

# STRATEGY BUILDING FOR A KNOWLEDGE REPOSITORY WITH A NOVEL EXPERT INFORMATION FUSION TOOL

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## **Abstract**

Large digital knowledge repositories (DKRs) are an important component of Open Science. The latter is a challenging area of rapid technological and social development, where ICT innovations and their use cases are coordinated with research policy measures at different levels, from regional to European. DKR development is deeply rooted in the PEST environment and requires a thorough strategic plan of the social, economic and research impact over a mid to long-term perspective. It should also be aligned with technological progress, specifically in the emerging areas of Artificial Intelligence, Big Data, Internet of Things, and Global Expert Systems.

Despite of the aforementioned relevance, there exist very few publicly accessible DKR strategies or descriptions of strategy building approaches, and those available refer only to e-learning course repositories. This has created a need to develop methodological foundations for DKR-oriented strategic planning, to build new ICT-based tools and collaborative approaches, and apply them to satisfy the project goals in the context of EU S&T policies. This paper reports the strategy building process for an innovative knowledge repository (referred to as the Platform) developed within the flagship Horizon 2020 project “Training towards a society of data-savvy information professionals to enable open leadership Innovation” (acronym MOVING, [www.moving-project.eu](http://www.moving-project.eu)), its methodological background and outcomes. Relevant input to the strategy results from a forward-looking activity focussed on the identification of internal and environmental factors influencing the future performance and impact of the Platform. It combines a four-round/real-time novel policy and decision Delphi survey with an impact model established with Anticipatory Networks. The forecasting model parameters are those delivered as outcomes of the survey. They are supplied by the project partners, or result from the project Description of Work. The survey results are then used in a final collaborative roadmapping on the Platform exploitation in the PEST context.

The strategy building process presented here involves two stages. Stage 1 is devoted to establishing the boundary conditions for the Platform’s activity and user community building, while Stage 2 delivers the Final Strategy with plausible exploitation resulting scenarios. The second stage includes an action plan aimed at ensuring the Platform’s digital sustainability, financial viability and social acceptance. In this presentation of the DKR strategy building process, we will show in more detail the methodology of generating future visions of the Platform functioning with a flexible Delphi survey support system that is based on a novel forward extrapolation methodology. It offers a variety of question and/or statement types, sophisticated statistical analysis and other uncertainty handling methods, as well as a user-friendly interface. It can be run in various modes that suit the survey goals and gather expert knowledge in multiple rounds, as a real-time Delphi or as a hybrid of both. The cloud-based Delphi application is offered to the project team in SaaS mode, with some PaaS features ([www.moving-survey.ipbf.eu](http://www.moving-survey.ipbf.eu)). It can also be used as a basis for designing further customised expert information retrieval and fusion exercises for a broad spectrum of research needs.

**Keywords:** Policy Delphi, Strategy building, Knowledge repositories, Information fusion

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## Introduction

Rapidly growing digital knowledge repositories (DKRs) are an important component of Open Science. The latter is a challenging area of rapid technological and social development, where ICT innovations and their use cases are coordinated with research policy measures at different levels, from regional to European. With the existing OpenAIRE repository (<https://www.openaire.eu/>) and a recent initiative to launch the European Commission Open Research Publishing Platform <https://ec.europa.eu/research/openscience/index.cfm?pg=open-science-policy-platform>, building digital ecosystems comprising a repository user community and its research governance has been recognised by the European Commission (EC) as a major scientific and technological (S&T) policy issue. It is crucial to ensuring a positive impact and wide acceptance of EU-financed research in Horizon 2020 as well as in forthcoming community research programmes. When supported by public funds, DKR development is deeply rooted in the PEST (Political, Economic, Social and Technological) environment and requires a thorough strategic plan of the social, economic and research impact over a mid- to long-term perspective. It should be aligned with technological progress, specifically in the emerging areas of Artificial Intelligence, Big Data, Internet of Things, and Global Expert Systems [15].

This paper presents an application of a novel expert knowledge elicitation and processing tool that builds on the Delphi survey methodology to construct a DKR exploitation strategy and estimate its social and economic impacts. The repository, the subject of our research, has been developed within the flagship Horizon 2020 EU research project (under the acronym MOVING, [www.moving-project.eu](http://www.moving-project.eu)) and is available at [platform.moving-project.eu](http://platform.moving-project.eu). It stores online courses, scholarly papers, dynamically updated economic information, and other data. We will refer to this DKR as the MOVING Platform.

The strategy building process was split into the following two-stages:

1. Establishing the boundary conditions for the Platform activity, exploitation and user community building (Stage I).
2. Delivering the Final Strategy with plausible exploitation scenarios resulting from the survey (Stage II).

The latter stage includes an action plan aimed at ensuring the Platform's digital sustainability, financial viability and social acceptance.

Forecasts are obtained from experts at both stages as outcomes of the Delphi survey and used to build an anticipatory network (AN) impact model. The AN-based methodology has already proved useful in multicriteria strategic planning [14,17]. The ANs provide constructive algorithms to computing nondominated strategic plans that comply with a given anticipatory preference structure. The preferences of stakeholders, policy makers and other decision makers (i.e. all those responsible for shaping the platform's future and beneficiaries) can be taken into account. We will provide indications on how to apply anticipatory decision-making principles in constructing and filtering scenarios corresponding to rational and sustainable future DKR visions. AN-based assessment processes allow the analyst to select a subset of normative scenarios corresponding to the most preferred states of the future, then run an AN-based backcasting [9,14]. By definition, the best-compromise scenario describes the most desired future elicited from DKR stakeholders, starting from the current best-compromise decision of the DKR management team and passing through the intermediate states that correspond to reaching the interim goals of the DKR development project. The algorithmic strategy can be derived from:

- expert information concerning future trends;
- a study of the PEST environment followed by a SWOTC (Strength, Weaknesses, Opportunities, Threats, and Challenges) analysis;
- an AN-based impact model within an analytic strategic planning process that follows a technological roadmapping scheme.

This analytic and collaborative process ensures the selection of the best-compromise decision sequence, or another scenario that comes close, in the sense of reaching the best expected values of the prescribed Platform performance criteria, under different forecasts of external circumstances. Specifically, given the forecasts or scenarios, the strategy algorithm computes decisions that correspond to the optimal social and economic impacts of the Platform operation. This is the core procedure of the backward planning process. As the Platform's external circumstances are policy-dependent, the above procedure allows us to determine policy measures that can make the above optimum provisions and favourite circumstances real. Assuming that the DKR operation principles do not considerably differ in EU countries, we can derive an indication of the functioning of digital repositories, libraries, and other knowledge platforms at an EU level.

## Methodological approach

Future visions of the Platform's function are fundamental to the strategy building process. These have been obtained from experts with a flexible Delphi survey support system (DeSS). Unknown future parameters to be inserted into the social and economic impact models resulted from a novel forward extrapolation approach used in the survey, which can be summarised as follows.

First, experts provide quantitative estimations of the relevant variables for a few predefined forecasting horizons. These estimations, together with a current state assessment, are then used to fit a regression curve that can yield significant extrapolations even beyond the farthest forecasting horizon. The survey offers a variety of question and/or statement types, sophisticated statistical analysis and other uncertainty handling methods, as well as a user-friendly interface. It can be run in policy or in decision Delphi modes [11], as well as gather expert knowledge over multiple rounds, as a real-time Delphi, or as a hybrid of both. The survey software used (Forgnosis<sup>TM</sup>, cf. [16] for details) provides a number of features. Among other things, it can detect duplicate replies, correlate replies, as well as check the content of each individual reply (e.g. detect random entries).

The objective nature of the information obtained from experts is ensured by the way in which the survey is organised [3]. A preceding "Round 0" is established to allow all the project partners determine the scope of the survey. The first stage is aimed at reaching an internal consensus among project's decision makers and experts, while the main goal of the second is to expand the future vision and seek new opportunities and challenges, cf. [16,19]. Both stages consist of two rounds. Rounds 1 and 2 are performed in multiround mode [16] while Rounds 3 and 4 are organised as a real-time Delphi [2] – an adaptive advisory activity, to be pursued until the project end. Participation in the survey was open to the project staff as well as other employees of the partner institution who were not directly involved in the project execution, such as higher university management staff, members of the scientific and supervisory councils, etc.

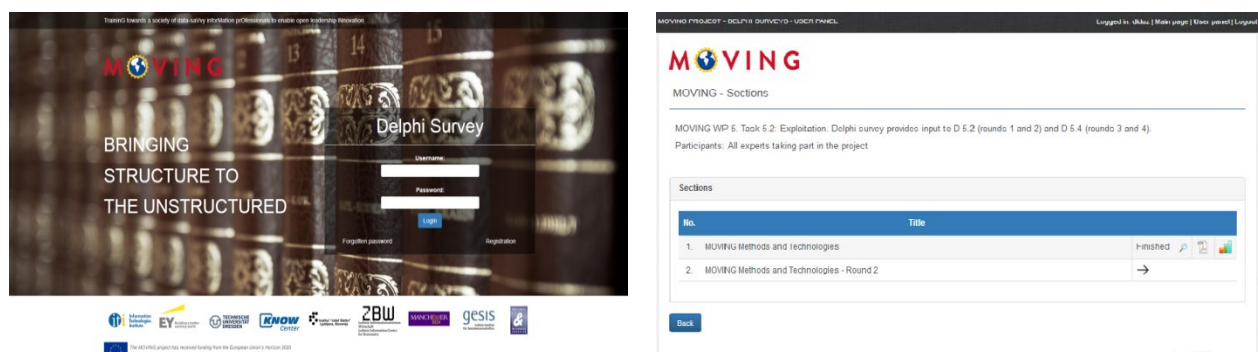
The results of the survey are intended to determine the internal conditions and external circumstances under which the MOVING platform will be exploited in the future. This information is necessary to build its sustainability strategy. Thus, the survey touched upon:

- Development trends of information technologies enabling the future evolution of the knowledge platform; these include relevant web technologies, Internet growth prospects, data mining techniques, content-based information retrieval, and multimedia search.
- Anticipated social, economic and political environments.
- Services and functionalities that may be offered in the future.
- Strategic goals and future business models of the MOVING platform.

The first stage of the survey was aimed at eliciting project staff opinion on the exploitation of the MOVING Platform during the project durability period 2019-2024 and beyond, until 2030. This stage corresponded to the well-known 'decision Delphi' [11] type of exercise, popular in corporate foresight activities since 1979 when the above cited paper of Rauch was published. Its characteristic feature is involving decision makers that may have some influence on the future visions provided in the survey. According to the 'decision Delphi' principles, Rounds 1 and 2 were focused on an internal consensus building as regards all aspects of the platform's sustainability, in particular the digital sustainability, cf. [1]. Therefore, the participants were recruited from the project staff. In addition, participation in the survey helped the technical project staff to understand diverse aspects of MP exploitation and their relation to its technical development. Rounds 3 and 4 consist of the questions that did not yield consensus during the first stage of the survey. Besides reaching a consensus, the aim of Stage 2 is also to detect any change in the internal or external circumstances that might affect the MOVING Platform's further development, performance and the exploitation after the project end.

### *Hybrid Delphi survey performance and sample results*

The Delphi survey variant with confidence management was selected as best suited for this type of survey, where the participants are experts in specialised fields [16]. According to its principles, the survey questions are presented to all the participants but not all of them are obligated to reply to all of the questions. Experience resulting from earlier surveys within thematic areas related to e-learning and learning support systems has been taken into account [5,6,7].



**Figure 1.** Two screenshots from the survey login page [www.moving-survey.ipbf.eu](http://www.moving-survey.ipbf.eu) (left) and the survey selection page (right)

The replies obtained from different respondents to the same question have been fused together using weighted averaging approaches and triangle fuzzy values to take into account confidence coefficients. An initial value for “degree of confidence” (usually based on a 5-value Likert scale) could be self-assessed by the respondents for each question or group of questions responded to. This made it possible to consider opinions of those respondents who are not experts in a specific field covered by the survey but are nevertheless capable of contributing valuable ideas, yet with a lower weight. Uncertainty handling with random-fuzzy distributions turned out to be a suitable technique for this kind of data. The fuzzy factors described the uncertainty related to diversified competences, while the stochastic properties of the reply dataset were used to fuse individual replies. The overall methodology is explained in detail in a context-based online help available to the users after logging-in to the survey system at <http://www.moving-survey.ipbf.eu>, cf. the Figure 1 above.

Another screenshot from the DeSS applied to the MOVING Platform strategy building (cf. Figure 2) demonstrates the survey in action, namely a questionnaire that includes three subordinated questions of one major question concerning the risk factors that may affect the MOVING Platform.

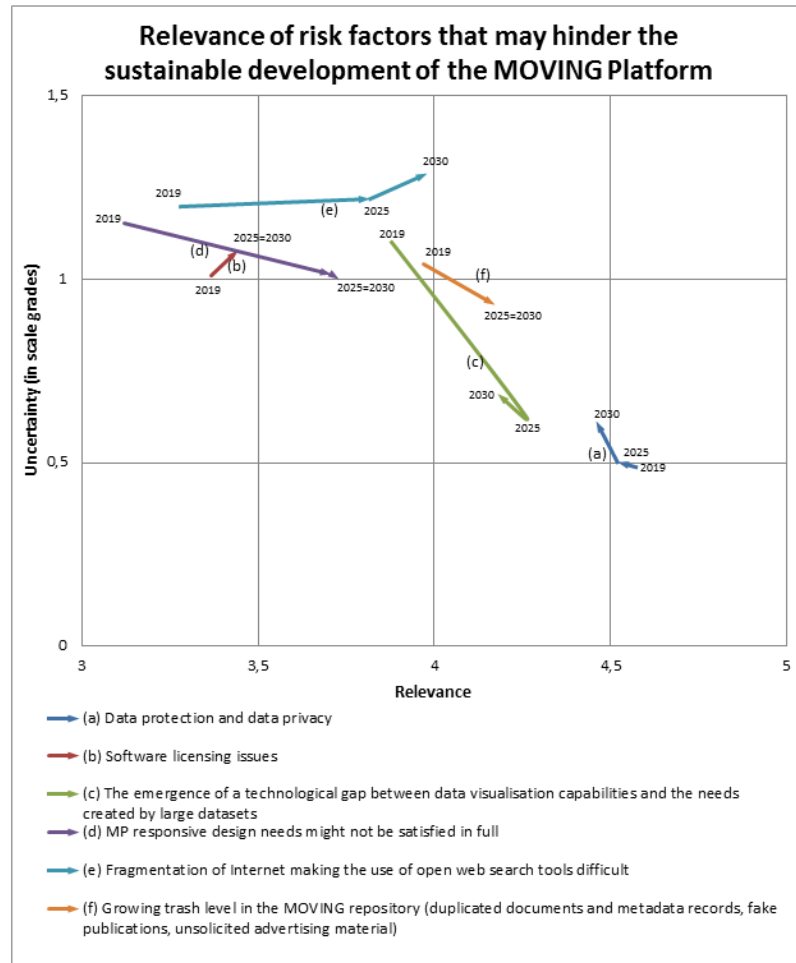
MOVING PROJECT - DELPHI SURVEYS - USER PANEL										Logged in: dkluz   Main page   User panel   Logout	
6. Relevance of risk factors that may hinder the sustainable development of the MOVING Platform											
6a) Data protection and data privacy	1st round	Average:	relevant (+)	relevant (+)	very relevant (+)	relevant (+)	User's comments	probability is significant (-)	<input type="button" value="Assess in 2nd round"/>		
		Standard deviation:	10.44 %	10.44 %	10.09 %	13.75 %					
	Your reply:	relevant	relevant	relevant	relevant	only expressing my subjective opinion					
		2nd round	Your updated reply:	rele	rele		rele	rele	only express		
6b) Software licensing issues	1st round	Average:	neutral (+)	neutral (+)	neutral (+)	neutral (+)	User's comments	fairly certain	<input type="button" value="Assess in 2nd round"/>		
		Standard deviation:	22.07 %	22.4 %	23.02 %	23.02 %					
	Your reply:	relevant	relevant	relevant	relevant	only expressing my subjective opinion					
		2nd round	Your updated reply:	rele	rele		rele	rele	only express		
6c) The emergence of a technological gap between data visualisation capabilities and the needs created by large datasets	1st round	Average:	neutral (+)	relevant (-)	relevant (+)	relevant (+)	User's comments	fairly certain (-)	<input type="button" value="Assess in 2nd round"/>		
		Standard deviation:	22.50 %	18.09 %	15.02 %	15.02 %					
	Your reply:	relevant	relevant	very relevant	very relevant	only expressing my subjective opinion					
		2nd round	Your updated reply:	rele	rele		ver	ver	only express		

83.3%

**Figure 2.** A sample survey question concerning the relevance of the future risk factors that may affect the platform (subsection 3, question 6, [www.moving-survey.ipbf.eu](http://www.moving-survey.ipbf.eu))

An analysis of the replies (Figure 3) looks at the relevance of the six risk factors with the highest potential impact on the MOVING platform (horizontal axis) confronted with the uncertainty (vertical axis) of respondents assessing them. The latter is the standard deviation of replies. Both factors are expressed in 5-point Likert scale points, where the numerical values 1 to 5 correspond to the naturally ordered scale values: “irrelevant” (1), “low-relevance” (2), ... to “very relevant” (5). We can observe that data protection and data privacy have been identified as the most relevant risk factors, with slightly decreasing relevance until 2030. The uncertainty related

to the risk factor assessment increases with time for the three factors (a), (b) and (e), which may be explained as a natural consequence of confidence intervals growing with more distant forecasting horizons. However, an uncertainty increase accompanied by the growing relevance of the remaining risk factors (c), (d), and (f) indicates a growing consensus as regards expected threat growth. These results have been applied directly in the risk analysis component of the MOVING Platform's exploitation strategy.



**Figure 3.** Relevance/uncertainty analysis of risk factors with the highest potential impact on the Platform. The arrow directions coincide with time, starting from the first forecasting horizon (2019) and ending at the state expected in 2030. Values on both axes are expressed in 5-value Likert scale points

Presented below is another sample set of results for the following Delphi question:

*“Integration of knowledge on the Internet with the MOVING Platform will allow for a new quality of replies to queries, which is unavailable with contemporary analysis methods. Please specify in % the share of problems and queries which may get more relevant responses with the autonomous MOVING Platform services, compared to the queries replied by human experts non-supported by the MOVING Platform” (question 1.6, subsection 1).*

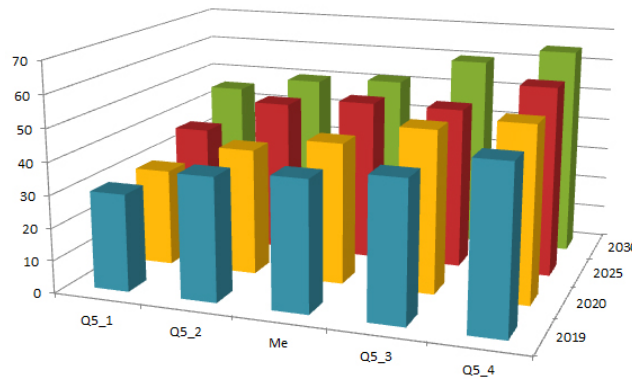
Table 1 contains a sample set of statistical characteristics of replies and a basic analysis. Unless indicated otherwise, table entries are given in percent or in percent points.

**Table 1.** Statistical analysis of replies to Question 1.6 ([www.moving-survey.ipbf.eu](http://www.moving-survey.ipbf.eu)).

I. Calculations without competence coefficients								
Forecast horizons	2019		2020		2025		2030	
	Round 1	Round 2	Round 1	Round 2	Round 1	Round 2	Round 1	Round 2
Average ( $\bar{x}$ )	46,67%	45,27%	49,20%	47,93%	54%	52,87%	58,33%	56,93%
Standard deviation ( $\sigma$ )	28,39	23,87	29,77	24,28	29,23	23,72	29,13	23,81
Std. semideviation left ( $\sigma_-$ )	17,15	13,93	18,64	15,17	19,14	15,77	20,49	17,5
Std. semideviation right ( $\sigma_+$ )	22,62	19,38	23,21	18,96	22,09	17,71	20,71	16,14
1. quartile (q1)	23,75%	30%	23,75%	30%	33,75%	42,50%	33,75%	47,50%
Median (2. quartile, q2)	35%	40%	36,50%	44%	45%	50%	52,50%	56%
3. quartile (q3)	60%	50%	66,25%	51,25%	68,75%	56,25%	76,25%	65,25%
IQR = q3-q1	36,25	20	42,5	21,25	35	13,75	42,5	17,75
Convergence between rounds $\xi(y):=(1 - y(round2) / y(round1))*100\%$ , $y=y1$ or $y=y2$ or $y=y3$								
$\xi(y_1)$ , where $y1:=\sigma$	15,92%		18,44%		18,85%		18,26%	
$\xi(y_2)$ , where $y2:=\sigma_- + \sigma_+$	16,24%		18,45%		18,80%		18,35%	
$\xi(y_3)$ , where $y3:=IQR$	44,83%		50%		60,71%		58,24%	
II. Calculations without competence coefficients								
Forecast horizons	2019		2020		2025		2030	
	Round 1	Round 2	Round 1	Round 2	Round 1	Round 2	Round 1	Round 2
Average ( $\bar{x}$ )	50,74%	46,34%	52,60%	48,05%	57,03%	53,54%	62,08%	56,87%
Standard deviation ( $\sigma$ )	30,22	24,52	31,05	24,66	29,22	23,11	28,04	22,95
Std. semideviation left ( $\sigma_-$ )	19,09	14,2	19,92	15,12	19,12	15,22	19,68	16,31
Std. semideviation right ( $\sigma_+$ )	23,42	19,99	23,81	19,49	22,09	17,39	19,98	16,15
1. quartile (q1)	23,09%	30%	23,09%	30%	35,28%	39,98%	41,21%	50%
Median (2. quartile, q2)	38,57%	40%	39%	43,58%	45%	50%	57,50%	51,65%
3. quartile (q3)	65,43%	50%	75,43%	50,83%	84,07%	55,83%	89,50%	61,83%
IQR = q3-q1	42,34	20	52,34	20,83	48,79	15,85	48,29	11,83
Convergence between rounds $\xi(y):=(1 - y(round2) / y(round1))*100\%$ , $y=y1$ or $y=y2$ or $y=y3$								
$\xi(y_1)$ , where $y1:=\sigma$	18,86%		20,58%		20,91%		18,15%	
$\xi(y_2)$ , where $y2:=\sigma_- + \sigma_+$	19,57%		20,86%		20,87%		18,15%	
$\xi(y_3)$ , where $y3:=IQR$	52,76%		60,20%		67,51%		75,50%	
No. of replies	17	15	17	15	17	15	17	15
No. of clusters of replies	2	1	2	1	2	1	1	1
Consensus reached	No	Yes	No	Yes	No	Yes	No	Yes
No. of outliers eliminated	2	0	2	0	2	0	2	0

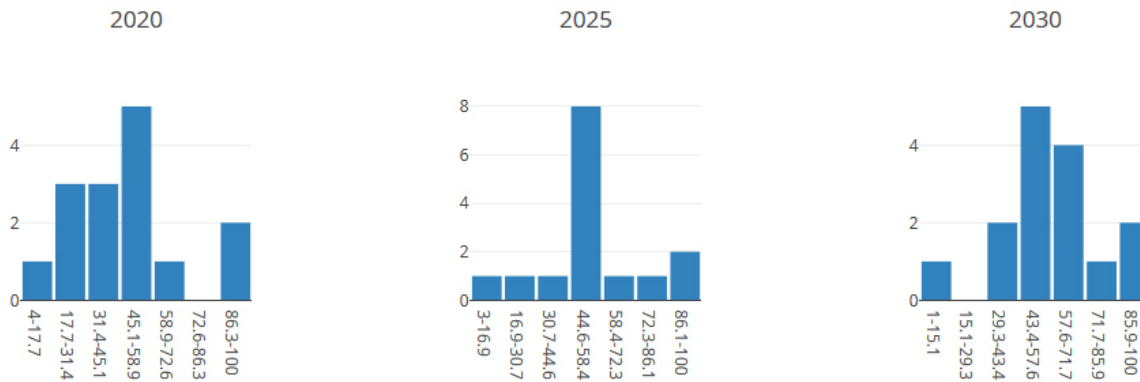


The quartiles provided in Table 1 are complemented by the quintiles shown in Figure 4.



**Figure 4.** Quintiles and median of weighted replies to question 1.6 ([www.moving-platform.ipbf.eu](http://www.moving-platform.ipbf.eu))

Figure 5 shows the histograms of replies to question 1.6 for the forecasting horizons 2020, 2025, and 2030. They have been used to determine the number of clusters of replies. The emergence of statistically significant clusters indicates a lack of consensus but provides indications as regards the potential existence of several exploratory scenarios of the investigated factor or variable. It is worth noting that in the case of the above question, there was only one significant cluster of replies for all forecasting horizons. A consensus was reached in Round 2 for all forecasting horizons.



**Figure 5.** Histograms of replies to Question 1.6 for the forecasting horizons 2020, 2025 and 2030

Table 1 provides the values of classical consensus measures  $y_i$ ,  $i=1,2,3$ , for question 1.6, where  $y_1$  is the standard deviation  $\sigma$ ,  $y_2$  – the sum of standard semi-deviations,  $y_2=\sigma_-+\sigma_+$ , and  $y_3$  is the *interquartile range* (IQR), by definition  $IQR:= 3^{\text{rd}} \text{ quartile} - 1^{\text{st}} \text{ quartile}$ . The above measures have been used to measure consensus achievement for all questions. The convergence between rounds has been measured as

$$\xi(y):=(1 - y(\text{round}2) / y(\text{round}1))*100\%, \text{ where } y=y_1 \text{ or } y=y_2 \text{ or } y=y_3 \quad (1)$$



or as the Kullback-Leibler divergence [4] of the empirical reply distributions in the  $n$ -th and  $(n+1)$ st rounds. It should be noted that a consensus, in terms of  $IQR/2 < 20\%$ , was reached for 48 out of 96 questions in Round 2 for the main forecasting horizon of 2025, which is also the durability period end. The number of questions with consensus decreased to 41 out of 96 for the year 2030. However, all but one of the Delphi statements exhibited a convergence between subsequent Rounds 1 and 2 with respect to all the indicators (1) with  $y=y_i$ ,  $i=1,2,3$ , and the Kullback-Leibler divergence, for the forecasting horizon 2025 overlapping with the end of the project durability period.

The cloud-based Delphi application is offered in Software-as-a-Service (SaaS) mode, with some Platform-as-a-Service (PaaS) functionalities. The DeSS may serve to design further customised expert information retrieval and fusion exercises for various research needs. More details on the DeSS and the underlying methodology are provided in [16]. The survey is available at [www.moving-survey.ipbf.eu](http://www.moving-survey.ipbf.eu), where experts can register to participate in the ongoing activities.

### *Expert information fusion for building an anticipatory network*

The outcomes of the survey are used as the input needed to build an anticipatory network that models all relevant future impacts relative to the Platform. The network includes all relations between actors, factors, trends, and plausible random future events. ANs are a relatively new tool in decision theory, rooted in anticipatory system theory [12] and strongly combined with researching the future [17]. This theory formalises and fuses multi-stage multicriteria forward planning and multicriteria backcasting [14]. ANs generalise earlier anticipatory models of decision impact in multicriteria problem solving and constitute an alternative decision model to utility or value function estimations and to diverse heuristics [17]. An AN is a directed multigraph with nodes modelling the decision problems, and edges modelling the relations between them. A starting node in an anticipatory network is a node with no predecessors. Every AN must have at least one starting node which models a present-time multicriteria decision problem. The other nodes model decisions made for future multicriteria problems that will be solved by the same or other decision makers. The edges of the first kind model the causal dependence of decision problems on previous solutions to other problems. There may be several causal relations and corresponding edge classes in one network. Subsequent decisions made along a chain of causal dependences in an anticipatory network model the consequences of decisions made at earlier nodes in the chain.

The decision is made after a constructive analysis of causal relations that link the outcomes of the current problem with their future consequences [14]. It is assumed that decision makers responsible for solving problems defined as nodes take into account the anticipated outcomes of some future decision problem linked by the causal relations with the problem being solved. This supplements the causal network of decision problems by the relations of *anticipatory feedback*. The edges corresponding to the anticipatory feedback relations constitute the second type of edges. The latter relations allow the decision makers to confine the sets of admissible nondominated decisions at the starting node(s) of anticipation.

In the anticipatory network application presented in this paper, decision makers can impose causal dependences on constraints and preferences in future decision problems, depending on the outcomes of the decision just made. Since only some decisions may lead to desired consequences, this allows the decision makers to construct an additional preference structure that supplements the one existing at the initial problem. Thus, further analysis involves appropriate simultaneous handling of both types of relations, causal and anticipatory. It uses

forecasts and exploratory scenarios regarding the future decision model parameters derived from the quantitative outcomes of the second stage of the Delphi survey [16].

To sum up, the following information about the future obtained from experts within the survey is used to build an anticipatory impact model:

- Exploratory scenarios or forecasts concerning the parameters of future decision problems represented by the decision sets  $U$ , criteria  $F$ , and preference models  $P$  of each future decision maker. Attitudes towards anticipatory planning (rational/partly rational/irrational) are also taken into account.
- Causal relations  $r$  linking the nodes in the network.
- Anticipatory feedback relations (AFRs) pointing out which future outcomes are relevant when making decisions at end nodes of AFRs and specifying the anticipatory feedback conditions.

The information contained in the anticipatory network can then be applied in algorithms filtering the plausible exploratory scenarios to be used in strategic planning, provided that:

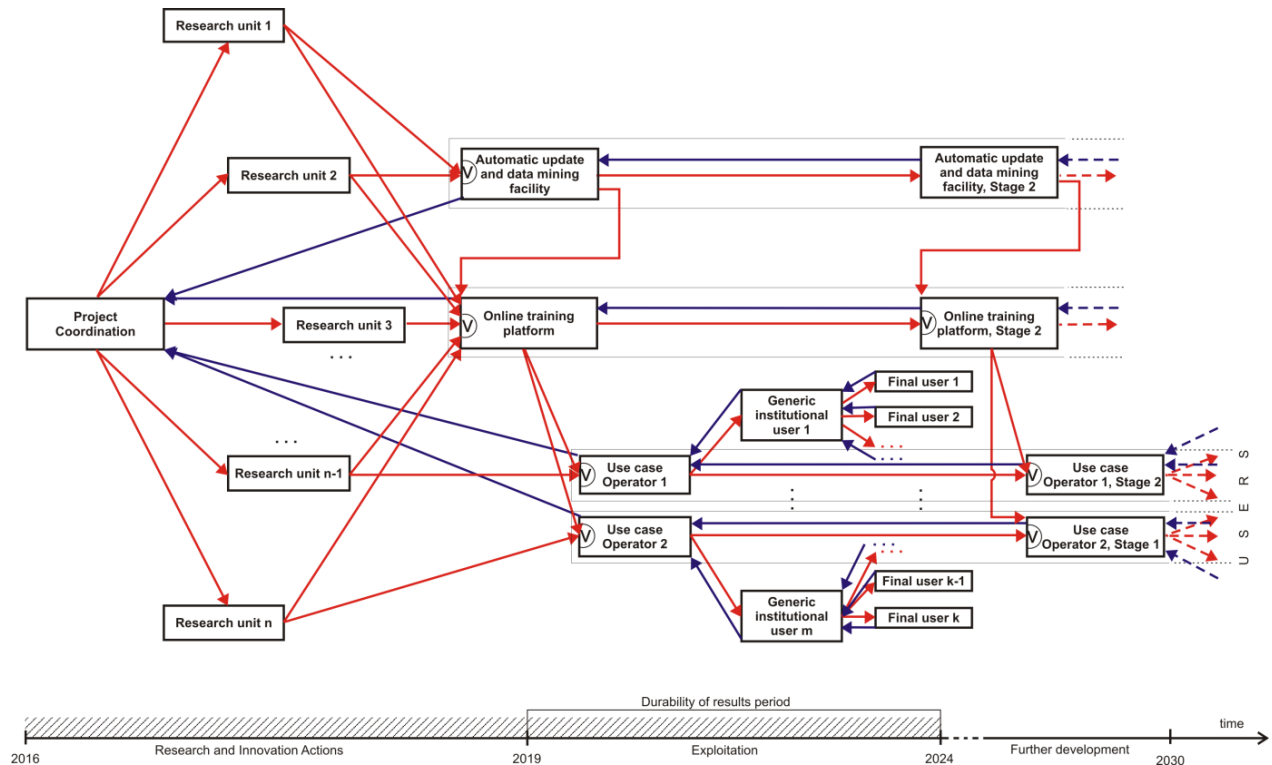
- i. All future agents whose decisions are modelled in the network are rational, i.e. they make decisions consistent with their own preference structures.
- ii. An agent can assess to what extent the outcomes of causally dependent future decision problems are desired. This relation is described by multifunctions linking present-time decisions with future constraints and preference structures.
- iii. Assessments (i) and (ii) are transformed into decision rules to be applied when filtering future scenarios and planning the strategies associated to those that were retained.
- iv. A relevance hierarchy  $H_1$  exists within the network  $G$ ; usually the more distant in time an agent is (modelled by a node in  $G$ ), the less relevant the choice of her/his solution.
- v. A family of relevance hierarchies  $H_2$  of anticipatory feedbacks exists within the network  $G$ ; usually the more distant in time a problem is, the less relevant the choice of this solution.

Both hierarchies allow the decision maker at the initial problem to derive a partial order that defines the sequence of operations in a decision selection algorithm.

## Results, discussion and implications

A real-life application example, where the above approach merging an informed Delphi survey and ANs turned out to be a particularly well suited for DKR strategic planning, is exploitation strategy building for innovative digital knowledge platform (cf. [www.moving-project.eu](http://www.moving-project.eu)). The strategy selection is regarded as a multicriteria problem, decomposed into the current and future-generation problems. The criteria are related to the financial sustainability, social impact and benefits, risks and threats, as well as the strategic position of the platform among similar knowledge-based web tools. 'Future generation' decision makers are included in the network as a new class of nodes and model the sustainability of the platform. Specifically, the causal relations modelling the influence of an 'earlier generation' decision maker on future management, exploitation and development decisions made by a 'next generation' decision maker fulfill a set of conditions ensuring sufficient scope and other preconditions of future decisions.

In this example, the initial problem corresponds to the decisions of the coordinating bodies of the consortium conducting the research project aiming the platform development, while the 'next generations' correspond to the future management of the platform. The other decision makers are responsible for user community building and technological development decisions. The anticipatory structure of this problem is shown in Figure 6 below.



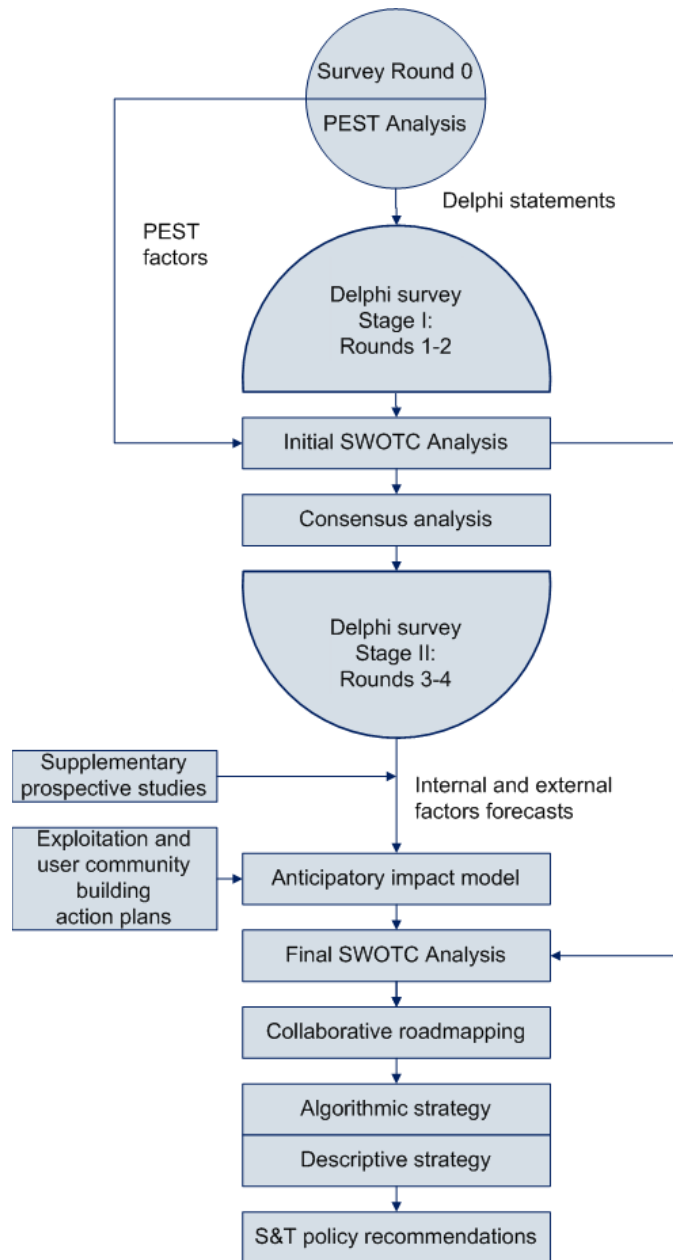
**Figure 6.** An anticipatory network modelling strategic decisions concerning a digital knowledge platform

The overall strategic planning process comprises:

- A forward-looking activity aimed at identifying the internal and environmental factors influencing the future performance and impact of the Platform. The activity combines a four-round/real-time novel policy and decision Delphi survey [16] with an impact model established with Anticipatory Networks (ANs). The AN parameters are those delivered as outcomes of the survey.
- A dynamic (2-stage, real-time) SWOTC (SWOT with Challenges) exercise which provides additional inputs to the Risk Matrix analysis and the final roadmapping.
- Stage 1 – strategic planning aimed at establishing the boundary conditions for the Platform's activity and paid user community building.
- Stage 2 – anticipatory planning that delivers the Final Strategy with three exploitation scenarios resulting from the Delphi survey and includes an AN- based action plan aimed at ensuring the Platform's digital sustainability, economic viability and social acceptance.

- Roadmapping-based strategic planning of the knowledge repository operation.
- Social impact analysis with ANs, cellular automata, and Bayesian network models.

A scheme of the strategy building process for the MOVING Platform as a representative case of a DKR is presented in Figure 7.



**Figure 7.** A scheme of the strategic planning for the MOVING platform

The collaborative roadmapping exercise is the final strategy building stage. This process uses a multivariate vision of the future in the form of scenarios derived from the Delphi survey and other (bibliometric, patentometric, webometric, economic, and social) prospective studies to establish relations between different future factors [8,17]. They serve, in turn, to identify a set of feasible actions out of a catalogue of exploitation and user community building activities. A social impact analysis is a supplementary activity that overlaps in part with the roadmapping process.

The information needed to perform the roadmapping is mostly provided by the Delphi survey, but it can also include publicly available statistics or result from statistical forecasting. Another characteristic feature of roadmapping-based planning is the need to take into account multiple conflicting criteria that describe the financial, technological and social goals of the planning object. These are an element of nondominated future plans. Multicriteria analysis and the corresponding decision support procedures have been applied by roadmapping experts to point out compromise solutions for real-life implementation. This process is dynamic and the plans, once chosen, can be updated to respond to varying external or Platform-dependent circumstances.

This roadmapping methodology complements the AN model when establishing a strategic plan for the above-presented DKR. The diversified scope of planned actions of the MOVING Platform contributed to a higher degree of complexity of strategy planning optimization. This was the reason for choosing a real-option oriented extension of the roadmapping methodology as a framework for the decision support to solve the above planning problem. As far as financial criteria are concerned, the real options turned out to be a natural and useful tool for describing the relations between different deployment variants of the Platform's components, services, and of the Platform as a whole represented as objects of the new product layer in the roadmapping diagram. Their deployment plans correspond to the retained optimal planning scenarios and associated financial yields. Moreover, the financial valuation of the operation plans can easily be combined with a previous SWOTC (SWOT with Challenges) assessment of roadmapping objects. Other suitable methods of optimality analysis often used in strategic planning, such as multivariate PERT diagrams, can also be applied.

Rights gained during the repository operation as well as liabilities can be modelled by long or short real-option positions, respectively. The iterative dependence of future investment opportunities on previous outcomes will be modelled by nested real options and embedded into an anticipatory network [14] that makes it possible to model the expected consequences of admitting a proposed operation strategy. The real option modelling includes switching, abandonment and continuation options, thus yielding a realistic model of a knowledge repository.

The provision of new content and services on the platform is modelled as an innovation development and market placement problem (NPD-MP) [8,18]. The latter is a dynamic four-criteria problem with options-enhanced NPV (ENPV) – aggregating subordinated momentary financial performance criteria, options-affected risk (ER), social impact index (SII), and the Strategic Position Index (SPI). The multicriteria optimization problem arisen can be solved during an interactive group decision procedure with the above roadmapping methodology. The solution process can be assisted by an interactive real option detection algorithm, repetitive SWOTC exercise, investment efficiency analysis based on an expert Delphi, standardized real option valuation procedures, and multicriteria analysis.

## Conclusions

The novel forward extrapolation methodology used in the above-presented flexible Delphi survey support system (DeSS) offers a variety of question and/or statement types, a sophisticated statistical analysis and other uncertainty handling methods as well as a user-friendly interface. It can be run in policy as well as decision Delphi modes, gather and fuse expert knowledge in multiple rounds, as a real-time Delphi, or as a hybrid of both. The cloud-based Delphi application is offered as a flexible research support tool in SaaS mode (cf. [www.forgnosis.eu](http://www.forgnosis.eu), [www.moving-survey.ipbf.eu](http://www.moving-survey.ipbf.eu)). The tool can serve to design further customise expert information gathering and fusion exercises for various research needs. We have shown in previous sections that the tool proved useful in building a multiple-context digital platform strategy exemplifying a larger class of similar applications. As the use of the survey is open to external experts, members of the FTA community are encouraged to test the system and/or become the survey respondents. The organisation of the Stage 2 real-time Delphi assures a persistent deployment of contributions from experts knowledgeable in the field of technologies and/or markets and business models for digital repositories.

When used together with an AN-based decision model, the Delphi survey support system can be applied in various forward-looking activities to provide fused expert data, for example to:

- Build a strategy for aligning R&D investment projects at regional or national level to a sustainable development strategy based on smart specializations. A real-life example: strategic planning for a regional Creativity Support Centre [14], where recommendations to R&D policy makers are derived with an anticipatory model.
- Select technological investment strategies for a software company, allowing a corporate user to embed the Delphi support system into their own enterprise resource planning (ERP) system or another type of decision-support system (DSS).

As a general conclusion, it should be noted that the computer architecture consisting of an online DeSS, an AN building tool, and generic roadmapping support system forms a DSS allowing an analyst to efficiently deploy technological (ICT) foresight results. Nevertheless, the above-presented DeSS can also be used as a stand-alone DSS. When used jointly with analytic impact modelling tools, future circumstances can be analysed quantitatively and algorithmic action plans can be defined for complex AI-based systems such as DKRs. Thanks to a growing number of publicly available foresight results and other open source web information repositories, the hitherto hardly affordable strategy building processes can be performed satisfactorily as a combination of an online Delphi survey, collaborative activities such as SWOTC, brainstorming and roadmapping, and computer-assisted interactive multicriteria decision making using anticipatory preference information together with the reference sets and trade-offs between criteria.

Finally, let us note that the models and applications presented in this paper benefit from a synergy with other further foresight and forecasting methods and IT tools such as foresight support systems (FSSs, cf. [13,20]) and the above-mentioned online roadmapping management system [18].

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