Research Article

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Penetration and impact of advanced car technologies

Abstract

This research investigates the penetration of Intelligent Transportation Systems (ITS) and Information and Communication Technologies (ICT), and assesses their potential impact on travel behavior in the years 2030 and 2050. It is achieved using the expert–based Delphi survey answered by Israeli and international experts. Results show that by 2030, about 40% of all vehicles will be connected to vehicle–infrastructure communication systems, and by 2050, all vehicles will be autonomous and will be automatically managed and administrated by a command and control center. Acceptable future scenarios are presented, proving the feasibility of the research to achieve widespread agreement and to reach a consensus out of uncertainty or a lack of empirical evidence. The Delphi method was found to be effective for this type of research due to high level of responsiveness among the experts, convergence of the results after two rounds, easy data collection and fast processing, efficiency, and at relatively low cost.

Keywords: intelligent transportation system, information communication technologies, scenario analysis, delphi method, travel behavior

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Introduction

Traffic congestion, pollution, crashes, and delays are still a major problem in many large metropolitan areas. Multiple ideas have been suggested to overcome these problems, ranging from safety systems that would lead to a reduction in severe injuries to road infrastructure that could help cope with traffic congestions. The incorporation of advanced and intelligent technologies in transportation systems could certainly lead to significantly better transportation systems and enhance transportation services. Hopefully, new technologies could contribute to the transport challenges we are facing today. While several technologies might look unrealistic, other are developed or used (e.g., autonomous vehicles, privately–owned flying cars).

Intelligent Transportation Systems (ITS) integrate advanced communication and information systems with electronic technology. They constitute a combination of communication technologies, electronics, navigation and advanced information processing, that help human action. Examples of ITS include advanced navigation systems (e.g., Global Positioning Systems – GPS), data communications and remote sensing platforms (e.g., radar and laser). Such technologies were designed to advance the performance of existing transportation systems by improving safety, efficiency, reliability and quality,[1] and reduce negative environmental impacts. Examples of ITS are traffic lights actively sending remote signals reducing cases of failure to comply with traffic signals, car speed limiters which are activated based on location (e.g., junctions, urban areas), tire pressure monitoring systems, and lane departure warning systems.

Information and Communication Technologies (ICT) integrate several communication components allowing data storage, quick access and fast computational operations. Such systems allow the possibility to perform actions remotely without limitations of time and distance, thus reducing the need to travel and allow the performance of various activities while travelling. ICT applications incorporate technology based communication products such as cellular phones, computers, networks, satellite systems and more. They also include various associated services, such as videoconferencing and distance learning systems. These technologies, which include data collection and transmission, have been available for many years and are gradually being brought into common use. Although it can contribute to reducing traffic congestion and air pollution, it is often argued that the development of ICT can also increase transportation use due to improving mobility and traveler experience. Nonetheless, ICT can foster huge changes in society–by encouraging daily activities without leaving the house (such as shopping, 'meetings' in social networks, etc.) and, thus, effectively reducing the amount of travel.

In recent years, there has been an acceleration of technological development. ITS and ICT applications have become more popular and available in transportation, achieving world–wide interest among transportation professionals, automotive industry, and policy makers. The increased awareness to the potential of ITS and ICT further enables the development of more sophisticated, reliable and affordable applications in a relatively short time. Various cutting edge technologies are adapted and incorporated within automated driving technology–a concept which captivates the imagination and attention of both the public and professionals world–wide.

Here, we address the impact of fully automated vehicles, known as driverless or self–driving vehicles, namely SAE levels 4 and 5 of driving automation.[2] Fully automated (driverless) vehicles are already being driven with human backup driver in some states and are expected to enter the market in the years to come. The ripening of driverless vehicles' technologies may demonstrate far–reaching implications on travel and mobility (e.g., safety, efficiency), as well as on many other fields.[3] It can affect the value of travel time, the amount of travel time, and the quantity and type of vehicle purchases, as well as long–term life decisions such as where to live and work.

It is difficult to predict and model these future changes; technological advancement does not lead directly to its adoption; it greatly depends on social, political, legal, institutional, industrial, and business factors. Currently, little understanding on the causal relationships between the ITS and ICT and their social effects is available. Statistical and behavioral models are limited in their ability to predict the influence of these systems, as such models are usually based on existing trends; forecasting future situations are based on observations of existing behavior. Therefore, predictions under significant behavioral changes of individuals or society as a whole remain questionable. In addition, predicting technological developments themselves is a considerably complicated task that cannot be addressed by such methods.

This study aims at presents a qualitative approach to assess the development and penetration of selected advanced car technologies as well as their future impact on several aspects of travel behavior of people. We focus on selected technologies which are expected to be part of future transportation systems. The Delphi expert survey method was used for this purpose using scenario building and analysis. This method was originally designed as a procedure to formulate and adjust predictions of expert groups. Its primary use was to generate widespread agreement and consensus within a group through a series of questionnaires combined, with controlled feedbacks, while avoiding direct confrontation between group members. This method can be used to predict future trends or phenomena, and can help in establishing a clear process of decision making under a high degree of uncertainty, or when analyzing situations from several different aspects is required. It was chosen as a result of its effectiveness in cases where there were no similar projects implemented (future technologies and innovations for example), and therefore no parametric estimation is possible.

The paper is divided into the following sections: Section 2 provides a brief literature review on scenario building and analysis, the methodology we use in this research, while Section 3 reviews the emerging technologies, applications, and future development addressed in this research. Section 4 presents the full methodology used. Section 5 presents results and discussion, and finally, Section 6 outlines the conclusions and future outlook of this research.

Scenario analysis and the Delphi method

Scenario building and analysis

Forecasting future trends (e.g., future technologies) can contribute to economic and social welfare through the process of evaluating effects, opportunities and possible risks. Having a good forecast of future demand and technologies can affect the desired investments in transportation today. For example, a potential new transport mode, such as Elon Musk Hyper loop, if succeed may make high speed rails useless, yet some governments still considering major investments in high speed rails. Scenario analysis is a qualitative method which explores future scenarios and outcomes. According to Kahn[4] a scenario is a “hypothetical sequence of logical and plausible events constructed in order to focus attention on causal processes and decision points”. Scenarios are structured stories designed to stimulate thinking about what might happen–rather than what will happen in the future.[5] Scenario analysis is particularly informative for long–term thinking, where complex situations are characterized by high levels of uncertainty Schoemaker[6] and is thus highly suitable for the examination of future outcomes of technological developments. For an overview of scenario planning, and the classification of different types of scenarios, see Amer et al.[7]

In the field of transportation, many studies have used travel demand models to explore future impacts of various transportation solutions. This method is tailored for the analysis of existing trends, generally assuming current behavioral characteristics. The accuracy of forecasts which are based on travel demand results has rarely been addressed, and some doubts have been raised concerning the related statistical results.[8] The field of transportation is characterized by a high level of uncertainty regarding future technological, economic and social developments whereby transport systems will function. Therefore, scenario building and analysis, which take into account factors of uncertainty in demography, socio–economic trends, technological development, behavioral changes, and decision making, is highly suitable as a complementary analytical tool. Scenario analysis can internalize such variables, which usually cannot be quantified. Additionally, it enables the exploration of a wide range of creative future scenarios and courses of action, thus identifying future opportunities and risks.

The Delphi method

The expert–based Delphi method of scenario construction is a popular structured communication technique for scenario analysis.[9] This method is based on a series of questionnaires, with a controlled feedback, allowing the comparison of experts’ opinions in an iterative manner in order to reach a consensus.[10,11] In order to maximize credibility and reliability, it is recommended to use a wide panel of anonymous experts. This allows for brainstorming and exchange of opinions, while at the same time eliminating different communication barriers which may be involved in face–to–face communication, such as political issues and hierarchy. Thus, this process results in more accurate forecasts,[12,13] encourages free expression of independent thinking as well as open critique,[14] and is characterized by higher response rates. Since the experts are required to re–evaluate their answers, the final consensus is the results of multiple dialogues and iterative feedback, and the process often stimulates new ideas and insights.[15] Moreover, participants comment on their own forecasts and on the progress of the panel as a whole. The controlled feedback is a statistical summary of the response group. The communication between experts, carried out by the research coordinator, reduces “group think” among panelists, and optimizes the forecasts.[16,17] The Delphi method was found to be quick, cheap and efficient for the integration of knowledge.[18] It works especially well when the goal is to improve understanding of the problems, opportunities, and solutions, or develop forecasts.[19]

The Delphi method is widely used in many research fields, including technology, education, health, and various other applications. Kauko et al.,[20] explored the Delphi method in forecasting financial markets. Wang et al.,[21] presented a new method that combines the Delphi method for estimating uncertainty distributions in Statistics. Modrak et al.,[22] used the Delphi method in forecasting tourism activity. Keller et al.,[23] used a real–time variant of Delphi method to analyze future directions of ICT. The authors conclude that ICT is likely to develop to more qualitative channels, such as interpretation, decision–making and implementation. Berg et al.,[24] used Delphi–based scenarios for ecosystem services tools, concluding that these scenarios provide “realistic and usable inputs”.

In the field of transportation several studies used the Delphi method. Shiftan et al.,[25] adopted scenarios building as a tool for planning a sustainable transportation system for the Tel Aviv metropolitan in Israel. Spector et al.,[26] used a four–round Delphi survey to forecast significant changes and interventions needed to future–proof New Zealand’s transport system. Several findings were presented, among them improve connectivity and integration across transport modes,

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improve cycling safety, and even change legislation and policies. Among others, these studies prove that the Delphi method is an effective tool which can be successfully used for this type of research.

Emerging technologies

Related work

Numerous efforts have been made to better predict technological acceptance, penetration, and impact in various fields and arenas, as well as to discuss possible pitfalls of models that attempt to provide accurate technological forecasts.[27–30] Several studies have attempted to forecast future penetration of transport technologies. Batten[31] discussed the interaction of transport and telecommunication technologies over time. Salomon[32] attempted to predict the degree of penetration of ICT (remote communication), distinction between penetration and adoption, where penetration of technology does not necessarily indicate the extent of its use. Balducci[33] examined the market penetration and adoption of hybrid electric vehicles in the USA according to three scenarios. In one of these scenarios, the Delphi method was used to evaluate experts' opinions under certain constrains.

There is an ongoing debate as to whether and when will large–scale deployment of autonomous vehicles take place on the roads. Only limited research has been conducted in recent years; only little is focused on the potential behavioral trends.[3] Some claim that fully automated vehicles will be available within the next decade.[34] Tesla Motors' CEO, Elon Musk, predicts that driverless vehicles will be on road by 2023.[35] In an interview with Forbes, Mark Fields, CEO of Ford, estimated that fully automated vehicles would be available on the market by 2020.[36,37] administered an online survey to 220 registrants in advance of the 2014 Automated Vehicle Symposium, aiming to explore the attendees' opinions about deployment forecasts for automated vehicles. The conclusion was that in 10–15 years automated vehicles–capable of handling urban highways and surface road and fully automated "robot taxis" would be introduced. At the same time, 25% of respondents specified that they would only let their children ride in such vehicles by 2040 or later, and nearly 8% said never. Other experts are skeptical regarding the actual likelihood that travelers will flock to automated vehicles so quickly. Haboucha et al.,[3] investigated individual motivations for choosing to own and use autonomous vehicles using a stated preference questionnaire distributed to 721 individuals. Results showed controversial opinions towards the adoption of autonomous vehicle, with 44% of choice decisions remaining regular vehicles. Other studies focused on the potential impact of transport technologies (e.g., ITS and ICT) on travel behavior and social change. Janelle et al.,[41] investigated the impact of ICT and ITS on transportation systems, focusing on socio–economic patterns and processes. They claimed that ICT can significantly influence transport infrastructure development. Zhang et al.,[42] investigated the characteristics and performance of new generation data–driven ITS, emphasizing their great potential in improving current transportation systems. Mecklenbräuker et al.,[43] discussed various aspects of Vehicle to Vehicle (V2V) communication, stating that several applications (e.g., traffic telematics) require urgent research and development; these applications are expected to significantly influence the transportation market in terms of safety and efficiency.

There are numerous attempts to develop and bring into fruition V2V and V2I (Vehicle to Infrastructure) communication technologies. V2I is expected to support autonomous vehicles and other emerging technologies.[44] Cellular device–to–device communication technology is expected to influence the direct transmission of data between vehicles, i.e., V2V communication.[45] The U.S. Department of Transportation (USDOT) is actively researching into both V2V and V2I communication technologies for crash avoidance systems. In the near future multiple systems focusing on safety, mobility, and environmental aspects, will communicate via wireless technologies.[43]

According to popular visions, flying cars will revolutionize personal transportation, providing solutions to various problems, e.g., traffic congestions, redundant infrastructure development or environmental damage.[44] However, despite technological feasibility, it is highly unlikely that this technology will be introduced to the market soon due to high safety risks, perceived low market potential, and legal aspects.[44,46]

In general, empirical–based studies on future transport technologies are very limited, and those that do exist focus on short–term and direct impacts. Some predictive studies show high level of complexity and uncertainty, where no actual predictions were presented. For example, Mokhtarian et al.,[47] investigated the relations between telecommunication and transportation technologies focusing on several types of interactions. The authors identified the complexity of investigating such interactions. Banister[48] examined the same relationship, claiming that the investigation has to be based on empirical evidence. Other studies estimated the potential impact of emerging technologies in various scenarios and under different assumptions on the demand. The drawback of many of these approaches is the need to make various behavioral assumptions. In essence, these methods are akin to "what if" scenario analysis, and are highly sensitive to various parameters and assumptions.

Selected technologies

This section presents the technologies that are the focus of this study. These technologies were chosen based on a preliminary pilot survey conducted using a limited number of Israeli experts. After technologies were chosen and finalized, they were divided into two categories:

1. Smart vehicle technologies and
2. V2I and V2V technologies.

These selected technologies are briefly described as follow:

Smart vehicle technologies

Smart vehicles enable driver–vehicle–road interaction to provide a safer, more efficient, and more environmentally friendly driving environment. Potential future developments may incorporate existing technologies not yet implemented to various ideas that are more visionary. The specific technologies presented to the survey respondents are:

Autonomous vehicle automatically performs the act of driving and does not require a human driver. We refer to the full self–driving automation stage (SAE levels 4 and 5), where the vehicle is designed to perform all critical driving functions and monitor roadway conditions.

Warning systems provide warning signals to drivers regarding dangerous situations that may occur. Such systems include lane deviation warning, pedestrian detection, night vision, cruise control, optical systems and more. Some of these systems are already fully or partially integrated in vehicles.

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Advanced Vehicle Control Systems (AVCS) are based on sensors, which are installed in vehicles and provide drivers with visual information and alerts in dangerous situations. These systems can provide automatic control of the vehicle, preventing erroneous human driving actions by responding to dangerous situations quickly and efficiently. Additionally, they improve vehicle behavior and road grip, and aim at increasing safety and reducing traffic congestion.

Modular train is a public transportation system consisting of small passenger cabins that comprise a modular train. This train can be operated by rechargeable batteries via solar panels placed on the roof of the vehicle.

Road train technology includes vehicles which can track other vehicles traveling to the same destination; in fact, only one driver drives a "train" of vehicles. Hence, other following vehicles are in a follow–up state and their drivers are free to do other actions normally impossible or prohibited for safety reasons (e.g., reading a book, watching a movie).

Flying car is a car that can both drive on roads and fly. Departure can be made from any standard road. It has distinct advantages, such as minimizing the use of road infrastructures, personal freedom to fly anywhere at any time, and eliminating traffic congestions.

V2I and V2V Technologies

Such technologies link vehicles to their physical surroundings and enable data exchange among nearby vehicles. The infrastructure plays a key role, as data collection on traffic and road conditions enables making suitable suggestions to vehicles. The specific technologies presented to respondents are:

V2I allows data transfer from infrastructure to the vehicle or to the driver. Examples to V2I systems include "smart" traffic lights, sending control signals to vehicles, and "smart" traffic signs installed at junctions warning drivers against potential accidents. For example, when the system detects a collision risk, it triggers flashing warning lights to drivers, increasing awareness and causing them to slow down and pass the intersection carefully.

V2V share advanced spatial information regarding the location of surrounding vehicles. V2V utilizes communication technologies (e.g., Wi–Fi) to warn drivers of potential dangers related to other cars within its vicinity. For example, short distance between vehicles in front, lane departing when overtaking a car, vehicles speeding up when failing to comply with a red traffic light, and so on.

Magnetic road systems control the driving speed using magnetic levitation technology. Vehicles slightly levitate above the road surface. Such a system ensures safe driving at an optimal speed. These systems are already integrated in trains.

Connecting track is a system in which vehicles connect to a physical track; drivers do not take any action.

Methodology

The methodology of the research at hand consists of using the Delphi method as a structured process to consolidate the opinions of the expert group and to achieve consensus. Since our research attempts to predict and model future technological developments, penetration and impact of the selected technologies presented above, it was particularly important to use a method that can handle issues of high uncertainty;[49] in addition, negative group effects can be avoided.[23]

We focused on the years 2030 and 2050 given the relatively slow development of technologies and long decision–making processes in transportation. These years represent short and long - time ranges, where short range predictions are considered to be more reliable, we are interested in the range of the forecasts and penetration of these technologies. In this sense these two time-frames also provide some range to the forecasts. The methodology is based on a two–round Delphi survey. The reliability of the method is highly depend on how group of experts is selected;[50] diverse opinions are needed in order to produce accurate results within the group.[13] The selected experts are therefore a group of 50 Israeli and 70 international experts, specializing in transportation, technology, policy, and economics, and divided into three groups: academics, consultants, and policy makers. We can't cover the entire spectrum of experts and opinion, the purpose is to reach an agreement about the main trends from a versatile group of experts. The main target is to reach an agreement on a qualitative future scenario with a range of penetrations for the various technologies in the short and long run. In this paper, we use the term "forecast" as a prediction based on experts' experience to help illustrate a somewhat objective grasp of the future. The questions posed to the panel were derived by through research, a series of discussions with a team of Israeli academics and pretests. Answers from the first survey were used to construct the scenarios, and answers from the second survey were used to investigate the extent of agreement. Figure 1 depicts the general scheme of the methodology of this research.

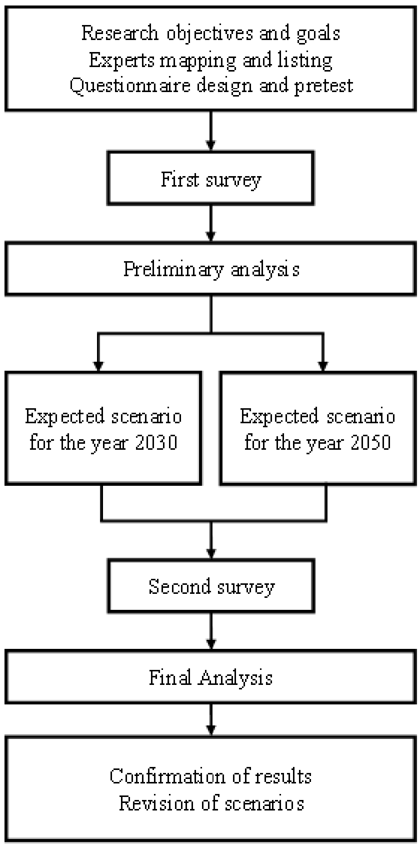

Figure 1 Schematic diagram of the research methodology.

For the quantitative analysis, frequency distribution analyses of the probabilities of possible emerging technologies were conducted. The experts' rates were classified and analyzed. Statistical measures and tests were performed, e.g., independent (unpaired) t–tests. These

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tests were performed to compare the probability rates of the different technologies, to examine if market penetration increases over time (between years 2030 and 2050), and to examine the assumption that market penetration forecasts are different between experts from Israel and abroad. Answers of experts to open–ended questions were organized and analyzed to draw qualitative conclusions, strengthening the credibility of the quantitative answers and providing a broader picture.

The Delphi method has various limitation including the difficulty in developing a good questionnaire, the potential impact of the way the questions are presented, and the experts chosen, and the impacts of all these on the results. Its reliability have been criticized in the past (e.g., Goodman[51]), still, recent studies showed valid and reliable results.[52,53] We found it the most appropriate method to respond to our research question regarding the penetration of advanced technologies.

The first survey

The questionnaire of the first survey was designed following a literature review and consultation with experts in the field, and then pre–tested among some of the experts. In this round, experts were given a questionnaire, together with a short appendix providing information regarding the various technologies mentioned above (section 3.2). For each technology, they were asked to evaluate the penetration probability in percentages for the two future years, 2030 and 2050, on a scale of 0–100; a zero means no market penetration and a 100 represents a complete penetration. They were also asked to answer few open–ended questions using their experience and knowledge. They were further encouraged to suggest additional technologies, not included in the questionnaire, that have a chance to penetrate the market by 2050. First survey's open questions were:

1. What is your vision of how cars will look and operate in 2050? Are there additional technologies that may penetrate the market in addition to the ones mention above? Please describe in short any additional thoughts about the future of cars in 2050.
2. How do you think the future car and technologies you vision for 2050 will affect individuals' travel patterns and activities? Are there any other impacts you vision?
3. How do you vision V2I and V2V communications for the year 2050? Are there additional technologies that may penetrate the market? Please describe in short any additional thoughts about the future of system interaction in 2050.
4. Express your opinion whether the future interaction systems and technologies you vision for 2050 will affect individuals' travel patterns and characteristics. What would be the effects?

Experts were also asked to provide personal background:

I. **Professional background:** employment, expertise and years of experience, and

II. **Personal information:** country and name (optional). Using the results of the first Delphi survey, preliminary statistical analysis was carried out, and two expected scenarios were constructed – one for the year 2030 and another for the year 2050.

Each scenario was constructed according to the technologies that received the highest probability rates. These are projective scenarios, although the experts did not explicitly define the path leading from the present situation to the expected image of the future.

The second survey

The purpose of the second round is to encourage the experts to revise their earlier answers in light of the replies of other members of the panel. Generally, it is expected that during this process, the range of the answers will decrease and the group will converge towards an agreed–upon answer. The scenarios, derived from the first round, were presented to the experts. They were then asked to express their opinion and level of agreement of this new expected scenario derived from the results of the first round, using the following open–end questions:

1. Do you agree with the scenario for 2030? What would you change in this scenario?
2. Do you agree with the scenario for 2050? What would you change in this scenario?
3. Having seen the scenarios we developed based on panel experts' opinions, does this alter your initial opinion? If yes, please explain.

In addition, the experts were asked to rate, again, the penetration percentage probabilities for the most probable technologies selected for the years 2030 and 2050.

Results and discussion

First Delphi round

The response rate was 35% (45% and 30% response rates among Israeli and international experts, respectively). Out of 42 questionnaires received, three experts (7%) did not respond to the open–ended questions; therefore, 39 questionnaires were used for the qualitative analysis.

Quantitative analysis results

Table 1 depicts the estimated probabilities of market penetration rates for emerging technologies by 2030 and 2050, based on the results of the first and second rounds of the survey. The mean value represents the average expected penetration rate, averaged across the panels' experts, and the standard deviation (SD) value represents the dispersion of the answers. Results regarding the second round that appear in this table (columns 3–4 and 7–8) will be discussed later.

The first round results for 2030 and 2050 demonstrates that the highest penetration rates were obtained for AVCS (59% and 79%, respectively) and warning systems (55% and 79%, respectively). Both technologies are likely to penetrate the market by 2030 and certainly by 2050. V2I and V2V communications also showed high probability rates; however, a disagreement among the experts is identified by the relatively high SD values. According to the survey, autonomous vehicle technology is likely to penetrate by 2050. However, a lack of agreement is exemplified by the large SD value (specifically, several experts even predict a penetration rate of 100% by 2030). The estimated market penetration rates for a flying car (8% by 2050) and magnetic roads technologies (25% by 2050) show that the majority of the experts deem these technologies as unlikely. Finally, the results for modular and road trains were inconclusive.

As expected, the predicted penetration rates are significantly higher for 2050 as compared to 2030 (see Table 1). t–tests and paired–sample t–tests, indicated that all these differences were statistically significant at 10% level and most at 5%. These findings support the significant change in experts' forecasts between 2030 and 2050, indicating higher

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market penetration probabilities for all the technologies over time (Table1).

Table 1 A comparison of the mean and standard deviation penetration rates for selected technologies for the years 2030 and 2050 according to first and second Delphi round (all values in %)

	The year 2030				The year 2050			
	First round		Second round		First round		Second round	
Technology	Mean	SD	Mean	SD	Mean	SD	Mean	SD
AVCS	59	9.1	67	23	79	22	93	16
Warning systems	55	9.1	73	22.1	79	23.9	92	20
V2V communication	48	32.7	47	28.9	63	34	83	20.6
V2I communication	44	25.7	48	25.6	70	31.6	82	22.4
Autonomous vehicle	35	10	21	20.5	50	35	61	33.8
Connecting track	26	28.5	–	–	46	33.4	–	–
Road train	20	4.2	–	–	37	28.5	–	–
Modular train	16	3.6	–	–	29	28.5	–	–
Magnetic roads	11	16.9	–	–	25	26.5	–	–
Flying car	2	0.2	–	–	8	12.3	–	–

Qualitative analysis results

The responses to the open question and the following qualitative analysis revealed a few major trends. Technology implementation would be much easier than physical changes in transportation infrastructure, since it is software and hardware based. Moreover, the more a technology is linked with safety aspects, the better its chances to penetrate the market. Finally, mobility in cities is expected to be mostly based on public transportation, and private transport in cities will be limited to pedestrian and bicycle, since private vehicles will be limited mainly to intercity transport.

Despite problematic issues which may delay the penetration of autonomous vehicle technology (e.g., cyber security), most of the respondents believe in its ability. The majority of respondents forecast the penetration of autonomous vehicles by 2050. About 70% predicted full penetration by 2050; the remaining 30% predict that human drivers will control most vehicles, yet vehicle control will be automatic in long–distance trips and in low–density areas (e.g., intercity roads). Other related predictions were that autonomous vehicles will become part of a public transport system by 2050. These vehicles will respond to predefined orders of passengers who define parameters, e.g., number of passengers, destination, and urgency level. No interaction between privately–owned vehicles (that are not part of the public transport system) or pedestrians and these vehicles will exist, thus they are expected operate continuously and without disturbances. All autonomous vehicles will be managed and operated from a command and control center, based on encrypted and fast communication. All vehicles will be electric and highly efficient in terms of driving range and energy consumption. Charging will be accomplished via a wireless technology installed beneath the roads.

More than 20% of respondents predicted that by 2050 traveling will be mostly based on large scale deployment of dynamic ride sharing or Personal Rapid Transit (PRT), improving the public transport system in terms of information, payment, schedule, routes, etc. Thus, public transport will demonstrate a much higher efficiency than today. Under the assumption that by 2050 vehicles will be autonomous, some experts predicted that vehicles will actually constitute small units of the public transport. About one fifth of the experts predicted that PRT will provide the optimal solution in 2050. Only 12% of the experts expressed their opinion on the flying car technology, and among these a consensus was reached that it will not penetrate the market. One answer from the survey illustrates this statement. "Flying cars as a technology looks very 'cool', but its efficiency (energy, safety) against other means of transportation is very limited. Flying cars as a solution to urban transport are unreasonable and unacceptable danger". About 38% of the respondents predicted that V2V communication will penetrate the market and will be an integral part of all vehicles. Yet, no consensus was reached regarding this claim. One expert described: "By 2050 I guess the cost of communication components will be marginal, and in all vehicles such components will be installed". In contrast, 15% of the respondents stated that this communication technology would not likely exist, as expressed in one response: "Communication between vehicles is problematic because the benefit of the individual purchasing this technology heavily depends on the number of other vehicles that have already purchased it".

Future technological impact on activity patterns and travel behavior

No consensus regarding the future amount of travel and technological impact on activity was reached. About 15% of the respondents predicted an increase in travel. Half of them stated that the reason lies in expected technological development. The other half stated that technological improvements may lead to a situation of traffic overuse, and therefore might cause a capacity problem. About 22% of the respondents foresaw the opposite situation; activity patterns will be based on communication rather than physical driving. Technological advancement will allow performing various activities from home (e.g., education, shopping, working, etc.).

According to 33% of the respondents, mobility and safety will be the main contribution of technological development. Half of the respondents claimed that one of the most significant impacts of the progress in communication technology is increased mobility, resulting from real–time information that will facilitate a more efficient use of the road system and better distribution of congestions. Vehicle will be able to choose optimal routes by communicating with traffic lights (junctions) and a central control unit. Traffic will be evenly dispersed

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across parallel routes. However, 8% of respondents predicted that this could effect on efficiency and travel time will not be dramatic. One third of respondents predicted that the most significant contribution of communication technologies is a safer transport system. Improved safety systems will be an integral part of future vehicles. Several respondents claimed that by 2050 mobility (i.e., the quality or state of being mobile) will remarkably improve, and traffic accidents will become a thing of the past.

Several respondents argued that the conventional public transportation system will be expanded, with a higher percentage of users, and will more efficient. More than 20% of respondents claimed that the concept of private and public transportation will blur. Privately owned vehicles will disappear, but small–automated vehicles will operate on a guide way network (similarly to Personal Rapid Transport (PRT)) as a part of a large transport system.

According to 20% of the respondents, one of the most significant changes about to occur is optimal time utilization and maximal travel quality. Travels will be able to sleep, use the internet, or work, while driving. Most of the respondents believe that travel will be optimized as a result of avoiding congestions and engaging in various activities while traveling. The other third believe the reason lies in the ability to schedule their travel optimally and in advanced; therefore, using time more effectively. Some experts believe that optimal time utilization will be a result of future communication technologies. One expert's answer demonstrated this drastic change in utilizing travel time to do other tasks: "In 2050 there will be no drivers at all. Getting around will be extremely efficient. Passengers will leave the doorway to the sidewalk with the arrival of an available vehicle that will drive them directly to the desired destination at the shortest and fastest path. Without the presence of pedestrians on roads, smoother and safer traffic flow will be at hand". About 15% of the respondents believe that technology development will significantly affect population dispersion, on one hand, and the concentration of workplaces on the other hand. Some believe that this will lead to a major leap in urban population growth in cities, since modern buildings will contain workplaces, residences, and leisure activities in a single place and some people will not be required to leave these buildings too often.

Expected scenarios for the years 2030 and 2050

Scenarios were constructed following the analysis of the first survey's results, and include technologies for which a consensus was reached, supporting high penetration probability. For a technology to be included in these scenarios, more than half of the respondents had to indicate a penetration probability rate of over 50%. Results from the first round were analyzed into two summarized scenarios, described as follow:

Expected scenario for the year 2030

About 40% of all vehicles will be connected by V2I communication technology. Information technologies will remain as today with only slight improvements in systems that provide real–time information to passengers and drivers. Vehicles will include sensors by which a driver can receive visual information on traffic and situations of danger. Alternatively, this system will be able to provide automatic control of the vehicle and the capability to react quickly and efficiently when needed. Systems that improve vehicle behavior and road grip will emerge and increase safety levels. Vehicles will incorporate warning systems, e.g., lane departure warning systems; pedestrian detection systems, night vision systems, and optical systems to avoid "dead spots".

Expected scenario for the year 2050

In addition to AVCS and warning systems, which will have already penetrated the market years earlier, all vehicles will be autonomous and will travel on roads according to parameters such as the number of passengers, destinations, urgency and so on. All autonomous vehicles will be managed from a command and control center. Communication components will be incorporated within all vehicles. As a result, V2I and V2V communication technologies will constitute an integral part of the transportation system. No separation of these technologies will exist: all vehicles will be connected to a control center, accountable for the communication between infrastructure and vehicles. Vehicle will be directed to optimal routes by communicating with traffic lights (junctions) and with a central control unit. Traffic will be evenly dispersed across parallel routes. The public transportation systems will remain as today but much larger in scale and with a greater percentage of users. Autonomous vehicles will constitute small units of a broad public transport system. Accordingly, in areas with high percentage of such units, privately owned vehicles will not exist on roads.

Second Delphi round

The second Delphi round was a shortened questionnaire designed to confirm and validate the results of the first round. It included four questions regarding the experts' extent of agreement with the constructed future scenarios for 2030 and 2050. Questionnaires were sent by e–mail alongside a summary of the results obtained in the first round. The rate of response was 66% (75% and 62% response rate among Israeli and international experts, respectively).

Quantitative analysis results

The experts were asked to predict the probability of market penetration of the emerging technologies in respect to the scenarios. Table 1 shows the results for the second Delphi round. Indeed, results for 2030 show a significant increase in market penetration rates for the majority of the selected technologies. AVCS and warning systems were predicted to fully penetrate the market, despite a higher dispersion of opinions in relation to the 2050 scenario (relatively higher SD values). A very slight increase in the predicted penetration rate of V2I technology suggests that the proposed scenario did not influence experts' opinion. In contrast, the predicted penetration rate for autonomous vehicle technology has significantly decreased in the second round. According to the proposed scenario, this technology is unlikely to penetrate the market by 2030, thus altering the predictions of experts who believe in it. The results for 2050 demonstrate significantly increased mean market penetration rates (more than 10% per each technology). By this year all vehicles will be autonomous. V2I and V2V technologies will be an integral part of vehicles and infrastructure. A decrease in SD values between the first and the second rounds show a better conversion of opinions, likely due to the presented scenarios.

Qualitative analysis results

For the 2030 scenario, an analysis of the responses reflected the following trends. About 84% of the respondents agree with the proposed scenario. The rest of the respondents do not agree with the proposed scenario and believe it is too optimistic. About 28% of all respondents think that the proposed scenario is too pessimistic. Out

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of these, 42% believe the scenario is expected to be transpired before 2030 and less than a third believes it is too conservative or pessimistic. About 8% of the respondents think that this scenario can indeed occur but only in large metropolitan cities.

About half of all respondents agree with the proposed scenario of 2050. Only 2% of them believe that the scenario will transpire before 2050. About 41% agree with the scenario but with some observations. Of these, 22% think that the scenario is expected to be transpired but in later years. One third believes that autonomous vehicles will not fully penetrate the transportation market. Another third think that the transport system will be controlled by a large number of control centers (as opposed to a single one). About 11% think that this scenario is expected to transpire but only in large urban areas. About 14% of respondents think that scenario is not expected to be transpired at all.

Comparison between Opinions of Israeli and International Experts

Comparison of probabilities of market penetration rates between Israeli and international experts reveal interesting gaps. The results for the years 2030 and 2050 of the two Delphi rounds are depicted in Table 2. The results for the first round show a clear trend of predicting higher penetration rates among Israeli experts as compared to their peers around the world. For 2030, particularly notable is the disagreement about autonomous vehicle technology (52% and 19% among Israeli and international experts, respectively) and AVCS (71% and 45% among Israeli and international experts, respectively). However, both Israeli and international experts reach a certain agreement concerning the penetration of warning systems in 2030 (59% and 49% among Israeli and international experts, respectively), as well as the inability of flying car, modular train and road train technologies to penetrate the market. In 2050, both Israeli and International experts predicted a much higher penetration rate for autonomous vehicle technology (72% and 33% among Israeli and international experts, respectively) but keeping the gap between them. However, there was a consensus among the experts that AVCS and warning systems will penetrate the market. Still, the expected penetration rates for AVCS are 20% higher among Israeli experts than among experts from around the world.

In contrast, results of the second round show that mean penetration rates among international experts for 2030 are slightly higher than those predicted by Israeli experts (except for the AVCS technology) showing certain convergence. Penetration rates for autonomous vehicle and AVCS technologies between forecasts among Israeli and international experts were statistically different at the 5% significance level for the year 2030. Similarly, penetration rates for flying car, autonomous vehicle, AVCS and warning systems technologies between forecasts of Israeli and international experts were statistically different for 2050. It seems that the international experts converged to the opinion of the Israeli experts (according to the expected scenarios). It can be suggested that the opinions of the Israeli experts were more robust and were less affected by the presented scenarios. As expected, penetration rates in 2050 are higher in the second round than those of the first round for both Israeli and international experts, yet, only minor differences were detected between them. Another explanation for this gap can be that Israeli experts are more technology optimists and accept technology more easily. Similar conclusions were drawn by [3] who examined user preferences regarding autonomous vehicles. Comparing individuals living across Israel and North America, the authors suggest that Israelis tend to have a greater trust in this technology. However, another explanation may be that different trends indeed may be expected in different places in the world.

Table 2 A comparison of predicted mean penetration rates between Israeli and international experts for the years 2030 and 2050 according to first and second Delphi rounds (values in %)

	The year 2030				The year 2050			
	First round		Second round		First round		Second round	
Technology	Isr.	Int.	Isr.	Int.	Isr.	Int.	Isr.	Int.
AVCS	71	45	69	65	90	70	96	91
Warning systems	59	49	73	74	90	70	88	95
V2V communication	58	31	42	52	74	44	81	85
V2I communication	50	37	46	51	82	58	85	80
Autonomous vehicle	52	19	19	23	72	33	62	60
Connecting track	24	32	–	–	49	40	–	–
Road train	25	14	–	–	45	30	–	–
Modular train	18	12	–	–	39	20	–	–
Magnetic roads	14	7	–	–	34	12	–	–
Flying car	3	1	–	–	15	3	–	–

Conclusion and future work

The purpose of this study was to develop a qualitative approach to estimate the future penetration of advanced car technologies and to assess their potential impact on travel behavior and activities. Such estimations are important for policy makers at different regional levels to prepare cities and states for the penetration of future technologies from different points of view: infrastructure investments, policy instruments, legal and institutional issues and more. While such a study can't stand alone for policy making, it can be an important, easy to obtain, initial estimate of the level and timing of penetration. With specific to driverless cars and new transport services this can have an impact on infrastructure investments and other important policy decisions. Knowing the range and potential schedule for such

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penetration can be used to maximize economic and social benefits, thus, positively affecting long-term planning. The Delphi method has been proven to be as a suitable tool for this type of research and was thus used in combination with scenario analysis. Obviously, such an approach can't replace a thorough assessment of the current use of technologies and their main driving factors and obstacles behind penetration rates, but rather complement it and serves as a first easy to obtain estimates for further analysis. Its importance lies mainly in technologies that are not currently used yet. While the driverless technology already exists it is not used for various reasons which make it penetration highly uncertain.

Results from the first round were used in order to construct scenarios for the years 2030 and 2050. All the experts who participated in the research were convinced that a significant progress will take place between the years 2030 and 2050. It was predicted that the more the technology is safety related the more likely it is to penetrate the market. For the year 2030, experts forecasted that permanently–activated AVCS will be an integral part of all vehicles, providing drivers with essential visual information and automatic control. Warning and road safety systems will be installed in every vehicle. About 40% of all vehicles will be connected to vehicle–infrastructure communication systems. As expected, penetration rates were estimated to be higher for 2050. By 2050, experts believe that all vehicles will be autonomous and will be automatically managed and administrated by a command and control center according to predefined factors. V2I and V2V communication technologies will be fully integrated, i.e., optimal routes will be determined by communicating with traffic lights and central control units. Experts also forecasted the development of a large–scale PRT system, which will be used as the main, and almost only, service for the general public to reach from one place to another. This future mass transit system will handle a much larger number of passengers, while it will consist of small autonomous units.

In terms of potential impact on activity patterns and travel behavior, our experts' panel believe that mobility and safety will be the main contribution of the expected technological development and progress. Optimal time utilization and travel quality would be the most significant changes in the future, allowing passengers to make the optimal use of their time. Several experts believe that emerging technologies will cause significant population dispersion on one hand and concentration of workplaces on the other hand. Others believe that this will lead to a major leap in urban population growth in cities.

Our results indicated a profound difference between forecasts of Israeli and international experts, where the former forecasted a more optimistic future for technological penetration. This trend is consistent for both years, 2030 and 2050, and across the vast majority of technologies. The differences are depicted in the means obtained in the first round of the survey, but this trend does not hold for the second round of the survey. Interestingly, the consensus results for the second round for the year 2030 show that estimates are closer to the first round's estimates of the Israeli experts, with the exception of the autonomous vehicle technology. It can be concluded that that Israeli experts are more technology optimists and accept technology more easily. However, further research is required in order to understand the background and reasons for this gap. Expanding the research and focus to the influence of technologies on travel behavior can contribute to a deeper understanding of its impact, and may aid in future management and decision–making policies.

The results of this study show that the Delphi technique is indeed a suitable tool for investigating future technological trends and penetration, due to its flexibility and the relative ease at which data and results can be obtained. The estimations obtained through this study can help guide policy makers in their decisions pertaining to transportation projects, technologies, and investments. Future studies are required to better predict penetration according to different regions and cultures, and various external variables, and in order to better examine the social and economic impacts, and, more specifically, the potential impacts on travel behavior, activities, and land use. As no consensus was obtained in this study regarding future amount of travel and the technological impacts on activity patterns, this questions remain unresolved.

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Conflict of interest

The author declares there is no conflict of interest.

References

1. Merzouki R, Samantaray AK, Pathak PM, et al. Intelligent transportation systems. *Intelligent Mechatronic Systems*. 2013;769–867.
2. SAE On–Road Automated Vehicle Standards Committee. *Taxonomy and definitions for terms related to on–road motor vehicle automated driving systems*. Information Report J3016. Israel; 2014.
3. Haboucha CJ, Ishaq R, Shiftan Y. User preferences regarding autonomous vehicles. *Transportation Research Part C: Emerging Technologies*. 2017;78:37–49.
4. Kahn H, Wiener AJ. The next thirty–three years: a framework for speculation. *Daedalus*. 1967;96(3):705–732.
5. Van der Heijden K. *Scenarios: the art of strategic conversation*. 1996;321.
6. Schoemaker PJ. Scenario planning: a tool for strategic thinking. *Sloan management review*. 1995;36(2):25.
7. Amer M, Daim TU, Jetter A. A review of scenario planning. *Futures*. 2013;46:23–40.
8. Flyvbjerg B, Skamris Holm MK, Buhl SL. How (in) accurate are demand forecasts in public works projects?: The case of transportation. *Journal of the American Planning Association*. 2005;71(2):131–146.
9. Linstone HA, Turoff M. *The Delphi method: Techniques and applications*. Addison–Wesley Reading, MA. 1975(29).
10. Gupta UG, Clarke RE. Theory and applications of the Delphi technique: A bibliography (1975–1994). *Technological forecasting and social change*. 1996;53(2):185–211.
11. Linstone HA, Turoff M. Delphi: A brief look backward and forward. *Technological Forecasting and Social Change*. 2011;78(9):1712–1719.
12. Graefe A, Luckner S, Weinhardt C. Prediction markets for foresight. *Futures*. 2010;42(4):394–404.
13. Kerr NL, Tindale RS. Group–based forecasting?: A social psychological analysis. *International journal of forecasting*. 2011;27(1):14–40.
14. Lummus RR, Vokurka RJ, Duclos LK. Delphi study on supply chain flexibility. *International Journal of Production Research*. 2005;43(13):2687–2708.
15. Sackman H. *Delphi critique: Lexington Books, Lexington*. Massachusetts, USA. 1975;2(2).
16. Yousuf MI. Using expert's opinions through Delphi technique. *Practical assessment, research & evaluation*. 2007;12(4):1–8.

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DOI: 10.15406/mojce.2018.04.00117

17. Rowe G, Wright G. Expert opinions in forecasting: the role of the Delphi technique. *Principles of forecasting.* 2001;125–144.
18. Everett A. Piercing the veil of the future. A review of the Delphi method of research. *Prof Nurse.* 1993;9(3):181–185.
19. Skulmoski GJ, Hartman FT, Krahn J. The Delphi method for graduate research. *Journal of information technology education.* 2007;6:1–21.
20. Kauko K, Palmroos P. The Delphi method in forecasting financial markets – An experimental study. *International Journal of Forecasting.* 2014;30(2):313–327.
21. Wang X, Gao Z, Guo H. Delphi method for estimating uncertainty distributions. *An International Interdisciplinary Journal.* 2012;5(2):449–460.
22. Modrak V, Bosun P. Using the Delphi method in forecasting tourism activity. *International Letters of Social and Humanistic Sciences.* 2014;25:66–72.
23. Keller J, Heiko A. The influence of information and communication technology (ICT) on future foresight processes – Results from a Delphi survey. *Technological forecasting and social change.* 2014;85:81–92.
24. Berg C, Rogers S, Mineau M. Building scenarios for ecosystem services tools: Developing a methodology for efficient engagement with expert stakeholders. *Futures*. 2016;81.
25. Shiftan Y, Kaplan S, Hakkert S. Scenario building as a tool for planning a sustainable transportation system. *Transportation Research Part D: Transport and Environment.* 2003;8(5):323–342.
26. Spector S, Stephenson J, Hopkins D. *Interventions for a sustainable transport system for New Zealand: results from a Delphi study*. Energy Cultures research programme, Centre for Sustainability, University of Otago, New Zealand. 2017.
27. Wise G. The accuracy of technological forecasts, 1890–1940. *Futures.* 1976;8(5):411–419.
28. Peterka V. Macrodynamics of technological change: market penetration by new technologies. Laxenburg, Austria: *International Institute for Applied Systems Analysis*. 1977.
29. Straub D, Keil, M, Brenner W. Testing the technology acceptance model across cultures: A three country study. *Information & Management.* 1997;33(1):1–11.
30. Turner M, Kitchenham B, Brereton P, et al. Does the technology acceptance model predict actual use? A systematic literature review. *Information and Software Technology.* 2010;52(5):463–479.
31. Batten DF. The future of transport and interface communication: Debating the scope for substitution growth. *Transportation for the Future*. 1989:67–86.
32. Salomon I. Telecommunications, cities and technological opportunism. *The Annals of Regional Science.* 1996;30(1):75–90.
33. Balducci P. *Plug–in hybrid electric vehicle market penetration scenarios*. PNNL–17441 Report. Pacific Northwest National Laboratory. Richland, WA. USA; 2008.
34. Silberg G, Manassa M, Everhart K. *Self–Driving Cars: Are We Ready*. USA; 2013.
35. Kaufman A. *Elon Musk: We'll Have Driverless Cars By 2023*. USA; 2014.
36. Su JB. CEO Tech Talk: Ford Expects Fully Autonomous Cars In 5 Years. *Forbes*. 2015.
37. Underwood S. *Automated vehicles symposium attendee survey results.* Paper presented at the Automated Vehicles Symposium. USA; 2014.
38. Janelle DG, Gillespie A. Space–time constructs for linking information and communication technologies with issues in sustainable transportation. *Transport Reviews.* 2004:24(6):665–677.
39. Zhang J, Wang FY, Wang K, et al. Data–driven intelligent transportation systems: A survey. *IEEE Transactions on Intelligent Transportation Systems.* 2011;12(4):1624–1639.
40. Mecklenbräuker C, Bernadó L, Klemp O. Vehicle–to–Vehicle Communications. *Pervasive Mobile and Ambient Wireless Communication.* 2012;577–608.
41. Haendeler S, Lewandowski A, Wietfeld C. *Passive detection of wrong way drivers on motorways based on low power wireless communications.* Vehicular Technology Conference. USA; 2014.
42. Chen W. *Vehicular communications and networks: Architectures, protocols, operation and deployment*: Elsevier. 2015.
43. Schneeberger J, Jacobi A, Torng GW. *Transit Vehicle–to–Infrastructure (V2I) Applications: Near Term Research and Development; Transit Bus Stop Pedestrian Safety Application: Operational Concept*. USA; 2014.
44. Rajashekara K, Wang Q, Matsuse K. Flying Cars: Challenges and Propulsion Strategies. *IEEE Electrification Magazine.* 2016;4(1):46–57.
45. Loch C, Sommer SC. *Vol de Nuit. The Dream of the Flying Car at Lemond Automobiles SA*. USA; 2003.
46. Seidel M, Loch CH, Chahil S. Quo vadis, automotive industry? A vision of possible industry transformations. *European Management Journal.* 2005;23(4):439–449.
47. Mokhtarian PL, Salomon I. Emerging travel patterns: Do telecommunications make a difference? *Perceptual motion: Travel behavior research opportunities and application challenges*. USA; 2002.
48. Banister D, Stead D. Impact of information and communications technology on transport. *Transport Reviews.* 2004;24(5):611–632.
49. Czaplicka–Kolarz K, Stańczyk K, Kapusta K. Technology foresight for a vision of energy sector development in Poland till 2030. Delphi survey as an element of technology foresighting. *Technological Forecasting and Social Change*. 2009;76(3):327–338.
50. Rowe G, Wright G, McColl A. Judgment change during Delphi–like procedures: The role of majority influence, expertise, and confidence. *Technological Forecasting and Social Change*. 2005;72(4):377–399.
51. Goodman CM. The Delphi technique: a critique. *J Adv Nurs* 1987;12(6):729–734.
52. Landeta J. Current validity of the Delphi method in social sciences. *Technological forecasting and social change*. 2006;73(5):467–482.
53. Parente R, Anderson–Parente J. A case study of long–term Delphi accuracy. *Technological Forecasting and Social Change*. 2011;78(9):1705–1711.