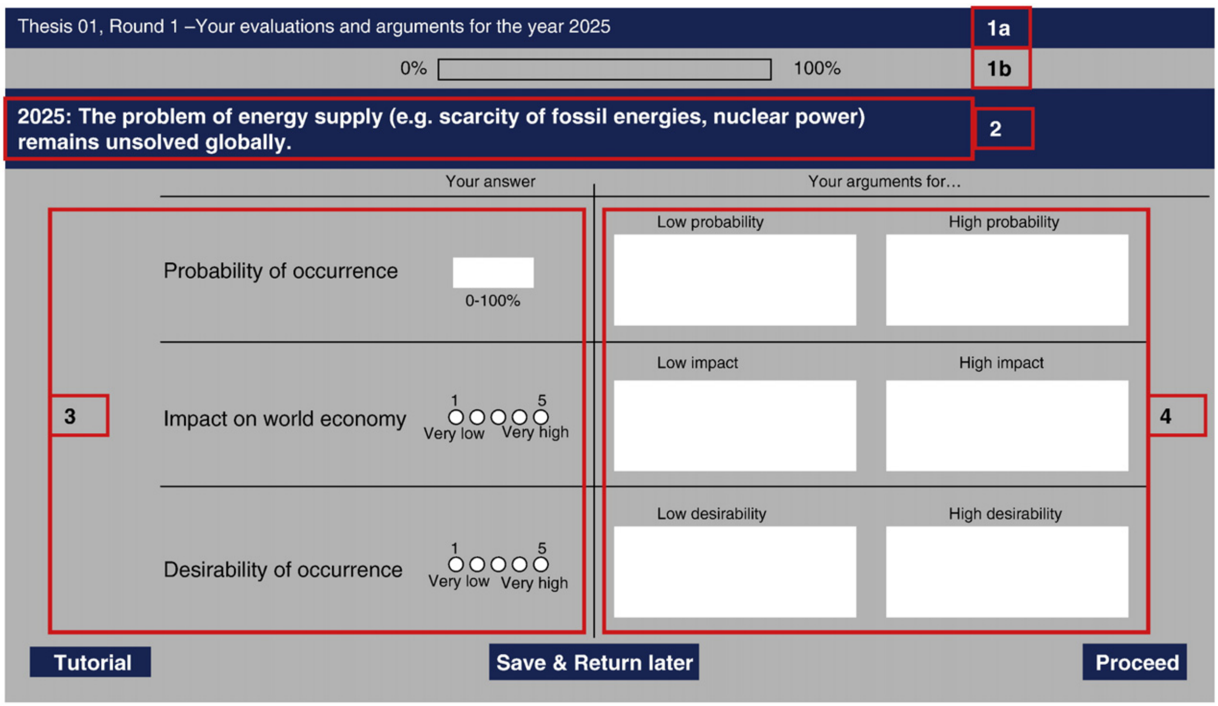

Fig. 1. Real-time Delphi survey questionnaire screen for the initial assessment.

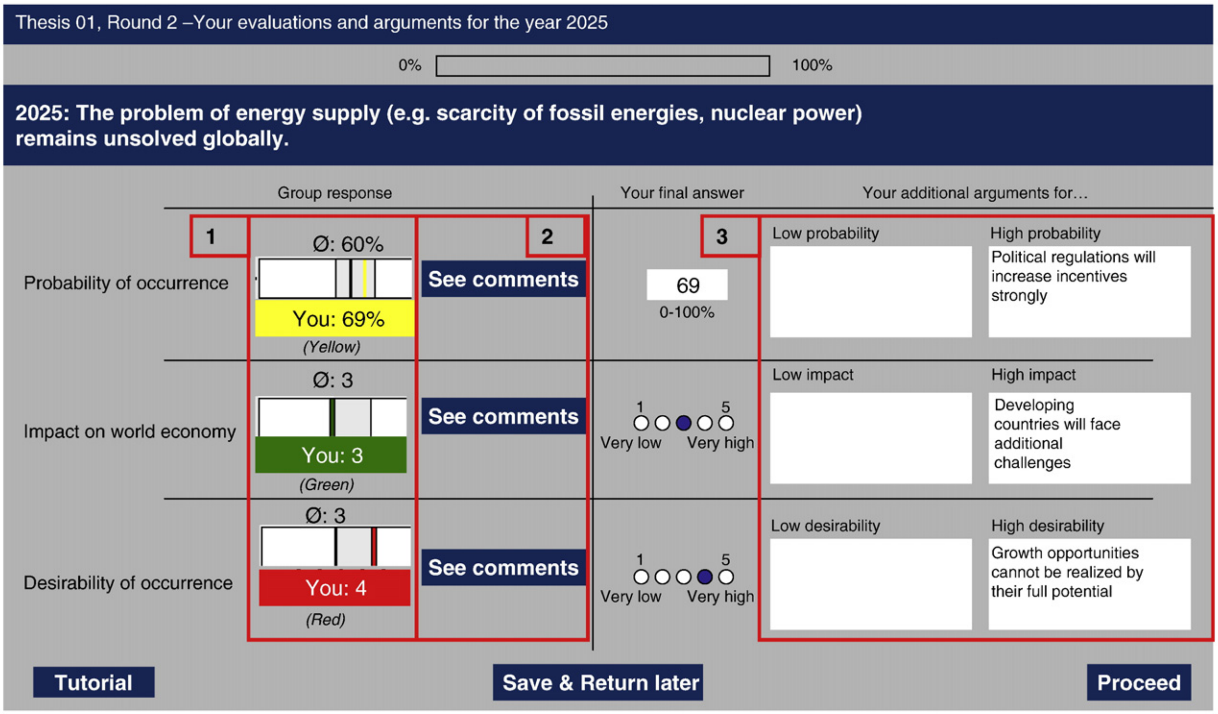

Fig. 2. Real-time Delphi survey feedback screen.

After anonymously providing assessment on the three evaluation categories of the projections, participants have two options as to how to proceed: They can either choose to leave and come back to the survey at a later point in time by clicking on the "save and return later" button, or to continue with the survey directly by clicking on the "proceed" button, as illustrated in Fig. 1. If the participants decide to continue directly they are forwarded to the second round survey screen which provides controlled feedback and statistical group response.

2.2. Controlled feedback and statistical aggregation of group response

Feedback plays a vital role in the Delphi method and is crucial for the survey's success [2,10]. Previous research has analyzed the role and effect of feedback and iteration for changes in expert estimates [24]. Effective feedback ensures that the experts' individual assessments converge towards an objectified group result or cluster around alternative viewpoints. Especially for probability forecasts, judgement accuracy can be improved through feedback [10]. According to Best [24], the accuracy of results can be improved if experts are equipped with both statistical and qualitative arguments. Therefore, the real-time Delphi tool provides both types of feedback to participating experts. While statistical feedback is given automatically by the Delphi portal, qualitative arguments have to be released by the facilitator. The facilitator is informed via email every time a new participant joins in the study. The facilitator then immediately logs in to the administration portal to continuously make the participant comments public for all participants. These comments are shown and labelled with a time stamp generated by the system. The facilitator compares the new participants' arguments with those arguments already in the system. Non-repetitive arguments are copied manually into the system for the ongoing Delphi discussion process. Thus, the facilitator published all provided qualitative arguments except for two cases[1].

a) Arguments were already provided by other experts. By doing so, we aimed to avoid information overload [25].
b) Arguments exhibited spelling mistakes. In this case, the facilitator eliminated the spelling mistakes and published the arguments afterwards.

Fig. 2 depicts the graphical design of the feedback screen. Experts view three different boxplot diagrams (number 1), summarising the groups' assessment on the previously evaluated future projection. Basic characteristics of different data sets, such as outliers or the general tendency hidden in the data, can thereby be compared [e.g. 26]. In order to assure that each participant understands the statistical illustration, a detailed explanation can be opened up via a mouse-over effect when experts navigate the

[1] We consider it valuable to note, that we applied the same criteria for the feedback process in the conventional Delphi.

Table 1
Colour-codes for individual assessment.

Colour	Relation to group opinion and feedback	Individual assessment
Green	Within group opinion	± divergence of max. 10% of IQR from median
Yellow	Moderate divergence from group opinion	± divergence of max. 20% of IQR from median
Orange	Significant divergence from group opinion	± divergence of max. 40% of IQR from median
Red	Strong divergence from group opinion	± divergence of more than 60% of IQR from median

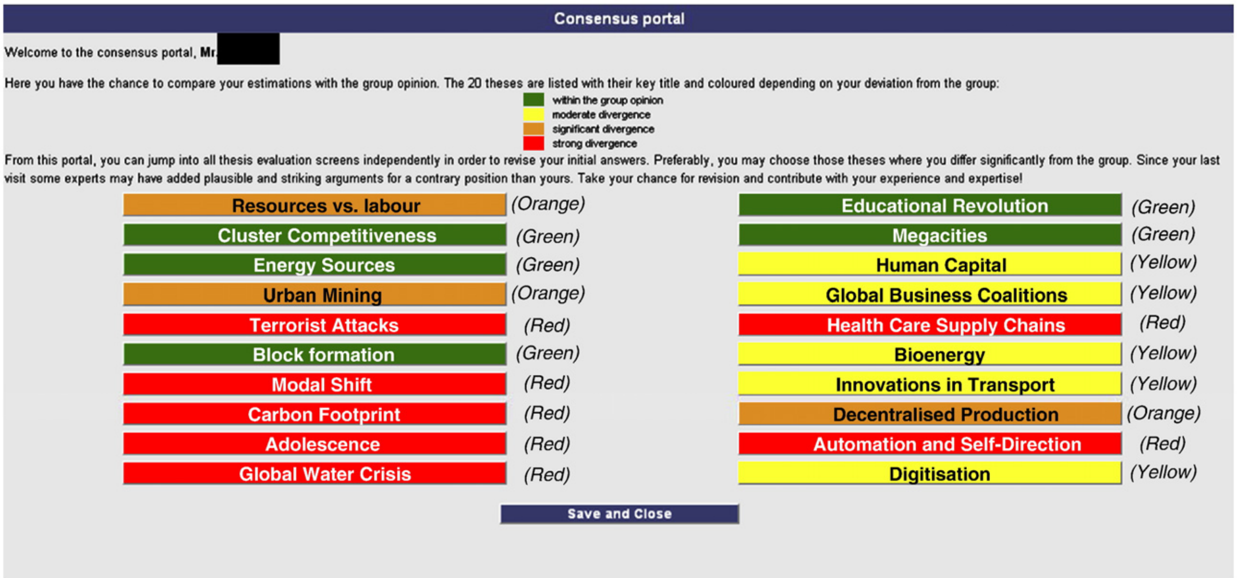

Fig. 3. Real-time Delphi survey consensus portal.

cursor on the presented box-plot diagrams. The boxplots are separated into four quartiles. The second and third quartile is shaded in grey and represents the interquartile range (IQR), which is also a preferred consensus measurement instrument in Delphi research [27,28]. The grey area indicates in which range 50 percent of all participating experts' assessments on probability, impact or desirability fall. Additionally, second and third quartiles are divided by the median, indicated by a thick black line. Experts' individual assessments are shown below the boxplot diagrams by "You:" and the respective first answer. Colour-codes are used as an outlier-labelling rule, offering insights whether experts are within or beyond group opinion [e.g. 29].

Table 1 summarises the colour-coded feedback provided to experts, depending on how their quantitative assessment complied with median scores. The stronger experts diverge from the median score, the more "alarming" the resulting colour-code[2]. In case of an extreme assessment outside the quartiles, this is indicated by the additional label "out of group opinion". Thus, experts receive a broad and illustrative statistical feedback of their first round assessment compared to the group opinion.

Participants can further study qualitative, anonymous comments of other panellists by clicking on the "see comments" buttons (number 2 in Fig. 2). If these buttons are clicked, a new browser window opens, showing a summary of pro and contra arguments for expected probability (EP), impact (I), or desirability (D) respectively. In order to minimise the risk that experts' initial assessments are biased by arguments provided earlier, other participants' arguments can only be accessed after providing an own assessment. After considering the feedback, participants can easily change their initial assessment on the right side of the survey screen, where first round answers and arguments are repeated. The participant may then proceed with the subsequent projections via "proceed". Again, experts can also leave the survey and continue at any later point in time or access the tutorial.

After experts have evaluated all survey projections, they are forwarded to a *consensus portal*. This portal was designed to provide a quick overview of how an expert's assessments compares to the aggregated group results (Fig. 3). By using the same colour code as for individual assessments, experts can easily view the summary of whether their assessments fall within or outside the group opinion for expected probability. If desired, experts can click on respective projections and are forwarded to the projection's screen II, as presented in Fig. 2 for monitoring or revision purposes. For better orientation, each projection button is labelled with a short title of the projection.

[2] We would like to emphasize that 'alarming' colour codes could put pressure on participating experts to conform to group opinion. It may be risky to operate with those colours. However, we adhere to Gordon's approach to running a Delphi study with having "attention-getting flags"[30].

2.3. Iteration

The Delphi survey can be re-accessed at any point in time via the consensus portal until the study is closed. To do so, experts simply have to use their invitation hyperlink again. Thus, participants can check whether changes in experts' assessments have occurred in the course of time. Moreover, participants can access new arguments, which have been given by other panellists and released by the facilitator in the meantime. A participant may either change or stay with his estimations. By being able to re-access the portal several times, experts are also able to track changes in the progress of the survey towards consensus building.

By changing the survey's iteration and feedback procedure, a significant modification was made to the conventional Delphi process. The motivation for this modification was twofold: On the one hand, immediate feedback presumably reduces the time required for experts to participate in the survey, since they have to access the portal only once (even though they can access it as often as they wish) [30]. On the other hand, the drop-out rates during the survey process may be reduced due to the shortening of the Delphi survey process. While in conventional Delphi surveys, the facilitator provides experts with a summary of the judgements of the respondents after all panellists participated, the feedback in the real-time Delphi tool is provided immediately after each expert has answered a specific question (see Fig. 4).

Therefore, the iteration and feedback process is not initiated after a completed round by all panellists but initiated after a completed contribution by one expert. Iteration and controlled feedback, as suggested by Rowe et al. [9], are provided. Thus, the main characteristics of Delphi are addressed by our real-time Delphi survey tool and its process and task characteristics, although they are implemented differently in comparison to the conventional Delphi method. Those differences could have effects for the Delphi results [8]. In order to analyse the potential effects that these procedures may have, we compare the results of a real-time Delphi survey with a conventional, round-based Delphi study in the next section.

The description also shows that our real-time Delphi process is based on the idea of Gordon and Pease's [5] real-time Delphi innovation. However, there are several differences between the real-time Delphi technique presented in the paper at hand and the one introduced by Gordon and Pease [5]. The first difference relates to the layout and questionnaire design. While Gordon and Pease use a matrix-format, presenting the alternative strategies and criteria at one glance, we rely on a one-question-one-screen format that contains a single future projection and three distinct dimensions of evaluation (expected probability, impact and desirability). The rationale behind this modification was that with a one-question-one-screen format, the potential threat of information overflow for participants can be circumvented.

The second difference refers to the point in time when the average group response and quantitative feedback is revealed to participants: Gordon and Pease designed their portal in a way that participants can see the group results even before assessing the question the first time (see page 330 of [5]). In contrast, the real-time Delphi at hand is designed so that participants can only see average group response and qualitative feedback after they have assessed the future projections for the first time. We modified Gordon and Pease's real-time Delphi approach to exclude the possibility that experts' initial assessments are affected by assessments given by other experts beforehand.

The third difference is the extent of feedback. While Gordon and Pease's real-time Delphi only informs experts about average group responses, our real-time Delphi informs experts about average group response, the median, and the interquartile range. Moreover, Gordon and Pease draw attention to questions in which respondents' answers differ considerably from the group average by a single-colour, shaded background (see page 330 of [5]). In contrast, the attention-getting indicator in our real-time Delphi comprises four different colour codes, according to the degree of divergence from the median (see Table 1). Therefore, experts are equipped with comprehensive feedback. The motivation for this change was twofold: First, a more distinct differentiation of the feedback enables participants to receive a better understanding of their degree of deviation from the group opinion. Second, by providing more comprehensive feedback, experts should receive in-depth information on how other participants assessed the questions under review [31].

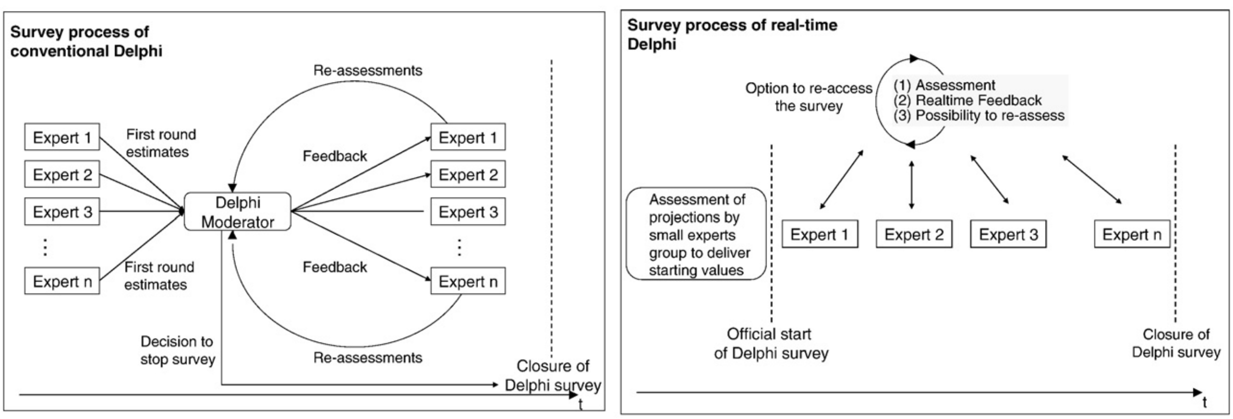

Fig. 4. Survey process of conventional and real-time Delphi.

Table 2
Comparison of real-time Delphi approaches.

	RT Delphi [1]	Real-time Delphi as presented in this paper
	Differences	
Questionnaire design	Evaluation of alternative strategies and criteria	Evaluation of future projections
Layout	2-dimensional real-time Delphi (matrix-format)	1-dimensional real-time Delphi
Presentation of questions	All questions at once	One-question-one-screen
Scale	Criterion Weights (10 = absolutely essential in any rational decision; 1= contradicts the decision)	Percentage for expected probability (0%-100%) and 5-point Likert scales for impact and desirability
Average group responses shown before initial assessment?	Yes	No
Type of feedback	Average group response	Average group response; median, inter-quartile range
Attention-getting indicator	indicator flag	Colour codes
Facilitator's role	determines cut-off point	determines cut-off point; controls qualitative feedback
	Similarities	
Provision of initial conditions?	Yes, derived from judgmental responses from a beta test panel	Yes, derived from judgmental responses from a small expert group
Possibility to provide qualitative assessments (comments)?	Yes	Yes
Operational modus	Online	Online
Anonymity of participants' responses ensured?	Yes	Yes
Process characteristic	asynchronous	asynchronous

[1] cf. Gordon & Pease (2006).

The fourth difference refers to how qualitative feedback was given. While Gordon and Pease provided a rather automated process to publish qualitative arguments, in our real-time Delphi method, arguments were communicated manually. By doing so, we aimed to eliminate repetitive arguments and spelling mistakes.

The fifth differences refers to the field of application: The approach of Gordon and Pease was illustrated by presenting an application that involved priority setting among strategies for dealing with anticipated terrorist activities that are initiated by a single deranged individual (illustrative example form the Millenium Project) [5]. In contrast, our real-time Delphi survey was applied in the field of future of logistics.

Table 2 summarizes the main differences and similarities between the different real-time Delphi formats.

3. Comparison of conventional and real-time Delphi methods

For the comparison of conventional and real-time Delphi results, we draw from two different studies conducted in 2008: Study 1 represents a conventional Delphi survey in which 30 designated logistics experts participated and evaluated 30 projections on the future of the logistics industry. Likewise, 62 experts evaluated 20 projections on the future of logistics in study 2, in which we applied the previously described real-time Delphi survey tool. The purpose of both studies was to illustrate the possible future of the logistics industry and to identify trends which impact the industry in 2025. Fig. 5a and b illustrate the panel compositions of the real-time and conventional Delphis.

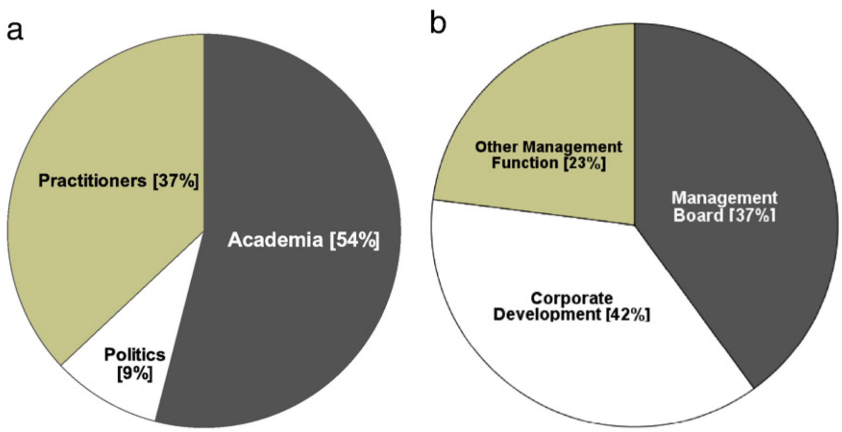

Fig. 5. a. Panel composition of real-time Delphi panel. b. Panel composition of conventional Delphi panel.

Table 3
Comparison of real-time and conventional Delphi.

		Real-time Delphi	Conventional Delphi
Differences	Sample size	62	30
	Number of projections	20	30
	Number of arguments provided by participants	826	799
	Number of probability (EP) changes	275	230
	Geographical focus	global	Germany
	Survey period	March - May 2008	September - November 2007
Similarities	Topic	Future of Logistics in 2025 comprehensive procedure	
	Development process of future projections	along 4 quality criteria	
	Face validity	Checked by experts	
	Reference model	PEST Framework according to Wilson & Gilligan (2005)	
	Questionnaire design	Evaluation of future projections along 3 dimensions (expected probability, impact, and desirability)	

The results of the two studies are comparable for several reasons. First, both the conventional and the real-time Delphi study address the same content: the future of the logistics industry in the year 2025. Second, both studies rely on the same process for the development of future projections. Since the design of the survey questionnaire is of utmost importance for a study's success, the same comprehensive procedure and rules to develop adequate projections were followed for both studies [32–34]. Among others, these rules included projections (1) without ambiguity, (2) without conditional statements, (3) without unknown terms or expressions, and (4) with agreed upon definitions. Furthermore, for both studies, projections were checked by experts for completeness (face validity), accuracy of the content, and plausibility. The PEST[3] framework was used as a reference model in order to maintain a comprehensive perspective on the logistics industry in both cases [e.g. 35]. Finally, experts of both the conventional and the real-time Delphi studies were asked to evaluate projections in terms of expected probability (EP), impact (I), and desirability (D). Table 3 summarizes the differences and similarities of the two studies.

Since we intend to analyse whether the survey procedure used for the real-time Delphi affects the study outcome, we are interested in potential differences in the results of the two studies. Such differences could be induced by modifying the procedure or tasks (i.e. conventional versus real-time). However, we cannot rule out that certain differences are also induced by differences in the study design (e.g. panel composition, geographical focus, geographical background of participating experts, point in time when surveys were conducted, etc.). Therefore, we are cautious in interpreting the differences between the two studies.

In the following sections, we evaluate whether the levels of participation differed between the Delphi studies. To do so, we analyse (1) how many arguments and expert statements were provided and (2) how often experts accessed the real-time Delphi portal. We also pay attention to the fact that the conventional Delphi clearly exhibits the characteristics of an iterative process. In the first round of the survey process, experts provide their initial assessment to the Delphi facilitator who, in turn, aggregates experts' assessments and provides controlled feedback. In the second round, experts are able to re-assess their initial assessment and re-send their assessment to the facilitator again. The Delphi facilitator aggregates group results and once again provides feedback. This process is repeated until the facilitator decides to stop the survey process. In contrast, in the real-time Delphi survey process, the facilitator, in our case a monitoring team, of the survey provides 'initial conditions' to ensure that even the very first participating experts receive feedback. To do so, the Delphi facilitator provides an initial quantitative assessment (by participation himself) to the survey questions as well as qualitative arguments. These initial conditions could have an impact on the survey process. First, initial conditions could influence final results if experts use these conditions as an anchor for their revised assessment. Second, experts participating early in the survey process (e.g. the first 20 participants, hereafter called *early participants*) receive feedback which is strongly based on the facilitator's assumptions and could therefore be biased. Only after a certain number of experts have participated in the survey, the feedback presented to participants becomes less biased by the facilitator. Consequently, it could be argued that experts participating later on in the survey process (e.g. the 21st participant and all other experts participating later, hereafter called *late participants*) receive better feedback than early participants. We call such a possible effect the *initial condition effect*.

After initial conditions are set, the real-time Delphi survey starts. From then on, experts can assess the questionnaire and provide their assessments on questions under review. As described in Section 2, real-time Delphi studies do not rely on the iteration principle based on rounds completed by all panellists but on individual participant rounds. After having provided their first assessment, experts receive immediate feedback and can re-assess and adjust their estimations. Consequently, the provision of feedback given in real-time differs from feedback given in conventional Delphi studies. The different feedbacks may have an impact on experts' (final) judgements. We call this potential effect the *feedback effect*.

Additionally, experts can re-access the survey at any convenient time during the survey period, leading to an ongoing 'quasi-dynamic' Delphi survey procedure. Thus, the iteration principle of the Delphi method is modified. This modification of the iteration principle could have significant consequences for the outcome of the Delphi survey. As experts have the opportunity to change their assessments as often as they like – independent of definite survey rounds – opinion convergence could be affected. Therefore, we term this potential effect the *iteration effect*.

[3] PEST represents the first letters of four dimensions shaping an industry's contextual environment: political, economical, social-cultural, and technological dimension.

3.1. Comparison of participation

The success of Delphi studies strongly depends on a high level of motivation among participating experts and the panel's willingness to participate in several rounds. It is important for the study facilitator to reduce panel attrition and drop-out rates in order to achieve reliable research results [36]. Thus, we compared drop-out rates in our conventional and real-time Delphi surveys. As stated previously, 30 experts participated in the conventional survey format and fully completed both round 1 and 2 of the survey. That is, all experts provided their initial assessments in round 1. In round 2, all experts received feedback and were able to revise their initial assessment if desired. Therefore, we recorded a drop-out rate of 0% in our conventional Delphi.

Likewise, we also observed a drop-out rate of 0% in the real-time Delphi. First, experts provided their initial assessment on a projection under review. Second, they clicked on the "proceed" button, received immediate feedback and were able to revise their prior assessment. Thus, experts proceed through two theoretical rounds in the real-time Delphi automatically if they complete the survey for the first time. In addition to that, experts' participation was higher than just the completion of one round, as depicted in Table 4.

Table 4 illustrates that nine experts participated in the survey only once, i.e. completed Delphi screen I and II for each projection, thereby fulfilling the minimum criteria of a Delphi with one assessment and one revision of a set of projections. The participants made initial assessments, received immediate feedback, and did not return to the survey again. However, 38 participants re-accessed the real-time Delphi survey a second time to check for changes in group opinions. Furthermore, 15 experts re-accessed the portal more than three times. These findings are a good indicator for the effectiveness of the real-time Delphi survey and the convenience of this survey approach. Participants voluntarily decided to re-access whenever it was convenient for them in order to check for changes in survey results. Furthermore, it gives reason to consider whether the internet-based, real-time Delphi survey format could be – among other aspects such as changing the order of projections – a potential solution to deal with the problem of research fatigue in Delphi studies [36].

Another comparison of the conventional and real-time Delphi can be made by comparing the number of provided comments. As demonstrated in Table 3, the total number of provided arguments in the conventional Delphi format is smaller than in the real-time Delphi format. However, since the number of projections and the number of participants differed between the survey formats, we calculated the ratios of how many arguments were provided per expert and per projection. On average, 0.89 and 0.66 arguments were provided per participant and per projection in the conventional and the real-time Delphi formats, respectively. Thus, more arguments per participant and per projection were provided in the conventional Delphi (*M*=*0.89, SD*=*0.11)* compared to the real-time Delphi (*M*=*0.66, SD*=*0.39)*. The results of the independent *t*-test underlined a significant difference between the ratios of the two Delphi formats with $t(48) = 2.97$, $p<0.01$).

This difference may be explained by the fact that the conventional, round-based Delphi procedure produces more redundancies when it comes to the provision of qualitative arguments compared to our real-time approach. While participants in the conventional approach provide any argument which comes to mind in survey round 1, participants in our real-time Delphi could check whether 'their' arguments were already provided, once participants clicked on the proceed-button and received feedback. Thus, if participants in the real-time Delphi recognised that their argument was already provided, participants would not need to add it once again. If their argument was not mentioned, however, experts could complement the list. Hence, redundancies in arguments could be reduced, which may also explain the significantly lower ratio of arguments in the real-time Delphi method.

3.2. Analysis of initial condition effect

As previously mentioned, the provision of initial conditions could adversely affect the final survey results. Since the facilitator of the real-time Delphi survey is the first participant who provides an assessment, which serves as feedback for subsequent experts, final results could be biased. Furthermore, early participants receive feedback which is primarily based on the initial conditions than feedback given to late participants. Thus, initial conditions could cause different correction behaviour between early and late participants.

To study whether initial conditions adversely affect survey results, we test the following null hypothesis:

$H0_1$: There is no adverse effect of initial conditions on final results.

To test $H0_1$ we conducted a regression analysis with initial conditions and final results. While initial conditions are the expected-probability (EP) values which have been provided by the study facilitator for every projection in the real-time Delphi study, final results refer to final EP assessments which have been provided by the experts participating the study. Consequently, we were able to analyse whether initial conditions provided by the study facilitator influenced adjacent panellists and final results.

Table 4
Level of participation in the real-time Delphi.

Number of completed assessments	Number of cases	Percentage of experts
1	9	14,5%
2	38	61,3%
3	5	8,1%
4	5	8,1%
5	5	8,1%
	$\Sigma = \mathbf{62}$	$\Sigma = \mathbf{1}$

In our regression model, we define initial conditions (i.e. facilitator's EP assessment) to be the independent variable and final results (i.e. final EP values) to be the dependent variable. The results of the regression analysis reveal that there is no significant influence of initial conditions on final results with a slope coefficient $b_1 = 0.197$ ($p = 0.167$). Furthermore, initial conditions are not able to explain a significant portion of variance of final results ($R^2 = 0.10$; $F(1,19) = 2{,}08$, $p = 0.167$). Consequently, $H0_1$ is supported.

Furthermore, we test whether initial conditions cause different correction behaviour between early and late participants. Through the data collection process of the real-time Delphi survey, a comparison of experts' quantitative assessments of future projections with aggregated group results was possible. We were able to reconstruct which average values were provided as feedback to experts at the point of time when they made their assessments. Thus, it was possible to observe whether an expert's individual assessment deviated from the average group opinion, and if so, how strong this deviation was. Moreover, we were also able to analyse whether experts changed their assessment after receiving information about group averages and, if so, how radical the change was. Thus, we recorded deviations from the average expected probability for each expert and for each projection as well as correction assessments after having received feedback.

Based on this data from the real-time Delphi survey, we are able to study whether early participants' correction behaviour differed from late participants' behaviour. If such an effect exists, late participants who receive more feedback should exhibit different correction behaviour than early participants who may be biased by the initial value set by the study facilitator.

To test whether correction behaviour of early participants differed from late participants', we used a linear regression model and account for the dependencies between observations that arise from the panel data structure using clustered robust standard errors [37].

$$cor_{ij} = \beta_o + \beta_1 * dev_{ij} + \beta_2 * \varphi_i + \beta_3 * \left(\varphi_i * dev_{ij}\right)$$

where $i \in \{1,\ldots,62\}$ indexes the experts participating in the real-time survey and $j \in \{1,\ldots,20\}$ the projection. Cor_{ij} denotes how strongly the EP (i.e. experts' expected probability) assessment was corrected after feedback was given and dev_{ij} represents the value of how strongly an expert deviated from the average EP value. $\varphi_i \in \{0,1\}$ denotes an indicator variable which takes on the value 1 if the expert *i* belongs to the group of the early participants and 0 if the expert belongs to the group of late participants. The model predicts how the deviation from average EP impacts corrections while accounting for possible differences between early and late respondents. The results demonstrate a valid regression model ($R^2 = 0.22$; $F(3,61) = 9.02$, $p < 0.001$) with $\beta_1 = -0.21$ ($p < 0.001$). However, neither the indicator variable nor the interaction term (i.e. $\beta_3 * (\varphi_i * dev_{ij})$) is statistically significant ($\beta_2 = 1.06$, $p = 0.24$ and $\beta_3 = -0.03$, $p = 0.71$ respectively). The feedback given to early participants did not cause significant differences in the correction behaviours compared to feedback given to later participants.

Consequently, the results provide support for $H0_1$ and we can conclude that an initial condition effect does not exist in the real-time Delphi study.

3.3. Analysis of feedback effect

As a next step, we studied whether the participants react differently to feedback in the conventional and real-time Delphi studies. This analysis accounts for the fact that feedback processes in both Delphi studies differ fundamentally. While participants in the conventional Delphi survey did not receive feedback until a certain number of other experts had completed a survey round, participants in the real-time Delphi study received immediate feedback after having provided their first assessment. This short time period between assessment and feedback may induce different reaction to feedback. To account for a potential *feedback effect*, we tested the following null hypothesis:

$H0_2$: There is no difference between participants' reaction to feedback given in real-time and conventional Delphi surveys.

Fig. 6 illustrates a relationship between a participant's deviation from the average expected-probability (EP) value (indicated on the x-axis) and the strength of the expert's correction of this value. The scatter plot suggests a negative relationship between

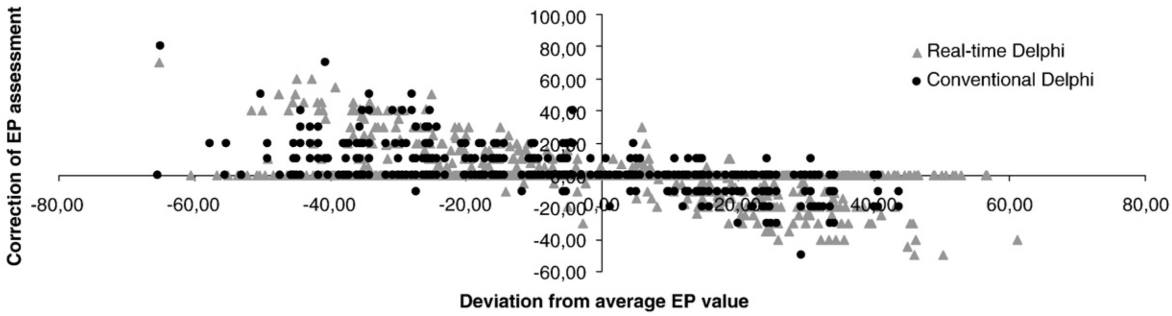

Fig. 6. Relationship between deviation from EP and correction of assessment in conventional and real-time Delphi.

deviation and correction. A participant tends to increase (decrease) his EP estimation if his assessment is below (above) the group average. However, the plot also shows that numerous experts do not change their assessment even though they deviate from the group opinion.

Again, we used the modelling approach discussed above to test $H0_2$:

$$cor_{kl} = b_o + b_1 * dev_{kl} + b_2 * \gamma_k + b_3 * (\gamma_k * dev_{kl})$$

where $k \in \{1,\ldots,92\}$ indexes participants of both the conventional and real-time Delphi studies and $l \in \{1,\ldots,L_s\}$ is the projection dependent on s which indicates whether the projections are from the real-time ($s = 1$) or conventional ($s = 2$) Delphi study. As in the first model, cor_{kl} denotes how radically the EP assessment was corrected after feedback was given and dev_{kl} represents the value of how strongly an expert deviated from the average EP value.$\gamma_k \in \{0,1\}$ denotes an indicator variable which takes on the value 1 if the expert k belongs to the real-time and 0 if an expert belongs to the conventional Delphi study. The model explains how deviation from average EP values explains correction from previous assessments. Thereby, the model includes a fixed effect and an interaction term (i.e. $b_3 * (\gamma_k * dev_{kl})$) that account for the possible differences in participants' responses to feedback given in the real-time and conventional Delphi studies. Our results revealed a valid regression model ($R^2 = 0.25$; $F(3,91) = 24.00$, $p < 0.001$) with $b_1 = -0.26$ ($p < 0.001$). Again, neither the indicator variable nor the interaction term is significant ($b_2 = -0.84$, $p = 0.14$ and $b_3 = 0.04$, $p = 0.45$, respectively). Consequently, the results provide support for $H0_2$ and we conclude that a *feedback effect* does not exist.

3.4. Analysis of iteration effect

After having analysed how experts react to feedback given in the real-time Delphi survey, the convergence process was examined. Convergence processes in conventional and real-time Delphi studies could differ due to the modified iteration process. In conventional versions, experts can adjust their assessment only once per round, while participants in real-time Delphi studies have the opportunity to access the survey and change their assessments as often as they wish. Studying the convergence process is important because convergence is a prerequisite to achieve consensus [2,38] and consensus is one of the central objectives of the majority of conventional Delphi studies. Thereby, consensus is achieved through a convergence process in which participants' variance in responses decreases and opinions approximate to the 'correct' answer [39]. A great portion of researchers agree that convergence occurs over several rounds in the Delphi process [e.g. 9,40]. As the real-time Delphi method described in this paper does not adhere to the idea of having several, sequential rounds and thus a modified iteration process takes place, it is necessary to further investigate the consensus building process during the survey and to study whether a possible iteration effect influences convergence processes. Therefore, we tested the following null hypothesis:

$H0_3$: There is no difference in the convergence process between the real-time Delphi survey and conventional Delphi survey.

In order to test $H0_3$, a comparison of changes in standard deviations (SD) in expected-probability (EP) estimations in the conventional and real-time Delphi was conducted. An SD reduction over 'rounds' can be interpreted as convergence of opinion and as an approximation towards consensus [2,41]. For the conventional version, we calculated SD changes by comparing SD of EP estimates in the first round with SD of EP estimates in the final round. Average SD changes were found to be -14.66 percent. Regarding real-time Delphi data, we ascertained SD changes by considering experts' first estimates (assessments in Delphi screen I of each projection) and final estimates (values when closing the survey portal). On average, SD changes of -15.85 percent were observed in the real-time Delphi survey. Thereafter, we analysed whether the decreases in standard deviations of EP evaluations in the conventional Delphi study differ significantly from those in the real-time version. First, we studied whether the observed SD changes in conventional and real-time Delphi studies were normally distributed by conducting a Kolmogorov-Smirnov test. The results revealed that SD changes were normally distributed in the conventional ($p=0.882$) as well as in the real-time Delphi ($p=0.924$) study. Thus, we were able to conduct an independent-samples *t*-test to check for significant differences in convergence processes between the two survey formats.

The *t*-test requires equally distributed variances in population. The Levene's test revealed that the assumption of homogeneity of variances was fulfilled and that variances did not differ significantly ($p=0.709$). Finally, the results of the *t*-test indicated that differences between the means of SD changes in the conventional and real-time Delphi studies were not significantly different ($t(48) = 0.651$, $p = 0.518$). Since differences in the convergence process of the conventional and real-time Delphi are not significant, the null hypothesis $H0_3$ is supported. We therefore conclude that the convergence process in real-time Delphi works as effectively as in the conventional format.

3.5. Comparison of selected projections

Our previous analyses provided strong evidence that differences in the process and task characteristics of conventional and real-time Delphi methods do not have a significant impact on the study results. In this section, we intend to provide further support for this by analysing the final results (i.e. expected probability (EP) assessments) for identical or very similar projections included in both surveys. We assumed that the final results (i.e. EP assessments) for identical or very similar projections of the surveys would also not differ, leading to the following hypothesis:

$H0_4$: Results of the real-time Delphi survey and the conventional Delphi survey do not differ significantly.

Table 5
Equalling projections surveyed in conventional and real-time Delphi.

Topic	Projection	Average EP estimates		Mann-Whitney test	
		Conventional	Real-time	U	Sig.
Energy Supply	The problem of energy supply (e.g. scarcity of fossil energies, nuclear power) remains unsolved globally.	69.00	69.15	827,5	0.387
Emerging Countries	A multitude of developing and emerging countries has narrowed the gap to the industrial nations by economically catching up in the tertiary and quaternary industry sector.	67.33	64.58	924,0	0.96
Innovations	Innovations in transport logistics (e.g. new types of vehicles, alternative propulsion, innovative materials) have substantially contributed to the reduction of resource consumption.	64.33	67.73	829,0	0.392

Table 5 provides an overview of the projections surveyed in both Delphi studies and the respective average EP estimates. At first glance, it is obvious that the probabilities attached to the projections do not differ strongly. However, to confirm this initial evaluation, we analysed whether statistical differences can be observed between the assessments of the projections in the conventional and real-time Delphi studies. Since participants' assessments for the projections were not normally distributed, we conducted the non-parametric Mann-Whitney-U test to test for statistically significant differences between the two Delphi methods [38].

The results demonstrate that differences in probability estimates for the projections on energy supply, emerging countries, and innovations do not differ significantly (p-values of 0.387, 0.96, and 0.392, respectively). Consequently, hypothesis $H0_4$ is supported and it can be concluded that the questions surveyed in conventional and real-time Delphi studies do not yield significantly different results.

4. Conclusion

The objective of this paper was twofold: We aimed to extend Gordon and Pease's [5] innovative idea of an internet-based, almost real-time Delphi survey. In order to do so, we developed additional features, as suggested by the authors to eliminate the weaknesses previously identified in the online Delphi method. Thereby, we refined the graphical layout and feedback provided to experts. By adhering to the four main characteristics of Delphi, we outlined how an internet-based, real-time Delphi survey tool equipped with these elements increases the validity and reliability, as well as usability considerably. Furthermore, we developed a consensus portal and graphical real-time feedback features to make participation more convenient for participants. In addition, the extended scope of operation of the internet-based, real-time Delphi study reduces the complexity and resources required to conduct this type of survey.

By comparing a conventional Delphi survey with a real-time Delphi survey, it was shown that the internet-based, real-time Delphi works as effectively as the conventional, round-based Delphi method. Due to the modified iteration and feedback processes of the real-time Delphi method, several comparisons were made. By using a robust linear regression model, we studied the *initial condition effect* and *feedback effect*. In addition, we studied whether a potential *iteration effect* could affect the convergence building processes (i.e. the way consensus among participants is achieved) by applying an independent-samples *t*-test. Finally, by analysing the results of three identical projections in both studies, we demonstrated that the results of both studies do not differ. Thus, we were able to address the lack of replication of results, which has been one of the major criticisms about Delphi surveys in the past [42]. In summary, the comparison analyses showed no significant differences between conventional and real-time Delphi survey methods. Therefore, we argue that the results of the real-time Delphi survey tool are as robust as the results generated by a conventional Delphi survey.

However, our research results are not exempt from some limitations. The comparison between conventional and real-time Delphi methods was based on two studies, whereby it might be beneficial to compare more than just two surveys. In addition, the comparisons are based on Delphi formats in which future projections had to be evaluated in terms of expected probability, impact, and desirability. Further research is required to study whether differences between conventional and real-time Delphi emerge if other types of questions, such as the estimation of times of occurrences, feasibility or urgency would have to be evaluated. In addition, we call attention to the fact that we used 'alarming' colour-codes in our feedback processes. Future research should address how the use of these alarming colours may influence experts' correction behaviour. Moreover, we cannot rule out that the two survey methods do not differ due to the fact that adequate initial conditions were provided in the real-time Delphi study. Future analyses could study whether differences between conventional and real-time Delphi methods occur if other initial conditions were provided.

In essence, Gordon and Pease's [5] idea of an online-based, real-time Delphi study method represents a considerable contribution to the scientific community and reduces the complexity of the conventional Delphi approach. Our research results support the validity and effectiveness of such an innovative approach and thus constitute a valid basis for additional applications of the real-time Delphi survey format.

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