Expert Delphi Survey as a Cloud-Based Decision Support Service

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***Abstract* — The essence of the online Delphi method is multiple round interviews of an expert group who answer questions in a structured e-survey and verify hypotheses called Delphi statements or questions. These can be defined by the client contracting the study or the core experts employed by the Delphi supplier, usually a consulting or research institution. The questions can have various forms: binary ("yes/no"), qualitative - Likert-scale-valued, or quantitative. A flexible survey system should offer a variety of question and/or statement types, as well as a user-friendly interface to reply or verify them. Additionally, the replies should be analyzed by strict statistical and uncertainty handling methods to yield consistent recommendations to the survey stakeholders. The 'decision Delphi' is a survey variant that corresponds most strictly to the needs of organizations that seek expert knowledge concerning specific technological, market or other business problems. This type of survey also fits the needs of medical research on future therapy, epidemics, health care issues, etc. Its characteristic feature is the participation of the client's staff or the decision makers themselves. The cloud-based application Forgnosis™ is a modern implementation of a decision and policy Delphi endowed with sophisticated analytic features. We will present its capabilities based on a recent survey and analysis case carried out for the EU Horizon 2020 flagship project MOVING. This system is offered in the SaaS mode, with many PaaS functionalities. The latter include a variety of programming tools for designing the organization's customized survey.**

Keywords — online Delphi survey; corporate foresight; multi-round Delphi; statistical analysis; group decision support; strategic decision making; technological scenarios

I. An Introduction to the Delphi Survey Method

The expert survey method often referred to as Delphi analysis was developed at Rand Corporation [3] in the 1950s. Since then, it has been widely used in technological, economical, and social foresight, as well as in decision support processes, especially in the context of choice problems with multiple conflicting criteria, see e.g. [16]. Delphi studies are often interdisciplinary. For example, in technological foresight, economic, environmental and social conditions are also examined. Therefore, the surveys are usually subdivided into separate research areas, hereinafter referred as 'survey sections'. Usually, each survey section corresponds to an appropriate thematic panel of experts.

A standard Delphi survey questionnaire comprises of 20-200 questions subdivided into thematic sections. Each section usually contains 10-30 questions, which cover technological, economic and sociological problems or hypotheses. Each question is associated with a specific trend, event, technological or investment priority, market expansion direction, etc. Respondents can select sections or questions which correspond to their particular area of expertise. If an expert is not able to reply a question, this respondent can select the option "no opinion" and move on to another question.

A characteristic feature of the Delphi method is its multi-round knowledge elicitation process, in most cases two or three rounds. Subsequent rounds contain the same, modified or extended questions, based on the results of the previous round. The aims of this procedure are listed below:

- Verification of results obtained in the previous rounds by making them available to experts responding to the same or similar questions. This is designed to facilitate responses mainly to questions which were ambiguously answered. In the case of questions with quantitative responses, this procedure aims to reduce standard deviations of previous-round replies.
- Clarification of previous-round replies with detailed questions that refer to the unresolved or unclear aspects of the corresponding questions, by asking for justification of particular responses, and showing the causes of identified trends or events.
- Including questions that complete or update the question set used during the previous round.

The credibility of subsequent rounds can be increased by filtering the group of experts so that the least reliable respondents do not continue to participate in the survey. After the final round, a panel discussion is often organized to validate the results before presenting them to the client.

The survey questions most frequently touch upon:

- The possible implementation time of a new technology or product.
- The probability of various events occurrence over one or more possible forecasting horizons.
- Innovativeness, relevance of technologies, events, trends, etc.
- Limitations and potential barriers or other difficulties that may arise in relation to the implementation of particular technologies.
- Assessment of available research and development infrastructure.

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- Position of a competitive technology, industry, or product on specific markets or compared to other products, technologies or industry branches.
- Social and environmental aspects of technology implementation, including their impact on employment.

Respondents may indicate relationships between questions, e.g. by pointing out conditions that must be fulfilled to ensure a positive or negative occurrence of an event or trend. The next round respondents have access to a summary analysis of replies to all questions in the previous rounds. Influenced by the summary opinion of other experts, the respondent can maintain his/her opinion or change it. An inter-round assessment of anonymized individual replies makes it possible to assign or update the trust or competence coefficients of experts and to eliminate outliers, for all thematic sections separately. The latter features can be efficiently provided in computer-based Delphi systems only.

From the above description, it follows immediately that the overall survey process can be greatly facilitated by using an interactive application to provide replies. Indeed, a computer supported Delphi appeared relatively early in the digital era, in the 1970s, see e.g. [23] or Chapter 7 in [9]. With the development of the Internet, email and web-based surveys gained popularity, almost completely replacing traditional paperwork. Due to the increasingly complex structure of surveys, including contingent questions, filling in a questionnaire sent as a file would significantly complicate further statistical analysis of the results. Therefore, specialized survey applications are commonly used, while an email-based dispatch of questionnaires is used for small or sporadic Delphi exercises only. The emergence of another variant of the method, *"real-time Delphi"*, was possible only due to the development of online Delphi support systems. This variant allows experts to enter an unlimited number of updates to their opinions, while the interim results of the survey can be seen immediately after an entry is made [4],[5]. If the replies are based on different prior information, this mode may affect their independence and statistical significance.

However, the online applications supporting the Delphi exercises are most often simple survey software adapted to Delphi needs. They inherit a narrow scope of question types, most often confined to multiple-choice questions with Likert scales [8] and single numerical entries, rudimentary descriptive statistical analysis, and no machine learning mechanisms. Only a few Delphi-dedicated applications offering adequate statistical analysis are available on the market. Consequently, most expert Delphi surveys are performed either with typical simple survey software with no multi-round data management or with customized applications designed for a specific survey or a series of them.

The multi-round version of the survey (Forgnosis^{TM}) presented in this paper provides a sophisticated, universal, yet affordable solution to any organization seeking specialized expertise on a given topic. It is offered as *Software as a Service* (SaaS), SaaS with consultancy support, and also in *Platform as a Service* (PaaS) mode due to its advanced survey design capabilities. Other features include a novel trust, credibility and competence coefficient management system, facilitating the achievement of a consensus in an efficient way, clustering replies conforming to the statistical analysis of reply distributions, concerning their unimodality, clustering with *k*-means and Gaussian mixture identification algorithms [10], data imputation, correlation and causal analysis of replies to different questions.

In Section II, we present the organizational aspects of using the Delphi-support application in SaaS mode. Then, in Section III, the scope of the statistical analysis and verification of results offered as the system's autonomous services are briefly characterized. Section IV is devoted to a consensus reaching check, which is particularly important in the case where Delphi is performed with SaaS support. These services are illustrated by a case study of a recent survey performed to support strategic planning of an innovative knowledge platform development within the flagship EU Horizon 2020 project MOVING [11].

To sum up, the methods presented in this article and their web implementation enable decision support, both directly, through Delphi questions concerning preferences, and indirectly, by building a decision model based on forecasts and scenarios derived from the Delphi survey.

Further information on the Delphi research method is included in the classic monograph edited by Linstone and Turoff [9], while information about applications and implementations of the online surveys can be found e.g. in [12] or [7]. The implementations of foresight support systems, including Delphi surveys, are discussed in a series of articles, cf. e.g. [15],[14] and [22]. For a discussion of the role of the Delphi method in decision support and forecasting, the reader can refer to [2].

II. Organization of the Survey

The Delphi survey is often preceded by an exploratory study conducted in the form of an online questionnaire, which is not part of the main survey process. It is aimed at selecting research issues relevant for the stakeholders commissioning the *survey-as-a-service*. This initial needs analysis is often called the survey's "*Round 0*". The participants can be, for example, the decision makers as well as the senior managerial or technical staff of the organization interested in results of the study. The latter will be termed the *sponsor* of the survey, while the survey provider will be termed *consultant*. "Round 0" can be also open to external participants who contribute independent views on the subject of the planned survey. Based on the results of this initial exercise, the sponsor and stakeholders, together with the consultant's staff assisting the survey process, define statements and questions to be used in the first round of the survey.

The thematic expert panel is simultaneously developed. The panel members are selected from among the consultant's expert pool and the sponsor's staff according to the following criteria and constraints:

- The expert skills/knowledge must cover the full scope of the survey.
- The panel should consist of at least 20 experts; the maximum number depends on funding and on the survey subject. Usually, more experts can take part in medical surveys, and fewer in highly specialized areas such as future of knowledge repositories.
- The proportion between the sponsor's staff and independent experts recruited by the consultant should be pre-defined in the contract and observed while the survey is being conducted.

The survey sponsor can also fully rely on their own experts and perform an analysis of results on their own as well. This mode may be useful when confidential or classified data is being handled during the survey. In this case, the service is a pure cloud-based SaaS. In both cases, a *survey assistant* should be assigned. This person is responsible for handling the platform and for the survey running smoothly.

A dedicated web application was developed to ensure the effectiveness of the expert selection and management process. This system effectively manages the consultant's pool of experts, from registration and verification of expert candidates, through innovative competence management, and intelligent mailing, to experts' remuneration.

As mentioned in the previous section, the scope of the survey can be determined by the sponsor, or in cooperation with a consultant, based on results of "Round 0". Survey statements and questions can also be derived in a similar way or supplied by the sponsor or consultant. The survey may consist of thematic sections containing complex statements (or '*theses*'), i.e. groups of questions concerning the same subject or hypothesis.

Before they begin answering questions, the experts selected to take part in this exercise specify their level of knowledge on the topics included in the different survey sections. They fill out a two-stage form, where their knowledge of a topic is specified e.g. as *"expert-researcher*", "*expert-practitioner*", " *expert-researcher and practitioner*", "*I've just started studying this topic*". They can also provide additional clarifying information, cf. Fig. 1. Moreover, the survey assistant has the possibility of assigning to each individual expert additional competence factors. This external assessment is independent for each survey section.

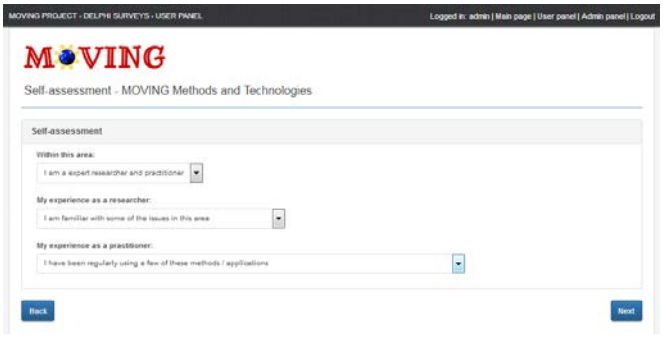

Fig. 1. Self-assessment form of experts answering the Delphi survey.

The self- and external assessments may be aggregated, yielding normalized credibility coefficients $\varphi_{ij} \in [0,1]$, for each *i*-th expert and *j*-th competence area. These are used as weighting factors in the statistical analysis of the replies.

After completing the self-assessment form, the experts can start filling in an online questionnaire, where they:

- verify asked hypotheses (so-called Delphi statements);
- comment on future events and trends of a subjective character, i.e. not resulting from quantitative models;
- determine future values of key parameters of given objects (products, markets, technologies, etc.)
- determine the probabilities of future events or the conditions under which they may occur;
- make quantitative forecasts of the future development of a given area, usually within a 15-50 year horizon;
- specify the time horizon in which particular technological, scientific, market or social events may occur;
- identify new products and technologies, their barriers, growth factors and impacts;
- identify the consequences of the decisions made and define the reference points for the decisions [16].

Questions of any type can be accompanied by a request to specify the '*certainty level of the reply*' from a predefined list of values.

A. *Flexible Multi-Round Interaction*

The Delphi Support System presented in this paper does not require any preliminary limitation of the round number or even their synchronization. Its characteristic feature is that new respondents may join the exercise at any time during the survey period, even if other experts have already begun participating in the second or a later round. The opinion processing scheme is presented in Fig.2 below.

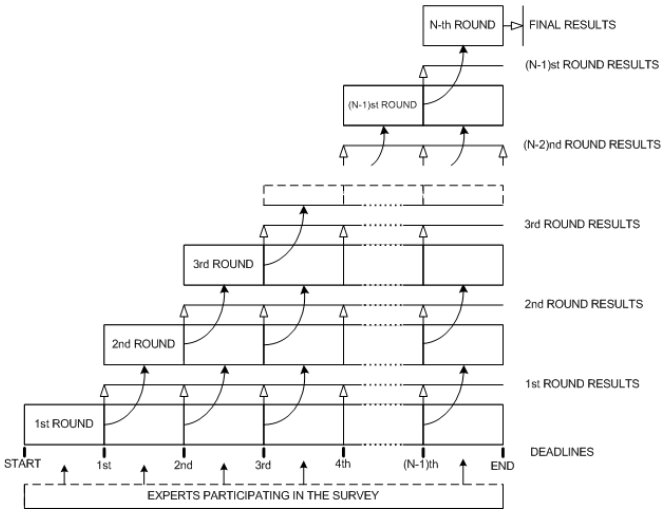

Fig. 2. A scheme of expert opinion elicitation in the Flexible Multi-Round Delphi survey. Darker arrows denote expert transitions between rounds, lighter denote information flows.

After each round, the research results are statistically processed and analyzed by the survey system to detect possible gaps and other issues. The consultant and/or sponsor determine the consensus conditions for each statement. If a consensus was reached for a given question, there is no need to continue research on this topic and the question is removed from the next round. If on the other hand the survey assistant identifies new problems that have arisen during the last round, new questions can be included in the next round. Particular attention should be paid to questions where a consensus was not reached and where inter-round convergence was slow. The second and subsequent rounds are generally directed to the respondents who most fully and reliably completed the questionnaire in previous rounds.

When providing replies in a *i*-th round, $1<i\leq N$, the respondents can see their earlier replies to the same questions and the statistical characteristics of all replies in previous rounds. This is illustrated in Fig. 3 below.

The number of panel experts depends i.a. on the subject matter and scope of the study. Usually, the more specialized the questions, the narrower the group of experts competent enough to give a reply. In engineering sciences, including computer science, it is assumed that the number of responses to each first round question should preferably exceed 20. Lower values are acceptable for subsequent rounds as they may be limited to a subgroup of experts participating in the previous round selected in a certain manner. For example, 25 experts participated in a typical decision-Delphi exercise conducted within the MOVING project [11], which strictly follows the recommended number of 20-30 experts for this survey type. On the other hand, the policy Delphi in the project SCETIST [18], which covered intelligent systems, was carried out on a sample of over 100 respondents.

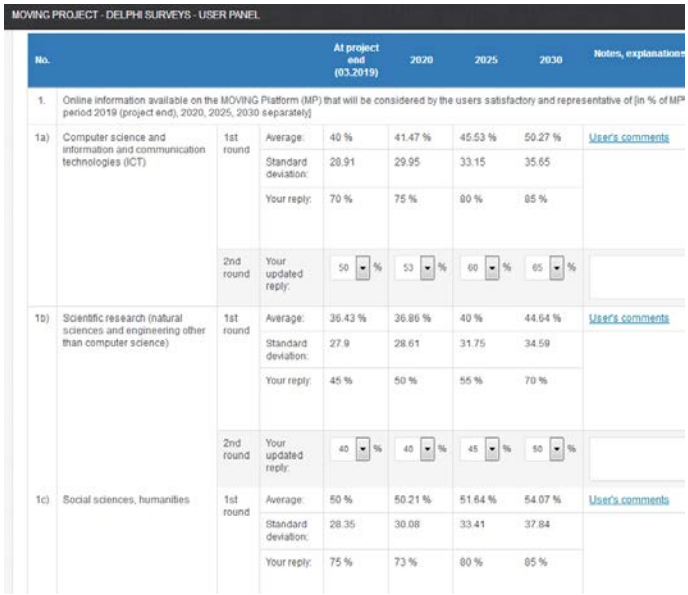

Fig. 3. A screenshot with an example of information on the results of the 1st round, which are visible for respondents participating in the 2nd round of the Delphi survey performed within the H2020 MOVING project [11].

The overall survey business process is shown in Fig. 4.

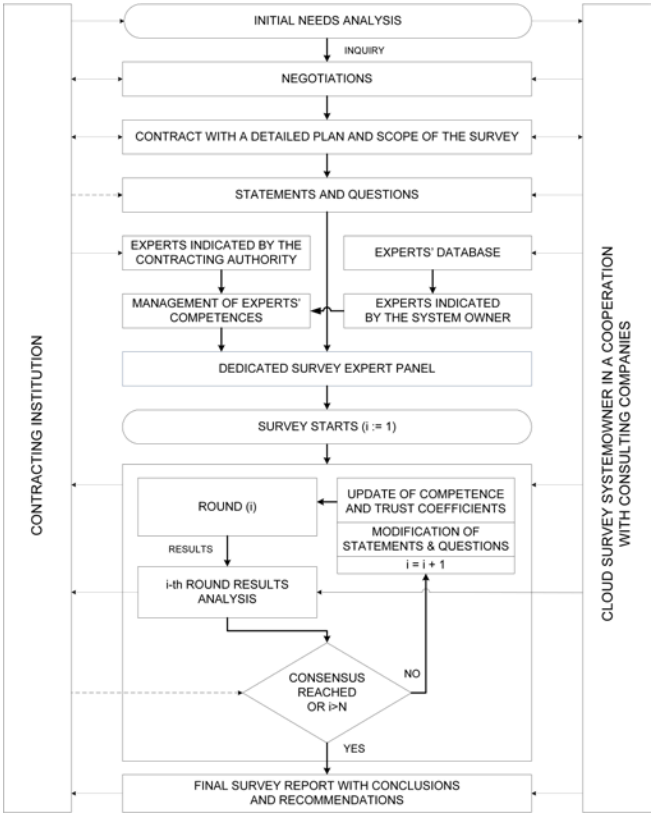

Fig. 4. An organization chart of multi-round Delphi study, in which the specialized software available as a service was used.

The above-presented multi-round online Delphi survey scheme does not impose any limits on the number of rounds. The subsequent phases of the study, which can be identified with completing the *i*-th round, are usually summarized at specialized panel discussions or seminars with both experts, sponsors, and research stakeholders. The purpose of panel discussions may also be a final description of the future development scenarios derived from the survey.

B. Survey Implementation for Research Project Exploitation Planning

As a Delphi survey case study, we will present the most important elements of the web-based platform used in the EU Horizon 2020 MOVING project (see: www.moving-survey.ipbf.eu). This survey sections are shown in Fig. 5.

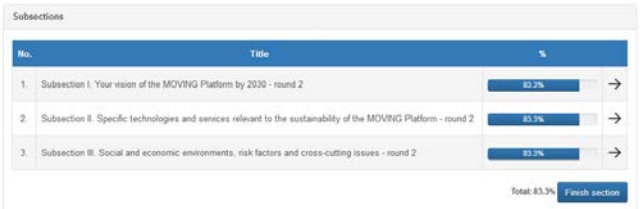

Fig. 5. An example of the Delphi study on ICT technologies composed of three sections and 96 questions. Percentages indicate the extent to which the selected respondent answered the questions on particular topics [11].

Delphi survey questions related to specific issues listed in Fig. 5 are complex and include structured elements such as check boxes, numerical fields and text boxes which allow the respondent to type descriptive comments and justifications. The design of the survey can be accomplished with a sophisticated administration panel. A screenshot of the panel with sample questions designed for the survey on a digital knowledge platform future is shown in Fig. 6.

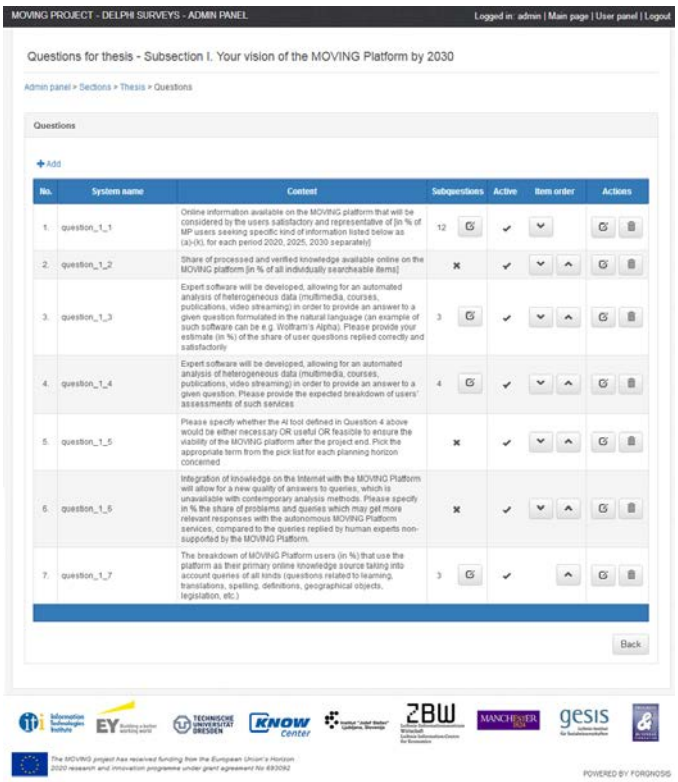

Fig. 6. An example of questionnaire design for the MOVING project [11].

In the extended SaaS and PaaS modes, the sponsor can use the administrative tools available in the panel to design the overall survey and enter the statements and questions.

Standard questions in the MOVING survey have a tabular form, where the respondents enter their replies in the columns corresponding to the specified time intervals. These are interpreted as the final and intermediate forecasting horizons. A separate table is assigned to every statement.

TABLE I. The scheme of a simple question consisting of one row (Type 1)

Question number	Present state (facultative)	State in year R1	State in year R2	State for year R3	Further development up to year R4	Comments sources, justifications	Degree of certainty of a reply φ
Reply	Reply field	Reply field	Reply field	Reply field	Reply field	Comment	Pick list

The questions of the second type may have additional, so-called subordinate questions. The third type of questions consists of interrelated groups of questions. These groups usually have a common introduction or share part of a question. Type 3 can be, for example, a group of questions concerned with the structure of a certain market, where each question is related to the forecast of a different market segment. The analysis of replies to subordinate questions should take into account the method used to relate these questions. It is often assumed that the sum of single-expert replies to sub-questions should amount to 100%.

Fig. 7 presents an example of a filled questionnaire of Type 1 used in the MOVING project (Section I, questions 1a,b,c,d).

Fig. 7. An example of questionnaire with replies to questions collected in Section I of survey performed within the MOVING project [11].

Due to the ease of reply quantification, the most popular and frequently used in qualitative questions in the MOVING survey was the Likert scale, particularly in its 5-grade version [8]. The next section contains further details related to the outcomes of this survey.

III. Analysis of Survey Results

A detailed statistical analysis of the survey results is one of the fundamental computational features of the application. Its scope can be defined either by the consultant (in SaaS mode) or by the sponsor (in PaaS mode). However, the results should in any case be pre-assessed by the survey assistant before their discussion is held by thematic expert panels. The analytical methods implemented in the survey management system are related mainly to descriptive statistics. They include an estimation of expected values, standard deviations and semi-deviations, as well as calculations of medians, quartiles, and quintiles. In its basic version the application is able to calculate any standard or weighted quantiles for a quantitative or quantified question.

The need to use weighted descriptors results from the assignment of weighting factors $\varphi_{ij} \in [0,1]$ to the experts' responses during the survey. They are first determined based on the competence assessment at experts' registration (cf. Section II), then updated based on and the evaluation of the expert's participation in earlier Delphi surveys or rounds. These factors can be used to optimize the results of advanced statistical analysis. Specifically, they can improve reply clustering, missing value imputation and correlation analysis. Updates of coefficients φ_{ij} may be performed after each survey round or after a final assessment of the quality of group decision support resulting from the entire study.

Expert trust and credibility analysis allows the survey assistant to identify those replies that despite their extreme views may best reflect the actual state. This conforms to the

principle that the main aim of Delphi research is to detect events and trends that are unexpected, and characterized by values of their parameters which are often far from the average and may be articulated by a relatively small group of knowledgeable experts. Secondly, the weights can reduce the influence of incidental mistakes on the results of the entire study [4]. Trust and credibility coefficients can also be the criteria for selecting experts for further studies.

The results of the previous Delphi survey research with the Forgnosis^{TM} system performed within the SCETIST [18], [17] and MOVING projects [11] show that taking into account trust, and competence factors improves the overall credibility of survey results and accelerates the arrival of a consensus. The selection of respondents with better access to the source information is also made possible.

In order to properly use the information obtained during a Delphi survey, one or more of the following standard methods of enhancing reply processing offered by the here presented cloud application are recommended:

- Verification of the quantitative responses supervised by a survey assistant or other experts. An acceptable form of verification is only the correction of obvious mistakes made by respondents, such as e.g. placing 1'000'000 instead of 1 in response to a question where the requested reply is in million units.
- Supervised verification of comments, which may result in the removal of an entire response in the cases where the comment or justification is clearly either unrelated to the subject of study or is found to have violated rules of the study or other rules.
- Semi-supervised assignment of appropriate numerical values to particular qualitative or descriptive replies, based on the extracted rules. Numerical values can be assigned automatically to Likert-scale replies making it possible to calculate statistical moments or quantiles weighted by credibility coefficients and returning to the qualitative assessments by finding the descriptor closest to the calculated numerical value.
- Complex quantitative indicators may be constructed, aggregating replies to a collection of questions related to the same or similar topics. Based on the qualitative value conversion presented above, the system enables a fusion of replies given in symbolic and numerical forms and their further statistical analysis.
- Statistical analysis and the identification of logistic trends is offered for questions that elicit probabilities of occurrence of a certain event in the future, for at least four forecasting horizons. The experts respond to questions of the type *"What is the probability that event X occurs in the year 2020, 2025 or until 2030 at the latest?* " If the logistic regression function is significant, this analysis also makes it possible to determine the expected year of occurrence of an event described by the estimated probability distribution.

The quantitative results of each round are generated in a collective form by the survey management system. An example of such an analysis is presented in Fig.8. The details of the calculations are described in Chapter 8 of [18]. All factors are calculated with reply certainty factors combined with trust coefficients and taken as weights (lower part of the screenshot) as well as without weights (upper part).


MOVING PROJECT - DELPHI SURVEYS - ADMIN PANEL

Logged in: admin | Main page | User panel | Logout

Results - Replies statistics - Online information available on the MOVING platform that will be considered by the users satisfactory and representative of [in % of MP users seeking specific kind of information listed below as (a)-(k), for each period 2020, 2025, 2030 separately]

Admin panel » Replies Statistics » Subsection I. Your vision of the MOVING Platform by 2030 » Online information available on the MOVING platform that will be considered by the users satisfactory and representative of [in % of MP users seeking specific kind of information listed below as (a)-(k), for each period 2020, 2025, 2030 separately]

Replies statistics

Online information available on the MOVING platform that will be considered by the users satisfactory and representative of [in % of MP users seeking specific kind of information listed below as (a)-(k), for each period 2020, 2025, 2030 separately]

a) Computer science and information and communication technologies (ICT)

Replies: Percent (min value: 0 max value: 100)

Calculations without certainty factor

Horizon	2019		2020		2025		2030	
	Round 1	Round 2	Round 1	Round 2	Round 1	Round 2	Round 1	Round 2
Average	43.33%	41%	44.28%	42.4%	48.22%	46.33%	52.17%	49.13%
Standard deviation	27.97	22.14	28.16	21.53	31.39	22.87	35.51	28.31
Standard semideviation left	19.66	16.07	19.45	16.12	21.83	17.01	25.48	20.64
Standard semideviation right	19.89	15.22	20.36	14.28	22.56	15.28	24.73	19.37
1. quartile	15%	18.75%	15%	26.25%	15%	30%	15%	15%
2. quartile (median)	40%	45%	30%	49%	40%	45.5%	40%	45%
3. quartile	67.5%	51.25%	67.5%	53.5%	77.5%	60%	87.5%	70%
q3-q1	52.5	32.5	52.5	27.25	62.5	30	72.5	55

Calculations with certainty factor

Horizon	2019		2020		2025		2030	
	Round 1	Round 2	Round 1	Round 2	Round 1	Round 2	Round 1	Round 2
Average	47.52%	42.39%	47.38%	42.24%	49.38%	44.59%	51.63%	46.2%
Standard deviation	28.17	23.05	28.95	22.28	31.9	23.05	35.77	27.88
Standard semideviation left	20.82	17.1	20.82	16.74	22.96	17.07	26.53	20.33
Standard semideviation right	18.96	15.46	20.12	14.7	22.15	15.48	23.99	19.06
1. quartile	15%	14.73%	15%	14.73%	15%	15%	15%	15%
2. quartile (median)	60%	50%	49.14%	50%	40%	45.47%	59.14%	46.3%
3. quartile	70%	53.17%	70%	55.01%	75.04%	58.84%	82.32%	70%
q3-q1	55	38.44	55	40.28	60.04	43.84	67.32	55

Fig. 8. A sample basic statistical analysis of the MOVING survey results

A. The expert consensus analysis

In addition to the aforementioned basic factors calculation, the analysis of results includes standard statistical tests and consensus-related properties of the set of responses:

- Standard semideviations σ_+ and σ_- and their sum, $\sigma_{+/.}$.
- *Interquartile range* (IQR), i.e. the difference between the 3rd and 1st quartiles.
- *Interquintile range* (IQVR, the difference between 4th and 1st quintiles).
- Number of reply clusters for each question based on Hartigans' unimodality test of reply distribution [6].

As stated above, the survey support system can calculate a novel measure of opinion consistency, stronger than IQR, termed the interquintile range. As the difference between the fourth and first quintile, it quantifies the consistence of responses included between the 20th and 80th percentiles. By a certain analogy to the famous Pareto principle, this indicator is also termed "*Pareto range*" [17].

The simplest way to determine the number of clusters consists of an analysis of reply histograms (cf. Fig. 9) and combining it with the results of unimodality tests. This method can be used even when the number of replies is lower than 30. Other clustering methods, such as *k*-means, can be used as well when the number of replies exceeds 30. In addition, the Shapiro-Wilk normality test of the distribution of responses [13] plays an auxiliary role in determining when it is necessary to use Gaussian-mixture-based clustering [10].

	2020			2025			2030		
	Range	Number of answers	Sum of certainty factors	Range	Number of answers	Sum of certainty factors	Range	Number of answers	Sum of certainty factors
1	[8-20]	5	1.56	[5-17.9]	6	1.91	[1-14.4]	2	0.91
2	(20-32]	4	0.9	(17.9-30.7]	0	0	(14.4-27.9]	4	1.25
3	(32-44]	0	0	(30.7-43.6]	4	0.9	(27.9-41.3]	3	0.3
4	(44-56]	2	0.51	(43.6-56.4]	0	0	(41.3-54.7]	0	0
5	(56-68]	2	0.9	(56.4-69.3]	0	0	(54.7-68.1]	1	0.35
6	(68-80]	3	0.87	(69.3-82.1]	5	1.83	(68.1-81.6]	2	1.22
7	(80-92]	2	0.85	(82.1-95]	3	0.95	(81.6-95]	6	1.56

Fig. 9. An example of a questionnaire with replies to questions collected in Section I of the survey conducted within the project MOVING [11].

To assess whether a consensus has been achieved for a given quantitative question $\boldsymbol{q}$, the *IQR*, *IQVR*, and $\sigma_{+/-}$, are divided by the length of the interval $[r_{q,max}, r_{q,min}]$, r_q, which reflects the span of all responses to $\boldsymbol{q}$ after eliminating outliers. This interval will be termed *reasonability range* for replies to $\boldsymbol{q}$. The r_q may also be defined independently on the actual responses in the survey. For example, if the respondents estimate probabilities, it may be predefined as 1. Dividing a selected consensus measure by r_q, yields the *consensus ratio*, to be compared after a *j*-th round to a certain acceptability threshold γ_q [17] in the following way

$$IQVR(j)/\, r_q \leq \gamma_q. \tag{1}$$

The value of γ_q may be common for all questions in the survey, in a section, or for a group of questions analyzed jointly. Observe that for a given γ, the condition (1) is obviously stronger than the condition $IQR(s)/r_q \leq \gamma$. No such rule can be derived for the indicators *IQR* and $\sigma_{+/-}$, however.

The selection of an indicator and a threshold to assess consensus achievement strictly depends on the type of questions and information provided by the experts in the survey. Usually, it should be determined empirically.

A consistency condition of type (1) can also be used as a measure of survey *inter-round convergence*. This is preserved if the consensus indicators decrease in subsequent rounds. This process does not need to be monotonic, i.e.

$$\forall s \geq 1\ \exists s_0 > s\ \ \forall t \geq s_0\ Y(t) < Y(s), \tag{2}$$

where *Y* is a given consensus indicator (*IQR*, *IQVR*, or $\sigma_{+/-}$) and *s* and *t* are round indices. The consensus is achieved if

$$\exists s_0 \geq 1\ \ \forall t \geq s_0\ Y(t)/\, r_q \leq \gamma. \tag{3}$$

According to the Delphi background [19], [20],[21], the lack of consensus cannot be identified with a failure of the exercise. Similarly, as in [17],[18], in the survey performed within the project [11], reaching a consensus was not set as the main objective. Instead, it has been assumed that the appearance of two or more clusters in a set of responses to a Delphi question indicates that the experts used various sources of information concerned with the topic in question. If the *ex-ante* credibility of these information sources is unknown, it prevents us from assessing which group of responses is more trustworthy. In this case we can calculate the sum of weights for each cluster of replies and assume that its overall credibility is proportional to that sum.

The intra-round convergence criteria (2)-(3) can also be applied to each of the reply clusters separately. In this manner, the hypothetical, most reliable estimate of the value of the studied variable might be the median response or average taken from the selected cluster. These values can then be used to build development scenarios for the technology, product or market under study, cf. [1].

IV. Final Remarks

A Delphi survey can be either an independent way of knowledge acquisition about the future or a complementary method of acquiring knowledge for other future studies. The latter may include biblio-, webo-, and patentometric trend elicitation and analysis, expert panels and workshops, product and technology inventories, etc.

The expert replies to Delphi questionnaires may be used in many different ways. They may serve to identify elements (subsystems, variables, structural coefficients) of socio-econometric and techno-econometric models [15] or to define characteristics of future decision problems included in anticipatory models [16]. They can also be used to create rankings of technologies, technological trajectories and technology development projects. Delphi exercises can help us to discover, confirm or exclude causal relationships between events, trends, and variables. The data gathered during a technological Delphi survey can serve to forecast financial factors, such as the average profitability of a user-defined ICT business model. The latter may depend not only on sales volume and other factors related directly to the market, but also implementation of new technologies.

Future technological trends that should be considered when elaborating on technological strategies can be detected with the Delphi studies with appropriately formulated questions. Therefore, an analysis of responses to a Delphi survey can serve as an important decision support tool, which can contribute to increasing the competitiveness of enterprises that use survey findings in their strategic planning.

The implementation of the Delphi survey presented in this article can be particularly useful for research project teams planning to commercialize their results as well as for innovative companies assigning funds to technological development projects. The latter can actually be the later stages of commercialized research projects.

A characteristic feature of the Delphi support system presented in this paper is that customers contracting the use of the application in SaaS mode simultaneously benefit from the knowledge and experience of a consultancy organization that provides an ICT platform and access to its expert pool. The client does not need to handle the organizational aspects

the survey, which are fully managed by the application, and specialized know-how is not required. The entire study, including advisory assistance in formulating the problems (statements or questions) presented to experts, the recruitment of experts, monitoring of the application performance, and the final statistical and descriptive analysis of results, as well as development of final rankings, is provided as an advanced research service. The Delphi survey results obtained in this way may yield both quantitative as well as substantial recommendations. They may further be used to determine trends, build scenarios and plan technological investment.

The Delphi survey results may also be used to generate market forecasts such as the prices of technologies, products and services, sales volumes, as well as macroeconomic variables. Thus, they may become significant components of an enterprise knowledge base that usually stores a time series with market data such as prices, sales and production volumes, as well as technological parameters of competitors' products. It may also contain rules that determine ways of processing its overall information contents. The survey is generally treated as anonymous in the sense that the subject of analysis is a set of statements, not the individual opinions of experts. Nevertheless, experts participating in technological Delphi surveys usually agree to express their views and justify particular replies during panel meetings.

Finally, it is to be noted that recruiting experts is one of the most difficult phases of the Delphi studies, effectively limiting access to this knowledge source for companies other than large corporations seeking solutions to the problems of technological development and market expansion. This barrier can be overcome when using the Forgnosis™ platform (www.forgnosis.eu) as its services are offered with a team of experts recruited from different scientific, industrial and social areas by the platform provider.

The above-presented instance of the survey was implemented on the dedicated website created for the Horizon 2020 project MOVING (cf. www.moving-survey.ipbf.eu).

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