# Using Information Aggregation Markets for Decision Support

**Patrick Buckley** Patrick.Buckley@ul.ie
*Department of Management and Marketing*
*University of Limerick*
*Limerick, Republic of Ireland*

**Abstract**

Information Aggregation Markets, often referred to as prediction markets, are markets that are designed to aggregate information from a disparate pool of human individuals to make predictions about the likely outcome of future uncertain events. This paper looks at how Information Aggregation Markets can be incorporated into the standard body of decision making theory. It examines how Information Aggregation Markets can be used as decision support systems, and provides empirical evidence from a wide variety of sources as to the effectiveness and practicality of Information Aggregation Markets. Finally, this paper details some future research questions to be addressed in the area of Information Aggregation Markets.

**Keywords:** Information Aggregation Markets. Decision Making, Decision Support Systems

## 1. INTRODUCTION

Organizations have always faced the problem of making decisions based on the predicted future outcome of large scale, uncertain and complex systems. For example, when a manufacturing organization needs to make a decision regarding current production priorities, its decision will be based in part on an estimation of the likely future demand for a product. An accurate prediction of demand for a product in turn involves determining the value of a product to the customer, consumer sentiment, economic factors, etc.

Two primary approaches have been identified for solving the problem of making predictions about complex systems [1]. The first approach is to develop a statistical model about the observed system that can be used to derive a prediction. However, in modelling very large and complex systems, these mathematical models are beset by a number of difficulties. Firstly, some variables are by their nature immeasurable, for example, consumer sentiment cannot be measured accurately. The number of variables that must be measured when modelling complex systems is often computationally prohibitive. It may be difficult or impossible to precisely define the nature of relationships between variables. The model maker may be completely unaware of important variables to include in the model. These factors place limitations on the accuracy that can be achieved with mathematical models.

The second approach is to identify an expert or group of experts who can make a prediction. These experts use internal models, called heuristics, and are based on an experts experience and wisdom. However, these heuristics are limited by a number of factors. Individuals suffer from bounded rationality and bounded awareness. This places fundamental limits on the accuracy and reliability of these heuristics. Also, these heuristics are usually tacit, which means they cannot be evaluated, transferred or made explicit.

Group decision making can ameliorate some of the problems associated with individual decision making. In this form of decision making, a group of individuals come together to exchange information, and make a prediction about the future outcome of an event. While group decision making can help to overcome the problems of bounded rationality and bounded awareness, group decision making structures also suffer from their own inherent limitations.

Information Aggregation Markets offer a new approach for making predictions. Information Aggregation Markets use a market to aggregate the opinions of a diverse pool of individuals. The assumption is that the market will cancel errors, while preserving and enhancing the accurate components of individual predictions. In this way, Information Aggregation Markets can provide accurate predictions about the future outcomes of large, complex, systems.

Information Aggregation Markets have already been used successfully in a number of areas. The two best known applications are opinion poll replacement and sports betting. This paper will look at how Information Aggregation Markets can be integrated into traditional decision making theory. This paper will also look at empirical evidence regarding the performance of Information Aggregation Markets. Finally, this paper will detail further research that the authors propose to undertake.

## 2. INDIVIDUAL DECISION MAKING

### 2.1 Classical Decision Making

Decision making is usually portrayed in the literature as the process of identifying a problem or opportunity, identifying alternative courses of actions, choosing between these alternatives to solve the problem or exploit the opportunity, and finally implementing the decision taken [2], [3], [4].

The classical decision making model describes an "economic" man who consistently makes decisions that are optimised with respect to the decision makers preferences with regard to consequences [4]. March and Simon present the following description as a model of how decision making occurs according to classical theory [5]. Classical decision making starts with the assumption that the decision maker has available to him the complete set of alternatives the actors from choose from in the given situation. Additionally, each of the possible alternatives has a set of consequences attached to it, which is to say the state of the world that will be instantiated given that the decision maker selects a particular alternative. The decision maker is also assumed to have a utility function which ranks consequences from most to least favorable. Thus decision making is conceptualized as the selection of the alternative that leads to the most favorable consequence as ranked by the decision maker's utility function.

This classical model of decision making contains a number of assumptions. The model assumes that the decision maker has perfect knowledge of the state of the world. It also assumes the decision maker has perfect knowledge of the set of alternatives to choose from.

### 2.2 Limitations on Decision Making

Research has shown that classical decision making model is limited in describing how decisions are actually made [5]. Cognitive, psychological and emotional limits are part of the human condition, and so must be taken as a given. It is not possible for an individual to have perfect knowledge of the state of the world or the set of available alternatives.

Simon points out that knowledge of possible consequences is always fragmentary, that the value assigned to future outcomes is always unknown and can only be estimated, and that humans will only ever be able to conceive of a limited set of responses or alternatives to any situation [4]. Bazerman tells us human rationality is very limited and bounded by the situation and by human computational powers [6].

### 2.3 Bounded Rationality

March and Simon present the concept of bounded rationality to describe some of the ways that the classical theory of decision making falls short of being a completely descriptive theory of decision making [5]. They introduce the concept of satisficing, and distinguish an optimal alternative from a satisfactory alternative. An alternative is optimal if "there exists a set of criteria that permits all alternatives to be compared, and the alternative in question is preferred, by these

criteria, to all other alternatives."

An alternative is satisfactory if "there exists a set of criteria that describes minimally satisfactory alternatives, and the alternative in question meets or exceeds all these criteria."

They describe human decision making as the process of evaluating an alternative to see if it is satisfactory or not. If it is satisfactory, then the alternative is selected, and the search terminates. If it is not satisfactory, then the search continues with the generation and evaluation of another alternative.

They also introduce the concept of a heuristic, which is defined as a rule that guides the search for alternatives.

The use of satisficing and heuristics by human decision makers inevitably leads to suboptimal decisions. Using the model outlined earlier, these phenomenon reflect a failure by the decision maker to identify available alternatives, and choose between these alternatives based on the expected consequences.

### 2.4 Bounded Awareness

Another phenomenon which can affect decision making is bounded awareness. Bazerman refers to bounded awareness as "cognitive blinders [which] prevent a person from seeing, seeking, using or sharing highly relevant, easily accessible and readily perceivable information during the decision making process" [7]. Put in terms of the classical model outlined above, this can be seen a cognitively limited individuals inability to have complete knowledge of the state of the world.

Bazerman and Chugh point out that bounded awareness can be caused by inattentional blindness, which is a failure to see easily identifiable information. For example, one experiment presents a video tape of two visually superimposed basketball teams, one wearing light coloured shirts and the other wearing dark coloured shirts. Participants in the experiment were asked to count the number of passes made between the two teams. To excel in this experiment, participants needed to pay close attention to the videotape. Yet, only 21% of the participants noticed a woman walking through the players carrying an open umbrella [8].

Bazerman and Chugh also point out another example of bounded awareness, which is the failure to seek information. This occurs when a decision maker intentionally or unintentionally does not seek out all the relevant information related to the decision [7]. They offer the example of the Challenger space shuttle disaster as an example of a decision making process which was flawed because the executives determining whether or not to launch did not seek information on the performance of the O-ring on the shuttle under the temperature regime that the launch would occur in.

The failure to seek information can be particularly dangerous when the decision maker has a conscious or subconscious bias towards a particular outcome, which may lead them to ignore information that contradicts or invalidates the decision that they wish to make.

Bounded awareness is also caused by a human decision maker not having access to information that may be critical to making a decision. The decision maker may be unaware of the existence of relevant information due to their incomplete knowledge of the world.

## 3. GROUP DECISION MAKING

### 3.1 Introduction to Group Decision Making

Group decision making refers to situations where the activities such as the identification of alternatives and the selection between competing alternatives are conducted by a group of people, rather then a solitary individual. Shaw offers the definition of a group as "two or more people who are interacting with one another in such a manner that each person influences and is

influenced by each other person" [9]. Many definitions of the term group exist. They generally share the some or all of the following characteristics. Firstly, members of a group share something in common. Groups may share a common motivation or goal. Groups may share a common fate, based on the consequences of the decision(s) that they make [10].

Group decision making means that additional factors enter the decision making process. In particular, the interaction of humans within group decision making situations means that additional social and psychological factors come into play. Issues such as power structures within a group and peer pressure to conform to group norms are important determinants in group decision making. Hitt, Black and Porter describe how using groups impacts on the decision process [2]. They suggest that in establishing alternatives, groups are typically superior to individuals. Similarly, in evaluating alternatives, group judgement is often superior to individual judgement because of the greater range of views and opinions that are considered. Group decision making leads to decisions having greater legitimacy, and thus being more acceptable. However, they also point out that individuals are better at implementing decisions, as individual responsibility is more likely to prompt action.

The above list identifies the two key impacts of group decision making. Firstly, a group decision making process tends to lead to greater approval and acceptance of the decision that is taken. Black and Gregersen showed that participation in the decision making process leads to greater employee satisfaction and improved performance [11]. They also showed that the greater the participation, the greater the improvements in satisfaction and performance. An individual who is part of a group tends to assimilate the goals of that group due to group pressure. Group pressure is created by identification with the group, uniformity of group opinion and group control over the environment [5].

Group decision making impacts positively on the actual process of formulating a decision itself. Using a group to make a decision increases the total amount of information available to solve the problem. The group as a whole has a greater cumulative knowledge of the state of the world then any of the individual members of the group. Similarly, a group's cumulative knowledge of the set of alternatives to be chosen should be greater than any one individual. Finally, a group should be better at choosing between the alternatives available. Assuming each person in a group makes a decision that is partly correct, and partly incorrect, provided the "incorrect" component of each individual's decision is independent of every other persons "incorrect" component, then the incorrect components should cancel or at least mitigate each other.

### 3.2 Combating Bounded Awareness

Bounded awareness refers to an individual having insufficient information available to them to make a correct decision. Human individuals are limited to their intellectual and information processing capabilities. As a general rule, groups have access to more information then any one individual can. Tiernan, Morley and Foley tell us that "Groups generally facilitate a large pool of information to be processed" [3]. Hitt, Black and Porter argue that "groups can accumulate more knowledge and facts" [2]. Ellis and Fisher tell us that individuals may lack "the required knowledge or ability to solve the problem", and contrast this with groups which can "draw on the available pool of information and talent" [10].

These authors make the same point. Group decision making allows information aggregation to occur. This information aggregation gives the group, as a whole, access to more information then any of the individuals comprising the group, and therefore provides the group with a superior knowledge of the state of the world and the set of available alternatives.

### 3.3 Combating Bounded Rationality

Bounded rationality refers to an individual's use of heuristics and satisficing over an objective utility function to choose between available alternatives. Under certain circumstances, group decision making can ameliorate the effect of bounded rationality. Ellis and Fisher point out that groups tend to perform better as the complexity of the task increases, which is equivalent to

saying as the number of alternatives to be chosen between rises [10]. They argue that this is the case because groups have access to more talent then individuals. A group may contain persons who are knowledgeable in an area that is of direct relevance to the problem being solved. They also point out that groups have a greater capacity to store and process information.

Ellis and Fisher also point out that groups are better at judgment decisions than individuals [10]. This is particularly the case where clear answers and clear rules on how to make a decision do not exist. These situations tend to rob an expert of many of her advantages. In situations where a number of alternatives exist and a value judgment has to be made to choose between them, groups generally outperform individuals.

A final area where groups tend to have an edge over individuals is in creatively developing new alternatives to meet challenges. Creativity is stimulated by interaction with others, which can lead to the generation of novel alternatives [10], [3].

### 3.4 Disadvantages of Group Decision Making Structures

The nature of group decision making is that it is a social interaction as well as a decision making process. The presence of interacting individuals inevitably adds complicating factors, which can have an adverse effect on the decision making process.

Some of the problems that are known to occur as a result of the social interactions involved in group decision making include groupthink, information cascades, group polarization and escalating commitments. [10], [2], [9], [3]. These disadvantages in group decision making can counteract the advantages group decision making has over individual decision making.

## 4. GROUP DECISION MAKING STRUCTURES

The simplest form of group decision making structure is the committee. A committee is a group of people who are assembled for the purpose of making a decision. The ways of forming such committee are many and varied.

- The committee may have a hierarchical structure, such as a chairman or some other person, or alternatively all member of the committee may be equal.

- The committee may have formal rules, such as points being made through the chair, or observing formal parliamentary rules or individuals may contribute to the discussion in an ad hoc and informal manner.

- The group may use advocacy, where the participants present alternatives to a single decision maker, or it may use a democratic process, where the group decides upon a course of action using some form of voting.
- The group may seek universal consensus, or it may use simple majority voting.

The above are just some of the ways that a committee can seek to make its decision. Committees offer the advantages for group decision making that are outlined above. However, a committee group decision making structure is also vulnerable to the problems outlined in Section 3.4. In order to minimize the social effects which cause problems in group decision making, a number alternative structures can be used in group decision making.

**Brainstorming:** Brainstorming focuses on the alternative generation phase of decision making. The goal of brainstorming is to “facilitate the development of creative solutions and alternatives” [3]. The key point to note is that brainstorming is only concerned with generating alternatives. It does not involve evaluating these alternatives or choosing between them [2]. The idea of brainstorming is to minimize criticism so that creativity is encouraged. By making the creation of alternatives rather than the search for consensus the primary goal of the group, brainstorming seeks to overcome groupthink.

**Nominal Group Technique:** Nominal Group Technique (NGT) is another group decision making structure. NGT consists of four phases [2]. First, individual members of a group silently and independently generate an alternative course of action. Next, each individual presents his or her idea to the group, without any discussion. After all the individuals have presented their ideas, a round robin discussion to clarify the ideas occurs. Finally, each individual silently and independently ranks the alternatives. The alternative is chosen by the pooled outcomes of the individuals' rankings.

NGT seeks to minimize the amount of discussion and interaction that occurs within a group. Reducing interaction and discussion should in turn reduce the effects of groupthink and reduce the likelihood of information cascades. At the same time, it should allow for at least some information aggregation to occur, during the presentation and question-and-answer phases.

**Delphi:** The Delphi method is even more concerned with removing the effect of social interaction on the group decision making process. When the Delphi method is used, participants never even physically meet. Instead, all group communications are mediated through questionnaires [12].

The three structures outlined above all attempt to impose a structure on group decision making that seeks to counteract the drawbacks and problems that are caused by social interactions, while at the same time allowing information aggregation to occur. Brainstorming seeks to remove the competitive element that enters any human interaction, by "accepting" all alternatives. Nominal Group and Delphi seek to limit the interaction that occurs between participants. Delphi seeks to ensure that even non-verbal cues and reputation issues do not affect the decision making process.

## 5. INFORMATION AGGREGATION MARKETS

### 5.1 Introduction to Information Aggregation Markets

A market is "a set of arrangements by which a buyer and seller are in a contract to exchange goods and services [13]. In a market, demand is the quantity of a good a buyer will purchase at each conceivable price, while supply is the quantity of a good sellers wish to sell at each conceivable price. The concepts of supply and demand lead us to the concept of an equilibrium price, which is the price of the good where the supply equals the demand.

The definition of a market above, which includes the concept of an equilibrium price, implies that information aggregation occurs in a market. All the information that is available to all the participants in a market with regards to the demand and supply of a product is aggregated into a single equilibrium price [14]. This is an example of information aggregation.

Hayek proposes two further attributes of markets. He states that markets operate as "near perfect transmitters" of information, and that markets could communicate with all the participants in the market instantaneously [15].

The two principles above led to the development of the "efficient markets hypothesis", which proposes that markets can aggregate and disseminate new information almost immediately [16].

Malkiel [16] points out that questions are continuously being raised about the efficient markets hypothesis. He cites events such as the spin off of Palm by 3Com and the technology bubble of the late 1990s as an example that markets do not assimilate all available information correctly and instantaneously. However, he answered these critics by showing that managed mutual funds do not perform any better than a simple index linked fund on average. The clear implication here is that even if markets do not aggregate information perfectly, they certainly outperform any existing model or individual.

Rather then viewing markets as instruments to distribute capital or share risk, some researchers have now begun to view markets as mechanisms for aggregating information. Markets which are designed to aggregate the markets participants' information about future events of interest are referred to as Information Aggregation Markets, although a number of other terms are used in the literature, including prediction markets, decision markets, electronic markets, virtual markets and idea futures [19].

No commonly agreed definition of an Information Aggregation Market has yet emerged. Berg and Rietz define an Information Aggregation Market as being a market "run for the primary purpose of using the information content in market values to make predictions about specific future events" [17]. Spann and Skierra describe it as being a market that allows a group of participants trade shares in virtual stocks, where "the stocks represent a bet on the future outcome of future market situations and their value depends on the realization of these market situations" [24]. Wolfers and Zitzewitz see them as being "markets where participants trade in contracts whose payoff depends on unknown future events" [18]. The definition preferred here is "Information Aggregation Markets are defined as markets that are designed and run for the primary purpose of mining and aggregating information scattered among traders and subsequently using this information in the form of market values in order to make predictions about specific future events." [19].

### 5.2 Information Aggregation Markets as Group Decision Making Structures

As pointed out previously, group decision making tends to outperform individual decision makers in certain situations because group decision making allows for information aggregation to occur. By allowing information aggregation to occur, Information Aggregation Markets offer the same advantages that group decision making techniques offer in terms of combating bounded rationality and bounded awareness.

When compared with group decision making techniques, Information Aggregation Markets also offer some advantages. When using an Information Aggregation Market, all information is transmitted through the medium of a share price, thus reducing the effect of social interactions that can otherwise affect group decision making structures.

Finally, as Plott and Chen point out, many business problems "share the following characteristics: small bits and pieces of relevant information exists in the opinion and intuition of individuals who are close to an activity. … In many instances, no systematic methods of collecting system information exist." [20] They move on to argue that while very little may be known by any one individual, the aggregation of the bits and pieces of information may be considerable. Information Aggregation Markets may offer an approach for efficiently gathering this information together and aggregating it.

## 6. INFORMATION AGGREGATION MARKETS IN PRACTICE

One of the most well-known and long running examples of an operating prediction markets is the Iowa Electronic Market (IEM). The IEM is a real time futures market in which contract payoffs depend on the results of economic and political events such as elections. The IEM was originally set up in 1988, and since then has been noted for delivering a series of predictions on the outcome of the US presidential elections, which were more accurate then opinion polls.

Joyce Berg and Thomas Rietz are two directors of the IEM. In their 2006 paper "The Iowa Electronic Markets: Stylized Facts and Open Issues", they offer a description of the IEM as being a "real-money, small scale futures market that focuses on the information revelation and aggregation roles of market prices, rather then on their role in determining allocations". The IEM is best known for its political markets, which attempt to aggregate information in order to create a prediction of the outcome of future political events, but also offers markets in a wide variety of other topics, such as legislative processes, international relationships, economic indicators, and many other topics.

Research has shown that the IEM is accurate, both relatively to the next best alternative (i.e. in the case of elections, opinion polls) and absolutely. The average absolute percentage error for presidential eve contracts is 1.33 percent. Further analysis shows that the IEM prices are closer to the actual election vote share in 76 percent of the cases [21].

Prompted by the success of the IEM, a large number of other prediction markets have been founded. Examples covered in the literature include:

*Trading Exchanges:* Tradesports is an Irish online trading exchange which was founded by John Delaney in 2000 [22]. In 2005, it was reported to have over 50,000 members and an average monthly volume of four million trades. It allows participants to speculate on the outcomes of future events in sports. Another example of a commercial prediction market in sports betting is offered by Betfair. In a similar vein, Newsfutures and Foresight exchange also allow users to participate in markets on the future outcome of sporting events. However, whereas Tradesports and Betfair offer markets using real currency, Newsfutures and Foresight allow participants to trade in virtual currency. [18]

Schreiber, Wolfers, Pennock and Galebach performed an analysis comparing the predictive power of Tradesports with that of Newsfutures. The authors demonstrated that both markets consistently outperformed the average investor at predicting the results of American football games [23].

*Virtual Stock Markets (VSMs):* Another application of Information Aggregation Markets is to gather information on the future performance of private sector returns. For example, the Hollywood Stock Exchange (HSX) allows people to use virtual currency on movie related questions such as opening weekend performance, total box office take, and who will win Oscars [18]. This information is beneficial to film studios, distributors and cinemas. Other examples of these VSMs include the Chart and Movie Exchange, which is used to track music single and album sales. Additionally, these VSMs could be used as tools to identify participants who are particularly good at making predictions. Researchers also posit that these VSMs could be used as early warning systems or "trend scouts" that could identify emerging trends within an industry or industry segment [24].

Spann and Skiera [24] performed an analysis of the HSX, which demonstrated that the market was able to consistently match or beat experts in predicting the outcome of the various events outlined above.

*Internal Business Planning*: A number of companies, including Microsoft, Google, and Yahoo have recently begun experimenting with using Information Aggregation Markets to improve internal decision making and prediction. Siemens created an internal Information Aggregation Market which predicted that it would be unable to complete a software project by a particular date, though standard modeling tools suggested otherwise. The Information Aggregation Market was proven correct.

Hewlette Packard (HP) are also heavily involved in using prediction markets. In 1996 Plott and Chen compared predictions for printer sales made by HP's internal models against those made by a prediction markets. In six out of eight tests, the prediction market outperformed HP's internal business models [20]. Plott and Chen also showed that the probability distributions calculated from market prices were consistent with actual outcomes [20]. Leading on from this, HP have developed the BRAIN process, which is a large scale program aimed at integrating a modified Information Aggregation Mechanism into their decision making structures.

Other examples of Information Aggregation Mechanisms being used in industry include markets on the future readings of economic statistics launched by Goldman Sachs and Deutsche Bank. Passmore offers the possibility that Information Aggregation Markets can be used to support Human Resource and other organizational functions. [25]

A number of authors including Hahn [26] and Hanson [27] conclude that Information Aggregation Markets could be used to help inform public sector decision making and legislation. However, the fate of the Policy Analysis Market, which was cancelled in 2002 after members of the United States Congress accused it of offering a way of betting on the possibility of future terrorist events, offers a warning that large scale use of prediction markets in such situations may not be easy. Additionally, the recent laws passed in the United States prohibiting online gambling raise questions as to the legality of operating Information Aggregation Markets in the United States. For example, Tradesports has been forced to cease operations in the United States, since its modus operandi violates the new law.

## 7. CONCLUSIONS AND FURTHER RESEARCH

This paper has argued that Information Aggregation Markets can be used as tools to support decision making within an organization. By showing that the information aggregation that occurs in group decision making is similar to that which occurs in Information Aggregation Markets, this paper supports the premise that Information Aggregation Markets can be used for decision support within organizations. Information Aggregation Markets use the mechanism of a share price to allow information aggregation occur, which may be less vulnerable to the social effects which affect other group decision making structures.

Empirical evidence has been provided from a large number of sources demonstrating the efficiency of currently operating Information Aggregation Markets.

The authors believe that further research in the area of Information Aggregation Markets should be pursued. Much research remains to be done in the area of the design of Information Aggregation Markets. In the context of this paper, the authors believe that one important research question is how managers will view Information Aggregation Markets as decision support systems. While most decision support systems are transparent, and show how a decision is reached, Information Aggregation Markets are opaque. Little or no information is available as to how a market reached a consensus as a price. This lack of transparency may raise barriers to the acceptance of Information Aggregation Markets as decision support tools, and requires further investigation.

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