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Convergence of Experts' Opinions on the Territory: The Spatial Delphi and the Spatial Shang

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Introduction

In forecasting and/or decision-making contexts, when quantitative data are insufficient or totally absent, subjective judgments are of extreme usefulness. Generally, no one individual has the sufficient expertise and knowledge to make the best forecast or to take the best decision, thus all along organizations have sought to gather the opinions of groups of individuals in an attempt to combine their skills and improve decision-making (Riggs 1983).

However, having a team of experts is not enough, because the way their views are collected is crucial, and without a rigorous methodology, any consultation process may become vain. Traditional methods of grouping experts, such as focus groups or face-to-face interviews, are very popular but have quite important drawbacks. In what we call here "interacting groups", compromise decisions are often reached, rather than

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consensus decisions, and the distortive factors of the interacting groups are widely discussed in the scientific literature (Van de Ven 1974; Riggs 1983; Di Zio and Staniscia 2014b; Grime and Wright 2016).

Following is a summary of such distortions:

- *The effect of the leadership*: When the highest-ranking of a hierarchy (e.g. military, political or academic) or a particularly dominant person expresses an opinion, the others usually tend to follow that judgment, in spite of contrary feelings. Thus, not everybody expresses thoughts freely, for the fear of coming into conflict with the leader. In other words, dominant personalities influence the group, and low-status members tend to go along with the opinions of high-status members (Torrance 1957; Chung and Ferris 1971).
- *The spiral of silence*: Those who agree with the ideas of the majority are more likely to feel confident in expressing their opinions, while those who are in the minority fear that manifesting their views will result in social ostracism; therefore, they are inclined to be silent. These perceptions can lead to a spiraling process, in which minority's views are increasingly restrained and, as a consequence, under-represented (Neill 2009).
- *The groupthink factor*: This distortion occurs when the pressure to conform within the group interferes with the group's analysis of the problem, to the point of producing poor decisions (Hoffman 1965). When the members of an interacting group strive for reaching a broad consensus, their motivation to assess alternative courses of action is affected, and the independent thinking is lost, in the pursuit of group cohesiveness (Hassan 2013). The expression "groupthink" indicates the situation in which, when searching consensus, in order to minimize the conflicts, the individuals renounce their ideas and opinions.

There are several ways to manage the previous distortions, for example, by avoiding face-to-face contacts and structuring the interactions anonymously. The aim is to prevent the association of the opinions to those who have expressed them, avoiding the errors arising out of the effect of the leadership and the spiral of silence. Moreover, instead of collecting the expert's judgments at one time, in the same place and within a limited time, one can structure the consultation in an iterative framework and asynchronously (i.e. at different times). By collecting the evaluations iteratively, the participants can review at least once their assessments, perhaps with the possibility of comparing them with the answers provided by the other experts of the same group (*controlled feedback*). The possibility for the members to interact at a distance and at different times eliminates the pressure to decide quickly, within a given time limit, so avoiding the groupthink bias.

The *anonymity*, the *iterative structure* and the *asynchronous communication* are the most used strategies for the elimination of the distortive effects typical of the interacting groups. All these features are present in the Delphi method, a very popular iterative technique for collecting expert's opinions, conceived to achieve consensus on a particular issue. Dalkey and his associates developed the Delphi at the RAND Corporation, a research institute founded in 1946 with the financial support of the US Department of Defense (Dalkey and Helmer 1963). Since its invention, the applications of the method were numerous, and over the past 60 years, many other methods related to it have been developed.

In this chapter, we briefly explain the origins and the evolution of the Delphi method, up to two recent variants, the *Spatial Delphi* and the *Spatial Shang*, specially designed to treat problems related to the territory. With these two methods, the judgments of the experts are collected by means of points placed on a map, and the process of the convergence of opinions is built up with simple geometric figures (circles, rectangles or strips). During the iterations, the figures on the map move and become smaller and smaller, until to circumscribe a small portion of territory that represents the final solution to the research/decision problem. After the description of the methods and the presentation of the early applications, we discuss some possible evolutions that most likely will produce a future increase in the use of these techniques. In particular, we will talk about the *Real Time Spatial Delphi*, a real-time version of the Spatial Delphi.

The Delphi Method

The Delphi method is a technique that uses responses (typically opinions) to a questionnaire by a group of experts (*panel*) or social actors to solve a problem, generally in a decision-making context and/or a forecasting framework. It consists of a number of iterations, called *rounds*, during which the administrator of the process (*facilitator*) provides statistical summaries of the answers given by the members of the panel. The experts communicate with each other anonymously, at distance and asynchronously, and, as seen above, these features resolve several problems typical of other methods of group decision-making.

This method was born in the 1950s, but only later (in the 1960s) it took the name *Delphi*, by the RAND Corporation. The first application, commissioned by the Government of the United States of America, concerned the use of expert's opinions for selecting an American industrial target and estimating the number of atomic bombs needed to reduce the American arsenal by a predetermined amount, all seen from the point of view of a Soviet strategist.

At that time, there were also alternative methodologies, but they consisted of complex mathematical models, requiring a lot of data, very long procedures and expensive computers. Curiously, in the following years, those sophisticated models were applied, but the surprise was that the results of the Delphi were better. This explains why, after more than half a century, the method remains valid in situations in which it is difficult to get quantitative data, and/or for long-range forecasting, when expert's opinions are the only source of information.

Due to the secrecy of the first study, the method was disclosed only after several years. Two papers are recognized as the basic literature of the Delphi, one by Norman Dalkey and Olaf Helmer, which describes the methodological and philosophical foundations of the method (Dalkey and Helmer 1963), and the other by Theodore J. Gordon and Olaf Helmer, entitled "Report on Long-Range Forecasting Study" (Gordon and Helmer 1964).

From that time, the Delphi has been used continuously in various substantive fields, often together with other methodologies and with a very high number of applications (Brockhaus and Mickelsen 1975).

Now, let us see how the Delphi works. The first step is the formulation of the topics, generally derived from the literature, from the available surveys or defined by a working group created specifically. Immediately after, you have to build the panel of experts (Gordon 2009a). Panelists are knowledgeable persons, generally identified through literature searches or recommendations from institutions or other experts, and must be selected based on their *expertise*. Nevertheless, the group should be heterogeneous, in order to ensure an adequate variability in the assessments and stimulate an exchange of views and knowledge (Rowe and Wright 2001). The size of the panel depends on many factors, such as the number of the topics, the fields of expertise, the expected response/acceptance rate and other issues, but considers that most applications use panels of 15–40 people. Each expert should be contacted individually, preferably by telephone, and informed about the study, the objectives of the research and the number of rounds.

The next step is to build and test the questionnaire, to find any flaws, and then it is sent to the participants, for example, by e-mail (Gordon 2009a). After collecting the answers, the facilitator summarizes the opinions expressed by the experts by means of appropriate statistical indices (Glenn 2009). The classic approach provides the calculation, for each question, of the median and/or the first and third quartiles of the distribution of the responses, resulting in an interval (called *quartile range*) that contains 50% of the estimates. This interval is the embryo of the consensus and constitutes a window of response for the second round of consultation.

The second round sees the administration of the same questionnaire, enriched with the synthetic results of the first round (e.g. the quartile range), thereby triggering the feedback process. The questions are the same of the first questionnaire, but each expert is asked to answer inside the quartile range (invited but not obligated). In this way, if some expert revises his/her previous assessment to stay inside the proposed range, already from the second consultation the process of "convergence of opinions" begins. The panelists are also invited to give written reasons, especially if they give evaluations outside the proposed range.

The results of the second round are processed as before, and then in the third consultation, the panelists are asked to answer the questions trying to stay within the new quartile ranges. Now, the facilitator circulates anonymously the reasons provided in the previous round, and counter-arguments can be provided, so enriching the debate. Proceeding iteratively, the quartile range of each question should narrow more and more, until a value small enough such that the consensus is sufficient. When a predefined stopping point is reached (for instance a preset number of rounds, a consensus threshold or the stability of answers), the facilitator concludes the consultation and proceeds to the final elaborations (Grime and Wright 2016). Finally, the whole procedure ends with the presentation and comment of the results.

Although consensus can be used as a stopping criterion, unfortunately there is no guarantee that it is reached and, above all, there is a difference between "consensus" and "stability". In a Delphi study, it is important to check first the stability of the evaluations and only after verify whether there is consensus (von der Gracht 2012). There is stability when the results of two subsequent rounds are not significantly different, and it should be used as stopping criterion. A possible measure of stability is the percent change from round to round, and a 15% change (or lower) is considered a stable situation (von der Gracht 2012; Scheibe et al. 1975; Dajani et al. 1979). If stability is achieved, there may be consensus, but also other layouts of responses, like for example majority or plurality of views (Dajani et al. 1979). Nevertheless, the lack of consensus does not mean the failure of the Delphi exercise, because "the absence of consensus is, from the perspective of data interpretation, as important as the existence of it" (von der Gracht 2012).

A Delphi Variant: The Shang Method

The Delphi has been so widely used to the point that is considered the father of many other methods. To give some examples, in 1970 Murray Turoff proposed the *Policy Delphi* (Turoff 1970), a consensus-oriented method used for the analysis of public policies, while a different version, called *Public Delphi*, is based on the participation of the citizens. After a few years the *Mini Delphi* was proposed, also known as Estimate-Talk-Estimate (ETE), a technique that speeds up the procedure, as it is applied for face-to-face meetings (Gustafson et al. 1973; Van de Ven and Delbecq 1974). In 1974, De Groot (1974) laid the theoretical fundamentals of the *Markov-Delphi,* and then Chatterjee (1975) studied an alternative solution, based on variable weights.

In the same year, David A. Ford proposed the *Shang* method (Ford 1975), an interesting technique in which some characteristics of the classical Delphi are kept, but the trouble of asking to rephrase the evaluations at each round is eliminated.

Like in the conventional Delphi, the first phase of the Shang concerns the definition of the topics and the construction of the panel. In the first questionnaire, the experts are asked to express a minimum and a maximum of the value to be estimated, so the first round produces two distributions, one for the minimum and one for the maximum. Denoting with n the number of the responses, you get a vector $\boldsymbol{m}$ with n values for the minimum, and a vector $\boldsymbol{M}$ with n values for the maximum. For each vector, the facilitator calculates a statistical synthesis (e.g. the median), and these two values (here denoted by m_0 and M_0) define an initial evaluation interval: $[m_0, M_0]$. Then, the central value of this interval is calculated:

$$C_0 = \frac{M_0 + m_0}{2}$$

This number represents the basis of the second questionnaire where, differently from the Delphi, each expert is invited to compare the central value C_0 with what he/she believes more plausible, simply answering "greater than" or "less than".

If the majority of the estimates are greater than C_0, the new interval is $[C_0, M_0]$, while if the majority are less than C_0, the new interval is $[m_0, C_0]$. Accordingly, a new central value is calculated, say C_1, as the mean of the extremes of the new interval. The method proceeds iteratively, calculating subsequent intervals with the respective central values $(\ldots, C_2, C_3, \ldots, C_k)$, until a stopping point is reached.

The first advantage of the Shang is that the speed of convergence is greater than in the Delphi, given that is known a priori that at each iteration the interval is halved, while in the Delphi the width of the interval of consensus depends on the distribution of the answers. Second, the Shang does not push the experts to change their estimates at each round, asking to give assessments within an interval. In fact, if an expert has in mind a value, during the subsequent rounds he/she is not induced to modify it, because it is only asked if that value is below or above the proposed central value. Therefore, while the iterations of the Shang proceed and the central value changes, the estimate that an expert initially thought can remain the same until the end.

From Delphi to Spatial Delphi: Looking for Geo-consensus

Many mental operations and the ensuing decisions involve a spatial reasoning, like driving a car, searching for an address or looking for a hotel on the Internet. With the expression *spatial reasoning,* we intend a way of thinking which implies the use of a map, explicit if it is a paper or digital map, or conceptual if our brain uses a map at a cognitive level. The decisions that ensue can be defined *spatial decisions*. Starting from these considerations, in recent years some authors are developing a new line of research, in which the logic of the Delphi method is integrated in the context of spatial decisions.

Dragicevic and Balram (2004) defined the concept of "Collaborative Spatial Delphi" which makes use of the Geographic Information Systems (GIS) technology, to support the convergence of opinions obtained with the Delphi method. During the consultation, the experts draw polygons and write comments on a digital map; nevertheless, the convergence of opinions is still reached using the classical Delphi technique.

A bit later, Jankowski (Jankowski et al. 2008) proposed a web-based spatial multiple criteria evaluation tool for individual and group use, which supports sketches created on a digital map, documents and the construction of statistical indicators. The system includes "a vote aggregation function to collate individual option rankings into a group ranking, and measures of agreement/disagreement to inform the participants about a group-derived desirability of specific decision options" (Jankowski et al. 2008). Nevertheless, the Delphi does not yet have a spatial form.

After a few years, Di Zio and Pacinelli (2011) expressly spoke of "Spatial Delphi", a technique in which the logic of the Delphi method is fully integrated within a map. The basic idea is the narrowing of the opinions of the experts on the territory, in order to find a location in the area of interest—or at least a narrow region—on which there is consensus among the panelists.

As discussed by the inventors of the method, there are three categories of problems where the Spatial Delphi can be applied:

1. **The present**: choose the optimal geographical location to place goods, services or buildings, when quantitative data are not available.
2. **The future**: if a future event has a given probability to happen, it is important to predict *where* it will be most likely to happen (e.g. catastrophic events such as hurricanes, earthquakes, floods, fires and so on).
3. **The underground**: the search for non-visible underground elements is nowadays supported by technology, but the human experience still plays an important role. The Spatial Delphi can be used for the consultation of experts in order to find things that are not visible (archeology, geology, oceanography).

However, how does the Spatial Delphi work? The authors have retraced all the steps of the conventional Delphi, adapting them to a spatial context (Di Zio and Pacinelli 2011). First, the localization problem must be defined, as detailed as possible. The panel of experts must be built according to the principles of expertise and heterogeneity, but an additional requirement is necessary: each expert must know well the geography of the area under study. Then, the questionnaire is implemented on a paper or a digital map; here the GIS technology is essential for setting the map(s) and any supplementary materials.

After the preparatory stage, the steps of the iterative phase of the Spatial Delphi start.

Step 1 Ask the experts to locate k_1 points (the subscript denotes the first round) on the map, representing the most suitable sites to locate goods, services or buildings, or the places where a future event will likely occur, or the most appropriate places to dig for underground materials, etcetera. The result of the first round is a map with a cloud of n_1 geo-referenced points, called *opinion-points*. If E is the number of experts in the panel, then $n_1 = E \cdot k_1$.

Step 2 In analogy with the quartile range of the conventional Delphi, a circle containing 50% of the n_1 opinion-points is constructed, called *circle of consensus* or *circle of convergence*. Excluding different properties in different directions, the circle is the natural isotropic shape in a two-dimensional space.

The problem is that with n_1 points distributed on a plane, the number of circles containing $n_1/2$ points is infinite, so constraints are necessary. The first constraint is that the circle must be centered on one of the opinion-points. In this way, it is guaranteed that the center of the circle of consensus coincides with one of the locations expressed by the panelists and so the number of circles is restricted to n_1. Second, given that the goal is the convergence of opinions around an area as small as possible, among the n_1 possible circles the algorithm requires the choice of the smallest one. Thus, there is only one circle with a minimum radius, centered on one of the n_1 points, containing $n_1/2$ opinion-points.

Let us denote with cc_i the smallest circle centered on P_i (the generic *i-th* opinion-point, $i = 1, 2, \dots, n_1$), containing $n_1/2$ points if n_1 is even, or $(n_1 + 1)/2$ if n_1 is odd. With A_i and r_i respectively the area and the radius of cc_i. In the first round, there are n_1 of such circles and then a vector of areas $\boldsymbol{A} = \left(A_1, A_2, \dots, A_{n_1}\right)$. From this vector you need to determine the smallest value, $A^1_{best} = \arg.\min\left(\boldsymbol{A}\right)$, which represents the first *circle of convergence*, denoted by CC^1 (the superscript indicates the first round). The correspondent opinion-point is denoted by $\boldsymbol{P}^1_{best}$. From a technical point of view, a distance matrix $\boldsymbol{D}$ between all the n_1 points is calculated (size $n_1 \times n_1$). The *i-th* row of $\boldsymbol{D}$ is a vector (say D_{i°) containing the distances between the *i-th* opinion-point and all the other opinion-points. The median of this vector is the radius of cc_i ($r_i = median(D_{i^\circ})$), and consequently the area of the *i-th* circle is calculated as $A_i = \pi r_i^2$. Repeating this calculation for each row of the matrix $\boldsymbol{D}$, it results the vector $\boldsymbol{A}$.

The facilitator draws on the map the first circle of convergence CC^1, with area A^1_{best}, centered on the opinion-point $\boldsymbol{P}^1_{best}$, and this constitutes the base of the questionnaire of the second round.

Step 3 The map with the circle CC^1 is circulated among the panelists for the second round. The experts re-evaluate their opinion-points with the invitation of remaining inside the circle. According to the original version of the method (Di Zio and Pacinelli 2011), each expert must provide $k_2 = k_1 - 1$ points, that is one opinion-point less in respect to the first round, but the number of points can also be kept constant throughout all the rounds. In analogy to the conventional Delphi, if an expert wants to place a point outside the circle, he/she can do so, but is invited to give a motivation. After the second round, there are $n_2 = \mathrm{E} \cdot k_2$ opinion-points drawn on the map (if there are not dropouts). Di Zio and Pacinelli (2011) explain as "reducing the number of available points may improve respondents' psychological state because revising their evaluations panelists can eliminate the points outside the circle and keep those included in the circle. [...] the possibility of maintaining a part of the previous evaluation and eliminating or moving another part increases the degrees of freedom and should produce a better tendency to revise preceding choices."

Step 4 After the second consultation, a new circle of consensus CC^2 is calculated, following the same algorithm, with center P^2_{best} and area A^2_{best}, containing 50% of the n_2 opinion-points. The new circle is depicted on the map proposed to the panelists for the third consultation, and the procedure continues iteratively.

After a number of rounds, say s, there will be a circle CC^s representing the territory where the spatial convergence of the opinions is achieved (*geo-consensus*). From a geometrical point of view, if the procedure generates a consensus, the consecutive circles are smaller and smaller, namely $A^1_{best} \geq A^2_{best} \geq \ldots \geq A^s_{best}$.

Table 1.1 compares the main steps of the classical Delphi with those of the Spatial Delphi and helps to highlight similarities and differences.

When the stopping point is reached, the final circle represents the "geographical" result of the survey. However, there are also "non-geographical" results, like the comments of the experts and some measures of geo-consensus.

If you know the limits of the study region, a simple measure of geo-consensus derives from the ratio between the area of the final circle (A^s_{best}) and the surface of the study area:

Table 1.1 Delphi and Spatial Delphi in comparison

Delphi	Spatial Delphi
1. Formulation of the topics, selection of the panelists and construction of the first questionnaire	1. Formulation of the topics, selection of the panelists and construction of the map with the spatial question(s)
2. Administration of the first questionnaire	2. Administration of the first questionnaire. The panelists answer by locating k_1 opinion-points on the map
3. Calculation of the first quartile range (50% of the evaluations)	3. Calculation of the circle CC^1 (50% of the k_1 opinion-points)
4. In the second questionnaire, the panelists are asked to give assessments inside the quartile range. External evaluations should be argued	4. In the second questionnaire, the panelists are asked to locate k_2 points inside the circle CC^1. External points should be argued
5. Calculation of the second quartile range, which is shown in the third questionnaire, together with the reasonings	5. Calculation of the circle CC^2, which is shown on the third map, together with the reasonings
6. Administration of the third questionnaire. In case of evaluations external to the quartile range, the experts are invited to argue the choice	6. Administration of the third questionnaire. Panelists are asked to locate k_3 points inside CC^2. External points should be argued
7. Iterate, until the stopping point (stability, consensus)	7. Iterate, until the stopping point (stability, consensus)

$$MC_1 = 1 - \frac{A_{best}^{s}}{M}$$

where M is the surface area of the region. The closer MC_1 comes to one, the smaller the final circle is, compared to the study area, therefore indicating a high degree of geo-consensus (Di Zio et al. 2016).

Another relative measure of convergence, especially useful when the study area is not bounded, is the percentage ratio between the final circle and the initial one:

$$MC_2 = \frac{A_{best}^{s}}{A_{best}^{1}} \cdot 100$$

This quantity varies between 0 and 100, and a value close to 0 denotes a high degree of geo-consensus, because the final circle is small compared to the initial one (Di Zio et al. 2016).

In addition to the measures that consider the circles, there are also some indicators of geo-consensus based on the entire cloud of points, generated at each round. The *K function* is a measure of the spatial dependence between point-events as a function of the distance (Ripley 1976; Bailey and Gatrell 1995). By denoting with R the region of interest, with n the number of opinion-points and with d_{ij} the Euclidean distance between points i and j, the following expression provides an estimator for K (Bailey and Gatrell 1995):

$$\widehat{K}(h) = \frac{R}{n^2} \sum\sum_{i \neq j} I_h(d_{ij})$$

Here h is the distance and $I_h(d_{ij})$ is an indicator function with value 1 if $d_{ij} \leq h$ and 0 otherwise. If the n points are scattered, we have $\widehat{K}(h) < \pi h^2$, while for clustered points $\widehat{K}(h) > \pi h^2$. To interpret $\widehat{K}(h)$, the graphical representation of the following transformation shall be used:

$$\hat{L}(h) = \sqrt{\frac{\widehat{K}(h)}{\pi}} - h$$

If $\hat{L}(h) > 0$, the opinion-points are clustered; therefore, this function is an indicator of the geo-consensus. On the contrary, negative values of $\hat{L}(h)$ occur when the points are scattered, a situation where the panelists have not reached a convergence of opinions on the space. A plot of $\hat{L}(h)$ versus h for each round of the Spatial Delphi helps in evaluating the degree of geo-consensus. In Fig. 1.1, there is an example of $\hat{L}(h)$ estimated on a simulation with three rounds, where it is evident that the degree of spatial consensus increases as the rounds proceed.

Di Zio and Pacinelli (2011) proposed also another indicator of the geo-consensus that is the fractal dimension (FD). The FD estimated on a cloud of points measures how the points "cover" the surface. It varies

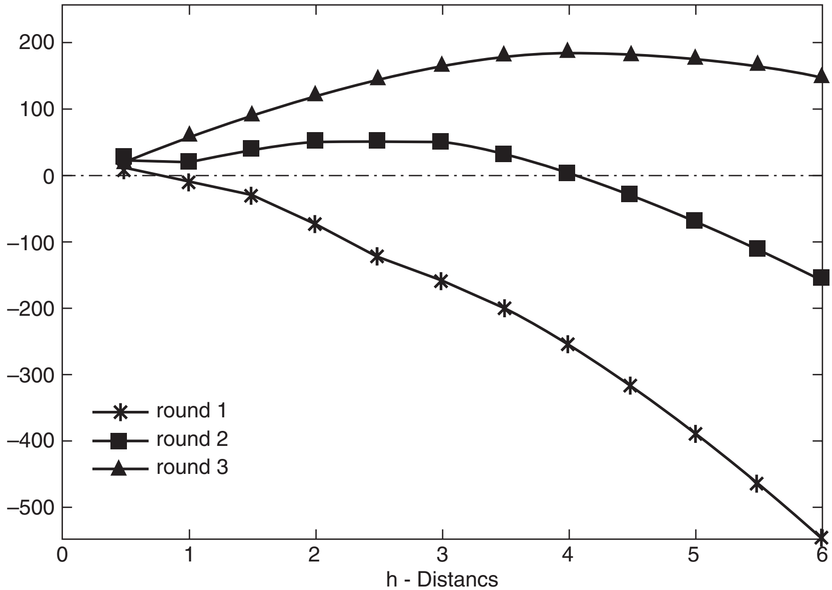

Fig. 1.1 Example of *L* functions

between zero (clustered points, high geo-consensus) and one (scattered points, low geo-consensus). For the estimation of the FD, we use the *correlation dimension* method (Hastings and Sugihara 1993). If from the first to the last round of the Spatial Delphi the FD decreases, one has an indicator of the spatial convergence of opinions.

The indices MC_1, MC_2 and FD can also be used to measure the speed of convergence and to check for stability. For example, from one round to the next, a change in the FD less than 15% can be considered an indicator of stability.

The Spatial Shang

The *Spatial Shang* is a variant of the Shang method and arises from the same considerations which have led to the Spatial Delphi. Like the Spatial Delphi, it is applicable whenever the research problem concerns the choice of a geographical location (Di Zio and Staniscia 2014a).

First, the location problem must be defined carefully, and the panel of experts (say n participants) must be built according to the principles of the expertise, the heterogeneity and the knowledge of the region under study. Like for the Spatial Delphi, the GIS technology is an excellent tool for the preparation of the maps, and any supplementary materials.

Then, the steps of the iterative phase are the following:

Step 1 The experts are invited to draw four points on the map, to delimit the area where, for example, it is assumed to occur in a future event. Two points are the extreme positions along the North-South direction and two are the extreme positions along the East-West direction (Di Zio and Staniscia 2014a). For the generic expert i^{th} a point (say N_i) is the north limit beyond which the expert considers that the event under study will never occur. On the opposite side, a second point expresses the south limit (S_i). In the direction of longitude, the other two points represent the leftmost limit (W_i) and the rightmost limit (E_i). Thus, these four points identify four imaginary lines that surround the area with a rectangle, which represents the initial solution of the spatial problem for the i^{th} expert. Of course, there will be n rectangles, one for each expert.

Step 2 The result of the first consultation consists of four vectors of n values. One vector, say $\boldsymbol{N}$, containing the n evaluations for the north limits, one for the south limits ($\boldsymbol{S}$), one for the east limits ($\boldsymbol{E}$) and one for the west limits ($\boldsymbol{W}$). These vectors generate n different rectangles on the map and, in analogy with the classical Shang, in order to have a unique solution, we have to compute a statistical synthesis for each vector (e.g. the medians or the arithmetic means). We denote these indices with N_0, S_0, E_0 and W_0 (see Fig. 1.2). Of course, N_0 and S_0 are values of latitude, while E_0 and W_0 are values of longitude.

These four values define the first rectangle of convergence (*ABCD* in Fig. 1.2), with the vertices having the following coordinates: $A(W_0, N_0)$, $B(E_0, N_0)$, $C(E_0, S_0)$ and $D(W_0, S_0)$. This rectangle, denoted by R^0, represents the average rectangle and is the analogous of the initial interval of the conventional Shang. The area of R^0 is $A_0 = (|E_0 - W_0|) \cdot (|N_0 - S_0|)$.

By using the four indices (N_0, S_0, E_0, W_0), two central values are calculated, one for the latitude: $C_{0,LAT} = (N_0 + S_0)/2$, and one for the longitude: $C_{0,LONG} = (E_0 + W_0)/2$. These are two geographical coordinates identifying the center of gravity of R^0, namely $\boldsymbol{G}_0(C_{0,LONG}, C_{0,LAT})$. Two orthogonal lines passing through $\boldsymbol{G}_0$ divide the rectangle R^0 in four sub-rectangles, each having area A_1 equal to a quarter of A_0, namely $A_1 = A_0/4$. Starting from the north-east and proceeding clockwise, we denote these sub-rectangles with *NE*, *SE*, *SW* and *NW* (see Fig. 1.2).

Step 3 The map with the rectangle R^0 and the four sub-rectangles is submitted to the panel for the second round. Each expert is asked to locate an opinion-point somewhere in one of the sub-rectangles. In other words, it is like asking the expert which sub-rectangle he/she considers the most appropriate for the solution of the spatial problem. Like in the Spatial Delphi, the answer is very easy and fast to be given.

Step 4 The sub-rectangle that received the highest number of points becomes the new rectangle of convergence (R^1) which will be divided, in its turn, in four sub-rectangles on the basis of a new center of gravity $\boldsymbol{G}_1$. The area of each new sub-rectangle (A_2) has a 16th of the area of the initial rectangle R^0, namely $A_2 = A_0/16$. Let us take an example. If the sub-rectangle *SW* receives the majority of the opinion-points, the center of gravity $\boldsymbol{G}_1$ has the following coordinates: $C_{1,LAT} = (S_0 + C_{0,LAT})/2$ and $C_{1,LONG} = (W_0 + C_{0,LONG})/2$ (see Fig. 1.2).

In case two or more sub-rectangles receive the same higher number of opinion-points, the choice will fall on the rectangle that contains the

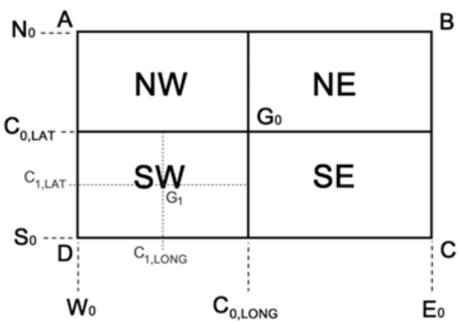

Fig. 1.2 Schematic representation of the Spatial Shang

farthest points from the center of gravity. This is the advantage of asking to locate the opinion-points and not simply the choice of one of the four sub-rectangles (Di Zio and Staniscia 2014a).

Step 5 Further rounds are performed, selecting new sub-rectangles and new centers of gravity, until a stopping point is reached, for example, after a number of rounds or when a sufficiently small portion of territory is delimited and the spatial consensus can be considered reached. For example, you can decide that the final rectangle must be smaller than a certain fraction p of the initial rectangle ($0 < p < 1$), so the stopping criterion is $A_k \leq pA_0$.

If k is a generic round, at each iteration the area of each sub-rectangle (A_k) is reduced by a factor of $1/4^k$,namely $A_k = A_0/4^k$, and this means that the process of convergence is very fast (one of the peculiarities of the Shang method).

Benefits and Limitations of the Spatial Delphi

Even though many decision/forecast problems concern the territory, until today in almost all the Delphi applications the geographic element has been greatly overlooked. The Spatial Delphi and the Spatial Shang fill this gap. We consider these methods complementary, and not alternative, to the conventional Delphi. Our suggestion is that when in a research problem there are issues related to the territory, a conventional Delphi questionnaire can be supplemented with a number of questions of a Spatial Delphi/Spatial Shang.

Given the above, we now turn to a brief description of the advantages and limits of the Spatial Delphi that, in principle, also apply to the Spatial Shang.

In the design phase, the typical problems of the conventional Delphi about the choice of the response scales (dichotomous scales, rating scales, etc.) and about the number of response categories (three-point scales, five-point scales, etc.) are not present in the Spatial Delphi, whatever the spatial issue. The positioning of a point on a map is quick and intuitive, and does not force the participants to complex reasoning on the questions, as occurs in any conventional questionnaire. The method is easily accessible and understandable, even for a non-specialized audience, given that we are used to reading maps since we were kids, and this shortens the duration of the survey and reduces the dropouts (Di Zio and Pacinelli 2011). With the Spatial Delphi, the computation of the measures of geo-consensus and stability is easy and intuitive. Additionally, the interpretation of the feedbacks and of the geographical results is trivial, and does not require any statistical processing, unlike the other versions of the Delphi method.

Of course, in view of these advantages, there are also weaknesses. Like the conventional Delphi, the Spatial Delphi consists of a certain number of rounds, so the participants are forced to respond at any round and within the requested temporal intervals. The Spatial Delphi is based on a non-interactive map; therefore, the research team must decide the type, the scale and the extent of the map a priori. This is a limitation because respondents are not allowed to change the type of map, or explore the study area by moving the map or zooming on it, such as it happens with any interactive map (Di Zio et al. 2016).

The supporting materials are separated from the map and, inevitably, the number of maps and documents is limited. For each new application, all the necessary must be specially prepared; therefore, the time and costs for the preparation of a survey are considerable. Another disadvantage is that all the boxes for the reasonings are external to the map and, above all, are not interactive, as, for example, it is in the Real Time Delphi (Gordon and Pease 2006; Gordon 2009b), and this can discourage the participants in giving arguments.

Examples of Applications

The earliest application of the Spatial Delphi concerned the identification of the riskiest and safest areas in case of an earthquake (Di Zio and Pacinelli 2011). The study area was a surface of 2700 sq km around the city of L'Aquila, in the Abruzzo region (Italy). The aim was not to find the area where a possible earthquake is more or less probable (which is typically a geological issue), but two little areas considered the most dangerous and the most secure in case of a future seismic event. The authors, in 2010, organized a panel of 12 experts, who knew the area very well and with different expertise (geologists, seismologists, geographers, sociologists, demographers, architects and construction engineers).

The experts responded anonymously to three Spatial Delphi rounds, by placing on a map respectively three, two and one opinion-points for the places deemed riskier, and three, two and one for the safer. In the first round, the question posed to the experts was "In the event of an earthquake […], please indicate three human settlements on the map that you believe have the greatest risk and three you believe have the lowest risk" (Di Zio and Pacinelli 2011). After collecting the answers, a circle of consensus for the maximum risk and one for the minimum risk were constructed. In addition to the basic map, also supporting maps were included (road network, major resorts, a relief map, a satellite image and a seismic hazard map).

In the second round, the maps with two circles of consensus were circulated among the panelists, which were asked to locate two points for the major risk and two for the minor risk, preferably inside the two circles. With the two clouds of points, two new circles were calculated and proposed to the panel for the third round of consultation, for which only one opinion-point for each circle was asked. Some expert gave points external to the circles, giving also reasoning which circulated anonymously.

The Spatial Delphi was stopped after the third round, and in Tables 1.2 and 1.3, we report, for each round, the total number of collected points, the area of the circle of consensus (A_{best}), the indices MC_1 and MC_2, and the

Table 1.2 Results for the major risk

Round	n	A_{best} (Km^2)	MC_1	MC_2	FD
1	36	286.52	0.8939	100.00%	0.400
2	24	43.47	0.9839	15.17%	0.180
3	12	2.06	0.9992	0.72%	0.060

Table 1.3 Results for the minor risk

Round	n	A_{best} (Km^2)	MC_1	MC_2	FD
1	36	591.37	0.7810	100.00%	0.631
2	24	122.72	0.9545	20.75%	0.350
3	12	23.84	0.9912	4.03%	0.122

estimated fractal dimension (FD). It is worth noting how the size of both circles decreases rapidly during the rounds, until the identification of two small areas in respect to the study area. In fact, in the final round, the indices MC_1 are both very close to one and MC_2 very close to zero.

In addition, the estimated FDs confirm the fast convergence of the spatial opinions and the final geo-consensus. It is also evident that in the case of major risk the convergence was faster and the final geo-consensus greater compared to the minor risk. Thus, in the study region, it was easier for the experts to identify the most dangerous area than the safest. The L functions (not reported here) confirm these conclusions (Di Zio and Pacinelli 2011).

It is interesting to note that in this application there have been no abandonments of experts. In Fig. 1.3, we have all the 36 opinion-points given by the experts in the first round for the major risk question, together with the resulting first circle of consensus (CC^1). In Fig. 1.4, the three circle of consensus—CC^1, CC^2 and CC^3—are depicted without the opinion-points, in order to show as the circle moved and reduced during the survey.

We now report the first application of the Spatial Shang, made by Di Zio and Staniscia (2014a). In 2001, an Italian National Law (L. 93/2001, art. 8) established the *Costa Teatina National Park*, on the east coast, but did not define its boundaries. A number of questions have arisen: Which municipalities in the area should be included within the Park? What are the criteria to define the boundaries? What are the procedures? For more than ten years, an agreement was not reached, so a research group of the nearby "G. d'Annunzio" University (Chieti-Pescara) proposed the application of a Spatial Shang with the involvement of the local stakeholders, including local public authorities, local communities, enterprises, NGOs and associations. The spatial problem concerned the definition of a buffer small enough to help in defining the boundaries of the Park. A panel of 62 stakeholders ($n = 62$), representing the community from different perspectives, participated in the study and were selected on the basis of three criteria: (1) deep knowledge of the territory and of the conflict about the Park; (2) capacity to represent a clear position in the conflict and (3) capacity to give voice to the category they were representing (Di Zio and Staniscia 2014a).

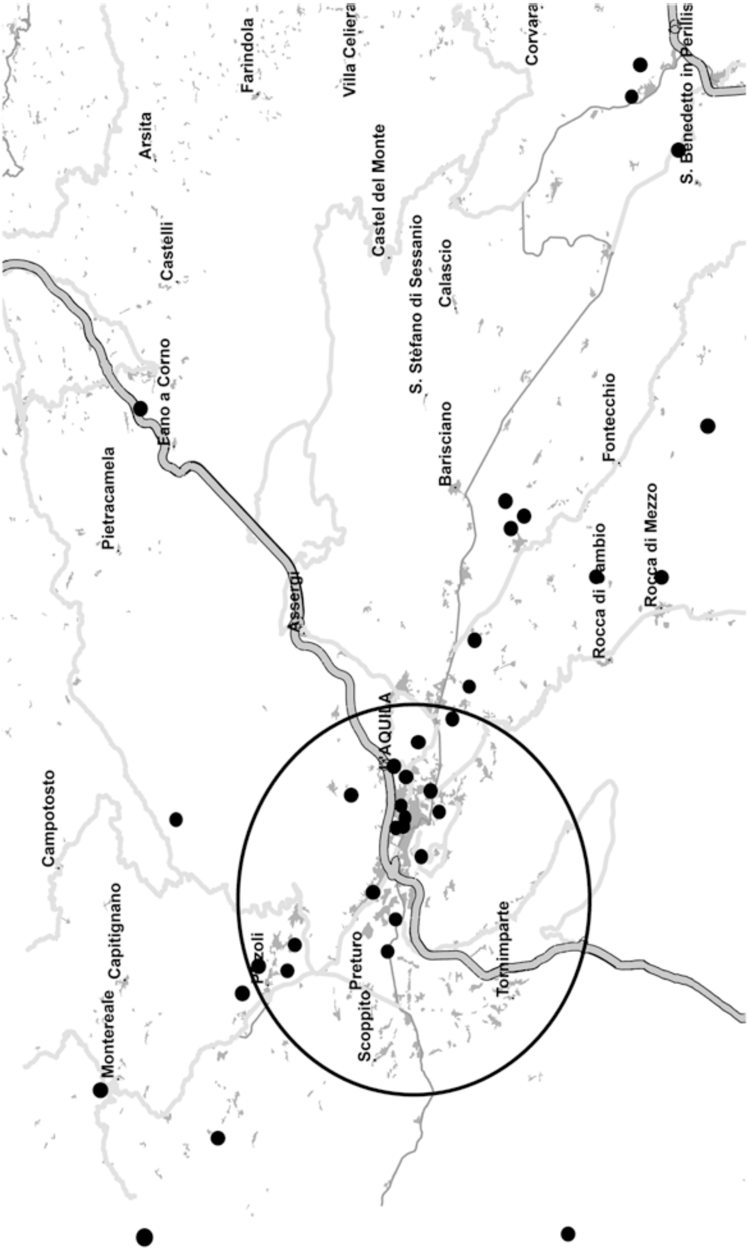

Fig. 1.3 Opinion-points and relative circle of consensus

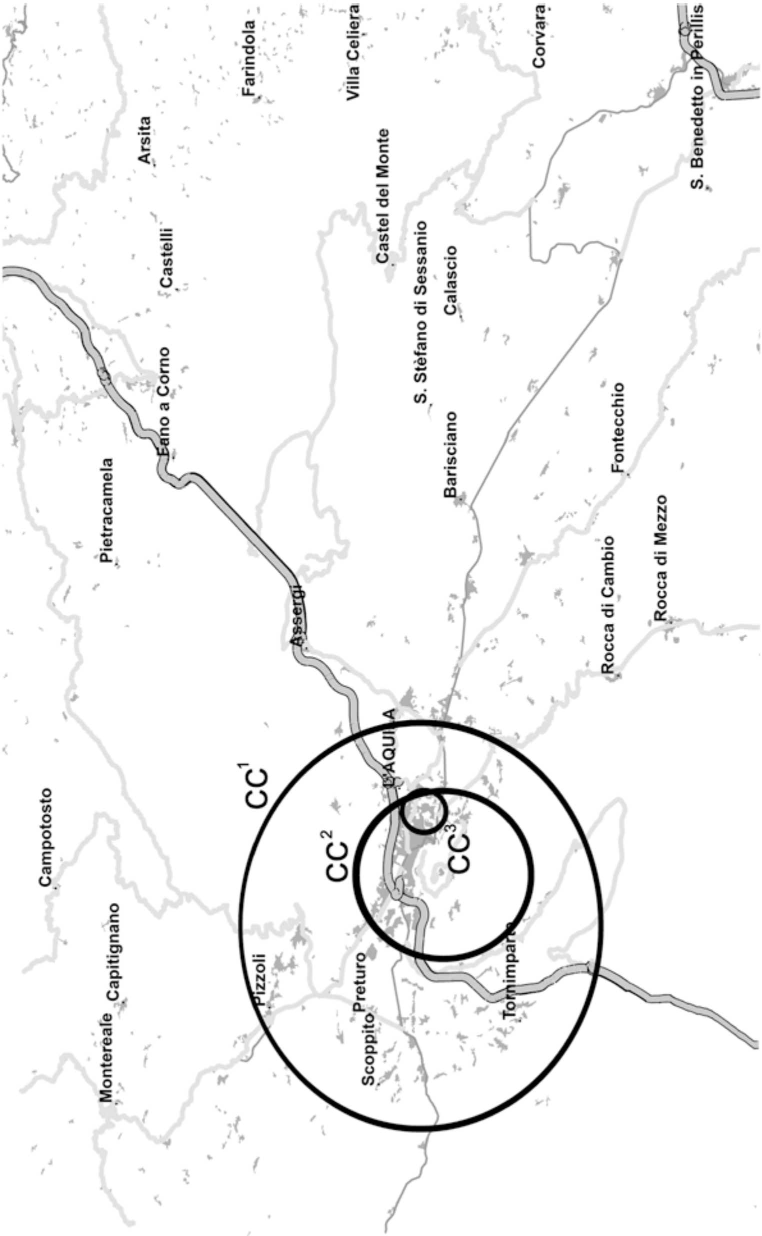

Fig. 1.4 The three circles of consensus for the major risk

Given that the problem of the boundary comes down to a line at a certain distance from the shoreline, the Spatial Shang was reduced from two dimensions to one. Therefore, the analysis was conducted only in one direction and precisely that of longitude (East-West).

On a map containing the eight municipalities involved in the park's area, the stakeholders were asked to indicate two points, representing the minimum and maximum distance of the boundary from the coastline. After the first round, the data consisted of two vectors, one for the east limits (***E***, representing the minimum evaluations), and one for the west limits (***W***, representing the maximum evaluations), both with n values. All the points were transformed in distances from the coastline (with a GIS software), and two arithmetic means were calculated. The results were $E_0 = 2.0$ km and $W_0 = 3.1$ km identifying two lines parallel to the coastline, which delimited a first big buffer of convergence, 1.1 km wide (see Fig. 1.5). The first central value was then $C_0 = 2.55$ km.

In the second round, the stakeholders were asked whether the limit of the park should have been back or ahead the line, drawn on the map, 2.55 km away from the coast. At the second consultation, only 35 stakeholders responded to the Spatial Shang questionnaire, and this high

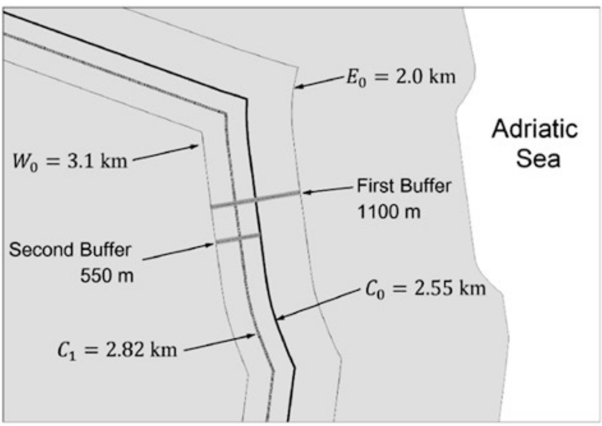

Fig. 1.5 Results of the Spatial Shang

dropout rate was due to the strong conflicts, which have arisen among the stakeholders around this issue (Di Zio and Staniscia 2014a).

Since 65.7% of the respondents declared a limit above the central line C_0, the new area of convergence resulted in a buffer of 550 m, confined between 2.55 km and 3.10 km from the coastline (Fig. 1.5). With these two extremes, the second central value was found to be $C_1 = 2.82$. Given that the area of convergence was small enough, the research group decided to conclude the iterations, and the geographical result was that the boundary of the park should be at about 2.8 km away from the coast and preferably in a strip of land between 2.55 km and 3.10 km from the coastline.

According to the research group, the application of the Spatial Shang had the advantage of stimulating a debate among the main players and represented a way to mitigate the conflicts. The geographical solution was proposed to the competent authorities as a decision support for the definition of the boundaries of the park.

Conclusions and Future Developments

We have seen how the Delphi method is extremely helpful when quantitative data are insufficient or absent, and why it is one of the most widely used techniques to overcome the distortions inherent in the interacting groups (effect of the leadership, spiral of silence and groupthink).

The structuring of the communication among the panelists according to the principles of the anonymity, the iterative structure and the asynchronicity are the main features of the Delphi technique, and all the other methods derived from it, developed in more than half a century, revolve around the same pillars.

In recent years, some scholars developed a new line of research, based on the introduction of the geographical element and the GIS technology (Dragicevic and Balram 2004; Jankowski et al. 2008; Di Zio and Pacinelli 2011). The Spatial Delphi (Di Zio and Pacinelli 2011) and the Spatial Shang (Di Zio and Staniscia 2014a) are the two methods discussed in this chapter and have been designed to treat forecast/decision problems related to the territory. The main innovation resides in the transition from the concept of "consensus" of the conventional Delphi to the new concept of "geo-consensus", in which the experts pursue a convergence of opinions on a limited geographical area.

The experts of the panel answer the spatial questions simply drawing points on a map, and the process of the convergence of opinions is leaded by means of geometric figures. The whole process is fast and easy, and allows for the calculation of a number of measures of geo-consensus and stability. The results are both geographical (the circles or the rectangles) and non-geographical (the comments of the experts and the measures of geo-consensus).

Some of the limits of the Spatial Delphi are the same of the classical Delphi, such as the presence of rounds, the manual computation of the synthesis and the non-interactive structure of any component (questionnaire, supporting materials and boxes for reasonings).

One interesting version of the Delphi method, which overcomes the previous limitations, is the Real Time Delphi invented by Gordon (Gordon and Pease 2006; Gordon 2009b). It is a computerized Delphi, which does not provide for subsequent rounds, therefore leading to a greater efficiency in terms of execution time. The absence of repeated rounds allows the simultaneous computation and delivery of the responses, the possibility of using a large number of participants, low realization costs and high efficiency with regard to the time frame needed to perform the survey. With this method, respondent are not compelled to complete the entire questionnaire in one working session, and can benefit of interactive boxes for comments and reasons.

Recently, a new version of the Spatial Delphi has been developed, from bringing together the logic of the Real Time Delphi, which is roundless and interactive, and the potential of the Spatial Delphi in the management of geographical issues. The method is called *Real Time Spatial Delphi*, which allows the consultation of experts on issues related to the territory in an efficient, real-time way, with very short times and low costs (Di Zio et al. 2016). The system automatically calculates and displays the circles of consensus that shrink and move in real-time during the survey, as well as the measures of geo-consensus and stability. The authors applied the method to the zoning of street prostitution, in Italy, identifying five areas of consensus where the experts considered the zoning most appropriate.

This method preserves most of the advantages of both the Spatial Delphi and the Real Time Delphi, minimizing the disadvantages and opening the way for a number of possible future developments. As suggested by the authors, examples of fields of applications are “architecture, landscape gardening, war games, pinpointing points of origin and potential courses of epidemics, location of future crimes, location of computer hackers, planetary exploration” and even 3D spatial application (Di Zio et al. 2016). The *Real Time Spatial Delphi* runs on a WebGIS platform, with a number of tools and functionalities that make it flexible and usable for a wide range of applications.

We are currently working on further developments of the system, like the *Real Time Spatial Shang*, which uses interactive rectangles instead of circles. Furthermore, we are working on the automatic detection of clusters of opinion-points. In fact, in real applications, starting with a single circle of convergence is a limitation, because it could happen that on the map emerges a number of clusters of points, denoting that the number of suitable places for the solution of the spatial problem is greater than one.

It is worth noting that these studies are inserted in a wider line of research, where the judgments of a panel of experts are collected via web GIS applications. We already have applications in tourism satisfaction (Sarra et al. 2015), in geo-marketing (Di Zio and Fontanella 2012), and for the perception of the risk of terrorist attacks. More precisely, in these applications, the elaborations of the results of the consultation have been performed with a statistical modeling approach known as *Item Response Theory* (de Ayala 2009; De Mars 2010).

In conclusion, the *geographical space*, the *Delphi* logic and the *real time* approach can be combined and constitute the key features of these new methods. Further potentials will be achieved when they will be used in combination with other methodologies, like scenario method techniques, technology list or others.

References

Bailey, T. C., & Gatrell, A. C. (1995). *Interactive Spatial Data Analysis*. New York: J. Wiley.

Brockhaus, W. L., & Mickelsen, J. F. (1975). An Analysis of Prior Delphi Applications. *Technological Forecasting and Social Change, 10*(1), 103–110.

Chatterjee, S. (1975). Reaching a Consensus: Some Limit Theorems. *Bulletin of the International Statistical Institute, 46*(3), 156–160.

Chung, K. H., & Ferris, M. J. (1971). An Inquiry of the Nominal Group Process. *Academy of Management Journal, 14*(4), 520–524.

Dajani, J. S., Sincoff, M. Z., & Talley, W. K. (1979). Stability and Agreement Criteria for the Termination of Delphi Studies. *Technological Forecasting and Social Change, 13*(1), 83–90.

Dalkey, N. C., & Helmer, O. (1963). An Experimental Application of Delphi Method to the Use of Experts. *Management Science, 9*(3), 458–467.

de Ayala, R. J. (2009). *The Theory and Practice of Item Response Theory*. New York: Guilford Press.

De Groot, M. H. (1974). Reaching a Consensus. *Journal American Statistical Association, 69*(345), 118–121.

De Mars, C. (2010). *Item Response Theory. Understanding Statistics Measurement*. Oxford: Oxford University Press.

Di Zio, S., & Fontanella, L. (2012). Public Geomarketing: Georeferencing IRT Models to Support Public Decision. *Statistica Applicata—Italian Journal of Applied Statistics, 24*(3), 301–320.

Di Zio, S., & Pacinelli, A. (2011). Opinion Convergence in Location: A Spatial Version of the Delphi Method. *Technological Forecasting and Social Change, 78*(9), 1565–1578.

Di Zio, S., & Staniscia, B. (2014a). A Spatial Version of the Shang Method. *Technological Forecasting and Social Change, 86*, 207–215.

Di Zio, S., & Staniscia, B. (2014b). Citizen Participation and Awareness Raising in Coastal Protected Areas. A Case Study from Italy. In A. Montanari (Ed.), *Mitigating Conflicts in Coastal Areas Through Science Dissemination: Fostering Dialogue Between Researchers and Stakeholders* (pp. 155–197). Rome: Sapienza Università Editrice.

Di Zio, S., Castillo Rosas, J., & Lamelza, L. (2016). Real Time Spatial Delphi: Fast Convergence of Experts' Opinions on the Territory. *Technological Forecasting and Social Change*, on line doi:10.1016/j.techfore.2016.09.029.

Dragicevic, S., & Balram, S. (2004). A Web GIS Collaborative Framework to Structure and Manage Distributed Planning Processes. *Journal of Geographical Systems, 6*(2), 133–153.

Ford, D. A. (1975). Shang Inquiry as an Alternative to Delphi: Some Experimental Findings. *Technological Forecasting and Social Change, 7*(2), 139–164.

Glenn, J. C. (2009). Participatory Methods. In J. C. Glenn & T. J. Gordon (Eds.), *Futures Research Methodology*, *CD-ROM Version 3.0*. Washington: The Millennium Project, American Council for the United Nations University.

Gordon, T. J. (2009a). The Delphi Method. In J. C. Glenn & T. J. Gordon (Eds.), *Futures Research Methodology*, *CD-ROM Version 3.0*. Washington: The Millennium Project, American Council for the United Nations University.

Gordon, T. J. (2009b). The Real-Time Delphi Method. In J. C. Glenn & T. J. Gordon (Eds.), *Futures Research Methodology*, *CD-ROM Version 3.0*. Washington: The Millennium Project, American Council for the United Nations University.

Gordon, T. J., & Helmer, O. (1964). *Report on a Long-Range Forecasting Study. R-2982*. Santa Monica: The Rand Corporation.

Gordon, T. J., & Pease, A. (2006). RT Delphi: An Efficient, "Round-Less" Almost Real Time Delphi Method. *Technological Forecasting and Social Change, 73*(4), 321–333.

Grime, M. M., & Wright, G. (2016). *Delphi Method*. New York: Wiley StatsRef: Statistics Reference Online: John Wiley & Sons.

Gustafson, D. H., Shukla, R. K., Delbecq, A. L., & Walster, W. G. (1973). A Comparative Study of Differences in Subjective Likelihood Estimates Made by Individuals, Interacting Groups, Delphi Groups, and Nominal Groups. *Organizational Behavior and Human Performance, 9*(2), 280–291.

Hassan, G. (2013). Groupthink Principles and Fundamentals in Organizations. *Interdisciplinary Journal of Contemporary Research in Business, 5*(8), 225–240.

Hastings, H. M., & Sugihara, G. (1993). *Fractals: A User's Guide for the Natural Sciences*. Oxford, UK: Oxford University Press.

Hoffman, L. R. (1965). Group Problem Solving. In L. Berkowitz (Ed.), *Advances in Experimental Social Psychology*. New York: Academic Press.

Jankowski, P., Swobodzinski, M., & Ligmann-Zielinska, A. (2008). Choice Modeler: A Web-Based Spatial Multiple Criteria Evaluation Tool. *Transactions in GIS, 12*(4), 541–561.

Neill, S. A. (2009). *The Alternate Channel: How Social Media Is Challenging the Spiral of Silence Theory in GLBT Communities of Color*. Washington, DC: American University.

Riggs, W. E. (1983). The Delphi Technique, an Experimental Evaluation. *Technological Forecasting and Social Change, 23*(1), 89–94.

Ripley, B. D. (1976). The Second-Order Analysis of Stationary Point Processes. *Journal of Applied Probability, 13*(2), 255–266.

Rowe, G., & Wright, G. (2001). Expert Opinions in Forecasting: The Role of the Delphi Technique. In J. Scott Armstrong (Ed.), *Principles of Forecasting* (pp. 125–144). Boston: Kluwer Academic.

Sarra, A., Di Zio, S., & Cappucci, M. (2015). A Quantitative Valuation of Tourist Experience in Lisbon. *Annals of Tourism Research, 53*, 1–16.

Scheibe, M., Skutsch, M., & Schofer, J. L. (1975). Experiments in Delphi Methodology. In H. A. Linstone & M. Turoff (Eds.), *The Delphi Method: Techniques and Applications* (pp. 262–287). Reading: Addison-Wesley.

Torrance, P. E. (1957). Group Decision Making and Disagreement. *Social Forces, 35*(4), 314–318.

Turoff, M. (1970). The Design of a Policy Delphi. *Technological Forecasting and Social Change, 2*(2), 149–171.

Van de Ven, A. H. (1974). *Group Decision Making and Effectiveness: An Experimental Study*. Kent: Kent State University Press.

Van de Ven, A. H., & Delbecq, A. L. (1974). The Effectiveness of Nominal, Delphi, and Interacting Group Decision Making Processes. *The Academy of Management Journal, 17*(4), 605–621.

von der Gracht, H. A. (2012). Consensus Measurement in Delphi Studies. Review and Implications for Future Quality Assurance. *Technological Forecasting and Social Change, 79*(8), 1525–1536.