Liquid Decision Making: Applying the Market Metaphor to Collective Decision Making

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Abstract

In today's business world, decisions have to be made on different levels, including strategic, tactical, and operational levels. Decisions on the strategic level are characterized by their complexity, longevity and impact. Such decisions can benefit from the participation of a large, diverse group of people as they contribute different background knowledge, perspectives, and evaluation criteria. Typically, such decisions need to be considered over a prolonged period of time as opinions may need to be formed or may change due to the availability of new information. The goal of people in group decision making situations is typically to achieve good decisions. A mechanism is thus desirable that is capable of addressing the aforementioned challenges and of producing a good decision. For this work, a decision is thought to be good if it is predominantly based on the sincere opinions of the participants.

In this thesis, we investigate the market metaphor as a promising approach for group decision making. Markets are attributed with the capability of gathering and aggregating assessments from people in a single indicator, the price. They allow for a continued participation over a prolonged time, reversibility of one's market position by repeated trading, and the usage of individual evaluation criteria. For investigating the application of the market metaphor to decision making, we develop Liquid Decision Making, a market-based approach for group decision making. There, we represent a pending decision as a market and the decision options as stocks. Participants then buy shares of their favored stocks and sell shares of the stocks they dislike. High demand leads to price increase whereas low prices are the result of low demand. The most favored decision options can be identified from the ranking of the stocks according to their prices. To support the achievement of a good decision, we model the market behavior of participants, devise design principles, identify suitable application scenarios, and determine appropriate functionalities for a market software. We furthermore devise the concept of market perturbations for uncovering the trading intentions of participants.

We furthermore implement a web-based software prototype of Liquid Decision Making. It provides functionalities for decision making, market trading, user handling, information exchange, and market perturbations. Participants there trade their favored stocks using virtual play money. We test the Liquid Decision Making approach and its software prototype in an EU-funded project, in a lab study, in the selection of research proposals, and in a university seminar for scenario building.

Zusammenfassung

Entscheidungen müssen in Unternehmen auf unterschiedlichen Ebenen getroffen werden. Besonders strategische Entscheidungen sind oft komplex, langwierig und haben weitreichende Auswirkungen. Die Beteiligung einer großen, heterogenen Personengruppe kann solche Entscheidungen begünstigen, da sie unterschiedliches Hintergrundwissen sowie verschiedene Perspektiven und Bewertungskriterien beisteuern. Oft werden solche Entscheidungen über einen längeren Zeitraum getroffen, da die Beteiligten sich ihre Meinungen erst bilden müssen, oder diese sich durch neue Informationen ändern. Um dabei gute Entscheidungen zu treffen, sollte ein Ansatz dazu unter den geschilderten Umständen ein gutes Ergebnis liefern können. Als gutes Ergebnis wird in dieser Arbeit eine Entscheidung angesehen, die hauptsächlich auf der ehrlichen Meinung der Teilnehmer beruht.

In dieser Arbeit untersuchen wir die Marktmetapher als vielversprechenden Ansatz für die Entscheidungsfindung. Märkten wird die Fähigkeit zugeschrieben, Informationen von verschiedenen Personen in einem einzigen Indikator, dem Preis, aggregieren zu können. Sie ermöglichen dabei eine kontinuierliche Teilnahme über einen längeren Zeitraum, eine Änderung der Meinung durch wiederholtes Handeln sowie die Anwendung von individuellen Bewertungskriterien. Für unsere Untersuchung entwickeln wir Liquid Decision Making, einen marktbasierten Ansatz für die Entscheidungsfindung in Gruppen. Eine anstehende Entscheidung wird darin als Markt repräsentiert und die Entscheidungsoptionen als Aktien. Die Teilnehmer kaufen Anteile ihrer favorisierten Aktien und verkaufen die Anderen mittels virtuellem Spielgeld. Eine hohe Nachfrage führt zu hohen Preisen, niedrige Nachfrage zu niedrigen Preisen. Aus der Rangfolge der Aktien nach ihren Preisen kann dann die bevorzugteste Entscheidungsoption identifiziert werden. Um eine gute Entscheidung mittels Liquid Decision Making zu erreichen, erstellen wir ein Verhaltensmodell der Teilnehmer, Entwurfsprinzipien, geeignete Einsatzszenarien und geeignete Funktionalitäten für eine Software. Außerdem entwickeln wir das Konzept der Marktstörungen um Handelsintentionen der Teilnehmer in Erfahrung zu bringen.

Diese Aspekte setzen wir in einer webbasierten Software um, die Funktionalitäten zur Entscheidungsfindung, zum Handeln, zur Nutzerverwaltung, zum Informationsaustausch und für Marktstörungen enthält. Liquid Decision Making sowie die Sofware testen wir erfolgreich in einem EU-Projekt, in einer Laborstudie, bei der Auswahl von Forschungsvorhaben und in einem Universitätsseminar zu Szenarioentwicklung.

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Publications of the Author

1. Stephan Leutenmayr, François Bry, Tom Schiebler, and Felix Brodbeck. Work in Progress: Do They Really Mean It? Assessing Decision Market Outcomes. In Hans-Ulrich Heiß, Peter Pepper, Holger Schlingloff, and Jörg Schneider, editors, *INFORMATIK 2011 Informatik schafft Communities, Berlin, Germany, 2011*, Lecture Notes in Informatics, Bonn, Germany, 2011. Gesellschaft für Informatik.

2. Stephan Leutenmayr and François Bry. Liquid Decision Making: An Exploratory Study. In David Taniar, Eric Pardede, Hong-Quang Nguyen, Wenny Rahayu, and Ismail Khalil, editors, *Proceedings of the 13th International Conference on Information Integration and Web-based Applications and Services, Ho Chi Minh City, Vietnam, 2011*, iiWAS '11, pages 391–394, New York, NY, USA, 2011. ACM.

3. Stephan Leutenmayr, Sven Ziemer, and François Bry. Decision Markets for Continuously Reflected Collective Decisions. In *Proceedings of the 3rd International Conference on Social Eco-Informatics (SOTICS), Lisbon, Portugal, 2013*, Wilmington, USA, 2013. IARIA XPS Press.

4. Stephan Leutenmayr, Fabian Kneissl, Sven Ziemer, and François Bry. Gameful Markets for Collaboration and Learning. In Markus Krause, François Bry, and Mihai Georgescu, editors, *Proceedings of Disco 2013, Workshop on Human Computation and Machine Learning in Games at HComp, Palm Springs, USA, 2013*, Palo Alto, USA, 2013. The AAAI Press.

The author of this dissertation contributed to publication 1 the distinction between prediction markets as a way of making predictions and decision markets as a way of selecting a decision alternative, the identification of two different incentives for participation, namely the contribution of one's sincere opinion and the achievement of a reward, the quality definition of market results, and the design and architecture of the market software. François Bry and the author of this dissertation devised the approach of market perturbations as a method of determining the trading intentions of participants. The evaluation from a psychological perspective based on framing different settings was conceived by Felix Brodbeck and Tom Schiebler.

To publication 2, François Bry and the author of this dissertation contributed the introduction of Liquid Decision Making as a way of making decisions using a market-based approach and the concept of market perturbations. The author of this dissertation complemented the design and evaluation of the laboratory study, including results on the market application, market perturbations, trading patterns and the market software.

The author of this dissertation contributed to publication 3 the design principles of collaborative decision, user involvement and dual incentives, the market software functionalities for decision making, trading, commenting and rating, and the description and evaluation of the *Szenario Börse* case study, including results on the market application, design principles, market perturbations, and the market software. Together with François Bry, the author of this dissertation contributed the concept of Liquid Decision Making. Sven Ziemer complemented the considerations on related decision making approaches.

To publication 4, the behavior models for different types of markets, the forecast context and the decision making context, the reward design of outcome vs. performance and the suitability of different rewards for different market goals were contributed by the author of this dissertation. Together with François Bry, the author of this dissertation added the description of Liquid Decision Making. Fabian Kneissl and François Bry complemented the aspect of human computation as well as the description of Metropolitalia to publication 4. The aspect of learning in markets was contributed by Sven Ziemer, Fabian Kneissl, François Bry and the author of this dissertation.

Some ideas, figures and expressions presented in this work previously appeared in the aforementioned publications of the author. In particular, Chapter 3 of this work extends on the application of markets to decision making (publications 1 and 2), the behavior models (publication 4) and the different types of markets (publications 1 and 2), the forecast and the decision making context (publication 4), the identification of two different types of incentives for participation (publications 1 and 2), the design principles (publication 3), the quality definition of market results (publications 1 and 2), and the approach of market perturbations (publications 1 and 2). Chapters 4 and 5 elaborate on the design, architecture and implementation of the Liquid Decision Making system (publications 1, 2 and 3). Finally, the laboratory study and the *Szenario Börse* case study are evaluated in more detail in Chapter 6 (publications 2 and 3, respectively).

Contents

Part I

Foundations

CHAPTER 1

Introduction

Decision making is an everyday's task of our business and personal life. In business, decisions need to be made on an individual, organizational and strategic level. Consider for example the design and development of an aircraft. Several decisions have to be made there, including its desired range, target market, transport capacity and geometric configuration. An aircraft is nowadays a rather complex entity which needs to be considered from various perspectives including aerodynamics, structure, propulsion and manufacturing. Economical, ecological, and societal aspects need to be taken into account, too. The more strategic decisions are characterized by their complexity, longevity and impact on the development processes and the final product.

Due to this complexity and impact, strategic decisions often need to be made, or benefit from, the participation of a large, potentially diverse group of people from different domains with different expertise. These people contribute different perspectives on the subject, bring various experiences and often utilize different assessment criteria. Most often, however, a comprehensive and in-depth evaluation of all possible alternatives is not feasible due to temporal and other constraints. Furthermore, some decisions need to made over a longer period of time. On the one hand, people need time to gather relevant information and to form an opinion on the subject at hand. On the other hand, some decisions may only gradually become apparent and the corresponding decision alternatives may emerge or change over time.

Participants in such strategic decision making efforts typically care for the realization of the solution that is best from their point of view. To this end, participants assess the decision alternatives using their own evaluation criteria and contribute their resulting opinion to the joint decision making. Participants contribute their sincere opinion on the decision alternatives, as this brings forward the realization of their most favored decision alternative.

1.1 Motivation

Under the terms *Web 2.0* and *Social Media*, paradigms of user engagement and participatory content creation have emerged over the recent years. People create, share and utilize information concerning their topics of interest in a large and distributed fashion over the Web. The market metaphor is one element of these social media approaches. Economic markets are attributed with the capability of aggregating information from people in an intuitive indicator, the market price. Supply and demand of goods determine their market prices. The resulting prices can be interpreted as the effective assessment of all traders of that good. This effective assessment has been mediated through the market. *Assessment* refers to the determination of the value that people assign to a certain good. Low demand results in lower prices and can be interpreted as an indicator for negative assessments whereas high demand and thus higher market prices can be interpreted as indicators for positive assessments.

The market metaphor has been successfully applied to gathering assessments from large groups of people in the prediction of the outcome of uncertain future events in the form of so called *prediction markets*. In prediction markets, the potential outcomes of a future event are represented as stocks on a virtual market and participants trade shares in these stocks. The resulting market prices are interpreted as the aggregated assessment of the likelihood of the underlying event outcome. At the occurrence of the event, the market is closed and participants are rewarded for each stock that they hold of the actual outcome. The other stocks are voided. Such prediction markets have been found to be at least as accurate in the aggregation of predictions as other means of forecasting [11, 12, 35, 102]. Furthermore, they provide incentives for participation as people who are confident with their opinion can earn some reward from correctly predicting the outcome of the future event. Prediction markets also allow for a continuous participation, repeated revisions of one's share holdings, and the application of individual assessment criteria and they provide a promptly feedback on one's market actions.

Other contexts besides forecasting can also benefit from gathering information from large groups of people, for example in the generation and evaluation of ideas, in the collection of product feature preferences, and in the management of research portfolios. The market metaphor has been applied in these contexts to aggregate information with the goal of benefiting from the aforementioned appealing characteristics [14, 22, 34, 53, 58]. However, the characteristics exhibited by the market metaphor in prediction markets are related to the circumstances of such prediction efforts and may not be fully preservable if the market metaphor is applied in other contexts. This thesis is motivated by the observation that a straight-forward application of the market metaphor in the standard prediction market way to other contexts can have its pitfalls. Rather, only specific situations may be suitable for the application of the market metaphor for gathering information from groups of people and for aggregating it into a useful result.

In this thesis, we investigate the application of the market metaphor in the context of decision making in *decision markets*. A decision market is a market that has been established with the goal of aggregating the assessments of a group of people to select a decision option from a set of options. In our investigation of the different applications of the market metaphor for aggregating people's assessments, we noticed that a lack of properly designed incentives in certain settings of market applications can lead to participants not contributing their sincere opinions. This in turn seemed to lead to an inferior usefulness of the market's result for the respective organizer who is interested in those sincere opinions. Thus, one goal of this thesis is to investigate proper designs of market applications for achieving useful market results, that is, decisions. For this work, we term such useful market results as *good decisions* if they are predominantly based on the contribution of sincere opinions by the participants. We also assume that participants are knowledgeable on the respective decision topic at hand and that they are able to contribute that knowledge in a market-based decision making effort.

Voting represents another means for gathering the assessments of people and for achieving a joint decision. However, the market metaphor exhibits capabilities that are not found in typical voting mechanisms. Voting is mostly a one-time effort, that is, the votes are collected over a short period of time and the result is presented subsequently without the opportunity to react to the result and to change one's vote. The market metaphor in contrast allows people to observe the market, incorporate new information from the market as well as from outside sources, and to form their opinion on the market topic. The market metaphor allows participants to repeatedly trade and to change their share holdings according to their current opinion. The immediate price feedback of the market metaphor provides a prompt insight to the opinions of the other traders. The price mechanism of the market metaphor provides for a first-mover advantage and encourages decisiveness among its traders. Over the runtime of the market, favored stocks may increase in price. Hence, people who buy early when prices are low have an advantage. The same is true for decisiveness. Indecisive traders who spread their share holdings among many stocks may have to pay higher prices towards the end of the market runtime for their favored stocks.

1.2 Research Questions

In the preceding section, we outlined that care should be taken in the aim of transferring the approved characteristics of the market metaphor in prediction markets to other contexts of information aggregation from groups of people. In the following, we provide four research questions that guided our research on the application of the market metaphor to decision making. These research questions concern the aspects of the market application, the functionality of the supporting system, the behavior of the users, and the nature of the decision making situation. We devised these questions from literature survey as well as own observations in studies that we conducted.

RQ 1: How can the market metaphor be applied to group decision making? The first research question refers to the general application of the market metaphor to group decision making. We observed that differing levels of emphasis on the market nature of the approach have an impact on the behavior of participants and the achievement of the decision making goal. Thus, the first question deals with the general application of the market metaphor to a decision making effort.

RQ 2: Which functionalities are appropriate for market-based group decision making? The second research question refers to the functionalities that can support users of a market based decision making approach in achieving a joint decision. The functionalities can be subdivided into functionalities for inspecting the decision and the decision options as well as for contributing new ones, functionalities for trading in the stocks of the single decision options and functionalities for keeping people up-to-date on the market status and their respective holdings and changes on the market.

RQ 3: Which incentives encourage the contribution of sincere opinions by participants? The goal of the application of the market metaphor to decision making is to achieve a good decision in a group of people. A decision is assumed to be good if it is based mostly on the sincere opinions of the participants. This achievement is impacted by the behavior of the participants. In some cases, participants may mainly act in speculative and trend following ways and may not contribute their sincere opinions. In other cases, people may mainly act according to their sincere opinions and guided by the desire to achieve a good decision. This behavior is influenced amongst others by the incentives that are provided to the participants. The deliberate provision of incentives should thus support the continued participation of people, the contribution of meaningful information and, finally, the achievement of a good decision.

RQ 4: Which scenarios favor the achievement of a decision that is predominantly based on sincere opinions? A decision making effort is characterized by several external factors of the decision making situation. Some of these factors are under control of the group whereas others have to be taken as is. Different values of these factors can be summarized in decision making scenarios. Some of these scenarios may be more suitable for market-based group decision making than others and may be more likely for the achievement of a good decision.

1.3 Results

This thesis summarizes the results of our research regarding the aforementioned research questions. For investigating the aforementioned issues, we devised Liquid Decision Making (LDM), a market-based approach for decision making, and tested this approach in case studies.

1.3.1 Findings

We gained the following insights on the application of the market metaphor to decision making by iteratively advancing the concept of LDM, by implementing a prototype and by applying it in case studies.

Applicability The market metaphor allows for the aggregation of information from a large and heterogeneous group of people. We found that this capability can be fruitfully used for decision making by applying the identified correspondence between elements of the market metaphor and decision making, and by following the design principles that we devised in this research for the design of installments of LDM.

Incentives The behavior of participants in decision markets is influenced by the provided incentives. We found that incentives in decision markets should primarily encourage participants to contribute their sincere opinions rather than to gamble for the maximization of their portfolio worths. The design principles of this research provide useful guidance for adjusting such incentives.

Judgment of participants' motivations The trading behavior of participants in decision markets is also guided by their goals and intentions. Market organizers are interested in a decision as a market result that is predominantly based on the sincere opinions of the participants. We found that market perturbations can be utilized for judging the sincereness of the participants' contributions.

Feasible application scenarios The circumstances of an application of the market metaphor to a decision making situation have an impact on the achievement of a good decision. We found that such scenarios should favor the achievement of a good decision that exhibit direct result utilization, personal stakes of the participants, and incentive objectives based on contributions are likely to foster the achievement of a good decision.

1.3.2 Liquid Decision Making

The aforementioned findings were gained by iteratively devising and testing LDM. LDM consists of theoretical foundations for market-based decision making, a system concept for supporting such decision making, and a software prototype.

Foundations

This part of LDM provides the theoretical foundations for the application of the market metaphor to decision making. The foundations deal with the correspondence between the elements of the market metaphor and of decision making, the behavior of participants in virtual markets, design principles for decision markets, the concept of market perturbations, suitable application scenarios, and application steps.

Market Approach The market metaphor allows for the aggregation of information from a large group of people into a single indicator, the stock price. Based on these prices, a ranking of the stocks can be generated and the most favored stocks can be identified. In LDM, we utilize this information aggregation capability for achieving good decisions in decision making. To this end, we set the correspondence between elements of decision making and of the market metaphor. A decision corresponds to a market and a decision option refers to a stock of that market.

Virtual Market Model Participants in virtual markets can exhibit various trading behaviors, for example based on the contribution of one's sincere opinion or based on the maximization of one's portfolio worth. These trading behaviors may be more or less beneficial for the achievement of a good decision. To better understand the origins of these behaviors, we devise a virtual market model comprising the factors of market design and application scenario as the main influencing factors for the behavior of participants.

Design Principles We develop the design principles of a collaborative decision, of user involvement and of dual incentives for appropriately designing installments of LDM. The goal of these design principles is to guide the trading behavior of participants towards the achievement of a good decision.

Market Perturbations Despite the design principles, participants may behave detrimentally to the achievement of a good decision. For such situations, we devise the concept of market perturbations for learning to know the trading intentions of the participants.

Application Scenarios Some application scenarios may be more suitable for LDM than others. We identify two scenarios that should be most suitable for the application of LDM based on the factors of result utilization, stakes, and incentive objectives.

Application Steps For actually employing LDM in a decision making effort, certain design decisions have to be made during the setup. We provide the steps of selection, preparation, execution, and evaluation for this purpose.

System Concept

In the system concept of LDM, we identify the conceptual architecture of the LDM system as well as appropriate functionalities for supporting market-based decision making.

Conceptual Architecture For applying the market metaphor to decision making, we devise a conceptual architecture that builds on the ranking capability of the market metaphor for decision making. The architecture comprises furthermore different potential application domains.

Functionalities A system for market based decision making has to provide certain functionalities to its participants. For the LDM system, we identify appropriate functionalities in the categories of decision making, market trading, user handling, information exchange, and market perturbations.

Software Prototype

The third part of the LDM approach comprises the software prototype. We implement this software prototype as a web based system that provides participants with the identified functionalities for the creation of decisions and decision options, the trading of stocks in these decision options, the commenting on the market items as well as the perturbation of stock prices and provides the user with an overview on the market status and his respective share holdings and available cash.

1.4 Outline

This thesis is structured as follows. After this introductory chapter we provide a literature survey in Chapter 2. In the subsequent Chapter 3 we introduce the foundations of the

LDM approach and its application of the market metaphor to decision making. Chapter 4 then highlights the system concept of the LDM approach, based on the foundations introduced in the previous chapter. The software prototype of LDM is then introduced in Chapter 5. We finally report on the executed case studies and discuss their results in Chapter 6. We conclude this thesis by summarizing the executed work and by revisiting the research questions as well as by providing further research directions and an outlook in Chapter 7.

CHAPTER **2**

The Market Metaphor

The market metaphor has been successfully employed to forecasting uncertain future events and has also been applied in other contexts. In this chapter, we survey the basis of these applications of the market metaphor, including market design, market mechanisms, and the workings and capabilities of prediction markets.

2.1 Introduction

Markets are attributed with the capability of aggregating information in an intuitive indicator, the stock price [45]. More specifically, traders on a market strive to make profits through the trading of stocks. For this, they look for information on the profitability of the single stocks. Based on the gathered information, participants form personal profitability assessments on the single stocks. They convey these assessments to the market by their buy and sell orders. Participants buy shares of promising stocks and sell shares of overvalued stocks. This supply and demand is continuously reflected in the market prices of the stocks. Stocks that look promising to many traders and that are thus highly sought for get more expensive than those that are assessed to be overvalued and thus have high supply. In this way, the stock price aggregates the information on the assessments of the single traders. The core features include the trading of stocks on a market, the utilization of money for trading, and the interpretation of the resulting prices as an indicator for the demand of the stocks. We refer to these features in the following with the term *market metaphor*.

In this section, we introduce the general concept of the market metaphor as well as its application in different contexts for aggregating information from groups of people. We highlight their design, their promising capabilities, their different application forms, their market mechanisms, and the potential behavior of their participants as well as manipulatory and legal issues.

2.2 Prediction Markets

Complex problems today often require the gathering of information from a large group of people for solving these problems. The application of the information aggregation capability of markets to such information gathering problems is a promising way to tackle such problems. One of the first applications of the market metaphor as a dedicated information aggregation mechanism dates back to the Iowa Presidential Stock Market in 1988 [33]. There, the organizers employed the market metaphor in a so called *prediction market* in order to aggregate forecasts for the outcome of the then presidential election.

The general idea of such prediction markets is as follows. Organizers create a virtual stock market for an uncertain future event that they want to be forecast. On this stock market, they issue stocks of the potential outcomes of this uncertain event. Potential traders are then offered a pay-off corresponding to a reward scheme. For example, shares of the stock corresponding to the actual event outcome are payed off with $1 whereas all other stocks are valued to $0. Traders then receive virtual currency and buy shares of the event outcome they assessed to be most likely and sell shares of the other outcomes. The market mechanism then aggregates all trades and determines prices of the stocks accordingly. Over the runtime of the market, participants may change their share holdings in order to reflect changes in their assessment. In this way, the market organizer gets a real-time impression of the traders' assessments through the development of the stock prices. The prices are assumed to reflect the information that is available to participants. Competing influences on the stock prices balance each other and form an equilibrium between buy and sell orders. The prediction market is then closed prior to the occurrence of the event as traders would then know the outcome with certainty. After the closing of the market, its result is evaluated with respect to the occurred event outcome and participants are rewarded. A key element for this evaluation is the verifiable outcome at the end of the market.

Prediction markets are basically a bet that pays off if a particular outcome of the predicted uncertain event occurs. In contrast to betting, however, prediction markets allow one to revoke the bets by "reversing" the executed trades, that is, selling purchased shares. An example of this is given in Figure 2.1 which we adopted from Graefe et al. [35]. There, a trader in the market for forecasting the outcome of a presidential election estimates that the likelihood of Barack Obama being re-elected as President of the USA is 70%. The current price of the stock representing Obama's re-election, however, is at $45, which is lower than the expectation of our exemplary trader. Therefore, there is a potential for expected profit for this trader. He therefore buys 20 shares of the Obama stock. Upon the determination of the election result, traders in this prediction market are paid off according to their share holdings. Assume for this example, every stock of the occurred outcome pays $100, whereas the other stocks pay $0. Our trader then receives $\$100 \times 20 = \$2000$, as he holds 20 shares of the winning stock at market end. His net profit is then calculated by subtracting his purchasing price for these shares, which was $45. Thus, the resulting profit for this trader is $\$2000 - \$45 \times 20 = \$1100$.

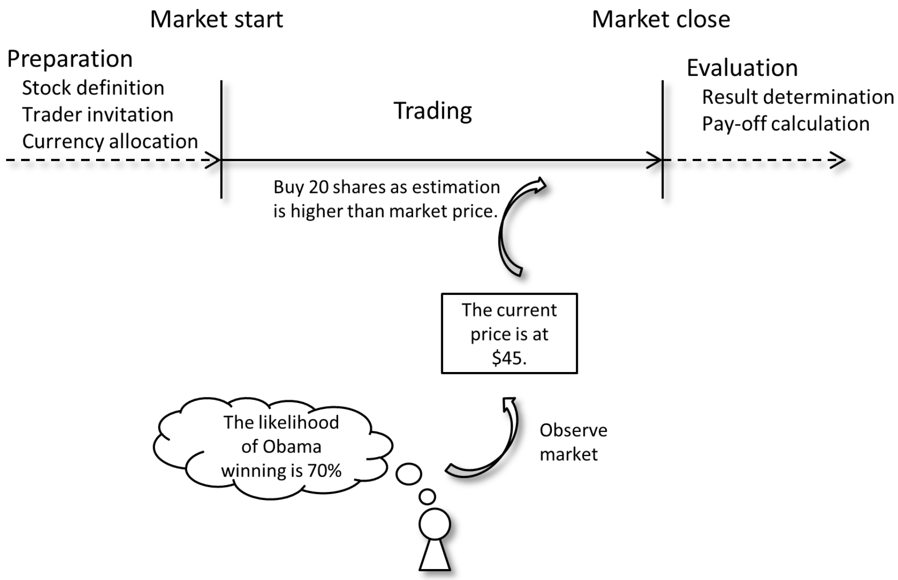


Figure 2.1: Example of a prediction market execution

2.3 Terminology

The terminology used in this work is as follows. A *market* represents a certain topic for which information is to be aggregated. For prediction markets, this topic is the respective event that is to be forecast. This market serves as a grouping entity for the available *stocks* on that market. These stocks in turn represent the single alternatives that are to be evaluated in the course of executing the market. With prediction markets, these are the possible event outcomes. A participant in a market is also referred to as a *trader*. Such traders can buy or sell *shares* of the available stocks. The term *holdings* denotes the shares that a trader owns. Based on the prices of the shares in these holdings, the *portfolio worth* can be calculated for each trader. A completed trade is termed a *transaction*.

2.4 Market Design

The market metaphor has been applied in various forecasting situations. Spann and Skiera analyze these settings and derive the three design steps of choice of forecasting goal, incentives for participation and information revelation, and financial market design as common traits of market designs [93]. Luckner highlights contracts, trading mechanisms, incentives, and traders as the key design elements of prediction markets [67]. Weinhardt and Gimpel have found the design elements of market outcome, agent behavior, market structure, and transaction object to be relevant for markets to properly aggregate the desired information in prediction markets [104]. In the following, we summarize these design elements for understanding prediction markets and other applications of the market metaphor.

Forecasting Goal A key design element of every prediction market is the definition of the forecasting goal. This includes the selection of the uncertain future event to be predicted and its detailed description. This description needs to be unambiguous so that participants clearly understand the prediction issue. This forecasting goal then constitutes the market. Furthermore, the pay-off modalities need to be defined so that participants are aware of their expected rewards [89]. Additionally, the single possible event outcomes need to be defined and represented as stocks on that market. Optionally, participants may be allowed to contribute further outcomes. However, an initial amount of stocks should be readily available for trading upon market start in order to avoid the problem of initially missing content [28]. Otherwise, people do not participate because of a lack of content and content is not contributed due to a lack of interested participants.

Participants Information aggregation from participants is at the core of prediction markets. These participants may be limited to a certain group of people or be open to the public. This depends on restrictions resulting from the application of the market (e.g. internal to a company) as well as from the necessary domain knowledge.

Anonymity Crowd-sourcing applications such as prediction markets are said to benefit from participants which are diverse and independent in their views [97]. Even if participants in such mechanisms exhibit such characteristics, they may be biased by social or hierarchical pressure and trade according to expectations by their superiors or companies and not according to their own belief. On the one hand, anonymity has been found to lower such conformity pressure in Group Decision Support Systems [51]. On the other hand, if participants are hierarchically independent from each other (e.g. from different companies or business units), then participation by real name could lead to an increase in discussion between participants. Thus, the level of anonymity that is granted to participants on a prediction market needs to be defined in the design of such a market.

Market Duration Market duration can generally be subdivided into short, medium and long term applications. In the forecast of uncertain future events with prediction markets, this time span is determined by the date of the event in question and by the current availability of information on that event. Short term markets would typically last for a few days to cover potentially unexpectedly arisen events in the near future. Medium term markets would last from several days to some weeks or few months. Such markets would be started well in advance in order to gather all relevant information and to include people that would not be able to continuously follow the market. Long term markets lastly cover one or more years. Such markets typically concern topics such as climate change, space travel to Mars, and similar topics of the more distant future.

Incentives Crowd-sourcing approaches typically rely on incentives in order to encourage people to participate [84]. Incentives for participating in prediction markets are typically based on competition, money, and reputation. Competition is one of the reasons traders participate in preference markets. In preference markets, there is typically a leader board given which shows the users with the highest portfolio worth. This creates an incentive for performing well in the market. In addition to fun, monetary rewards are a second incentive for participation. Reward schemes may be based solely on participation, that is, each participant receives a fixed reward, and they may be based on rewards per user event, such as transactions, logins, comments and such. However, such rewards are prone to being gamed, e.g. logging in very often without performing any actions, defeating the purpose of the reward. A lottery is another possibility for creating incentives for participation. There, every trader has the same chances of winning. Furthermore, a prize for the best-performing trader could be endowed. This would however not only incentivize participation but also trading according to maximizing one's portfolio worth. Lastly, some people strive to gain reputation among their peers, for example for being knowledgeable in a topic. Reputation can also serve for creating incentives. That is, making wise and successful trades in a preference market so that the respective trader is recognized by others.

Money A core feature of the market metaphor is the trading of shares using virtual money. This utilization of money differentiates the market-based approach from other group-based approaches such as for example the Delphi method. This virtual money in prediction markets can be backed by real money or it can be just pure play money that is granted to participants for example upon registration. Both real money and play money are used for trading in prediction markets today. The idea behind the utilization of real money is to create a strong incentive for performing well if the participants' own money is at stake. Real money could however be refused by experts who are not willing to risk a financial loss. Furthermore, trading with real money is considered as gambling in some countries, for example in the USA, and is therefore banned. In many other countries the legal situation is unclear. Accounting and administration costs are then another issue with real money [93]. The second alternative is to use play money. There, participants are granted an initial amount of play money upon registration for trading. Servan-Schreiber et. al. study the relationship between money and market performance for prediction markets regarding sports outcomes [85]. They report that play money markets perform as well as real money markets.

User Contributions The main contribution of participants in prediction markets consists of their trading actions for conveying their forecasts. Besides this, participants may also be allowed to create new markets and to add new stocks to an existing market. The list of stocks may be fixed in settings in which the tradeable alternatives are exogenously imposed. In other situations, the market may also serve as a mechanism for gathering additional stocks [58]. In this case, a mechanism needs to be determined for contributing new stocks. There may be free or judged contributions to a market. With free contributions, every participant is allowed to contribute new stocks without prior judgment. This simplifies the process of entering new stocks and thus may likely lead to more contributions. With judged contributions, designated participants assess the submitted stocks and decide which to enter into the market. This could increase the quality of traded stocks but also rule out relevant contributions.

2.5 Market Mechanisms

The trading of shares differentiates the market metaphor from other information aggregation approaches. In prediction markets, participants buy and sell shares of the stocks according to their assessments of the probability of occurrence of their underlying event outcomes. To enable this trading of shares, a mechanism is required for matching the buy and sell orders and for actually executing the trades. The term *market mechanism* is generally used to refer to the way in which prices are determined in a market, quotes are made and trades are settled. In the literature, two main mechanisms have evolved for use in prediction markets, namely the Continuous Double Auction (CDA) mechanism and the Market Maker (MM) mechanism.

2.5.1 The Continuous Double Auction Mechanism

The CDA mechanism is a market mechanism for matching buyers and sellers of shares of a particular stock in a market. Traders can place orders at any point in time in the form of bids (buy orders) or asks (sell orders). These orders are maintained in an order book which keeps track of all outstanding orders. Orders consist of a bid or ask price and the number of shares the respective trader is willing to trade. Trades are executed whenever buy and sell orders match in the order book and the highest bid price is equal to or exceeds the lowest ask price. The order book contains a bid and an ask priority queue. The bid queue is ordered by decreasing bid prices whereas the ask queue is ordered by increasing ask prices. In the case of price ties, time of order submission is the second criterion. The earlier a bid has been submitted to the queue, the higher is its priority. A transaction occurs if the highest bid is equal to or exceeds the lowest ask and thus involves the orders at the top of the bid and ask queues. The trade is executed at the price of the older of the two orders. Completed orders are removed from the respective queue. Partially fulfilled orders remain in the respective queue until they are completely fulfilled or removed by the trader. The advantage of the CDA mechanism is that it is easily understandable by participants as it corresponds to the intuition of people on directly buying and selling goods (see Figure 2.2) and it is typically employed on real stock market exchanges.

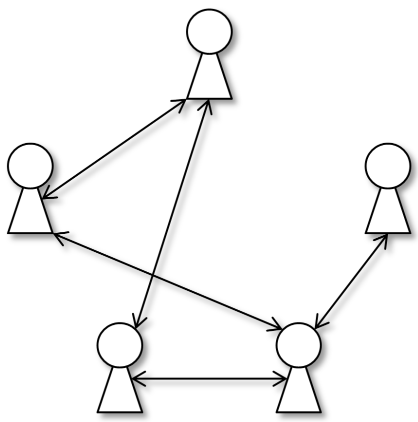


Figure 2.2: Direct trading between people with the continuous double auction mechanism

The second aspect besides order matching is price setting in a market mechanism. With the CDA mechanism, three prices can be quoted to participants. The highest bid price is the price of the highest currently unfulfilled bid order, the lowest ask price is the price of the lowest currently unfulfilled ask order and the last trading price is the price at which the last trade occurred for a given stock. Most relevant for information aggregation purposes is the last trading price as it indicates a consensus among traders on the price of a given stock. In certain information aggregation scenarios, there may be many markets for various topics of interest and a limited number of participants. This results in so called *thin markets*, that is, markets with at most a few traders per stock. In such markets, matching orders may not exist as traders may have too different conceptions on the prices of the stocks. Hence, no trades may be executed in such markets. Then, it would not be possible to quote the last trading price due to missing trades and no assessment would be gathered [61]. Even if there are bid and ask orders, the spread between their prices may be large. If a stock has poor price support (i.e. no open interest or large bid-ask spread), then observers learn little about its value, disabling the purpose of the market of indicating consensus on the prices [74]. Healy et al. also find that CDA markets fail to deliver results if markets are thin and the few traders in a given stock have to process complex information [46]. In such markets with few traders, participants may also have little incentive for discovering new information and for contributing it through trading as they would not be able to profit from such actions [90].

2.5.2 The Market Maker Mechanism

The MM mechanism represents a different approach to handling the trades and setting the prices in markets. The basic idea of a market maker is to provide a centralized trading entity, the market maker (see Figure 2.3). Market participants then do not trade directly with one another as with the CDA mechanism, but with the market maker who acts as an intermediary. The market maker accepts all buy and sell orders of participants right away [40]. A single order queue is maintained for organizing the orders by their arrival time and for processing them in the correct order. The market maker quotes buy and sell prices at which he is willing to trade with the participants. In real stock markets there is typically a spread between these prices, allowing the market maker to make a profit for his effort [9]. In prediction markets, there is no such spread as the market maker is typically automated and does not have to make money. Thus, buy and sell quotes are typically equal in MM markets. On contrary to the CDA mechanism, traders only specify the type of trade, the stock and the number of shares they want to trade, but not at which price, as the price is predetermined by the market maker. The market maker adjusts these quoted prices according to supply and demand of the respective stock. Stocks with high demand will get more expensive while those with high supply will get cheaper. In its application with prediction markets, traders can buy as many shares from the market maker as they can afford or sell as many shares as they own.

The main advantage of the market maker for prediction markets relates to the fact that it tackles the problem of thin markets with the CDA mechanism. The market maker represents an enduring counterpart for trading with the single participants and always offers to trade. Therefore, it provides liquidity especially in thin markets and participants

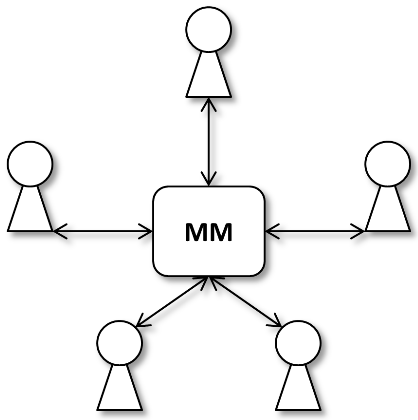


Figure 2.3: The market maker mechanism acting as a central trading counterpart

are able to contribute their assessments of a certain stock even if there is no matching trader as a counterpart. Moreover, with the market maker, a single trader executing a single trade in a given stock is sufficient for quoting a last trading price for that stock which it not possible with the CDA mechanism if there is no matching trade or a large bid-ask spread.

In the case studies that we conducted accompanying this research, we also identified a small caveat with the market maker mechanism. We noticed that participants may sometimes be confused by the price increases triggered by their own trading actions. Some participants seem to think that they can actually gain money by simply buying shares and selling them immediately afterwards because of the price increase. However, this is not the case, as market makers for prediction markets are typically designed in order to avoid being “money pumps”. A money pump would exist if there would be a difference in the cost for buying a certain amount of shares and the profit of immediately selling the same amount back to the market maker. In market makers for prediction markets, the absolute value of trading cost for a given amount of shares is equal, regardless of selling or buying them. More specifically, market makers are typically set up to increase and decrease prices per share that is traded. Thus, participants end up with no gain from such buy and sell actions. This simply has to be conveyed to participants comprehensibly at the beginning of any given market effort as a precautionary measure.

A MM mechanism needs some function for actually determining the cost it is going to charge the traders and the prices it is going to quote. For prediction markets, the form of an inventory-based market maker was developed by Hanson [42]. The term inventory-based refers to the fact that the market maker maintains a list of how many shares of all stocks of a certain market are issued to the traders. The market maker then uses a cost function which records how much money traders have collectively spent so far for these shares. For this cost function, Hanson devised the logarithmic market scoring rule [42]. This cost function is used in different public online prediction markets today.

Hanson develops the logarithmic market scoring rule from general scoring rules. Scoring rules are used to elicit probability estimations for event outcomes from people and to determine rewards depending on the accuracy of the estimates. A person can there improve his score and thus his expected reward by improving his estimate for the probability of a given event outcome. If there is more than one forecaster the question arises how to combine the probability estimate of each forecaster into one estimate. For this, Hanson devised what is known as market scoring rules. The idea is there to combine the advantages of scoring rules (incentive) and of bet markets (collective estimate) into sequentially shared scoring rules [42]. The step from scoring rules to market scoring rules is to have one commonly shared estimate that can be sequentially changed by multiple forecasters. From the market metaphor, participants cannot arbitrarily change the estimate but have to buy the changes in the form of shares. The scoring rules can then be used to calculate the cost of trading these shares.

The market scoring rule of Hanson only depends on the number of outstanding shares. Given a number of stocks $i = 1..n$ each representing an outcome of an uncertain future event, for each stock q_i shares are issued. Then, the cost function for calculating the worth of these outstanding shares is

$$cost = b * ln \sum_{k=1}^{n} e^{q_k/b} \tag{2.1}$$

The parameter b there determines the depth of the market, that is, the number of shares required to be traded to induce a certain change in stock price. For calculating the actual cost charged to a trader for buying m shares, the market maker determines the costs of the outstanding shares before the transaction and afterwards. The difference is the actual cost for the trader, $cost = cost_{afterwards} - cost_{before}$. That is, the trader has to pay for the additional cost the newly issued shares cause. If the trader wants to sell shares, the resulting cost is negative, meaning a payout for the trader.

The market maker does not only calculate the cost of trading but also quotes current prices to traders. For this it applies the derivative of the cost function 2.1. This determines the price for buying or selling a minuscule amount of shares. Then the price of one share of the i^{th} stock is determined by

$$p_i = \frac{e^{q_i/b}}{\sum_{k=1}^{N} e^{q_k/b}} \tag{2.2}$$

2.6 The Workings of Prediction Markets

The application of the market metaphor in prediction markets has been found to produce a quality of the results that is comparable to or even surpasses that of other methods for group based forecasting [35]. The quality of a prediction market result is typically determined by the accordance of the market forecast with the occurred event outcome. This successful application of the market metaphor in prediction markets is based on certain aspects of the market metaphor as well as of the context of forecasting. In this work, we investigate the application of the market metaphor to decision making. To this end, we want to understand the basis of the effectiveness of the market metaphor in prediction markets.

2.6.1 Information Aggregation

Snowberg et al. highlight the capability of prediction markets to quickly aggregate information based on results from multiple prediction markets, including one market that predicted the killing of Osama bin Laden, and other markets predicting election outcomes for presidential elections in the Iowa Electronic Market, a prediction market run by the University of Iowa [91]. Hayek is among the first to highlight this information aggregation capability of markets [45]. More specifically, the pricing mechanism of a market serves to coordinate people in their trading actions and thus leads to the incorporation of the information underlying these trading actions in the prices. Furthermore, markets are quick to incorporate new information into prices. New information provide the potential to make a profit only as long as no other trader already conveyed this new piece of information by trading. Therefore, quick trading on new pieces of information pays off for participants. Snowberg et al. highlight the example of the killing of Osama Bin Laden for illustrating this rapid incorporation of new information in the commercial prediction market platform Intrade[1]. There, a prediction market existed for forecasting the likelihood of Osama being killed prior to December 31st, 2011. Upon the occurrence of this event, an official from the Ministry of Defense of the USA spread the news on Osama's killing using the short message service Twitter. This new piece of information was then quickly incorporated into the market as the price then rose from $7 to $99 within 25 minutes.

For prediction markets, information aggregation can be discerned at the individual and the market level (see Figure 2.4). At the individual level, participants gather information from various sources concerning the topic of the market. They aggregate this information by forming their personal opinion on the associated stocks. Participants then convey this aggregated information to the market by trading accordingly. The market gathers these trades and aggregates them into the stock prices. From these stock prices, a ranking can then be compiled, indicating the aggregated opinion of all participants.

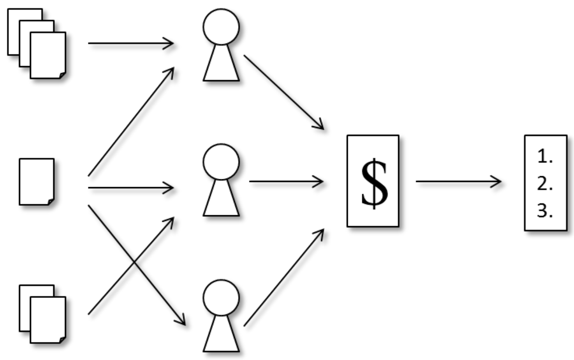


Figure 2.4: Information aggregation at the individual and the market level

[1] http://www.intrade.com

2.6.2 Incentive Compatibility

The second reason for the working of prediction markets as pointed out by Snowberg et al. refers to the incentives that organizers of markets can provide [91]. Market organizers in prediction markets offer their traders rewards for participation and for executing the work – forecasting – in the best possible way. These rewards are often based on the market performance of the traders. In prediction markets, this market performance is typically determined from their forecasting accuracy. That is, the better a given forecast is, the higher a reward the forecaster receives. Hence, participants have an interest in discovering novel information and in truthfully contributing their resulting best forecast to the market. This phenomenon is known as *incentive compatibility* in economic terms [20]. A mechanism is said to be incentive compatible if it encourages a participant to contribute his best effort in order to receive the maximum benefit [15]. This in turn comes in handy for organizers of prediction markets. There, the goal of the organizers is to obtain an accurate forecast.

2.6.3 Rational Choices

The reasons pointed out previously represent phenomena that have their roots in economic theories. There, the aim is to describe the behavior of participants in economic systems [81]. Relevant approaches for explaining behavior in applications of the market metaphor include rational choice theory, the notion of utility, and the maximization of this utility for personal benefit [47]. Rational choice theory aims to describe the actions of participants in economic contexts. There, it is assumed that individuals always make rational decisions in their self-interest for maximizing their benefit. For this, an individual person conceptually maintains a utility function for assigning utility values to the available goods in question. From the resulting utility values, a preference order can then be generated for the available goods. The person is then assumed to strive for the maximization of this utility, that is, for the achievement of the good with the highest utility associated. All actions taken for the achievement of the highest preference are then rational in the sense that they lead to this achievement.

2.6.4 Strategic Behavior and Speculation

Another basic consideration for the behavior of traders in a prediction market concerns their strategic orientation. This refers to the way in which participants prepare their next trading actions. For many investigations of the workings of prediction markets, traders are assumed to act *myopically*. Myopically refers to the fact that participants only consider the very next trading action without looking further into the future. That is, they select a trading action that they expect will maximize their utility in the very next trading step. Prediction markets using the logarithmic market scoring rule market maker are found to be myopically incentive compatible in the sense that the provided incentives always encourage the best action for a specific trader in a given market situation [41].

Strategic behavior on the contrary is exhibited by traders who take into account potential future market developments and plan ahead accordingly. Dimitrov and Sami investigate such strategic behavior of participants in markets [26]. An example for strategic behavior would consist of a trader who first misleads other traders by not truthfully revealing his true forecast but who rather executes trades in opposition to his forecast. If other traders then follow this untruthful trading, the original trader may make a greater benefit at the disadvantage of the other traders by then revealing his true forecast and profiting from the cheap prices of the respective stocks. Such strategic behavior may also be seen as a form of speculation as traders speculate on future price developments and reactions of the other traders.

2.6.5 The Principal-Agent Paradigm

Prediction markets are typically counted among the crowd-sourcing approaches as they engage a large group of people into solving a challenge [27]. The situations in prediction markets is usually as follows. The organizers of a prediction market are in need of a forecast on some issue. For obtaining this forecast, they decide to employ the market metaphor. They then need to attract people to contribute their forecast. Therefore, market organizers offer to reward the participation of people based on the accuracy of their forecast. People then participate for achieving this reward. Such situations typically exhibit the characteristics of *principal-agent* situations [59]. There, a *principal* needs some work to be carried out but also requires input or support for doing so. He therefore offers *agents* a reward for executing this work properly. The agents primarily participate for receiving this reward and they try to maximize their chance by best executing the provided work.

2.6.6 Fundamental vs. Technical Trading

Traders need a way to evaluate the topics of the available stocks and thus to identify promising stocks for investment. Two general approaches to this evaluation and the adjustment of trading actions can be discerned in economic markets. The first approach is based on the analysis of the underlying fundamentals of a given stock, hence termed *fundamental analysis*. In the case of the stocks of a company for example, a trader analyzes the current situation of the company, of its branch of industry, and of the economy as a whole in order to determine the value of the stocks. From this personal evaluation of the stocks the trader then forms trading actions in order to best profit from his evaluations. In prediction markets, this corresponds to dealing with the actual event to be forecast.

The second approach to evaluating stocks is concerned with the sole analysis of the stock price development of a given stock. This is referred to as *technical analysis* [72]. There, traders analyze the history of price movements of a given stock and also of related stocks in order to discover patterns. Based on such patterns, traders try to forecast the future development of the stock's price and to benefit by trading in this stock. Technical analysis can also be executed in prediction markets by looking at the price development of the stocks rather than at the likelihood of the event outcomes.

2.7 Promising Capabilities

The market metaphor has already been applied in various prediction market settings. Several promising capabilities have been identified for the market metaphor. These capabilities include their information aggregation capability, their prediction accuracy, their real-time feedback on contributions, the revisability of one's opinion and share holdings, their encouragement for first-movers and for decisiveness, the applicability of individual evaluation criteria, their provision of anonymous participation, their incentive for information discovery and their scalability in terms of users.

Information Aggregation The aggregation of information held by its participants is the most notable capability of the market metaphor. In his article "The Use of Knowledge in Society", Hayek suggests that markets are able to coordinate people who have different pieces of knowledge on a topic [45]. They convey their individual information through trading and contribute to the price containing information from all participants. Forsythe and Lundholm find that markets in lab experiments are able to aggregate information from participants with differing personal information [32].

Accuracy The objective of forecasting methods for predicting uncertain future events is typically to achieve a high accuracy in their predictions. In efforts to compare the prediction market approach to other means of forecasting, forecasting accuracy is therefore one of the main criteria for evaluation [11]. Studies concerning elections, sports results, and business forecasts have shown that prediction markets are able to produce forecasts that are at least as accurate as other means of forecasting [8, 35, 77]. A characterizing factor is the information heterogeneity among participants. A high level of information heterogeneity is found to positively impact the forecasting accuracy [102].

Real-time Feedback Most other forms of user participation in the forecasting of uncertain future events rely on predefined evaluation cycles for processing the contributions of people. That is, participants have to wait for the processing and subsequent publication of their efforts in order to check on their impact on the overall prediction. The market metaphor, especially in its market maker variant, does not have such long processing cycles. Rather, participants contribute their assessments through the trading actions they execute. These actions are immediately processed by the market mechanism and result in a promptly reflection of one's contributions, potentially motivating a continued participation [36]. Also, other participants can observe these contributions more quickly and can react to it more quickly.

Revisability The predictions of people regarding the outcome of an uncertain future event are likely to change over time until the event actually occurs. This is mostly due to the availability of new information on the future event and on factors influencing it. In one-time prediction efforts, participants are not able to reflect such changes in their assessments accordingly. With the market metaphor, however, markets can be open for trading by the participants over a prolonged period of time. That is, traders can revise their share holdings at any point in time during the runtime of the market and thus represent their changed assessments.

First-Mover Advantage In other group assessment approaches, it makes no difference whether participants contribute their opinion late or early during the runtime of the effort. Sometimes, they may even profit from contributing late as they would be able to adapt their contributions to those of the others without drawbacks. A promptly change in one's share holdings, however, is beneficial for participants in a prediction market. There, a participant may be able to trade earlier if he changes his assessment of the outcome likelihoods and may thus profit from still cheaper market prices. Other participants, who trade at a later point in time, may have to deal with already increased stock prices [70].

Decisiveness Participants are likely to exhibit a spectrum of degrees of decisiveness in their forecasts about the future. These levels of decisiveness will also be reflected in the applied prediction mechanism. Mechanisms that allow for repeatedly changing one's assessments may encourage indecisive behavior as participants are always able to redistribute their votes later on until predictions are evaluated. The market metaphor, however, discourages indecisive behavior due to its use of prices. In markets, indecisive traders are characterized by spreading their money over a large set of stocks or do not invest their money at all. Such indecisive traders may then be forced to trade at more unfavorable prices than others. For example, if they hesitate to invest in a given stock and that stock price increases, they need to spend more money on one share of that stock.

Individual Assessment Criteria For predicting uncertain future events in a group of people, assessment criteria are required by which the group members create their assessments. With other forecasting methods, a fixed set of criteria is typically defined by the creators of the method or its users. In a homogeneous group of people, this may be advantageous as everyone is employing the same scheme. Prediction markets, however, potentially benefit from the participation of a more heterogeneous group of people as they contribute different perspectives to the assessment of a prediction task. In such situations, a fixed set of criteria could be limiting for some members of the group. The market metaphor does not require the definition of a fixed set of assessment criteria in order to function. Rather, each participant may utilize his own criteria set according to his perspective on the topic of the prediction task.

Anonymity In situations of information aggregation in a group, social, for example hierarchical, pressure may lead to the contribution of pleasing information instead of one's true opinion. One of the major gains of so called group decision support systems is enabling the participants to contribute their opinions or perspectives anonymously. Thus, conformity pressures are lowered [51]. Likewise, applications of the market metaphor may also be designed for anonymous trading. That is, participants use fictional user names in order to conceal their identities while at the same allowing the market to track their trading actions for proper accounting.

Information Discovery Prediction markets offers rewards for the most accurate predictions. In order to make accurate predictions, participants need information for assessing the potential outcomes and for evaluating their likelihood of occurrence. Therefore, participants have an incentive to discover additional information on the prediction topic of the prediction market [70].

Scalability Information aggregation situations may require to include differing numbers of participants or the addition of people during their run time. Markets scale well in the number of participants and can also handle the addition of traders at any point in time during their execution.

2.8 Market Application Domains

The market metaphor has been successfully applied in prediction markets for forecasting elections, sports results, and business figures. Several promising capabilities have been identified for this kind of information gathering mechanism, as highlighted in Section 2.7. Due to these positive characteristics, the market metaphor has also been applied in other domains for aggregating information from groups of people. In the following, we provide an overview of these domains according to their intended information aggregation goals and the respective application of the market metaphor. We start with the tried and tested domain of prediction markets and continue with so called *preference markets* and markets for decision support.

2.8.1 Prediction Markets

Prediction markets pose the original form of applications of the market metaphor for information aggregation. Tziralis and Tatsiopoulos subdivide these applications into markets for academic research, sports results, business figures, and politics [101]. In academic markets, the goal is typically to investigate market design variations and their impact on people's trading behavior and on the forecasting accuracy of the respectively designed markets. In the application on sports results, business figures, and politics, the stated goal is to obtain a joint forecast on the outcome of a future event from a variably large group of people.

2.8.2 Preference Markets

Information aggregation situations besides forecasting may also benefit from the involvement of a large group of people and from the promising capabilities associated with the market metaphor. Therefore, the market metaphor has also been applied in domains that require the aggregation of people's preferences. These domains include idea and innovation gathering and selection, product development, management of research portfolios, and evaluation of early stage technologies. Such markets go by the names of idea market, innovation market and preference market, amongst others. We refer to this kind of markets as *preference markets* as the intention of these markets is to gather the preferences of the participants on the tradeable items. The general idea is to represent preference options, for example product features, as stocks on a market and to have traders assess these preference options and convey their resulting preference ranking through trading. The stock prices then indicate highly favored, that is expensive, options and unattended, cheap options.

LaComb et al. set up their idea market at GE with the goal of both gathering new ideas from employees as well as having them rate these ideas using the market metaphor [57]. In their market, they find that the market metaphor was capable of producing more ideas than with alternative approaches and that they were able to attract more participants from the workforce. They also note, however, that the trading of participants was guided by the two intentions of true preference contribution and of portfolio worth maximization [58]. Similarly, Kamp and Koen investigate the application of the market metaphor in the context of idea screening [53]. They also find that participants in such markets can be driven by different intentions. Another idea gathering and evaluation mechanism based on the notion of the market metaphor is described by Lavoie for application in his company Rite Solutions [60].

Chen et al. develop their I-PREFS market application for the identification of emerging technologies and for ranking their innovation potential [17, 18]. They find that their market application is suitable as a scalable screening process for early stage technologies.

The development of new products requires the identification of relevant product features and the selection of a preferred subset of them for actual realization. The market metaphor has been applied for such product development objectives. Dahan et al. utilize a preference market in order to capture the preferences of the participants on product features [22]. In their market design, traders buy shares of the features they would want to be realized in a hypothetical product and sell shares of the features they would not like. A similar market approach has been used by the Ford Motor Company to identify and rank vehicle features according to their popularity with the traders [71].

In an attempt to find people for actually trading in a preference market for product development, Spann et al. investigate the applicability of the market metaphor to the identification of so called *lead users* [92]. Lead users represent a concept from market research and depict users with demands that represent a certain group of buyers. In this application, the market metaphor is deemed capable of identifying such lead users as they are likely to perform better in an appropriately designed market.

2.8.3 Markets for Decision Support

The market metaphor has also been proposed to support decision making in public issues as well as in corporate environments [4, 37, 40]. There, the proposed approach is as follows. A certain goal needs to be achieved and it has to be decided which action from a set of potential actions serve best for meeting it. In politics, these actions for example correspond to potential policies that may be enacted in the future. For supporting the decision on the best action, a group of people is involved for contributing their knowledge and their assessments. There, the group members are expected to forecast the likelihood of achieving the aspired goal dependent on the respectively chosen actions. A market is then set up for representing this goal and the single stocks correspond to the available actions. Such markets whose prices are used to inform decision making are typically called *decision markets*. However, we refer to these markets as *decision* *support markets* in order to emphasize their utilization as decision support systems.

Large companies including GE, Hewlett-Packard, and Corning tested such market approaches in pilot studies [100]. Yassin advocates the application of the market metaphor as a form of business intelligence tool with the goal of supporting better informed decisions [106]. Managerial decision making is expected to benefit from the aggregation of information that is dispersed among the workforce of an organization. For such corporate settings, empowerment of employees and its positive impact on their morale is seen as an additional benefit of the market metaphor [96].

For the public sector, Einbinder suggests the utilization of the market metaphor to inform administrative policy making [30]. A market represents a certain administrative goal that is desired to be achieved. The stocks on that market then correspond to potential policies for realizing that goal. Traders evaluate these policies and place their bet on the most promising policy. Berg and Rietz also argue for the potential of the market metaphor to support decision making and analyze Presidential prediction markets for their informative qualities during the election seasons [13]. Tetlock et al. use a CDA based market for decision support and find that market organizers in such markets will likely need to subsidize liquidity in order to obtain useful information [99].

2.8.4 Other Applications

The market metaphor has also been investigated for other applications such as learning and peer review. Raban and Geifman design an information aggregation market for the purpose of introducing their students to the workings of markets and especially their information aggregation capability [78]. They find that students learn from the price developments of the stocks and adapt their subsequent actions to this development.

Robinson devises a market-based approach for the peer review of research articles [82]. There, the goal is to speed up feedback on articles and shorten review times. Another potential benefit is the creation of a “leading” publication metric rather than traditional “trailing” metrics. The market approach consists of participants backing their article ratings with the provided currency. Dividends are paid for each citation of the backed article. Furthermore, participants may redeem their shares they hold in an article at any time later on in the review process. In this way, participants indicate their expectations of the future development of an article by their trading shares of this article. Stock prices then again indicate the popularity of articles among participants.

Also related to academic research, Almenberg et al. design a market for testing scientific hypotheses [5]. There, the stocks of their market represent mutually exclusive hypotheses. The task of the participants is then to select the correct hypothesis by trading. In a similar fashion, Bell proposes to utilize the information discovery capability associated with the market metaphor to encourage scientific curiosity and inquiry [10].

2.9 Market Manipulations

Economic markets are subject to all sorts of manipulation attempts, mostly with the goal of personal enrichment. The term *manipulation* basically describes a “behavior that influences someone or controls something in a clever or dishonest way”, according to Macmillan Dictionary [1]. In economic markets, the goal of manipulation is to gain profit from exerting influence on stock prices by clever and mostly dishonest means. Therefore, manipulation is generally disliked in stock markets and mostly prohibited by law. Research focuses on how to avoid it and the effects in case it occurs.

2.9.1 Trading-based Manipulation

Different kinds of manipulatory efforts can also be discerned in prediction markets. The first is concerned with manipulation in the market through trading. There, participants trade not according to their actual evaluation of the available stocks but rather in strategic and manipulatory ways in order to gain a personal profit in the market. For example, they initially mislead other traders and then profit from correcting their misled trading actions. Market prices are then likely to no longer reflect the aggregated assessments of the stocks but are biased by the manipulatory trades and are thus of limited use for the market organizers. The suitability of prediction markets for effectively aggregating the assessments of participants has been questioned due to this possibility of market manipulation. Critics worry that manipulators in such markets can distort prices of stocks by trading accordingly and thus render the resulting prices useless.

Rhode and Strumpf analyze such manipulative attacks in three prediction markets: the Iowa Electronic Market in 2000, the historical Wall Street betting markets, and the 2004 TradeSports market for President [80]. Their findings suggest that it is very expensive for a manipulator to tamper with such markets over a longer period as he has to trade against the assessments of all other non-manipulating participants. Furthermore, Rhode and Strumpf figured out that prices returned close to their previous levels after a certain transition period, presumably due to the limited budgets of manipulators. This is also in line with findings from Deck et al. who investigate the impact of well-funded manipulators in a lab study [25]. According to their results, well-funded traders may very well distort stock prices over a longer period of time, given they have a motivation to do so.

Hanson and Oprea provide an explanation for these results of manipulation based on their findings from a controlled laboratory experiment [44] and from the analysis of a market micro structure model [43]. They argue that traders who suspect the presence of manipulators compensate for actions that might be based on manipulation. In their micro structure model, manipulators are treated as noise traders who trade according to considerations other than their best assessment. The trading actions of noise traders lead to a spread between the current stock price and the target stock price as assessed by non-manipulators and thus provide for additional returns for non-manipulators. This results in increased liquidity on the market as manipulators provide for additional trading opportunities for non-manipulators. One of the frequently cited advantages of prediction markets is their accuracy. They are able to produce the same or even more accuracy than other forecasting methods such as deliberation, polling or expert opinion-making when forecasting an event in the future. Hanson and Oprea point out that manipulation may actually be able to increase the forecasting accuracy as more transactions are performed and thus prices have more possibilities for leveling off. Takayama investigates the impact of stock price manipulation by a dynamic informed trader and finds that under certain circumstances (i.e. high informed trading probability) every market equilibrium involves manipulation [98].

Contrary to previous findings, Veiga and Vorsatz discover in their experiments with uninformed traders and assets with low fundamental value that an additional trader may distort stock prices [103]. In a similar direction, Hommes et al. investigate the formation of endogenous bubbles in markets and find that traders may learn to follow an evolving bubble instead of learning on the fundamental value of the stock [50]. Also, Chen et al. highlight that it may strategically be better for traders in a market to bluff and withhold information in order to realize gains later on in a market [19].

2.9.2 Outcome-based Manipulation

The second kind of market manipulations in prediction markets deals with outcome manipulation. There, traders can exert influence on the circumstances of the uncertain future event and therefore alter the likelihoods of the possible event outcomes. Therefore, participants who traded in favor of a certain outcome have an incentive to influence this outcome in coming true in the real world in order to increase their profit from their current share holdings [76]. Likewise, pessimistic traders have an incentive to hinder certain outcomes from coming true, for example by delaying a project. Shi et al. investigate market mechanisms that might not incentivize such outcome-based manipulations but find that it may be costly to decrease such manipulatory efforts [87].

2.10 Regulatory Issues

With the Iowa Electronic Market, aspiring traders have to change real-world money for virtual money in order to be able to trade in the political markets. In all other markets known to the author, participants receive an initial amount of virtual play money upon registration. In either case, some form of virtual money is used for trading in the stocks of the respective markets. This, however, may be considered as Internet gambling and may thus be subject to respective legislative regulations [8]. In the USA for example, regulative issues may arise both from the Commodity Futures Trading Commission (CFTC) as well as gambling acts such as the Unlawful Internet Gambling Enforcement Act.

The Iowa Electronic Market with its real-money trading operates under a special approval of the CFTC[2] of the USA. There, the operators of the Iowa Electronic Market are guaranteed that the CFTC will not enforce legal actions if they in return adhere to a prescribed scheme in their markets. This no-action letter, however, only applies to the Iowa Electronic Market and does not generally allow the operation of prediction markets by the CFTC. Hahn and Tetlock therefore suggest that such markets should be regulated based on explicit policies by the CFTC [38].

[2] No-action letter: `http://www.cftc.gov/files/foia/repfoia/foirf0503b002.pdf`

Part II

Liquid Decision Making

CHAPTER 3

The Foundations of Liquid Decision Making

Complex decisions can benefit from the participation of multiple people with different perspectives, background knowledge, and evaluation criteria [48]. In this chapter, we introduce LDM, a market-based approach that we developed for the application of the market metaphor to decision making in large and heterogeneous groups. We first highlight the decision making situation of a large and heterogeneous group of people. For this group of people, we identify characteristics with respect to decision making and its overall goal in such a decision making effort. Next, basic requirements are given for applying a market-based approach in such a decision making situation. Based on these requirements, we introduce LDM and its application of a market-based approach to decision making. We outline the correspondence of the single market elements to elements of a decision and provide a stylized description of an LDM installment. We then introduce a model of a virtual market for comparing different types of markets. From this, we discern the forecast context and the decision making context as application contexts of the market metaphor. LDM is geared towards an application in the decision making context. For this context, we identify suitable decision market scenarios as well as design goals of LDM. We then address these design goals in the three design principles of collaborative decision, user involvement and dual incentives. Lastly, we introduce market perturbations, a method for discerning market result qualities.

The considerations that we present in this chapter are based on our previous work on different kinds of market scenarios [64], on the design principles that we devised for achieving good market results [65], and on the concept of market perturbations for discerning market result qualities [62, 63].

3.1 Decision Making in Large and Heterogeneous Groups

Imagine the following situation: an aircraft manufacturer plans the development of a new aircraft. This aircraft shall meet future demands and shall be produced using new technologies. The design of an aircraft concerns different domains including technical, economical, ecological, and societal aspects. During the design process, several key design decisions need to be made, considering knowledge from these different domains. This knowledge may be dispersed over several experts, each holding different parts of relevant information and bringing different sets of evaluation criteria depending on their respective field. The assessments of these experts then need to be gathered and combined to achieve useful solutions to the key design decisions.

In such situations, several strategic decisions need to be made on key design issues. That is, the respective decisions need to be framed appropriately, decision options need to be identified for the pending decisions and the best decision option needs to be selected. Such decisions, especially strategic and complex ones, are ideally not made intuitively, spontaneously nor routinely but rather based on thorough investigation and by incorporating all relevant information.

At the beginning of such a decision making effort, not all relevant information may be readily available (1). Furthermore, not all decision options may already have been conceived for the pending decision (2). Thus, a thorough investigation typically requires the gathering of information over a prolonged period of time. Additionally, participants may form their opinions on the decision options incrementally over time as relevant information arrives and potentially new decision options become available (3). Despite such prolonged time spans for consideration, time and informational limitations may nevertheless prevent participants from examining all decision options to their fullest detail (4). Strategic decisions often involve multiple domains with different perspectives on the decision subject. These different perspectives contribute knowledge from different domains and assessments using different sets of evaluation criteria (5). The involvement of different perspectives typically entails the inclusion of several people in the decision making effort. These people bring heterogeneous knowledge backgrounds and are also likely to apply different evaluation criteria for selecting the best decision. The aforementioned characteristics of such a decision situation can be summarized as follows:

1. Unavailability of all relevant information
2. Gradual emergence of further decision options
3. Incremental information gathering and opinion forming
4. Time and resource constraints on detailed investigation of decision options
5. Involvement of different perspectives and evaluation criteria

The goal of this group of people is to collectively determine their favored decision option for the pending decision. The goal of each individual in the group is to realize his most favored decision option and to apply his respective set of evaluation criteria. As the group has to work with the selected decision option further on, the group's members are also interested in selecting an option that is reasonable to work with afterwards. In the aircraft example, a decision is deemed to be reasonable if it contributes to meeting the requirements of the aircraft project.

The selection of a reasonable decision option is likely to be achieved if people strive to consider all available information and to contribute their sincere opinions. A mechanism that is used for selecting a decision option should not be detrimental to these efforts. For the market metaphor, the contribution of one's sincere opinion may be biased by considerations concerning for example market performance. Furthermore, people may consider only market information and may disregard information external to the market. We call the result of a decision making mechanism a *good* decision if the mechanism does not tempt the participants to withhold their sincere opinions and to disregard available external information.

In its original application in prediction markets, the market metaphor is typically counted among the crowd-sourcing approaches [27]. The basic idea of crowd-sourcing is to solicit solutions to a problem from a large number of people. They produce their individual solutions which are subsequently aggregated to form the overall solution. Participants are typically only interested in the reward they receive for providing a good solution. LDM deviates from this principal-agent style involvement of people. Rather, the participants are assumed to have some personal interest in the result of the problem solving itself, in this case, the decision making.

During a decision making effort, participants gather information from the available sources and form their preferences for the single decision options, using their individual evaluation criteria. As a decision option has to be selected at some point in time, a deadline is defined at which the winning decision option will be determined. People may be dispersed over a large geographical area and may also participate at different points in time. The following requirements should therefore be met by an approach for supporting such groups of people in their decision making effort. The approach should allow for a continuous participation, anonymity, participation equality, an immediate feedback, and a low entry barrier. Also, it should be attractive to the prospective participants and encourage them to participate repeatedly. Lastly, the approach should scale well in the number of participants as well as decision options.

3.2 Applying the Market Metaphor to Decision Making

With the market metaphor, there are several beneficial characteristics associated. First, the market metaphor allows for a continuous participation. In this way, traders are able to revise their opinion during market run-time, for example based on new information, and then to represent this opinion change in the market by trading accordingly. Furthermore, the market metaphor provides for a real-time transaction handling and price setting. This enables participants to review the impact of their changes promptly and to react to this impact where appropriate. The market metaphor has been reported to effectively aggregate information from several people in different application domains (see Section 2.8). Based on these positive characteristics, we utilize the market metaphor for LDM for gathering the single opinions of the participants and for aggregating them into a single indicator on the commonly preferred decision option.

3.2.1 Correspondence between Elements

The correspondence between the elements of the market metaphor and of decision making in LDM is highlighted in Table 3.1. A pending decision is represented as a market

Decision Making	**Market Metaphor**
Decision	Market
Decision Option	Stock
Vote	Virtual Money
Vote for Decision Option	Buy Shares
Vote against Option	Sell Shares
Preference Status	Price Level

Table 3.1: Correspondence between elements of decision making and the market metaphor

and the single decision options correspond to stocks on that market. People are endowed with a limited budget of virtual play money in resemblance to votes in decision making. Using this virtual play money, people then buy shares of the decision options they favor and sell shares of the undesired decision options. In this way, the people's preferences for the single decision options are gathered as the stock prices develop according to supply and demand. From this, a ranking of the decision options is generated based on their stock prices. We call our approach *liquid* as it allows participants to repeatedly contribute their own opinion as well as to change it during the runtime of the market and to represent this on the market. We refer to the market itself incorporated in LDM as a *decision market* as the market metaphor is utilized for making a decision with decision options being traded. The final result of this decision market is then accepted as the jointly selected decision option by the participating group of people.

A stylized execution of such a decision market in LDM is highlighted in Figure 3.1. In the preparation phase, the stocks are defined in terms of the decision options, the intended trader audience is determined and invited for participation and the registered traders are endowed with an initial budget of virtual play money. The next phase is the trading phase. There, participants gather information, form their individual preference ranking of the decision options based on their assessments and trade shares of the stocks in order to convey their assessments and realize their preferences as much as their budget allows them to. For example, a participant prefers that decision option C is realized for the pending decision. He then observes the current market status and determines whether a trading action is required on his part. Assume that the preferred option C only ranks second at the time of observation. In the example, the trader then decides to buy 20 shares of decision option C in order to advance decision option C in the ranking of the decision options. The trader may also continue to observe both the market and new or updated information from external sources and adapt his trading actions accordingly. After the trading phase, the market is closed, that is, trading is stopped. In the evaluation phase, the market results are evaluated and the winning decision option is determined. Then, the trader can determine whether his favored decision option has been selected through the market.

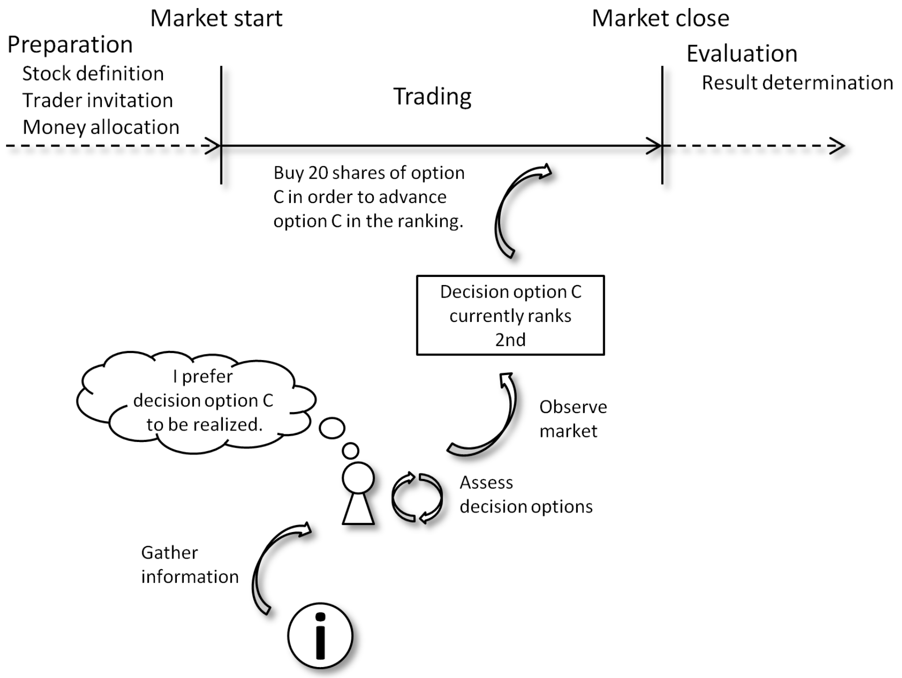


Figure 3.1: Example of a decision market execution

3.2.2 Transferring the Market Metaphor

In the application of the market metaphor as an idea collection and ranking mechanism, LaComb et al. find that the market metaphor is on the one hand able to encourage the contribution of several new and interesting ideas [58]. On the other hand, participants are reported to trade according to two intentions, namely the ranking of the most promising ideas and the maximization of their portfolio worths. These two intentions, however, need not coincide and thus need not lead to concurring trading actions. Thus, rankings can be the result of a mixture of sincere opinion indication and of profit-oriented trading. Dahan et al. similarly apply the market metaphor with the goal of gathering the individual preferences of participants with respect to product features [22]. They find that their *preference markets* are more likely to aggregate group opinion forecasts rather than to gather the sincere preferences of the single participants.

For the design of prediction markets, Spann and Skiera devised the three design steps of choice of forecasting goal, incentive design, and financial market design in order to achieve accurate forecasts [93]. Both LaComb et al. and Dahan et al. design their markets based on similar steps. While these steps provide a good starting point for the application of the market metaphor to an information aggregation task, they do not take into consideration the differences between prediction markets and other applications of the market metaphor. In the case of LDM, the goal is to achieve a good decision. As highlighted above, however, participants may follow different trading intentions which need not necessarily produce a good decision. Therefore, we investigate the application of the market metaphor more closely in the following sections and we check which measures need to be taken in order to adapt the design of a market-based application to the peculiarities resulting from the change from forecasting to decision making.

3.3 A Model of a Virtual Market

In the following, we devise a model of a virtual market to identify differences and commonalities between application types of the market metaphor. A virtual market is a market that is started with the intention of aggregating information from people and of interpreting the market prices as the aggregated result.

3.3.1 Characteristics

We first identify categories for describing instances of a virtual market. They include the organizer's goal, the market result, the trading objective, the trading incentives, the personal goal of the participants, and the type of participation.

Organizers' Goal An instance of a virtual market is employed by market organizers with a certain goal in mind. Typically, the goal is to achieve a useful market result.

Market Result The market result describes the final status of the market. This also includes its quality. This quality depends on the market goal of the organizer and the application situation.

Trading Objective To achieve their goal, organizers determine trading objectives for the participants and communicate them accordingly. The participants are then expected to follow these objectives and to adjust their trading actions accordingly.

Trading Incentives Trading incentives are provided to participants to encourage them to adhere to the trading objectives and, in doing so, to actually contribute to the achievement of the market goal.

Personal Goal Participants may also have personal goals in their participation in a market. These goals likely influence their trading actions.

Participation Type Participants may participate according to a principal-agent style type (see Section 2.6) and to a style in which they are involved with the actual result.

3.3.2 Stylized Workflow

In Figure 3.2, we highlight a stylized workflow for a virtual market. The preparation of the virtual market includes the definition of the market and the associated stocks. Furthermore, the group of traders is determined and invited for participation. Upon registration, they receive their allotment of virtual money. After the start of the market, the participants convey their evaluation of the alternatives by trading shares in the associated stocks. The participants observe the market, integrate new or updated information, adjust their evaluation, and trade in the market. A stock ranking is then generated from the resulting stock prices in descending order of their price levels. This ranking indicates the popularity of the alternatives associated with the single stocks. The participants are assumed to be utility maximizers and to derive their utility from the reward they expect from their market participation [68].

Two kinds of information need to be discerned. The first kind of information is information that a particular trader gains from different external sources on the topics of the market. He uses this information and his background knowledge to form his

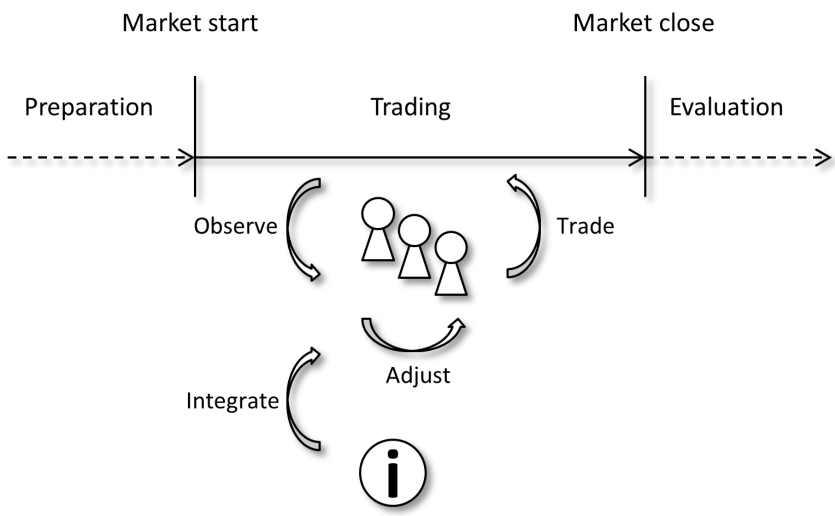


Figure 3.2: Stylized workflow of a virtual market

opinion on the stocks on the market. His opinion then represents his interpretation of the information and his background knowledge. The second kind of information is information that the trader learns from the market in the form of stock price developments and trading actions of the other traders. This information indicates the opinions of the other traders, but does not allow for a direct access to the underlying information of the other traders. Both kinds of information then form the basis for the trading actions of the trader.

3.3.3 Behavior of Participants

The trading behavior of the participants plays a crucial role in the achievement of the desired market result [64]. The term *trading behavior* refers to the kind and sequence of trading actions that a particular participant executes during market runtime. We identify two factors that in turn impact the trading behavior of the participants. The factor of virtual market design refers to the aforementioned characteristics of a given installment of a virtual market. The factor of application scenarios concerns the external conditions of a given market installment. This correspondence between the two factors, the trading behavior, and the market result is highlighted in Figure 3.3. For the decision market of our LDM approach, this correspondence also holds true. For appropriately designing this decision market of LDM, we need to understand the potential behavior of participants in a virtual market.

The behavior of participants is furthermore influenced by the degree of planning that they put into devising their trading actions in a given market. When acting *myopically*, participants only determine the very next trading action in a given market situation without looking ahead any further (see Section 2.6). Participants may, however, also behave strategically. That is, they devise a series of trading actions that they think is most likely to serve for achieving their desired market result. This strategic planning may indeed include a subset of market actions that contradicts in itself the final market result. In this thesis, we assume participants to act myopically in LDM in order to keep the model of the participants' behavior simple.

Behavior Activities

Our model of the participants' behavior builds on the behavior model that Dahan et al. devised for traders in their preference market applications [22]. We identify three steps as given in Figure 3.4 as the general sequence of the participants' behavior. In the first step, participants gather information on the available stocks as a basis for

Figure 3.3: Impact of virtual market design and application scenarios on trading behavior and market result [64]

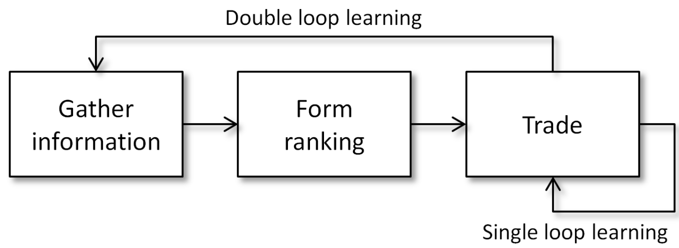


Figure 3.4: Generalized steps of behavior in a virtual market

their subsequent evaluation. In the next step, they evaluate each stock based on the previously gathered information and form a ranking based on the evaluation results. Then, they compare the current market ranking to their personal ranking and devise a trading action that aims at converging the market ranking towards their personal ranking as far as their money allows them to. They execute this trading action in a market trade.

Gather Information In the information gathering step, participants use different sources to inform themselves on the topic of the market and the associated stocks. These sources include the market status itself by its stock prices as well as information sources external to the market. Such sources include for example research results, consultations of other experts, and own experiences. The goal of the participants in this step is to gather sufficient information for the execution of the subsequent evaluation step. The selection of the information sources is impacted by the overall market goal and the personal goals of the participants. This step results in the participant understanding the market's topic and the single stocks.

Form Ranking In this step, participants evaluate the single stocks based on the individually gathered information. The result of this step is a personal ranking of the stocks and serves as an input for the subsequent trading step. The weighting of the information sources as well as their interpretation is impacted by the overall market goal, the personal goal of the respective participant and the nature of the rewards that are provided by the market organizers.

Trade The goal of the participants in the trading step is to convey their current personal ranking of the stocks to the market. They compare the current market ranking and their personal ranking and conceive a trading action that best realizes their personal ranking. Depending on their budget and the discrepancy between their personal ranking and the market ranking, participants may not be able to fully realize their personal ranking. Finally, they execute this trading action in a trade. The market mechanism then processes this trade order accordingly.

Learning in the Virtual Market Model

The repeated participation of traders enables them on the one hand to continuously strive to realize their personal rankings of the stocks on the market and on the other hand to revise their evaluation of the stocks and thus their personal ranking. The first effort may require participants to adapt their trading actions to changes in market status to realize their current personal ranking. The second effort may result from the participants learning new information during the runtime of the market, for example new research results or the availability of new information sources. This adjustment of trading actions and of stock evaluations is caused by the participants' learning of the new circumstances. For describing this learning effect, we relate to the learning model proposed by Argyris and Schön [7]. They describe two learning loops of people who want to achieve a certain goal. The first learning loop, called *single loop learning*, concerns actions to achieve a goal at hand under the given circumstances. The second learning loop, or *double loop learning*, in contrast, refers to the examination of the goal itself and to its modification where it deems required. The adjustments performed in both loops are based on the feedback that participants receive. In the following, we incorporate these learning loops in our virtual market model in order to describe the adjustments that participants perform in their behavior during market runtime (see Figure 3.4).

Single Loop Learning In single loop learning, market participants have already determined their evaluation of the stocks and created a ranking of them. The goal of the participants is then to realize the trading objectives and their personal goals (see Section 3.3.1). In single loop learning, the created ranking is fixed. Participants are concerned with choosing and adapting their trading actions in the trading step of our model (see Figure 3.4) in order to achieve the trading objective and personal goals. They receive their feedback directly from the reactions of the stock prices to their trading actions and adjust their actions accordingly. For this single loop learning, it is assumed that participants adjust their trading actions only based on information from the market, that is, the stocks prices. New outside information is only indirectly taken into consideration as it is reflected in the changes of stock prices caused by other traders.

This single loop learning is an important part of the working of markets as the prices act as a signal on the information of other participants. However, if participants solely focus on price developments, new outside information will not be directly incorporated in stock prices and will thus diminish to be aggregated by the market.

Double Loop Learning In double loop learning, participants re-assess their current ranking of the stocks due to the availability of new information sources or updated information. As a result, participants may change their evaluation based on new insights. Consequently, they also change their ranking of the single stocks. Thus, their current shareholdings may no longer reflect this new ranking and additional trading actions may be required to realize this new ranking on the market. This double loop learning describes participants adapting their rankings over the course of the market runtime based on new information. This learning loop is thus important for the incorporation of new information into the market.

3.4 Market Types

In the following, we utilize the previously introduced model of a virtual market for investigating the workflows of the participants, their behavior, and the two learning loops in prediction markets, preference markets, and decision markets.

3.4.1 Prediction Markets

The goal of the organizers of a prediction market is to obtain an accurate forecast for an uncertain future event from a large group of people. The trading objective that is issued by the organizer for the participants is to improve the forecast that is represented by the current market status. For attracting people and for encouraging them to contribute accurate forecasts, the organizers provide a reward to participants depending on the accuracy of their forecasts. The personal goal of the participants is typically assumed to be the achievement of the provided reward. As the reward is linked to the accuracy of the forecast, participants maximize their expected reward if they provide their most accurate forecast of the uncertain future event.

The Prediction Market Workflow

Figure 3.5 shows the overall execution of a prediction market in terms of the virtual market model of Section 3.3. First, the prediction market is prepared (not shown here). This includes the determination of the event to be predicted and of the potential outcomes. The event then forms the market and the stocks of that market represent the single event outcomes. Then, the market is started and participants begin to trade. They predict the likelihoods of the respective event outcomes based on their available information, trade in the market according to their forecasts, observe the market as well as new outside information and adjust their personal forecast where appropriate. Prior to the occurrence of the actual event, the market trading is closed so that traders cannot consider the actual outcome in their trading. After the occurrence of the event, the accuracy of the participants' forecasts is determined and they are rewarded accordingly.

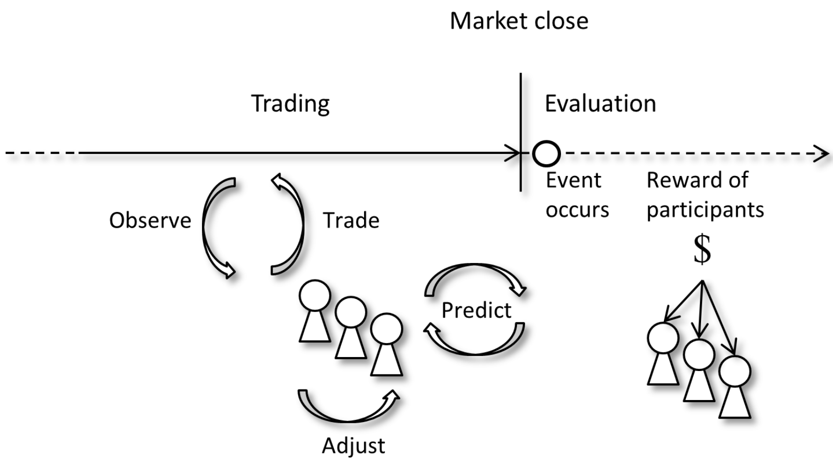


Figure 3.5: General execution of a prediction market

Market Behavior

In the following, we describe the potential behavior of participants in prediction markets based on our virtual market model. A model of their behavior steps can be drawn as seen in Figure 3.6 [64]. First, participants gather information on the event to be forecast and on the potential outcomes. Their goal is to learn to know the event and the potential outcomes and to get sufficient information for their subsequent evaluation. The kind of information that they gather is impacted by the trading objective and the personal goal of the participants. As their personal goal is to maximize their reward and this in turn depends on their delivered forecast accuracy, they have an incentive to gather useful information. As a result, they have enough information on the topic at hand.

In the next step, participants develop their personal event forecast. Their goal is to best forecast the likelihoods of the single event outcomes for maximizing their expected reward. This incentive compatibility conveniently contributes to the goal of the prediction market organizers which is to achieve an accurate forecast. Hence, the actions of the participants that are encouraged by the provided reward, contribute to, or are aligned with, the achievement of the goal of the market organizer. A core element is the external event that is to be forecast. This external event forms the objective basis for determining the accuracy of the participants' forecasts and thus their rewards. As a result, participants conceive their personal ranking of likelihoods of the single outcomes.

Next, participants trade in the market. In the myopic case (see Section 2.6), participants maximize their expected reward by truthfully contributing their personal forecast. Therefore, their goal in this step is to realize their personal forecast as far as their available money allows them. For this, they conceive their next trade action. They compare the current market status and their personal forecast and decide which stock to trade in, while considering their available money. Subsequently, participants execute this trading action and the market incorporates this new contribution.

The Two Learning Loops in Prediction Markets

The learning loops of our virtual market model can be discerned in prediction markets as shown in Figure 3.6. Single loop learning refers to the realization of a forecast. A given participant has already formed his forecast for the likelihoods of the potential event outcomes. The participant realizes his forecast by conceiving and executing an expedient trading action, observing the market status and trades of other traders, and

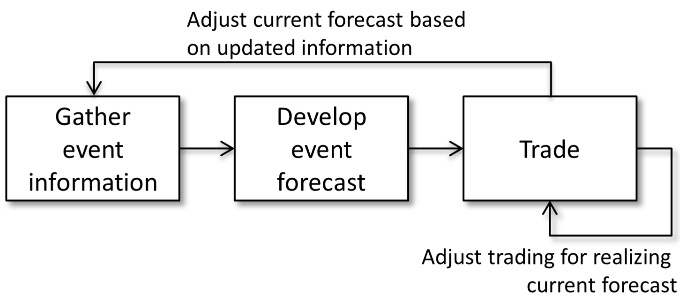


Figure 3.6: Behavior model of a user in a prediction market [64]

adjusting subsequent trading actions.

Double loop learning, in contrast, consists of the re-assessment of the goal at hand. In prediction markets, double loop learning occurs if traders examine their current personal forecast and adjust it if it seems appropriate (see Figure 3.6). Such an adjustment may seem worthwhile if updated information gets available regarding the uncertain future event. Then, the current personal forecast of a trader may no longer reflect his evaluation of the updated information. Thus, the trader needs to adjust his forecast and subsequently also his share holdings. This then requires the execution of further trading actions. At the end of this double learning loop, the trader has adjusted his forecast and also reflected this adjustment in his share holdings. In this way, new information has been aggregated into the market status.

3.4.2 Preference Markets

The market metaphor has also been utilized with the goal of aggregating preferences from people in the application as preference markets. With respect to our virtual market model, the goal of the market organizers in such a preference market is to obtain an aggregation of the sincere preferences of a group of people concerning some topic of interest [23]. There, the organizers strive to benefit from the capability of the market metaphor to aggregate the desired information from participants. From the point of view of the organizers, the participants' trading objective is to contribute their sincere preferences for the topic at hand via market trading. For example, in the composition of a research portfolio, participants would build their preference ranking of the available research topics based on what they individually think fits best for the portfolio composition. They would then trade shares of the preference options accordingly and update their preference ranking upon the availability of new information. In this way, an aggregation of all individual preferences for the single options would form.

The successful achievement of the market goal in prediction markets – an accurate forecast – is based on their incentive compatibility. This incentive compatibility is predicated on the existence of an objectively ascertainable external event which can be utilized to determine the reward of the participants. In prediction markets, such an external event exists as it is a central element of a prediction market. With preference markets, however, this external event is missing as on the one hand there is no a priori external source for validating such preferences and on the other hand the goal of such markets is to aggregate individual preferences rather than forecasts. Hence, forecast accuracy is no longer sought for and also cannot be utilized as a measure for determining the reward for participants.

Due to the missing external event and the changed goals in the preference market application, the accuracy metric of prediction markets cannot be called upon for encouraging people to perform at their best. The second learning loop consists of incorporating new or updated information and of updating one's ranking of the stocks. Without an external event, participants may base their ranking predominantly on market information while disregarding outside information. In such a case, however, the second learning loop of incorporating new outside information is missing.

Two approaches can be discerned in the literature for dealing with this missing

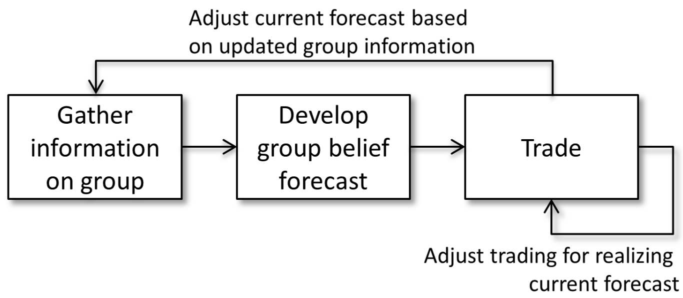


Figure 3.7: Behavior model of a user in a preference market with internal evaluation [64]

external event and the restoring of the second learning loop. The first approach is to reward participants based on their relative portfolio worths [21]. Portfolio worths are calculated based on the prices of the single stocks and the holdings of the respective participants. A ranking of the participants based on these portfolio worths can then be generated. The participant with the highest ranking then receives the highest reward. This closes the second learning loop again as participants now adapt to changes in this ranking. In this case, we argue that utility maximizing participants are rather likely to forecast the preferences of their peers and their subsequent actions in the market and to act upon this forecast. This also means that both learning loops receive their feedback for adaptations primarily from the market and not from an evaluation of the underlying topics and outside information. This guessing effect is also known as the "Keynesian Beauty Contest", described by economist John Maynard Keynes [54]. The core phenomenon of this beauty contest is that participants start to guess the votings of the other participants and adjust their votings in order to take advantage of it. More sophisticated participants may even take such guessing behavior into account and take the guessing to the next level. Ottaviani also recognizes that such markets may need some "grain of truth" for anchoring rewards and that endogenous rewards as in this case may lead to second guessing [75]. Marinovic et al. conclude from their investigations that the informational value of a market based on a pure beauty contest is negligible as participants only focus on publicly available information for performing well in the beauty contest and thus not on contributing any personal assessments [69]. They furthermore conclude that neither an increase in the number of participants nor an increase in publicly available information necessarily improve the informational properties of such markets.

In Figure 3.7, we adapt the model of Dahan et al. and show a simple cycle of such beauty contest-like actions [22]. They conclude that such setups of preference markets are capable of producing predictions on group opinions rather than aggregations of individual independent preferences. The prediction of group opinions, however, is actually not sought for in preference markets. Rather, the goal is to gather every participant's individual and independent assessment.

The second approach for tackling the missing external event and the open double learning loop is to artificially generate a surrogate event [23]. This surrogate external event typically consists of conducting a complementary preference ranking produced by an alternative method such as a survey of an external jury. The trading objective for participants in such a market is then to rank the preference options according to their

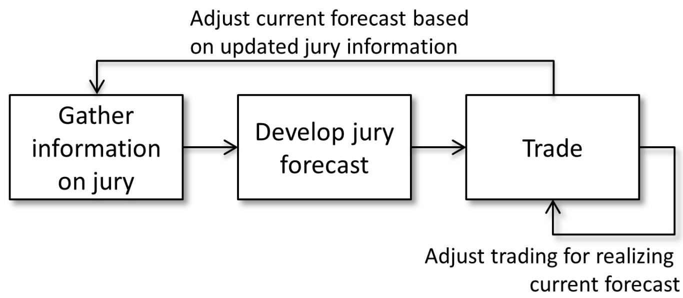


Figure 3.8: Behavior model of users in a preference market with external jury

sincere preferences. Their reward, in contrast, will be based on the accordance of their preferences, represented by their final share holdings, with the ranking generated by the external jury. Therefore, the jury ranking is typically not published to participants prior to market close as they could naturally maximize their reward otherwise.

For this case, we again assume that participants are utility maximizing. In such a market with an external jury verdict, the utility of participants originates from the reward that is provided based on their accordance with the external jury. Here, we argue that the contributions of participants to the joint preference ranking of the market are likely to be biased towards forecasting the external jury's verdict rather than contributing one's own evaluation of the preference options (see Figure 3.8). This, however, does not contribute to the aggregation of the individual preferences of the users and does not contribute to the often stated goal of preference markets to aggregate individual preferences.

In both approaches given above, the missing basis for rewarding participants is restored, however, incentive compatibility is typically not obtained with it. That is, the trading actions required to realize a forecast of the group's opinion in order to maximize their reward and the trading actions required to convey one's sincere preferences no longer coincide necessarily. Participants may need to decide between trading actions for contributing their preferences and trading actions for maximizing their reward if they do not coincide during market runtime. Thus, stock prices are likely to partially reflect reward maximizing intentions and partially sincere preferences.

3.4.3 Decision Markets

LDM utilizes the market metaphor for making a decision in a group of people. We therefore refer to this application of the market metaphor as a *decision market*. The market goal of this decision market is to aggregate the sincere assessments of the decision options from the participants and to produce a collectively selected decision option as a market result. Therefore, the trading objective for the participants is to contribute their sincere assessments of the single decision options. However, similar to preference markets, decision markets also lack an external event which the market result could be compared to and which could form the basis for rewarding the effort of participants. This is due to the fact that the decision is still to be made and the market result is used to determine that decision. Thus, the kind of incentive compatibility found in prediction markets does not hold for decision markets.

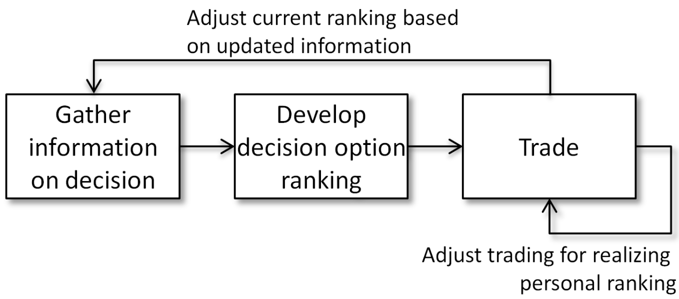


Figure 3.9: Steps of desired user behavior in a decision market [64]

The market goal of decision markets is to aggregate the sincere assessments from their participants. Consequently, the desirable behavior of participants is to develop and contribute their sincere assessments to the market. In the following, we describe this desirable behavior that would be beneficial for the achievement of the market goal, that is, the aggregation of the sincere opinions. We illustrate this in Figure 3.9 on the basis of our virtual market model [64]. First, participants gather information on the topic of the decision at hand and the available decision options as the basis for the subsequent assessment. Next, participants evaluate the decision options and form their trading decisions. For this, they evaluate the single decision options according to the gathered information, their own evaluation criteria, and the trading objective of the decision market. As a result, they come up with their personal ranking of the decision options. Participants then conceive a trading action for matching their personal ranking and the current market status and execute this in a trade. The market mechanism then gathers all the trades of the participants and produces a joint decision option ranking.

In decision markets, the single learning loop of our virtual market model consists of the observation of the market and the adaptation to changes in the market status. For this, participants continuously compare their current personal ranking of the decision options and the market ranking of the decision options. Participants then execute appropriate trading actions if both rankings deviate too much in order to realign them as far as their available money allows them.

The second learning loop of our virtual market model deals with the sustained reassessment of one's task. In a decision market, that translates into checking whether the current personal ranking of the decision options still serves the personal goal and whether adjustments are required due to updated information.

3.5 Market Application Contexts

In the previous section, we detailed the three market application types of prediction markets, preference markets, and decision markets. Based on the goals, trading objectives, and actual and desired trader behavior of these market types, we discern two major application contexts for the market metaphor [64]. The first application context deals with the collective forecast of a certain variable such as an external or surrogate event. This is typically found in prediction markets and preference markets. The second application context is concerned with aggregating the sincere assessments of a group of

	Forecast Context	Decision Making Context
Organizer's Goal	aggregate accurate forecasts	aggregate sincere opinions
Market Result	accurate event forecast	collective decision based on sincere opinions
Trading Objective	improve forecast, at the same time maximize reward	contribute sincere opinion on decision options
Question	which event outcome will most likely occur?	which decision option would YOU want to be realized?
Personal Goal	utility maximization	utility maximization
Participation Type	principal-agent	involved

Table 3.2: Comparison of the forecast and decision making contexts

people on a given topic. This is found in the decision market of our LDM approach and may also be the actual goal of some preference market applications, although it is not achieved in their current designs. We refer to the first application context as the *forecast context* as the primary goal of markets is there to aggregate forecasts. Likewise, we term the second application context *decision making context* as market organizers there want to learn the individual opinions of the single participants for making a joint decision.

Table 3.2 highlights differences and commonalities between the forecast and the decision making contexts. In the following, we evaluate both contexts according to their market goal, the desired market result, the trading objective for the participants, the inherent question that is asked to participants, and the personal goal of the participants.

3.5.1 The Forecast Context

Markets pertaining to the forecast context are characterized by the goal of aggregating forecasts from participants and of producing an accurate forecast. The trading objective for the participants is to improve the current market forecast by contributing their personal forecast. Participants in prediction markets are generally assumed to be utility maximizing and to derive this utility from the achievement of the provided rewards. The task of the market application is to gather the single forecasts of the participants and aggregate them into a combined forecast. Prediction markets are typically evaluated for the forecast accuracy they produce for a given event. According to Hanson, every market asks a question [39]: what is the value of a given asset? In the forecast context, this question can be phrased as follows: which event outcome will most likely occur?

Markets of the forecast context are incentive compatible as participants are rewarded based on their forecast accuracy (see Section 2.6). We illustrate this in Figure 3.10. There, both intentions of maximizing one's reward and developing an accurate forecast lead to the same evaluation of the outcome likelihoods and thus to the generation of the same trading action. This trading action is then executed as a trade and contributes to the market goal of achieving an accurate overall forecast.

We identify both learning loops of our virtual market model in the forecast context

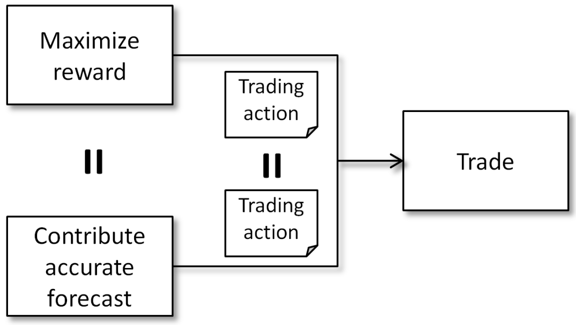


Figure 3.10: The development of an accurate forecast falls together with the maximization of the reward in the forecast context.

as follows. The single learning loop consists of the observation of the market and the selection and execution of trading actions according to the fixed likelihood evaluation. In this loop, participants strive to realize their likelihood evaluation on the market depending on their financial situation. The double learning loop contributes to the achievement of an accurate forecast. This loop is the result of participants forecasting the uncertain future event and incorporating new information as it becomes available to them. In this process, they adjust their evaluation of the likelihoods of the event outcomes to changes in information and devise trading actions if their new evaluation does not match with their current share holdings.

3.5.2 The Decision Making Context

The decision making context refers to applications of the market metaphor with the goal of gathering the sincere opinions from the participants and of producing a collective decision as a result. The question posed to participants is in this case: which decision option would you want to be realized? In markets conforming to the decision making context, there is no external event to be forecast and hence, forecast accuracy is no longer usable as a basis for rewarding participation. However, participants are also in the decision making context assumed to be utility maximizing. Basis for their utility includes the profit they may earn from speculating during the market runtime. That is, participants try to buy cheap and sell dear at a later time. Therefore, we can identify two kinds of intentions in the determination of trading actions. The first intention is related to the trading objective as given by the organizer of the market. The second intention is related to maximizing one's utility, for example an in-market profit. The trading actions that result from these intentions need however not coincide, as highlighted in Figure 3.11. A utility maximizing trading action may for example consist of selling shares of a given stock, while a trading action for contributing one's sincere opinion may call for buying shares of that stock. These differing trading actions then have different impacts on the nature of the market result. Hence, incentive compatibility is no longer given.

To goal of the market metaphor in the decision making context is to gather the participants' sincere opinions. This goal is also communicated to the participants as their trading objective. If participants then would follow these instructions, they would form their personal opinion of the given topics, generate a ranking based on these

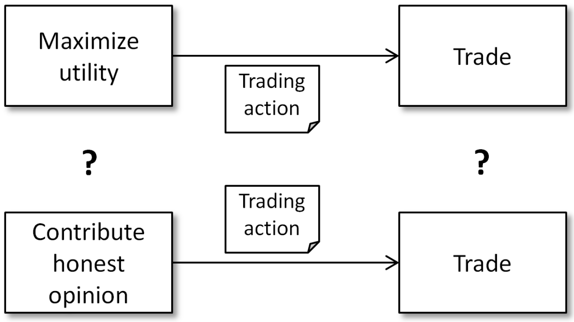


Figure 3.11: Different trading intentions leading to different trades

assessments and trade in order to best realize this ranking on the market. They would also update their assessments and ranking if new information would be available on the single topics. If all participants would follow this intention, the market result would represent the aggregation of their individual opinions of the single market topics.

While participants may be instructed to contribute their sincere opinion as their trading objective, they may very well also follow their own goals. As participants are assumed to maximize their utility, they may derive this utility for example from the profit they can make during the runtime of the market and from the joy of gambling in the market. From this striving for utility maximization, they also generate a ranking of the given topics based on the evaluation of which would best serve to maximize this utility. Participants then devise trading actions for realizing this ranking on the market and thus for maximizing their utility. Trading actions devised under both intentions by a single participant need not coincide due to the missing incentive compatibility. Evaluations may sometimes lead to the generation of identical trading actions and thus contribute to an sincere opinion aggregation. Sometimes, participants may also follow a mixed strategy and switch between intentions during the runtime of the market and they may thus partly contribute to the market goal of aggregating sincere opinions. Nevertheless, the missing incentive compatibility puts a strong bias on the usability of the market result as the collective opinion of the participants.

3.6 Decision Market Application Scenarios

In the virtual market model, we identified the two factors of virtual market design and of application scenarios to have an impact on the trading behavior of the participants and furthermore on the market result (see Section 3.3). Some application scenarios may be more suitable for the achievement of a good decision than others. In the following, we identify key scenario factors that should favor the achievement of a good decision, namely the utilization of the market results, the stakes of the participants in the market result and the objectives of incentives in the decision making effort. These factors influence the behavior of participants and thus the quality of the market result. We furthermore devise suitable scenarios based on the possible values of these factors.

3.6.1 Key Scenario Factors

This section details the factors that we identified to have an impact on the suitability of LDM for a decision making effort.

Result Utilization The factor of result utilization concerns the way the market result is utilized at market end. In standard prediction market scenarios, the results of the respective markets constitute an input to an overarching process. That is, participants contribute to the achievement of the goal of this process but their produced market result may be just one amongst many other inputs. The market result may also be the only defining result for the accompanying process, as with our LDM approach. There, participants know that the result they are going to produce will pose the binding decision for this decision making effort.

Stakes The factor of stakes refers to the involvement of the participants with the market result and its utilization. The typical scenario of prediction markets adheres to the principal-agent style involvement of participants. There, participants have no stakes in the utilization and impact of the market result. That is, they derive no utility from the market result. Rather, they are expected to deal with the provided problem to the best of their knowledge and to be motivated by the rewards that are offered to them based on their portfolio worths. Besides the principal-agent setting for prediction markets, people may also have stakes in the outcome of a market they are participating in. In such markets, they derive some utility from the achievement of a particular result and thus have a vested interest in achieving their most favored market result.

Incentive Objectives The factor of incentive objectives deals with the design of incentives accompanying the decision making effort. The design of prediction markets envisages participants to strive for the achievement of the reward that is provided by the market organizers. The allocation of this reward is based on the portfolio worths of the participants. Therefore, they are likely to optimize their market actions according to this measure. Decision markets in contrast benefit from a decision oriented view of their participants. There, the objective is to encourage participants to examine the decision topic and to contribute their sincere assessments of the available decision options.

3.6.2 Suitable Decision Market Scenarios

In the following, we describe scenarios that should favor the achievement of good decisions. These scenarios are based on the key market factors introduced beforehand. Table 3.3 lists the decision market scenarios and the accompanying values for the key market factors. We identify the Scenarios 4 and 8 to be most promising for achieving good decisions with LDM in a decision making effort.

Scenario 1 This scenario constitutes the typical prediction market scenario. The results of the market are utilized as support for some superordinate process, participants have no stakes in the outcome of the market and the objective of the provided incentives is to encourage the maximization of one's portfolio worth.

Scenario	Result Utilization	Stakes	Incentive Objectives	Rating
1	Support	No	Portfolio Worth	-
2	Support	No	Contribution	-
3	Support	Yes	Portfolio Worth	-
4	Support	Yes	Contribution	+
5	Direct	No	Portfolio Worth	-
6	Direct	No	Contribution	-
7	Direct	Yes	Portfolio Worth	-
8	Direct	Yes	Contribution	++

Table 3.3: Feasible Decision Market Scenarios

Scenario 2 The second scenario is similar to the preceding scenario, with the difference that the incentive objective is to encourage the contribution of true assessments.

Scenario 3 In this scenario, the result is again utilized for support in an superordinate process, participants have some stakes in the market result and are at the time incentivized to perform well in the market. In this scenario, interests of participants are in conflict between maximizing the portfolio worth and contributing sincere assessments of the decision options themselves.

Scenario 4 In scenario 4, the market application is targeted at aggregating the sincere opinion of participants. These have also stakes in the outcome of the market. However, the result of the market is only one input among several others in an superordinate process. In this way, participants only have limited influence on the overall decision. This scenario is suitable as a decision market scenario, however, the behavior of participants may be biased by the notion of not being able to directly influence the decision that is to be achieved overall.

Scenario 5 This scenario is characterized by a direct utilization of the market result as the final decision. However, participants do not have any stakes in the decision outcome and are furthermore rewarded based on their portfolio worths. Thus, they are unlikely to contribute their sincere opinion on the decision options. Rather, they are likely to strive for the maximization of their portfolio worths.

Scenario 6 In this scenario, participants directly determine the final decision by means of the market result and are expected to do so by contributing their sincere assessments of the decision options. However, they have no stakes in the decision outcome and thus have no increased motivation for engaging in thorough assessments and the contribution of their sincere opinions.

Scenario 7 Direct result utilization, stakes of the participants in the decision outcome and a reward based on the portfolio worth characterize this scenario. Similar to Scenario 3, participants are likely to have conflicting interests between serving the achievement of their individual stakes in the decision outcome and a maximizing their portfolio worth. There, the quality of market results is likely to suffer from this conflict.

Scenario 8 In this scenario, the market result directly determines the decision that is to be made by the market application. Participants have stakes in the outcome and the objective of the incentives is to encourage the contribution of their sincere opinion (see Section 3.8.3). The occurrence of this scenario should favor the achievement of a good decision the most. Participants feel a direct connection with the achievement of the result as they know that their actions directly contribute to the final selection of the decision option. They are motivated to contribute their sincere individual assessments of the decision options as they derive their utility from the final result of the market.

3.7 The Design Goals of Liquid Decision Making

The goal of the decision market in our LDM approach is to gather the sincere assessments of the single decision options, not a prediction of the group's opinion. That is, the decision market needs its participants to evaluate the single decision options, similar to fundamental trading in real markets [72]. There, traders estimate the value of a given stock by considering the fundamental value of the underlying asset, for example, the value of a company. In the preceding sections, we identified different potential trading behaviors of participants in decision markets and investigated key scenario factors that influence that behavior. From the potential values of these factors, we compiled decision market scenarios and evaluated them for their suitability for decision making using the market metaphor. Based on these investigations, we present design goals for LDM. The objective of these goals is to ensure the achievement of a good decision.

3.7.1 Goals Regarding the Market Application Scenarios

We identified the factors of result utilization, stakes, and incentive objectives to impact the quality of the market result. For the achievement of a good decision, these factors should be controlled as much as possible. However, not all factors are under full control of the decision making group.

Result Utilization The market organizer's goal is to aggregate the sincere opinions of the participants. On the one hand, people may contribute sincerely based on intrinsic motivations. On the other hand, markets also contain a gambling component, which may impair the sincere contributions, depending on the susceptibility of the respective person. To a certain degree, gambling may contribute to the liveliness of a given market, beyond that the quality of the market result is likely to deteriorate. There, we argue, participants should be encouraged to contribute sincerely. A direct utilization of the market result should provide a good encouragement to contribute sincerely, as participants should feel more responsible for their impact on the final result. The goal therefore is to select decision situations in which the result is directly utilized as the final decision.

Stakes As highlighted before, participants may contribute their sincere opinions intrinsically or they may need to be motivated extrinsically. In the forecast context, the extrinsic motivation typically consists of the reward the participants receive for their accurate forecasts. In the decision making context, a forecast-based reward cannot be established. We argue that the existence of a reasonable involvement of the participants with the decision outcome and thus the market result motivates the participants to sincerely contribute. With certain stakes in the outcome, participants have to deal with the result after market end and should thus be more likely to care for their contributions. Therefore, the goal is to apply LDM in situations with high enough stakes for the participants.

Incentive Objectives The objectives of the incentives that are provided to participants can typically be determined by the market organizers. That is, the market organizers are responsible for targeting the provided incentives in such a way as to foster sincere trading behavior and to restrain profit maximizing behavior.

3.7.2 Goals Regarding the Participants' Behavior

The main goal of LDM is to provide a mechanism that encourages participants to contribute their sincere opinions on a pending decision. In Section 3.4, we described two trading intentions, namely the contribution of one's sincere opinion and the maximization of one's portfolio worth. We identified trading behavior according to the sincereness intention to be more beneficial for the achievement of a good decision than behavior falling into the profit intention. Therefore, the overall goal regarding the participants' trading behaviors is to encourage sincere behavior and to discourage profit oriented behavior. In the following, we subdivide this overall goal into the disregard of one's portfolio worth, the contribution of one's sincere opinion and the encouragement of repeated participation.

Disregard Portfolio Worth The utilization of the market mechanism and money allow for the calculation of a participant's portfolio worth as well as for the participants to maximize it. Trading motivated by the maximization of this portfolio worth does not necessarily contribute to the achievement of a good decision as people do not necessarily contribute their sincere opinion. Encouraging participants to disregard their individual portfolio worth and to focus on the decision making goal should foster their contribution of sincere opinions.

Sincere Contribution Markets by their nature allow for speculation and gambling. While a certain amount thereof can contribute to market liquidity, to the liveliness of trading, and to the engagement of traders, results that are largely biased by speculation and gambling are less likely to represent the sincere assessments of the underlying decision options. A reduction in gambling and an encouragement for sincere contributions should thus contribute to the achievement of a good decision and reflect the aggregated sincere opinions of participants.

Repeated Participation The original prediction markets offer the potential to improve one's prediction by repeatedly trading during the runtime of the market even if the rank of a single stock does not change as a result. In decision markets, the absolute prices are of less concern. There, the resulting ranking determines the chosen decision option. That is, once a specific decision option has attained the desired rank in the overall market ranking, participants may settle and stop taking care of that favored stock. In order to decrease chances for the markets to drop off and thus not benefit from their continuity, repeated participation should be incentivized.

3.8 The Design Principles of Liquid Decision Making

Weinhardt and Gimpel identify the behavior of traders in markets as one of the key market engineering objects for achieving the desired market result [104]. This trading behavior is in turn influenced by the design of a market (see Section 3.3.3). Therefore, we devised design principles as part of LDM for guiding the design of a decision market [65]. The overall goal of these design principles is to foster the achievement of a good decision by addressing the goals regarding the participants' behavior as introduced in the previous section. To this end, we looked at the framing of the decision making situation, at the level of the user involvement, and the incentives provided to the participants. This resulted in the design principles of collaborative decision, user involvement, and dual incentives. In Table 3.4, we highlight the contributions of the single design principles to the achievement of the single design goals. In the following, we detail the single principles, their origin, purpose, and operation.

	Disregard Portfolio Worth	**Sincere Contribution**	**Repeated Participation**
Collaborative Decision	++	++	
User Involvement	++	++	+
Dual Incentives			++

Table 3.4: The contribution of the design principles for realizing the design goals

3.8.1 The Collaborative Decision Principle

LDM utilizes the market metaphor for aggregating the assessments of people on decision options of a pending decision. Markets by their nature allow participants to gamble and speculate on the stocks and, in this way, influence the stock prices. This gambling originates from the virtual money that is used for trading. Virtual money may be accreted, may be transferred between participants through trading, and may gain or lose purchasing power as prices decrease or increase. Due to this gambling or speculation, stock prices may not only reflect the sincere assessments of the underlying decision options but also the speculative expectations on the gambling potential of these stocks regardless of the associated decision options. In some cases, market results may be dominated by speculative trading, similar to so called technical trading which only considers trends and correlations between stocks [72]. In this way, however, participants do not learn about the sincere opinions of the others on the underlying decision options and a good decision based on the sincere assessments of the people is unlikely to emerge.

The goal of the application of the market metaphor in LDM, however, is to gather the sincere assessments of the participants. To enable the gathering of these sincere assessments, we devised the collaborative decision principle. The purpose of this principle in the design of a decision market is to encourage participants to focus on the contribution of their sincere assessments of the decision options. The basic idea of the principle is to highlight the collaborative effort of making a good decision to the participants. People shall recognize the result of the application of LDM to their decision making situation as the collaboratively chosen decision. They shall acknowledge the result as the decision they produced together for their own benefit, not for someone else's.

The collaborative decision principle works by de-emphasizing information that may encourage gambling or speculation and by emphasizing information that aims at encouraging sincere contributions. The leader board ranking of participants according to their portfolio worths is a considerable source of competitive effort among participants as we have learned from the studies accompanying this thesis (see Section 6). The aim of the collaborative decision principle is to de-emphasize those bits of information that may excite speculative market trading behavior, for example, by omitting the leader board ranking from the user interface. In contrast, the collaborative nature is emphasized by providing appropriately phrased introductions on the purpose of the market and the objectives of the participants, all highlighting the collaborative aspect. This focus on collaboration rather than the competitive market nature is also reflected in the integration of the market metaphor with the decision making architecture of the software prototype. There, the market functionality is encapsulated in a separate component that provides the trading and ranking functionalities for the decision making component.

3.8.2 The User Involvement Principle

People that have no stakes in the result of a task are likely to care less for the achievement of a good result in that task as they will not be affected by an undesired result. With prediction markets, stakes can be created by providing rewards depending on the delivered forecast accuracy. The better the forecast accuracy of a participant is, the higher a reward can be granted to the respective participant. In this way, people that decide to take on that forecast challenge have a stake in the result of their forecasting performance. Decision markets do not allow for providing such stakes based on forecasting performance as the decision is yet to be made and there is no external event to which the chosen decision could be compared to. Also, the aforementioned collaborative decision principle advises to omit competitive elements in order to decrease gambling and biasing market prices. Thus, the creation of stakes based on comparing the users' portfolio worths has to be ruled out. The provision of such stakes would be likely to induce speculation and gambling that is directed towards the achievement of such competitive measures and not towards the achievement of a good decision. To encourage participants of a decision market to take care of the achievement of a good decision, other means of providing sufficient stakes should be consulted.

To this end, we devised the user involvement principle. The basic idea of this principle is to establish personal stakes in the market result for the participants. The purpose of these personal stakes is to get the participants to care for the market result and to be interested in the achievement of a favorable result. Basically, the existence of personal stakes may lead to a decreased or an increased engagement with the decision at hand. A decreased engagement may be due to caution and a fear of taking the wrong actions. This would then result in taking none or only a few market actions and thus not contributing to the achievement of a good decision. We argue, however, that the existence of personal stakes in combination with the possibility to directly influence the outcome for these personal stakes in LDM is more likely to prompt participants to an increased engagement with the decision at hand.

The user involvement principle works by coupling the market result, i. e. the chosen decision, to the personal situation of the participants. An example for this coupling is the utilization of the decision in a larger process in which the participants then have to deal with the previously chosen decision option. The applicability of the user involvement principle there depends on the specific decision making situation. If the decision making situation does not allow for any kind of user involvement of the participants, personal stakes cannot be established. There, we argue, participants are likely to care less for the final result.

3.8.3 The Dual Incentives Principle

The formation of prices and of opinions in decision markets using LDM depends on the repeated participation by the traders. Therefore, it is desirable that people participate on a regular basis in the decision making effort and continually update their share holdings in the single decision options. Kamp and Koen suggest that incentives considerably influence the trading behavior of participants and thus the accuracy of idea markets [53]. They furthermore highlight that incentives should be properly aligned with the market purpose. We thus identified the need for two basic incentives for a successful application of LDM. First, people have to be attracted to participate in LDM in the first place. Second, people have to be retained with LDM to benefit from the continuous participation capability that the market metaphor offers.

To address these needs, we devised the dual incentives principle. The purpose of the dual incentives principle is first to ensure that decision makers actually utilize LDM and contribute their sincere opinions. Second, the dual incentives principle aims at encouraging traders to participate repeatedly in LDM. That is, we want to attract first timers and to retain participants for repeated contributions.

The attraction part of the dual incentives principle is realized by providing a decision that is beneficial to participate in and to highlight the benefits of the participation to people. Doan et al. suggest several approaches for retaining users with a given crowd sourcing system, including the provision of instant and helpful graphics and information, the provision of an enjoyable experience, the set up of a competition among participants, the establishment of fame or reputation, and the creation of an ownership situation [27]. In LDM, the approach of instant and helpful graphics and information is well applicable as the market mechanism always provides up-to-date prices. Furthermore, the development of prices allows for an optimal visualization using price charts. This is realized by providing participants with up-to-date information in both a pull and push notification fashion. The pull fashion includes the display and easy access to information on the market status on the market system. The push notification is realized by a periodical notification of the participants containing all relevant market status information in a personalized way. In other applications of the market metaphor, people reported the market mechanism to be fun to participate in due to its playful approach [22, 58, 60]. As LDM also applies the market metaphor, participants should also be likely to experience a certain level of fun from trading in the respective markets. This should then encourage people to repeatedly participate. Doan et al. furthermore suggest to set up a competition among participants as a further incentive. As highlighted in the collaborative decision principle above, this would lead to participants optimizing the underlying competition metric rather than contributing their sincere opinion. Therefore, the dual incentives principle refrains from such competitive measures. Another approach is to enable participants to establish reputation amongst each other. In LDM, people may earn themselves a reputation by using its commenting and rating functionality (see Section 4.4.2). For example, participants can build a reputation of competency by contributing their knowledge using the commenting mechanism. Originating discussions and the built up of reputation should encourage people to repeatedly participate in the respective market. Lastly, the market metaphor has also been reported to create a "sense of empowerment" and increased participation among people [96], addressing the ownership situation described by Doan et al. [27]. This sense of a more direct influence on the final result should also serve as an incentive for initial as well as repeated participation.

3.9 Discerning Market Result Qualities

Sometimes, the quality of a decision market's result may not be as expected despite the application of the previously introduced design principles. In this section, we introduce *market perturbations*, a concept that we developed for probing the intentions of participants and the quality of a market's current status [62, 63]. The idea of these market perturbations is to execute specific trading actions in a market and to observe the reactions of the other traders. The more robust a stock price is to such distracting trading actions, the more convinced the traders are assumed to be of that particular stock and thus, the corresponding decision option.

3.9.1 Qualities of Market Results

Consider the following situation. A group of people employs LDM for making a decision. Several trades have already been made, stock prices have developed and a ranking of the decision options can be generated. Despite following the aforementioned design principles, participants may not have fully contributed their sincere assessments so far to the market but may rather have followed the profit intention (see Section 3.5.2). This, however, does not contribute to a good decision. For this thesis, we discern the following qualities of market results.

Good Quality In this thesis, a market result is said to be of good quality if most trading actions are motivated by the desire to achieve a collective decision containing one's sincere assessments of the decision options.

Bad Quality A market result is considered to be of bad quality if most trading actions of participants are motivated by speculation and gambling efforts. Such market results are likely to be of limited use for decision making as they do not convey the sincere assessments and thus the collective opinion of the participants.

The group of people collaborating for a joint decision is assumed to be interested in a market result with a good quality. The goal is now to devise a mechanism that is capable of hinting at the actual quality of a given market result and even more influence participants to re-think their behavior.

3.9.2 The Market Perturbations Mechanism

The basic idea of the market perturbation mechanism is to execute dedicated trading actions and to observe the reactions of the other participants to the resulting price changes. As these trading actions do not originate from one of the regular traders, we refer to this approach as *perturbations*. The underlying assumption is that traders with different intentions react differently to such price changes. Traders striving to contribute their sincere opinion should be more willing to stand up for their beliefs and their share holdings, even in the face of losses or other market adversity. Traders exhibiting behavior matching with the profit intention should however be drawn to more promptly change their share holdings in order to cut losses or to make profit, e.g. abandoning stocks of falling prices faster or following rising prices more quickly.

The Perturbation Process

The approach of market perturbations consists of a series of steps for stimulating the envisioned trader reactions [63]. We discern between a market perturbation and perturbation actions. The goal of a market perturbation is to stimulate distinctive trading behavior with the participants. A market perturbation consists of one or more perturbation actions for realizing this goal. A perturbation action corresponds to a trading action in the respective market, that is, a buy or sell trade. Several perturbation actions may be required for the expected differences in trading behavior to be discernible. Furthermore, one single rather large perturbation action may be noticed as suspicious

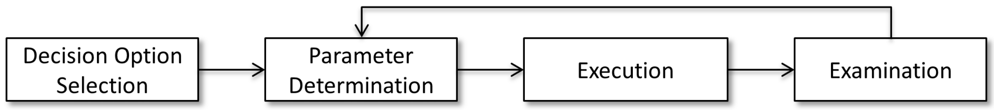


Figure 3.12: Steps of the perturbation process

by other participants. Therefore, more similar perturbation actions should come across more naturally.

The steps for the determination of a market perturbation are illustrated in Figure 3.12. First, a suitable decision option is selected as the target for the perturbation. Then, the parameters of the first perturbation action are determined and the corresponding trading action is executed. Lastly, it is determined whether the perturbation goal has already been achieved or whether another perturbation action is required.

Decision Option Selection The selection of a suitable decision option is the first step of a market perturbation. As all decision options are initial candidates for market perturbations, selection criteria are given in the following. First of all, the decision options at the top of the market ranking get the most attention of traders and price changes there are likely to be noticed quickly. Furthermore, potential candidates should have been in their equilibrium price for a considerable amount of time to be sure of a temporary consensus on this decision option. Therefore, we choose the decision option at the top of the ranking and with a price that maintained its equilibrium price for at least as long as the average duration of the previous equilibrium phases of this price. An equilibrium phase begins with the execution of a trade and lasts as long as the price changes only in the decimal place. The equilibrium price of this phase is then determined by the average price of the stock during this phase.

Parameter Determination After the stock selection, the parameters of the first perturbation action of this market perturbation are selected. First, the number of shares to be traded in this perturbation action is determined. The basis for this is the average price of all shares in the market. The perturbation action will then consist of so many shares that the price of the current stock is perturbated by a fraction of this average price. On the one hand, the price perturbation should be large enough to trigger responses from the regular traders. On the other hand, it should not arise suspicion among the regular traders if multiple large price changes occur. In the case studies that accompanied this work (see Section 6), price changes in the first digit of the respective stock price of up to 10% did not seem to be problematic in this regard. The perturbation action then needs to be executed. This execution is performed by one or more artificial traders. Their number is determined depending on the number of group members in the decision making effort. For small groups of approximately 10 people, one artificial trader suffices for the generation of the required number of traded shares and did not arise suspicion in the executed case studies. In larger groups, more than one artificial trader may be required for the execution of the perturbation action.

Execution of Perturbation Action In this step, the perturbation action is actually executed according to the parameters as defined in the previous preparation step.

Examination of Perturbation Action As mentioned before, a single perturbation action may not be sufficient for achieving the goal of the market perturbation. Therefore, the necessity of another perturbation action is determined in this step. Repetition criteria are based on time and price level. A perturbation will be repeated until a certain time has elapsed, the price has reached its original level prior to the begin of the perturbation or until the accompanying decision option is no longer the top stock in the ranking.

The Process Execution

The artificial traders that execute the perturbation actions need to be able to increase or decrease stock prices. For increasing prices, an artificial trader needs to be able to repeatedly buy shares. Therefore, the artificial trader is endowed with a considerably larger amount of money than regular traders. Ten times the initial money of the other participants proved to be a good starting point in the accompanying case studies. Furthermore, the artificial trader needs to be able to decrease prices of the top ranking decision options by selling shares of the particular stock. Ordinary participants do not own stocks initially in the LDM approach and short selling is not allowed for them. Therefore, the artificial traders are approved to short selling of the stocks in question. In this way, the artificial traders can decrease prices of stocks they do not own initially. The term short selling refers to the selling of shares a trader does not initially own. On real financial markets, short selling is realized by borrowing shares from a third party that currently owns the desired shares. Later on, the short seller returns the borrowed shares. In our current realization of market perturbations and the accompanying short selling by artificial traders, we do not consider the return of the shares that were sold short as the goal of short selling is not to make profits but to be able to change prices.

The Reactions of Traders

In Section 3.3, we introduced a model of the participants' trading behavior. As outlined in this model, participants gather information on the decision and the decision options, form their ranking of the decision options, devise their next trading action for realizing their previously formed ranking and execute the trading action subsequently. They incorporate new information from sources external to the market and from the market prices. During this process, participants should also react to price changes resulting from the trading actions of market perturbations.

In such reactions to price changes, participants evaluate whether their personal ranking of the decision options is still best expressed by their current share holdings or whether an adjustment to the holdings is required in order to reflect their personal ranking (cf. single loop learning in Section 3.3). In Table 3.5, the two trader types of a sincere trader and a profit oriented trader are contrasted with the two market perturbations of falling prices and rising prices. There, the possible reactions of the traders on price changes depending on their intentions and the market perturbations are indicated. Traders are assumed to already possess some shares in the stock whose

	Sincere Trader	Profit Trader
Falling Price	buy	sell
Rising Price	–	buy

Table 3.5: Trader reactions on market perturbations

price is changed by a perturbation. Sincere traders own shares because they favor the associated decision option whereas profit traders possess shares because they expect in-market profit from that stock.

Sincere Traders Traders with sincere intentions have the goal of realizing their personal ranking of the decision options. Therefore, they contribute their sincere assessments of the decision options. Such traders react to price changes in their share holdings according to the realizability of their personal decision option ranking. If their favored options drop in the market ranking of the decision options, they are assumed to back their favored options by buying additional shares in order to support these decision options. If a favored decision option rises in the ranking, this comes to pass in the favor of the sincere traders and thus does not stimulate additional trading actions.

Profit Traders Traders with profit-making intentions seek to trade in such ways as to maximize their profit from the market. Upon a price change, they evaluate the impact of this price change on the expected profit of their share holdings. If they perceive their expected profit to be threatened by the price change, they take counteractive measures in order to cut potential losses. Falling prices of a high-ranking decision option should induce the selling of shares in that stock in order to cut losses, whereas price increases should lead to the buying of shares of the respective stock in order to be able to cash in on the profit later on.

3.9.3 Perturbation Results and Utilization

The main variable to observe in the analysis of a given market perturbation is the reactions of other traders. These reactions manifest themselves as trading actions subsequent to the perturbating action or as the missing thereof. From these observations, we derive possible intentions of participants. Table 3.6 highlights our assumed correlation between trader reactions and their intentions.

	Buy	Sell
Falling Price	support decision option	avoid losses
Rising Price	expect to profit from rise	cash in on rise

Table 3.6: Interpretation of trader reactions following a market perturbation

The possible reactions of traders to a market perturbation are modeled as follows. The reactions are categorized as either the buying of shares, the selling of shares, or withholding further trades. This corresponds to the notions of correcting the prices to previous levels, following the price distortion and doing nothing about it.

A sincere trader is assumed to buy shares of a stock with a falling price in order to support this particular decision option. A profit-oriented trader is expected to sell shares of a falling stock in order to cut potential losses in portfolio worth. In the case of rising prices, a sincere trader is assumed to do nothing as this may further support his favored decision options. A profit-oriented trader is expected to either sell shares in order cash in on the rising prices or to buy shares in expectation of profits from further price increases. As this market perturbation of rising prices has some ambiguity of interpreting the buy and sell actions of the traders, we focus on market perturbations that lower high prices of top ranking decision options. It should be noted that sincere traders may also decide to sell shares in the face of falling prices, as their share holdings also represent a part of their budget tied up in the share value. The assumption of the market perturbation mechanism is that they will start selling falling shares much later than profit oriented traders.

The insights gained by the perturbation mechanism on the market result quality can be utilized further in different ways. First, the group can evaluate the insights after the market ended and decide on the acceptance of the market result. Second, the results of the single perturbations can be presented to the participants during the runtime of the market as a feedback on their trading actions.

CHAPTER 4

The Liquid Decision Making System

In this chapter, we describe the design of the LDM system. The LDM system refers to the actual system that we designed as part of our LDM approach. For this, we first identify practical application domains for our LDM approach. Based on these domains, we gather their requirements for designing the LDM system. We furthermore introduce the general workflow of the LDM system for its participants. Lastly, we present steps for applying the LDM system in a particular decision making situation.

4.1 Liquid Decision Making Application Domains

The basic application domain of LDM is the ranking of decision options. There, LDM is used for forming a ranked list of the most favored decision options. The second domain refers to the hierarchical ranking of decision options. Hierarchical ranking concerns a sub-division of the single decision options. In the third application domain, market organizers utilize the ranking capability of the LDM approach for making decisions on the structuring of topics, as for example in the building of taxonomies.

The outlined domains and the respective functionalities of LDM are depicted in the conceptual architecture in Figure 4.1. The basis of this conceptual architecture forms the market metaphor for gathering the opinions of the single participants and for aggregating these opinions into a single indicator, the stock price [63, 65]. Building on this aggregation capability, a ranking can be formed based on the stock prices of the single decision options. This ranking can be extended into a hierarchical ranking with sub-divided decision options. Based on the ranking or hierarchical ranking, a decision is then made by selecting the n topmost elements of the resulting ranking. The amount of selected decision options, n, depends on the requirements of the application domain. Using the LDM approach, different decision making domains can then be supported. These domains include simple selection domains such as research portfolio adjustment,

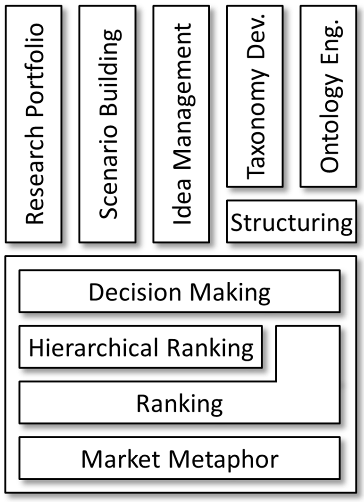


Figure 4.1: The conceptual architecture of the LDM system [65]

scenario building, and idea management, as well as more complex structuring domains such as taxonomy and ontology development, amongst others.

Generally, the different domains can be seen as decision making situations that require the ranking of decision options [65]. This perspective is highlighted in Figure 4.2. Examples of such decision making situations include the management of ideas, the assessment of new technologies, and the building of taxonomies, amongst others. These domains basically require the ranking of decision options. Therefore, a ranking mechanism is needed. This ranking mechanism is provided with the decision and the decision options and then produces a ranking of the decision options. The ranking approach is up to the mechanism. This thesis focuses on ranking using the market metaphor.

4.1.1 Ranking

The ranking of topics is the basic application domain of LDM. In this application domain, the goal is to make a decision based on a ranked list of decision options. The ranking is achieved by using the decision market of LDM. The decision options in this domain are assumed to be independent of one another, that is, trading in one of them does

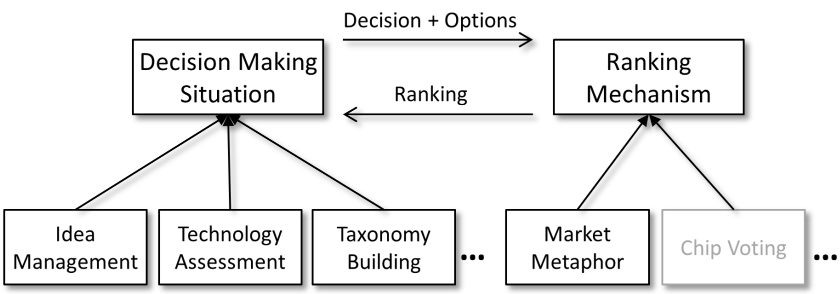


Figure 4.2: Integration of the market metaphor with a decision making situation [65]

not influence the price of any other decision option. They move independently on the ranked list depending only on their respective price. The context of this domain can be any decision making situation that requires the selection of one or multiple decision options. In this domain, the utilization of the selected winners is out of scope.

In some decision making situations, the market organizer is interested in the selection of only one decision option. In such situations, typically the highest ranking option is selected as the winning decision option from the ranked list. In other situations, multiple decision options may be sought for. This is the case for example in the selection of new technologies to include in a research portfolio. There, multiple winners are chosen beginning from the top of the ranked list.

4.1.2 Hierarchical Ranking

In certain decision making situations, the organizers of a decision market may want to subdivide some decision options into more fine-grained sub-options. Participants would then be able to more precisely indicate their opinions for the sub-options. Table 4.1 highlights such a hierarchical ranking. Decision options two to four are subdivided into two and three sub-options, respectively. Decision option one in contrast is not subdivided.

Rank	**Title**
1.	Decision Option 2
	Decision Sub-Option 2.1
	Decision Sub-Option 2.2
2.	Decision Option 3
	Decision Sub-Option 3.1
	Decision Sub-Option 3.2
	Decision Sub-Option 3.3
3.	Decision Option 1
4.	Decision Option 4
	Decision Sub-Option 4.1
	Decision Sub-Option 4.2

Table 4.1: Example for a hierarchical ranking using one level of sub-options

This explicit representation of decision sub-options then allows for a weighting of the relevance of these sub-options for the corresponding super-option and also for the final decision. That is, for a given composed decision option, participants may regard one or more sub-options to be of higher relevance for the final ranking than others and may thus want to give them larger weight. In this case, participants would buy shares only of these sub-options. The market mechanism would then determine the prices for these sub-options (see Section 4.4.4). Participants may still specify their opinion for the super-option directly. The realization of this hierarchical ranking and the determination of prices is described in Section 4.4.4.

4.1.3 Topic Structuring

The domain of topic structuring is based on the ranking domain. There, the context of the decision making situation is taken into account. Structuring in general is concerned with the building of relationships between topics. Examples for this are the development of a taxonomy of terms or the generation of an ontology from a set of concepts [49]. Such structures firstly need to be generated at all, but also need to be maintained and advanced further. In ontology development, for example, modifications to an existing structure may become desirable due to changes in the application domain, changes in the users' needs, and changed ways of organizing the information of the application domain. Fensel describes ontology evolution over time to be an "essential requirement for useful ontologies" [31].

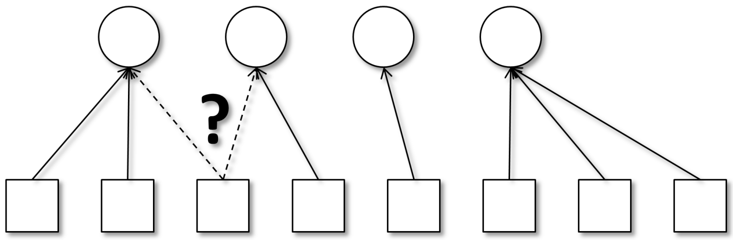


Figure 4.3: Example of a conflict in a structuring effort requiring a resolution

Figure 4.3 depicts a stylized example of such a structuring effort. There, elements of a set of topics are to be associated with categories. The topics are represented by the squares and the categories by the circles. In this example, a topic may be associated with at most one category. Participants in this structuring example have already specified associations for the single topics. However, for one topic more than one association has been proposed. That is, there exists a conflict between the two competing proposals. For a valid structure, this conflict needs to be resolved by deciding on which proposed association to finally approve. The decision making capability of LDM can be used for resolving this conflict by selecting the association that resolves the conflict. This works as follows. The decision to be made in LDM corresponds to the conflict to be resolved and the decision options correspond to the conflict resolution alternatives. Participants then trade shares of the resolution alternatives in order to collectively determine the most favored association.

4.2 Stakeholders in Liquid Decision Making

Among the steps of designing a system is the identification of the stakeholders that will employ the system. These identified stakeholders help in devising the functionalities for the system as well as for determining user access levels and access rights for different parts of the system. In this section, we describe the stakeholders that we identified for the LDM system.

Trader The trader uses the LDM system for expressing his assessments of the available decision options. For assessing and ranking the decision options, the trader engages in trading actions. He may also contribute new decision options to the LDM system if this is provided for. The trader may be governed by different intentions, including portfolio maximization and contribution of sincere opinions (see Section 3.3). It may be necessary to properly incentivize the trader depending on his interests. The trader expects an easy to use system with a comprehensible market mechanism.

Market Organizer The market organizer uses the LDM system for initiating a new decision making effort according to the purposes of the group. There, the market organizer defines the available decisions and the decision options. For the decisions and the options, he defines titles and descriptions for better understanding by the traders.

Administrator The administrator of the LDM system is responsible for the setup of the LDM system and the initial configuration such as the roles of the participants.

4.3 Liquid Decision Making Requirements

In this section, we describe the requirements that we identified for designing the LDM system and categorize them by their functionalities. Generally, participants shall be enabled to learn on the decision at hand, to survey the existing decision options, to contribute new decision options, to express their opinions on the single options using the market metaphor, to review the current market status of the decision options, to exchange views on the actions and options in the market and finally to determine the collectively chosen decision option. Table 4.2 gives an overview of the requirements.

4.3.1 Decision Making

The LDM system is a tool for decision making in groups of people. To this end, people need to be able to create a new decision, to add decision options, to express their opinions on the single decision options, and to determine the winning option. In the following, we highlight these requirements for supporting market-based decision making.

Decision Creation The decision making approach of LDM is organized around single decisions. These decisions need to be represented in the LDM system accordingly. Therefore, the LDM system requires functionality for creating a decision. This includes the specification of its title and description.

Decision Option Handling Decision options are associated with every decision. These decision options need to be handled by the LDM system as well. Therefore, the LDM system needs to provide for the creation of decision options as well as for associating them with a given decision. The specification of a decision option includes its title and description.

Opinion Contribution The goal of applying LDM is to produce a collective ranking of the available decision options based on the individual opinions of the single

Category	Requirements
Decision Making	Decision Creation Decision Option Handling Opinion Contribution Decision Making Overview Additional Decision Options Winner Determination
Market Trading	Order Triggering Order Execution Book Keeping Market Overview Trading Budgets
User Handling	Registration Authentication Access Restriction Roles Anonymity Personal Settings
Information Exchange	Comments Rating
Market Perturbations	Additional Trading Short Selling Review

Table 4.2: LDM requirements

participants. The participants therefore need to be able to contribute their opinion on the single decision options to LDM. The LDM system should therefore provide for gathering these opinions.

Decision Making Overview LDM features the characteristics of a continuous participation and real-time feedback. In order to provide this, the LDM system requires an up-to-date overview of the decision making status. The LDM system should therefore provide information on all decisions, the associated decision options, and their rankings as well as related information such as the latest contributed opinions.

Additional Decision Options During the runtime of a decision market, new potential decision options may emerge, for example based on new information. Depending on the decision making situation, it may be desired to add such new decision options to the list of available options. On the one hand, market organizers may simply add new decision options that they have identified. On the other hand, the participants may also be included in the process of adding new decision options. This would allow for a more diverse set of additions as a large group of participants would be more likely to produce diverse options. These options may then be checked for their admittance to the decision options list or may be added immediately. Immediately accepting all proposed decision options would bear the risk of also admitting unjustified or inept decision options. As LDM is targeted at directly using its result as the chosen decision option, the admittance of inept decision options may be undesirable. For situations in which the contributions of additional decision options by the participants is desired, the LDM system should provide means for proposing new decision options. For situations that require a screening of the proposed decision options, the LDM system should also provide means for accepting or rejecting them, and for adding them to the list of available decision options.

Determination of the winning Option Different decision making situations may require the selection of a different number of winning options. Therefore, the system should provide for the definition of a variable amount of winning decision options. These winning decision options should be highlighted accordingly.

4.3.2 Market Trading

The LDM approach utilizes the market metaphor for decision making. The trading of shares is an essential part of this approach for indicating one's opinion. We therefore identify the following requirements regarding the market capabilities of the LDM system.

Order Triggering Participants utilize the decision market in LDM for contributing their opinion on the single decision options. This contribution is realized by trading in the respective market. Participants therefore need to be able to trigger an order for contributing their opinion. This order triggering includes the specification of the respective stock, the amount of shares to be traded, and the action to be executed, that is, a buy or sell order.

Order Execution The ranking of the decision options is based on the market prices. Furthermore, participants may trade repeatedly during the run-time of a market. For prices to form, the single orders that are successively entered by the traders need to be executed accordingly. Therefore, LDM needs a mechanism for collecting all trading orders, for processing them according to their chronological sequence and their satisfiability, and for determining the prices of the traded stocks.

Book Keeping Trading in the market is based on the exchange of money for shares and vice versa. Therefore, updating the number of outstanding shares, the share holdings of the single participants and their cash is required for the LDM system.

Market Overview Participants need to be able to get an overview on the current market status. This includes their available cash for trading, their share holdings, their recent transactions as well as developments of their investments. Participants furthermore need to be able to get an overview on the overall market status including the prices of the single stocks and the resulting ranking of the associated decision options.

Trading Budgets Participants need virtual money for trading shares of the stocks. Therefore, the LDM system should allow for granting an initial amount of virtual money to participants. This virtual money does not need to be based on real currency. For LDM, we decided to utilize virtual play money without any real world countervalue (see Section 4.4.1).

During the run-time of a decision making effort, it may be required to distribute additional money among participants, for example as a bonus or due to an increased number of decision options. Therefore, the LDM system needs the capability of granting additional money to all as well as selected participants.

Participants are granted a certain amount of money for trading in the single decision options. In some LDM applications, more than one decision may be handled at a given time, for example in the structuring domain. For such decision making domains, it may be desirable to keep budgets separate and assign them to certain decisions, that is, markets. Thus, the LDM system should provide for such separate budgets per market.

4.3.3 User Handling

Market results in LDM emerge from the contributions of the participants. Therefore, LDM depends on the participation of people that convey their opinions on the single decision options. These users need to be handled accordingly by the LDM system.

Registration A particular capability of the market metaphor is to allow people to repeatedly participate and contribute their opinion through trading. A specific characteristic is the finiteness of the virtual money that participants receive. Therefore, it is necessary to be able to track participants over their single trading sessions and to account their spendings and share holdings accordingly. Thus, some form of identification across multiple trading sessions is required. Furthermore, the LDM system should provide means for validating the registered person.

Authentication Tracking the financial actions of the single participants is an important aspect of managing a market. To be able to track the actions of the single participants and to prevent them from capturing other traders' accounts, they need to authenticate themselves with the system. Therefore, the system needs to provide an authentication mechanism for identifying the single participants and for correlating their actions to their trading accounts.

Access Restriction Certain situations in decision making may require to restrict the group of participants to a certain range. Therefore, a means for restricting access to the decision making effort is required.

Roles The design principles of LDM emphasize the collaborative nature of decision making and the involvement of people with the decision at hand. Nevertheless, in some decision making situations, access to management functionality should be restricted to a certain subgroup. Hence, roles in the LDM system are needed for tasks including the management of the markets and decisions, the handling of proposed decision options and the granting of additional money. The LDM system is therefore required to support such roles.

Anonymity The market metaphor enables the direct participation of a large group of people without formal hierarchical constraints. In order to minimize hierarchical and social pressure, anonymity can be provided by the LDM system to the participants.

Personal Settings Participants need to be able to adjust individual settings for their trading account such as the consent for receiving a periodical newsletter by e-mail.

4.3.4 Information Exchange

In market-based approaches, participants primarily learn on the opinions of the other participants as well as contribute their own opinions based on the prices they induce through their trading actions. While the prices provide an intuitive indicator for one's assessments of the decision options, they do not convey additional information on the reasoning for specific trading actions or the information sources that have been used in coming up with a particular trade. Participants may want to provide reasoning for their trading actions and sources of their information. Furthermore, they may want to encourage other participants to take into account certain pieces of information or to convince them of their opinion on the decision options. In weblogs or blogs, a diary-like social media approach for sharing thoughts and insights, people are often allowed to comment on the entries in a given blog and thus are able to discuss topics [56]. Such a commenting system can also support participants in their exchange of information and in convincing other participants. Not all comments may be equally useful to participants. To indicate the usefulness of comments, a rating system can be put in place. The LDM system therefore should provide for commenting as well as rating by the participants.

Comments The pricing mechanism of the market metaphor is an intuitive indicator for the opinions of the participants in LDM. However, prices do not convey the reasoning of the participants nor their information sources and do not allow to convince others. A commenting mechanism can support participants in these additional ways of exchanging information. The LDM system should therefore provide such a commenting mechanism.

Rating People may want to rate comments in order to indicate their helpfulness for the decision making effort and for understanding the positions of the other traders.

4.3.5 Market Perturbations

The goal of market perturbations is to be able to gauge the quality of decision market results, that is, prices. To this end, additional trading actions are executed besides those of the participants. Then, the reactions of the participants to these trading actions are observed. Trend-following behavior is interpreted as an indicator for mainly speculation-based market results whereas resistant behavior is assumed to be indicative of market results based on sincere opinions.

The subsequent requirements build on top of the standard market requirements of order triggering, order execution, and book keeping. These standard market requirements are needed also for the successful execution of market perturbations.

Additional Trading The key element of the market perturbations approach is the execution of additional trading actions in order to influence prices. Therefore, it is required to execute these additional trading actions such that is seems to be a regular trade action to the other traders. The LDM system hence needs to be able to handle these perturbation trading actions accordingly.

Short Selling In LDM, additional trader accounts are utilized for realizing the additional trading actions of the market perturbations. These trader accounts are basically normal accounts as for any other participant. This also entails that these trader accounts do not own shares of any of the stocks they may be used for perturbation purposes. Especially top ranking stocks have been identified as promising for provoking trader reactions (see Section 3.9). Hence, a perturbation trader account should be able to perturbate such top ranking stocks by decreasing their prices artificially. As such a trader account does not own any shares initially, it needs to be allowed for short selling. Short selling refers to the selling of shares that one does not own initially.

Review Following the execution of one or multiple perturbation actions, the market organizer needs to be able to review the subsequent trading actions of the other participants. To this end, the LDM system should enable the market organizer to review the market activities of the traders.

4.4 The Concept of the Liquid Decision Making System

For applying the market metaphor to business forecasting tasks, Spann and Skiera analyze designs of different prediction markets for political events and of financial markets in general and derive three steps for designing a successful virtual stock markets [93]. The first step of design concerns the choice of the forecasting goal. There, the market organizer determines and describes the forecasting problem to be predicted, for example the prediction of an absolute or relative number or the occurrence of a particular event. The next step regards the design of the incentives. The market organizer determines the incentives that should encourage the participants to contribute their best possible forecasts. The last step concerns the determination of the financial market design. This primarily includes the selection of a market mechanism and the determination of appropriate parameters for it (see Section 2.5). Dahan et al. adapt the design steps for the design of their preference markets [22]. We also based our design of LDM on these design steps as they encompass the relevant aspects for designing a virtual market. In the following, we highlight these steps and discern between design steps that are determined by a market organizer who uses LDM for making a decision, and design steps that we fix for the concept of the LDM system. We furthermore take into account the application scenarios and requirements that we identified in the previous sections.

The adaptation of the design steps is highlighted in Table 4.3. The choice of the forecasting goal consists in LDM in the selection of the decision and the determination of the decision options. The design of the incentives is addressed by the previously

Prediction Market	Liquid Decision Making
choice of forecasting goal	definition of decision and its options
incentives	design principles
financial market design	market maker, virtual play money

Table 4.3: The design steps of prediction markets adapted for LDM

devised design principles. Lastly, the financial market design is fixed to the market maker approach and the utilization of virtual play money.

4.4.1 Design Decisions

In the following, we present design decisions that we fixed in order to make the market approach viable for decision making.

Decision Making

In Chapter 3, we describe the general correspondence between the market metaphor and decision making in groups as utilized in LDM. Following the aforementioned design steps of Spann and Skiera, choosing of the forecasting goal is adapted as determination of decision and decision options.

Market Design

Market Mechanism The market mechanism is responsible for handling the trades and for the setting of prices. As outlined in Section 2, the CDA mechanism and the MM mechanism can be identified as the two main market mechanisms for virtual markets from literature. We decided to use the MM mechanism as it allows for quoting of prices even in thin markets and features a trading intermediary that always accepts trades. In this way, participants are always able to trade. We furthermore opted to use an independent price setting for the MM mechanism. There, the price of a given stock is determined only by the shares that are outstanding for this particular stock. In this way, the prices of the single stocks of a given market develop independently.

Money A key element of the market metaphor is the use of virtual money as a means for contributing one's opinion. Both real money that is exchanged for virtual money and virtual play money have been used in applications of the market metaphor. We decided to use virtual play money for LDM which is not redeemable for real currency. This on the one hand should lower the entry barrier for prospective participants as no real money is at stake. On the other hand, it should also help in avoiding regulatory issues. Furthermore, the organizer of a decision market is not required to handle the real money accounting for all participants. For prediction markets, a study by Servan-Schreiber et al. indicates that the use of such virtual play money should produce similar market results as the use of real money [85]. Servan-Schreiber et al. attribute these findings to the motivation and expertise of the respective participants. We argue that LDM should also benefit from the advantages of using virtual play money.

Trading The trading of shares is the key for contributing to the formation of a joint decision in LDM. The basic trade orders include buy and sell orders for immediate execution. Some markets also allow for more advanced trade orders such as limit orders and for temporal restrictions on orders. Such orders are executed only if certain price or temporal conditions are met during the market runtime. In the design of LDM, we opted to restrict the available order types to direct market orders in order to keep the required trading knowledge and thus the entry barrier low.

Another variety of trades is the trading of shares one does not own, so called *short selling*. In this short selling, participants are allowed to borrow shares from the market system for selling them later on on the market. This short selling is handy if a trader expects prices to fall for a certain stock and if he wants to make money from this expectation. However, this trader also needs to cover for the risk of not being able to return the borrowed shares to the market system. This covering is typically realized by having the trader deposit the maximum possible loss of his speculation. Hence, the trader needs to deposit relatively large amounts of virtual currency for actually borrowing shares for short selling. In decision markets, this short selling may be employed for deliberately devaluing a particular stock in order to emphasize one's indisposition for this stock. In our first decision market study (see Section 6), this led to the situation that some participants ended up with little cash left as they had to cover for several short sold stocks. Some of them were even confused where all their money had gone. This is similar to results from Spears et al. who also noted participants to have been confused by the short selling mechanism in their market [94]. To avoid such confusion among participants, we decided that LDM will not offer the possibility of short selling. Another remedy to this consists of a different market design in which *yes* and *no* stocks are offered for each decision option. In this way, participants can explicitly express their consent for or their rejection of a given decision option. We argue, however, that this also increases the complexity of the market approach as it introduces another level of indirection to keep track of.

Prior to the start of a decision market, the initial price quotes and the initial portfolio composition have to be determined. We decided to determine the initial price quotes from the logarithmic market maker function. This function determines the prices based on the number of the outstanding shares of a given stock. As the number of outstanding shares is initially 0, the result of the market maker equation (2.2) is 0.5. We want prices to fall between \$0 and \$100, therefore, the result of 0.5 is multiplied by 100. Hence, the initial price quote is \$50 of the virtual play money. Upon registration with LDM, participants receive an initial amount of virtual play money. With this money, they start to build their portfolios. Initially, these portfolios are empty for each trader.

On real stock markets, the organizing stock exchanges typically charge fees for all kinds of market-related services such as the execution of trades [2]. These fees cover the expenses of the stock exchanges for providing the services. In virtual markets, it would also be possible to charge fees for trading and other services. Some publicly available prediction markets charge such fees for trading, for example Intrade[1]. For LDM, we chose not to charge any trading fees as we did not want to create a perceived barrier to trading.

User Handling

Participants contribute their opinions using the LDM system in order to form an overall decision. The LDM System therefore supports the registration of these participants, their authentication during their market usage, ensures their anonymity, and provides for restricting access to the market if required.

Registration The ranking of decision options in LDM is based on the repeated trading by the participants. This repeated trading requires the correct accounting of the participants' cash flows as well as their share holdings. To ensure this accounting, the tracking of the single participants across several distinct trading sessions is necessary. In order to track participants reliably and accurately, LDM provides a registration mechanism. There, participants are required to register themselves with the LDM system. Furthermore, participants are required to authenticate themselves with the LDM system at the beginning of each trading session. The registration asks a minimal amount of information in order to identify a given user and to be able to contact him for market information and in case of password loss. Namely, the registration requires the specification of a username, an e-mail address, and a password.

Anonymity The direct and egalitarian nature of LDM's decision market allows to bypass hierarchies and gather information directly from each participant. However, for this to be effective, anonymity is key for traders in such a decision market. This anonymity is guaranteed in LDM by a freely selectable username. Only this username is disclosed to the other traders in the display of personalized information in the LDM user interface.

Access Restriction Social media-like approaches based on user input may be open for everyone to participate or may restrict participation to a certain group of people. Several prediction markets are open to the public in order to gather as much and as diverse information as possible, such as for example the prediction market site Inkling[2]. In the case of LDM, we offer to restrict participation based on the identified principle of user involvement. Only people concerned with the decision at hand should participate in LDM as they are likely to contribute their sincere opinions. This can be achieved in two ways. First, participants can be selected prior to the opening of LDM and be given a secret key phrase for legitimating their participation. Second, it could be relied on the self-selection of participants, that is, one could expect that only concerned people will participate. The LDM system supports the use of such a secret key phrase to limit the audience.

[1]Intrade `http://www.intrade.com`, currently closed
[2]Inkling `http://home.inklingmarkets.com`

4.4.2 LDM Functionalities

The general workflow of an LDM application is as follows. Participants contribute proposals to the LDM system. These proposals may be checked by the market organizers for admission. Then, participants trade shares in the accepted decision options and share their insights on the single options. Prices then form from the transactions and a ranking or structuring is generated depending on the application domain of LDM (see Figure 4.4). In the following, we describe the single use cases that accompany this general workflow.

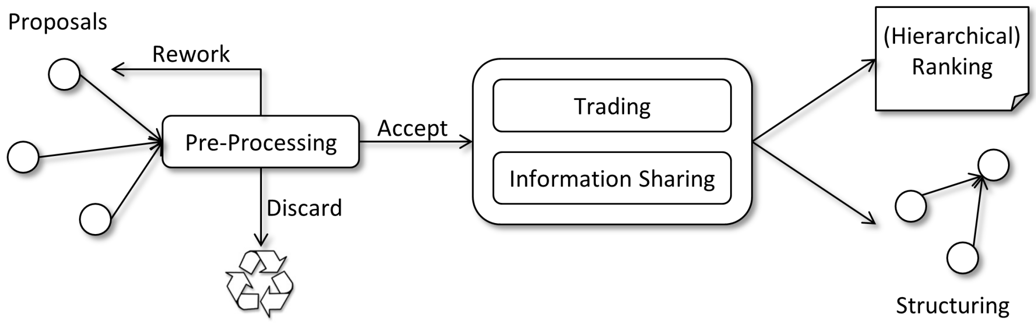


Figure 4.4: General workflow in the LDM system

Decision Making

As highlighted in Section 4.4.1, the determination of the decision to be made and the selection of an initial set of decision options is the task of the market organizer. Hence, functionality is required in the LDM system for creating the decisions and decision options.

Decision Creation For the creation of a new decision, a user in the LDM system has to have the role of a market organizer. This role is allowed to create new decisions. The respective user selects to create a new decision and enters the title and a description for the new decision. Upon submission, the LDM system stores the new decision in its database. As a decision corresponds to a market (see Section 3.2), the LDM system also generates a new market and associates it with this decision.

Creation of Decision Options Participatory systems with no initial content may suffer from the so called *cold start problem*. There, people do not participate because there is no content and content is not generated because there are no participants. An approach for overcoming this is to provide an initial amount of content. For the LDM system, this translates to the creation of an initial set of decision options for a given decision. For creating a new decision option, the market organizer first specifies the decision that he wants the decision option to be added to. He then creates the new decision option and gives the title and a description for the new option. The system then stores the new decision option for the specified decision. A decision option corresponds to a stock on a market. Thus, the LDM system also creates a new stock for this decision option.

The initial price of this new stock is determined by the price mechanism of the MM mechanism that is used in LDM.

Opinion Contribution The result of the LDM approach emerges from the contributions of the participants. The LDM system provides for the contribution of the opinions of the single participants. For this, a participant selects the decision and decision option he wants to contribute his opinion to. The actual contribution then consists of the specification of a trading action for the chosen decision option. At this point, the decision making effort and the market metaphor are linked together.

Decision Making Overview Participants in a decision making effort need to be able to retrieve an overview of the current status of the pending decision. This current status is formed by the prices of the decision options. Therefore, the LDM system offers a web page displaying all decision options with their current ranks and associated prices. For this overview, the LDM system retrieves the accompanying stocks for a given decision option and gets the prices of these stocks. The prices of the stocks are then displayed together with the titles of the corresponding decision options.

Proposal of a Decision Option In certain decision making situations, it may be desirable that participants can propose new decision options during the runtime of the decision making effort. For this, the LDM system supports the proposal of new decision options. The participant there specifies a title and description for the decision option he wants to propose. The LDM system then puts this proposal in a queue for processing by the market organizers. The market organizers then review the proposals in this waiting queue. There, they may either dismiss or accept the single proposals. Furthermore, they may make adjustments to the title and description and may specify a reason for their ruling. The LDM system then either promotes the proposal as a new decision option or marks it as rejected. In the latter case, the rejected proposal is kept in the proposal list for further reference. The proposing trader may then rethink the proposal based on the review given by the market organizer and propose a reworked version.

Determination of the Winning Option The amount of desired winning options may vary between decisions. Generally, winners are considered starting from the top of the decision option ranking. Therefore, the LDM system allows the market organizer to specify the amount of desired winners for a given decision. This amount is then reflected in the web page that displays the ranking of the decision options. The winning decision options are displayed in bold font face. Figure 4.5 gives an example for this highlighting of the winning decision options. In this example, the 10 topmost decision options were finally chosen from the decision market.

Market Trading

In the design of LDM, we keep a separation between the decision making and the market trading in order to emphasize the collective nature of achieving a joint decision and to de-emphasize the potentially competitive nature of markets. However, at some point

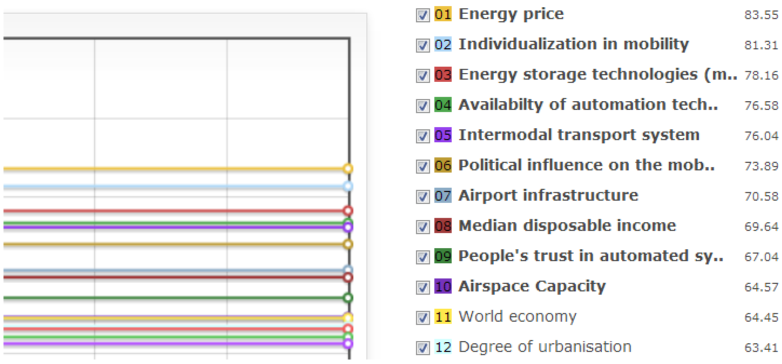


Figure 4.5: Detail of the price chart and decision option ranking indicating the collectively chosen options in bold face [65]

in the utilization of LDM for decision making, participants encounter the market part of LDM. This market part needs to support basic market functionality similar to that of real electronic markets. The functionality of real electronic markets typically comprises functionality for the input, execution and confirmation of trade orders, the transfer of shares between participants, the handling of cash transfer and the quotation of prices to participants [95].

Order Handling The triggering of trade orders is the means for participants to contribute their opinions. For triggering an order, the trader specifies the decision option, the amount of shares, and the action to be executed, either a buy or sell order. The LDM system then checks the submitted order based on the available cash of the trader or the available share holdings, depending on the kind of the order. If the order cannot be fulfilled due to low cash or low share holdings, the order is rejected. Otherwise, the LDM system executes the trade order and performs the necessary book keeping. For this, the LDM system determines the cost of this trade order based on the utilized market maker function (see Equation (2.1)). These cost and the number of traded shares are then settled with the budget and the share holdings of the respective trader. Furthermore, the LDM system determines a new price for the traded stock (see Equation (2.2)) and updates the price of the stock accordingly. This trade is then stored as a transaction in the transaction log of the LDM system.

Market Overview Opinion forming and repeated participation require that traders are able to keep themselves up-to-date on the current market status. For this, the LDM system offers a dashboard with relevant market information, an overview on the single decision options, and a ranked list indicating the current market winners. On the market dashboard, the LDM system displays the available cash of the respective trader, the latest overall market activities including the kind of trade and the resulting prices, the number of total as well as accepted proposals overall and for the respective trader, and the share holdings of the trader including their amount, current market price, and price trend.

Money Bonuses Participants in LDM receive an initial amount of virtual play money upon registration. During market runtime, market organizers may want to grant additional play money to all or a selected group of traders. The LDM system allows for the granting of additional money to participants. For this, the market organizer specifies the group of eligible traders and the amount to be granted. Upon confirmation, the LDM system updates the cash of the specified traders accordingly.

User Handling

Registration For correct accounting of cash flow and share holdings, traders need to be tracked across different trading sessions. Therefore, traders need to be uniquely identifiable. The LDM system provides for the registration of the users. A prospective participant visits the registration page of the LDM system and specifies the required information comprising a username, e-mail address, the registration key, and a password. The registration mechanism of LDM then checks whether the username is already in use, whether another account is already registered for the specified e-mail address, and whether the registration key is correct. If all specified information is correct, the registration mechanism creates a new user account with the specified information. This user account is marked as inactive. The registration mechanism then creates an activation token and sends out an e-mail to the specified e-mail address containing an activation link with the created activation token and the e-mail address. If the user follows this link in his e-mail, the registration system checks whether the activation token and the e-mail address belong together. If successful, the registration mechanism activates the user account and displays a message on the activation web page.

Login Users need to login to the LDM system in order to participate in the decision markets. For this, the user visits the login page of the LDM system and enters his credentials. The authentication mechanism then checks the specified username and password and loads the corresponding user account if successful.

Role Assignment Participants in a decision making effort may have different roles. For the LDM system, we identified the roles of trader, organizer, and administrator. These roles need to be assigned to the respective user accounts. Upon registration, each user account is assigned the role of a trader by default. Additional roles may be assigned by the administrator. The administrator selects the respective user from the list of users and chooses the roles that are to be assigned. Upon his confirmation, the LDM system saves the new role assignments for the specified user account.

Information Exchange

The stock prices indicate the joint assessments of the decision options by the participants. However, the prices do not indicate the underlying information or reasoning that has been used for the accompanying trading actions. The additional exchange of information between participants besides market prices may on the one hand increase the insight on the decision options that traders gain from their participation. On the other hand, participants can try to convince others of their opinion. The LDM system offers a commenting for such additional information exchange and a rating mechanism for indicating the helpfulness of comments.

Comments The market approach of LDM allows participants to utilize their individual evaluation criteria and to express their assessments in a uniform way through market trading. In this way, participants mutually learn on their respective assessments. For committing and gaining additional insights on the rationale of the other traders, the LDM system offers a commenting mechanism. This commenting mechanism allows traders to comment on their single trading actions while they trigger a certain trade order. Furthermore, traders can comment on decisions and decision options.

Rating Participants may contribute a large number of comments to the LDM system. Some of them are likely to be more helpful in understanding the rationale of the other traders than others. For being able to more easily discern those comments, users can rate the comments for their helpfulness. For this, the LDM system offers a simple rating mechanism with *yes* and *no* as rating options. The LDM system stores these ratings for every comment and displays them next to each comment. There, each participant is allowed to cast only one rating per comment.

Market Perturbations

For market perturbations, the requirements of additional trading, short selling, and a review capability have been identified (see Section 4.3).

Additional Trading Market perturbations are based on the execution of additional trading actions and the observation of the reactions of the other, real, traders. Currently, the market perturbation mechanism is designed for the execution of these additional trading actions by specific trader accounts. These trader accounts are basically normal trader accounts as utilized by the real traders. A designated participant then commands this perturbation trader account in order to execute the devised perturbations and perturbation actions.

Short Selling Top ranking stocks seem most promising for perturbations and for triggering reactions of traders. Decreasing the high prices of top ranking stocks should be most provoking. This requires the perturbation trader accounts to be able to sell shares of these stocks. However, the perturbation trader accounts initially do not own shares of the stock in question. Therefore, the LDM system provides for short selling for these perturbation trader accounts. To this end, these trader accounts are enabled to sell shares in stocks that they do not own. Technically, the short sold shares are accounted as a negative amount of shares in the trader account's share holdings. In this way, the overall number of outstanding shares is decreased for this particular stock and the price is thus decreased according to the market maker function.

Review The concept of market perturbations is based on the observation of the traders' reactions to the perturbating trade actions. The reactions are interpreted as an indicator for their trading intentions and for the overall quality of the market result (see Section 3.9). For the market organizer to review these reactions, the LDM system provides an overview of all transactions on a given market. There, the single perturbation actions are highlighted in bold font face for easy detection. Market organizers may then follow the reactions of the other traders subsequent to the perturbation actions.

4.4.3 Realizing the Design Principles

In Section 3.8, we devised three design principles for ensuring a meaningful result from LDM. In the following, we highlight the realization of these design principles in the LDM system. This description is based on our previous work on devising design principles for a successful application of LDM [65].

Collaborative Decision

The market nature of LDM may result in a competitive perception of the approach by the participants. Hence, participants may aim at excelling others instead of contributing their sincere opinions. This, however, may bias the decision quality. The goal of the collaborative decision principle as highlighted in Section 3.8.1 is thus to emphasize the collaborative perception rather than a competitive perception of participants.

For this, the design principle of a collaborative decision provides the omission of market information that may fuel gambling or speculation. For achieving this objective, we designed the LDM system as follows. The LDM system does not calculate the portfolio worth of each participant and does not compile a ranking from it. In this way, participants cannot easily compare their portfolio worths with one another. Without this striking cue on their ranking regarding their portfolio worth, participants should be less tempted to gamble in the market.

User Involvement

The quality of results of participatory approaches such as decision markets depends on the quality of the participants' contributions. As described in Section 3.8.2, participants with no stakes in the outcome of a decision market are likely to care less for its quality. The design principle of user involvement focuses therefore on the level of involvement that the participants exhibit with the decision at hand. The objective of this principle is to create sufficient stakes for participants that encourage them to contribute meaningfully to the selection of the decision.

The involvement of the participants is fostered on the one hand by providing them with a decision that they have some stakes in. On the other hand, the involvement of users is also ensured by providing additional functionality. In the LDM system, this is realized by the commenting and rating mechanism. There, participants are enabled to comment on the single decision options as well as the trading actions. The goal of this commenting is to help them understand the origins of the other traders' opinions. Furthermore, participants may rate these comments for their helpfulness for understanding these opinions. This increased understanding of each others' opinions should stimulate further examination of the decision options and also the involvement with the overall decision.

Dual Incentives

The achievement of a meaningful result in LDM depends on repeated contributions of the participants. We therefore devised the design principle of dual incentives with the goal of encouraging the actual participation of the group of people entrusted with making a given decision. The first incentive deals with attracting people to participate at all in the decision market effort while the second incentive regards their repeated participation. Attracting people to participate is firstly a matter concerning the contents of the decision rather than a matter of system design. However, the system has been designed as a web-based application for a low entry barrier and ease of use.

Encouraging repeated participation has been introduced in Section 3.8.3 to be achieved by providing up-to-date information to the traders. This up-to-date information is brought to participants by a newsletter sent periodically by e-mail as well as a market dashboard containing relevant information. This information includes in particular the available amount of cash for the respective trader, the latest market activities of all traders and of the respective trader, the current share holdings of the respective trader as well as their trends, the latest accepted proposals for new decision options, and the number of proposals by the respective trader.

4.4.4 The Funds Mechanism

In some decision making situations, market organizers may want to subdivide decision options in order to aggregate opinions in a more fine-grained way. In this way, participants may weight their assessments on several decision sub-options. A mechanism is thus required for gathering the weightings of the participants regarding the sub-options. The introduction of a separate voting mechanism for this weighting would require participants to learn another mechanism and to keep track of its status separately. Thus, we decided to employ the existing ranking capability of the market metaphor for this case. This is advantageous as participants are already familiar with the utilization of money for expressing their assessments of decision options and as they are not required to get acquainted with an additional voting mechanism.

The Concept of the Funds Mechanism

Real markets are familiar with the concept of stock funds. With such real market stock funds, stocks are grouped according to some criteria such as a certain country or a particular industrial sector[3]. One of the goals of such funds is that traders can invest in these grouped stocks simultaneously. That is, traders may acquire shares of such a particular fund. Prices of the shares of a given fund are determined proportionately by the prices of the stocks that are included in that fund. Higher priced stocks drive share prices of that fund upwards while cheaper stocks make the fund cheaper.

[3] U. S. Securities and Exchange Commission: `http://www.sec.gov/answers/mfstock.htm`

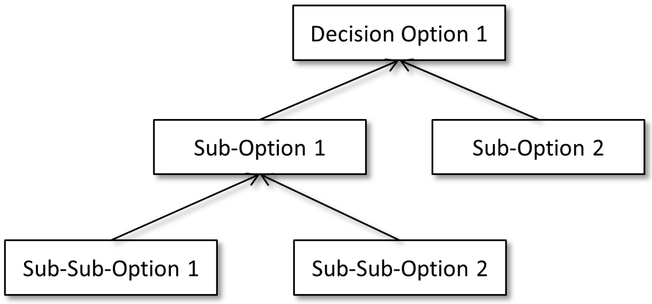
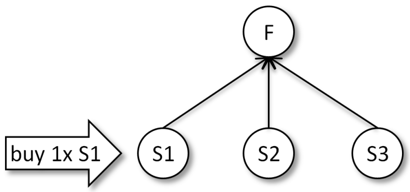


Figure 4.6: Tree of decision options and sub-options in the funds mechanism

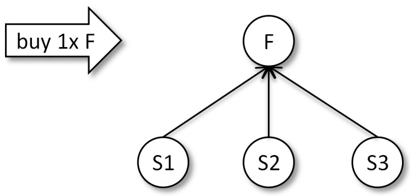
We followed this funds concept of real markets for realizing the weighting between decision sub-options and corresponding decision super-options and developed a similar funds mechanism. The general idea of that funds mechanism is to organize decisions and decision sub-options in a decision options tree (see Figure 4.6). The inner nodes of the decision options tree represent the funds. These funds in turn group several stocks and funds together. At the leaves of the decision options tree there are only stocks. Participants may then trade at any level of this decision options tree in oder to indicate their weighting for the respective options and sub-options. As the decision options and their sub-options are semantically correlated, a pricing mechanism for determining the trading costs and prices of the nested decision options should also reflect this correlation.

A pricing mechanism is required that allows participants to trade at any level of the decision options tree and that correlates the prices of the respective decision options and decision sub-options. For the definition of such a pricing mechanism, we first discern trading at the inner nodes and at the leaves of the decision options tree. In Figure 4.7, we provide a simple example of such a decision options tree with one fund F at the root of the decision options tree and three stocks $S_{1..3}$ at its leaves. We define trading at the leaves as the base trading case as depicted in Figure 4.7a. There, a trader buys one share of a stock at the leaf of the decision options tree. In Figure 4.7b, the funds trading case is highlighted. There, a trader buys one share of a fund at an inner node of the decision options tree.

A typical execution of this funds mechanism would be as follows in a decision making effort. A participant selects a decision that he wants to contribute his opinion to. He then surveys the single decision options, selects an option for closer inspection, and retrieves



(a) Base trading case



(b) Funds trading case

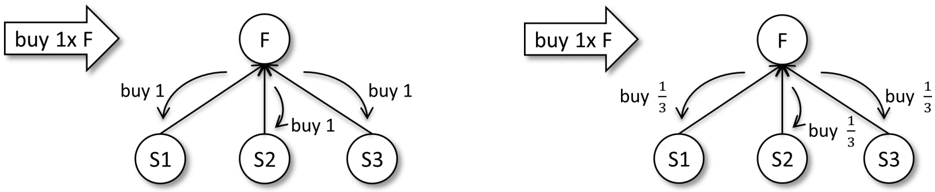
Figure 4.7: Trading at the leaves and the inner nodes of the decision options tree

a list of the included sub-options. He may then decide to trade on the super-option if he agrees with all the sub-options likewise. If he wants to weight one or more of the sub-options more prominently, the trader may also opt for trading only in his favored sub-options and to support the associated super-option in this way.

Price and Costs Calculation

In the following, we introduce the pricing mechanism that we devised for calculating prices and costs for trading at different levels of the decision options tree. The general idea of the pricing mechanism is to determine the trading cost as well as the price of a given fund recursively from the children of that fund. This means in effect that costs and prices are determined at the leaves of the decision options tree. At the leaves, we utilize the market maker approach to determine the actual costs and prices. These costs and prices are then propagated back to the fund that the trade originated from.

In the market maker approach of LDM, prices and costs are calculated by the number of outstanding shares of a given stock (see Section 2.5). Previously, we determined that costs and prices will be calculated at the leaves of the decision options tree. Therefore, we need to determine the amount of shares that is to be taken into consideration for this calculation of costs and prices. For this, we propagate the number of shares to be traded from the originating fund down to the respective leaves. For this, we devised the two modes of a *full propagation mode* and a *fractional propagation mode*. The full propagation mode posits that only whole-numbered amounts of shares can be traded at any level of the decision options tree. In contrast, the fractional propagation mode allows for trading of fractions of shares of stocks and funds. There, the fractions of shares to be traded at the children of that fund need to be determined. In Figure 4.8, the full propagation mode and the fractional propagation mode are highlighted for the example of buying one share of fund F.



(a) Full propagation mode (b) Fractional propagation mode

Figure 4.8: Propagation of shares to be traded in the decision options tree

Immediate feedback is one of the characteristics of the market metaphor. Therefore, trading at any level of the decision options tree requires an update of the prices of the funds and stocks upon each trade. Prices of the stocks at the leaves are updated according to the price calculated by the market maker mechanism. Prices of the funds need to be recalculated every time a price changes in their branch of the options tree, as funds prices are determined by the prices of their children. This price recalculation depends on the selected propagation mode. In case of the full propagation mode, prices simply add up from the leaves to the respective fund. This is given in Equation (4.1). For the fractional propagation mode, only the determined fractions of the prices are added up, as given in Equation (4.2).

$$p(F) = \sum_{i=1}^{n} p(S_i) \tag{4.1}$$

$$p(F) = \frac{1}{n} * \sum_{i=1}^{n} \frac{p(S_i)}{n} \tag{4.2}$$

The two propagation modes are highlighted in Figure 4.9. For the full propagation mode, the full prices of the stocks $S_{1..3}$ are added up in order to form the price of fund F (see Figure 4.9a). In contrast, Figure 4.9b highlights the fractional summation of the stock prices $p(S_{1..3})$ to form $p(F)$. In the following, we introduce the workings of the two propagation modes for the base trading case and the funds trading case.

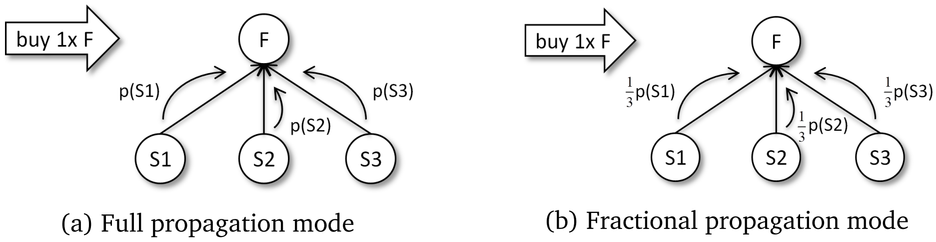


Figure 4.9: Price updates for fund F in the two propagation modes

Base Trading Case In the base trading case, trading occurs at a leaf of the decision options tree (see Figure 4.7a). Therefore, the number of shares for calculating the trading cost and the price of the respective stock can easily be determined. The number of shares simply corresponds to the number of shares that the respective trader specified in his order. Using the market maker, we can then determine the trading cost and an updated price for the specified stock. The trader is then charged the cost and his share holdings are updated with the corresponding number of shares.

The prices of the funds in the decision options tree are calculated from the prices of their children. We therefore need to propagate the newly calculated price upwards in the decision options tree. This propagation depends on the selected propagation mode.

Full Propagation Mode In the full propagation mode, only whole-numbered shares can be traded at the leaves. Therefore, the full propagation mode provides for adding up the full prices of the stocks and their funds. Figure 4.10 gives an example of this price update for the base trading case using the full propagation mode.

Initially, all stocks at the leaves start with a price of \$50 as determined by the market maker based on zero outstanding shares. For the case of the full propagation rule, the price of fund F is determined by adding up the prices of its n children, in this case of $S_{1..3}$. As the full propagation rule is utilized, the price of fund F is determined as given in Equation (4.1). This results in a price of \$150 for fund F. Then, a trader buys one share of stock S_1. The market maker calculates the cost of trading this share and determines the new price of this stock. For this example, the new price is assumed to

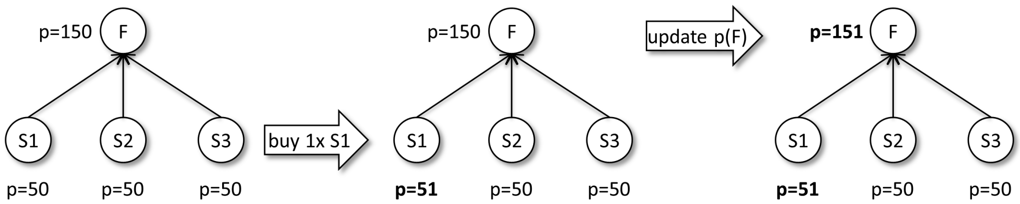


Figure 4.10: Base trading case with full propagation mode

be \$51 for S_1. Now, the price of the associated fund also needs to be updated. To this end, Equation (4.1) is applied for determining the new price of fund F. This results in a new price of \$151 for fund F.

Fractional Propagation Mode The fractional propagation mode provides participants to trade shares of funds in units of one share. As prices are determined at the leaves, this trading is then proportionately distributed amongst the child nodes. Hence, the shares to be traded at the leaves are only fractions of shares. This is relevant for the calculation of the updates prices in the base trading case. In Figure 4.11, an example of this base trading case using the fractional propagation mode is given.

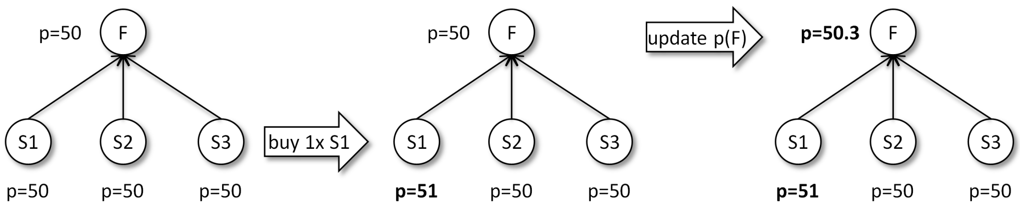


Figure 4.11: Base trading case with fractional propagation mode

Again, the prices of the stocks $S_{1..3}$ start with \$50 as determined by the market maker. In this case of the fractional propagation mode, however, the price of fund F is determined by adding up the fractions of the prices of $S_{1..3}$. Equation (4.2) highlights this with n being the number of children. In this example, it is $n = 3$, hence, prices of the stocks $S_{1..3}$ contribute $\frac{1}{3}$ to the price of the fund F. The resulting price for fund F is then \$50. In the base trading case, a participant buys one share of stock S_1. The market maker then determines the updated price for this stock to be \$51 (see Figure 4.11). This updated price needs to be propagated to the associated fund F. Using Equation (4.2), the price of fund F is calculated with \$50.3.

Funds Trading Case The funds trading case deals with trading at the inner nodes of the decision options tree, as depicted in Figure 4.7b. If a trader wants to trade shares of a decision option at any inner node of the options tree, that is, of a fund, we need to determine the cost of this trade and the new prices of the associated decision options. Our approach is to determine the cost of such a trade by the cost incurred by trading the associated children. That is, we recursively determine the cost of trading all child nodes and add up the single costs to form the overall cost of trading that fund. In effect, the price and cost determination occurs at the leaf level of the decision options tree.

Full Propagation Mode The full propagation mode provides for trading of whole-numbered shares at the leaves of the decision options tree. Therefore, in the funds trading case, the trading of one share of a given fund translates into the trading of one share for each of its leaves. Figure 4.12 gives an example of this.

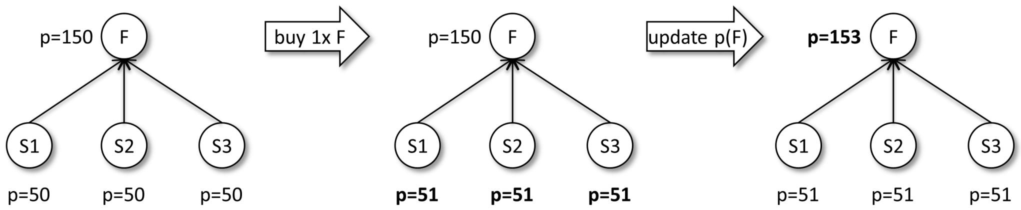


Figure 4.12: Funds trading case with full propagation mode

Initially, prices are set at \$50 for the stocks $S_{1..3}$ and at \$150 for the fund F as determined by Equation (4.1) for the full propagation mode. Then, a trader buys one share of fund F. According to the full propagation mode, this results in the trading of one share per stock at the leaves of the decision options tree. Hence, for all three stocks $S_{1..3}$, the market maker determines new prices for trading one share each. This results in a new price of \$51 for each stock. This resulting prices then need to be propagated to the fund F, using Equation (4.1) for the full propagation mode. Then, the new price of fund F is calculated as \$153.

Fractional Propagation Mode In the fractional propagation mode, shares and prices are calculated proportionately to the number of leaves of a given fund. An example of this funds trading case with the fractional propagation mode is given in Figure 4.13.

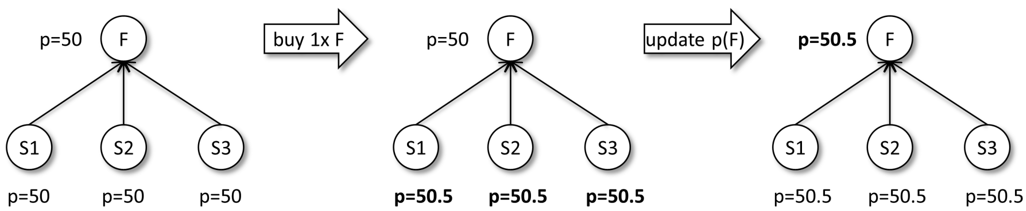


Figure 4.13: Funds trading case with fractional propagation mode

In this example, prices for the stocks $S_{1..3}$ are set at \$50 and for the fund F at \$50 according to Equation (4.2). Next, a trader buys one share of fund F. In the funds trading case with the fractional propagation mode, this translates into determining the cost and prices at the leaves proportionately. Hence, the market maker determines new prices for the stocks $S_{1..3}$. As there are three stocks associated with fund F, $\frac{1}{3}$ of a share is traded for each stock, resulting in a new price of \$50.5 per stock at the leaves. These new prices are then propagated to form the new price of fund F. For this, Equation (4.2) is consulted, which results in a new price of \$50.5 for fund F.

In a comparison of the prices of the fund F in the full propagation mode and the fractional propagation mode, it is apparent that the full propagation mode requires traders to pay much more for trading in any fund than with the fractional propagation mode. In decision options trees with several levels and branches, this may lead to exorbitant prices for funds at the upper levels. That is, it would be difficult to contribute to the assessment of multiple, expensive funds. Hence, traders may refrain from trading in such funds in order to save money for trading at the lower levels. As LDM lives on lively trading of participants in the available decision options, such savings behavior may be undesirable.

4.4.5 The Structuring Mechanism

In Section 4.1, we introduced the structuring of topics as one of the potential application domains for LDM. Structuring of topics refers to the definition of relationships between topics according to some topology. The generation of an ontology is an example for a graph structure whereas a taxonomy exhibits a tree structure. In the building of a tree structure, only one decision needs to be made for each topic: what is the parent topic to be for a given topic? In contrast, topics in a graph structure may be linked to an arbitrary number of other topics, leading to as many decisions to be made. For limiting complexity, we investigate the application of LDM to the generation of tree structures in this thesis. In such tree structures, a topic may be assigned to, at most, one higher-level topic. That is, for each topic, one needs to decide which its parent topic should be. If the taxonomy is to be built by a group of people, a decision making mechanism is required for gathering the opinions of the single group members.

Resolving Structuring Conflicts

For applying LDM to the generation of a tree structure, it would be conceivable to list all possible topic assignments for all topics. This, however, would lead to confusingly long lists of decision alternatives for each topic. Hence, the idea in our application of LDM to the generation of tree structures is to utilize LDM as a conflict resolution mechanism. A conflict arises if any topic gets assigned to more than one parent topic. That is, the opinions of two or more participants are in conflict on the assignment of that given topic. Such a conflict is depicted in Figure 4.14. There, topic T_2 is initially assigned to topic T_1. Then, another assignment is proposed between T_2 and T_3. As a topic is only allowed to be assigned to at most one parent topic, a conflict occurs.

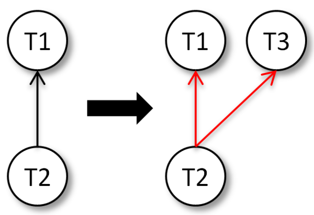


Figure 4.14: A conflict in the assignment of topics

This conflict needs to be resolved in order to restore a consistent structure. To this end, one or more conflict resolution alternatives need to be defined. In this case of structuring, the conflict resolutions are the different assignments that the participants provided for the given topic. Participants then resolve the conflict by trading shares of the conflict resolution alternatives and by thus identifying the most favored resolution

Structuring	**Market Metaphor**
Conflict	Market
Resolution Option	Stock
Conflict Winner	Highest Ranking Stock

Table 4.4: Correspondence between the resolution of structuring conflicts and the market metaphor

alternative. That is, a market corresponds to a conflict and groups the potential conflict resolutions together as the stocks. Table 4.4 highlights this correspondence.

Participants then trade shares in the potential conflict resolutions and indicate their preferences in the prices. The highest price then determines the effective resolution alternative. For the case of a tie between two or more conflict resolutions, the winner is determined by the time it reached that price level. The earliest stock to reach the tied price level is designated as the winner of the tie.

The Conflict Resolution Process

An exemplary execution is highlighted in Figure 4.15. Participant A specifies a topic T_1 to be the parent of another topic T_2. As no other parents have been specified for topic T_2 yet, a conflict does not occur. Then, participant B investigates this assignment and disagrees with its current status. He therefore specifies topic T_3 to be his favorite parent for topic T_2. Now, two topics have been specified as potential parents of T_2. In the generation of a tree structure, only one parent is allowed, however, for each topic. The LDM system detects this inconsistency in the structure and triggers a conflict for topics $T_{1..3}$. The conflict resolutions for this conflict consist of the two contributed assignments T_1T_2 and T_3T_2. In Figure 4.15, the conflicting assignments are depicted by the red arrows.

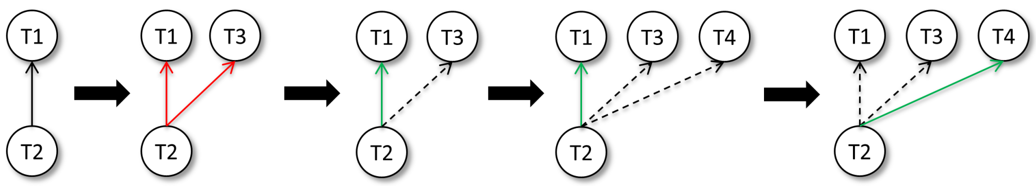


Figure 4.15: Example of a structuring effort with conflicts

The LDM system now generates a new market for this conflict and also stocks for each of these assignments. Participants are then able to resolve this conflict by trading shares of the two accompanying stocks. In this way, participants form a collective ranking for the two assignments based on the market prices and the winning assignment can be determined by the highest stock price. The winning assignment is indicated by the green arrow in Figure 4.15. The losing assignments are not removed from the market but are kept for further consideration by the participants (shown by the dashed arrow).

At a later time in the structuring process, participants may change their mind and favor one of the currently losing assignments instead.

A participant C may add another assignment T_4T_2 as a new conflict resolution alternative to the existing alternatives. The LDM system again creates a new stock for this alternative which is subsequently tradeable by the participants. Initially, this new alternative loses to the current highest ranking alternative, as no one has traded shares of it yet. In the example shown in Figure 4.15, some participants then regard this new assignment T_4T_2 to represent the best conflict resolution and buy shares in it. Thus, this assignment ends up in the highest rank among the conflict resolution alternatives and wins the conflict, again highlighted in green. This new assignment then persists until participants again change their minds and their share holdings accordingly.

Structures of topics may grow arbitrarily large. Topics down a certain branch of a topics tree depend on the position of their parents. With our mechanism, parents may be changed by participants at any time by trading in the respective conflicts market. Such changes in effective conflict resolutions then need to be reflected in the structure subsequently. These changes may be executed immediately after a conflict resolution changed or after a certain time threshold. A time threshold would avoid fast changes back and forth in the tree structure which could puzzle participants. But it would also require the definition of such a threshold and would require participants to wait for their changes to be realized in the actual tree structure. Depending on the expected attention such a threshold could be desirable.

Conventional voting approaches rely on scheduling a time threshold for settling a voting. After that threshold, votes are counted and defined as the consensus according to the settlement criteria. Resolving conflicts in the generation of a structure also requires to decide between competing resolutions at some point in time in order to be able to move on in building the structure. In our approach, changes in conflict resolutions are immediately reflected in structural changes.

4.5 Steps in Applying Liquid Decision Making

In Section 4.4.1, we described design decisions that we predetermined for applying the market metaphor to decision making. Not all design decisions have been predetermined, some have to be taken during the setup of an LDM installment. In the following, we introduce the four steps of selection, preparation, execution, and evaluation for successfully utilizing the LDM approach. These steps are inspired by the design steps proposed by Spann and Skiera [93]. In Table 4.5, the steps and the single properties to be determined for a given LDM installment are listed. In this thesis, design principles have been devised for achieving a good decision using the market metaphor. These design principles are to be kept in mind during the setup of a given LDM installment and are highlighted for the single steps where appropriate.

In the selection step, the overall applicability of the LDM approach is checked based on the design principles that have been devised in this thesis. The next step refers to the preparation of the specific LDM installment. There, the decision type, decision, decision options, audience, and amount of money have to be determined. In the execution step, the audience is invited, the market is started, supervised, and closed at the desired end

Step	Properties
Selection	Applicability Check of LDM
Preparation	Decision Type Phrasing of Decision Decision Options Perturbation Planning Audience Duration Money
Execution	Audience Invitation Market Tutorial Market Start Operation and Supervision Market Close
Evaluation	Winner Determination Evaluation of Perturbations Consideration of Comments

Table 4.5: Steps in the application of LDM to a decision making effort

date. In the evaluation step, the market results are evaluated and the winning decision options are determined.

4.5.1 LDM Selection

LDM has been devised with the goal of making good decisions in large groups of people in mind. Therefore, the first step in the application of LDM is to check whether the decision making situation at hand is suitable for LDM. As highlighted in Section 3.2, LDM is generally suitable for situations in which decision options need to be ranked, in which information is dispersed among a large group of people, in which information may become available over time on the decision, in which opinions on the decision options need to be formed over a longer period of time, and in which people want to apply their individual decision making criteria.

However, not all situations with these characteristics may be equally well suitable for the application of LDM. In Section 3.6.2, criteria have been identified for determining suitable application scenarios for LDM. These criteria include the utilization of the market result, the stakes of the participants, and the objectives of the incentives. Based on these criteria, the most promising scenario has been identified as one with a direct utilization of the market result as the final decision, with participants that have stakes in the decision outcome, and with incentives objectives that encourage a result oriented view of the participants rather than a view that is oriented on portfolio worths.

In Section 3.8, the three design principles of collaborative decision, user involvement, and dual incentives have been proposed for fostering the achievement of a good decision. Of these design principles, the user involvement principle builds on the aforementioned stakes of the participants. The user involvement principle posits that a good decision is more likely to be achieved if participants have stakes in the outcome of the decision or if such stakes can reliably be generated for them. Hence, LDM should be chosen for such decision making situations in which participants have stakes in the decision outcome.

4.5.2 LDM Preparation

After the selection of LDM as the means for decision making, the application of LDM to the decision making effort needs to be prepared. This preparation includes the determination of the decision type, the phrasing of the decision, the definition of the decision options, the selection of the price calculation in case of hierarchical ranking, the admission of additional decision options, the planning of potential perturbations, the determination of the audience, the overall duration, the available money, and a potential bonus scheme for granting additional money.

Decision Type In Section 4.1, we identified ranking, hierarchical ranking, and topic structuring as potential application domains for LDM. The first decision in the preparation of LDM is the determination of this application domain for the decision making effort at hand. The decision and the decision options have then to be arranged according to the respective domain.

Decision Phrasing In the next step, the pending decision needs to be phrased appropriately. In Section 3.8, three design principles have been devised for a successful application of LDM. According to the design principle of a collaborative decision, participants should perceive the decision to be a collaborative effort rather than a competition. Furthermore, the design principle of user involvement stipulates to phrase the decision in such a way that participants feel their personal involvement with the decision at hand. An example for such a decision is: "which factors do you think are most relevant for the development of the new aircraft concept?"

Determining Decision Options After appropriately phrasing the decision, the decision options are determined. Even if participants are allowed to contribute additional decision options, an initial set of options should be provided. This initial set of decision options helps to avoid the phenomenon of people not participating in a mechanism due to missing content. Likewise, content will not be generated because people do not participate. Related to this, it has to be decided whether participants are allowed to contribute additional proposals for decision options. For these additional proposals, an acceptance mode has to be determined as well as persons for processing the pending proposals. Pending decision options can be accepted by default or can be added to a queue for acceptance or rejection by designated participants.

Hierarchical ranking is among the application domains of LDM. Decision options can be subdivided into sub-options for a more fine-grained contribution of opinions. Prices in this hierarchical ranking can be determined by a funds-like mechanism (see Section 4.4.4). For such a hierarchical ranking, the calculation of the prices and trading costs in this funds-like mechanism have to be defined.

Perturbation Planning In this thesis, the concept of market perturbations has been devised as a means for learning to know the trading intentions of the participants (see Section 3.9). The application of these market perturbations comprises the steps of selecting a decision option, determining a perturbation action, executing this perturbation action, and examining the reactions to the perturbation action. In the preparation phase of applying LDM, the market organizer should decide whether to employ market perturbations and to which extent. This basically includes the frequency with which decision options will be subjected to market perturbations, the number of designated user accounts to utilize, and which termination criteria to employ. Finally, the market organizer should create the respective number of user accounts and assign them with the role of executing the market perturbations.

Audience The result of the decision market in LDM is based on the contributions of the participants. This audience of the LDM application also needs to be determined. First, participation may be completely open to the public. That is, anyone might register with the LDM system and start contributing to the pending decisions. Then, participation may be restricted to a pre-determined audience. This audience may already exist as a group for making that decision or may be formed for that purpose by means external to LDM. Criteria for deciding on the degree of openness include the nondisclosure of corporate know-how, the deliberate restriction to certain groups of expertise as well as the reach of the LDM application for tapping as much and diverse knowledge as possible.

Duration Decisions typically have to be settled at a certain point in time. This point in time as well as the duration of the accompanying decision market have to be defined. In the literature, different time spans are utilized in prediction markets and preference markets, ranging from a few hours to several weeks. For decision markets, the duration depends on the one hand on external constraints on the decision deadline and on the other hand on characteristics of the decision. These characteristics include the formation of the group, the time required to gather substantial information and to form an opinion as well as the availability of the participants. In a corporate environment for example, this availability may range from few to several minutes per day. In a private environment, people may be available not as regularly and may thus require a longer market runtime.

Money Participants contribute their opinions by trading shares in the respective decision options. For this trading, participants need to receive an initial amount of money at the start of a decision making effort. This initial amount has to be determined and may be subdivided into separate budgets for the single decisions or may be spendable across decisions. Budgets may on the one hand be defined to be separate in order to encourage participants to trade in all decisions. On the other hand, a single budget across decisions may indicate preferences of participants for a certain decision if they spend disproportionately large amounts of money on a single decision.

During market runtime, additional money may be required in order to compensate for many new decision options, to encourage further trading or to reward specific behavior. If several decision options are added during the market runtime, participants may request additional money in order to respect all options adequately. For this granting of additional money, a bonus scheme should be determined prior to the start of the market and may also be communicated to the participants.

4.5.3 LDM Execution

In the execution phase of the LDM application, the decision market is executed as planned in the preparation phase. There, the audience is invited and provided with a comprehensive market tutorial, the market is started and operated, and the market is finally closed at the predetermined point in time.

Audience Invitation Prior to the start of the decision market, the intended audience has to be invited. This invitation is typically performed by sending an e-mail and including a link to the Web address of the respective LDM installation. The invitation may also include an authentication token if the registration with the LDM system is restricted.

Market Tutorial Some people of the intended audience may not have come across such a market-based approach to decision making. They may therefore be unfamiliar with the market concepts of LDM. Hence, it should be beneficial to provide the audience with a tutorial on the general workings of this decision making approach, on their possibilities to contribute to the decision at hand, and on the meaning of their trading actions in the market. Of particular interest is the proper introduction of the market maker market mechanism that is utilized in LDM. As highlighted in Section 2.5, the market maker acts as a trading intermediary and sets prices of stocks according to supply and demand. However, participants are not able to make a profit from buying some shares and immediately selling them afterwards. This should be communicated to participants for avoiding confusion during trading.

Market Start For the actual start of the decision making effort, a certain date is typically defined. At this date, the market organizer enables trading in the decisions and notifies the audience of the start by e-mail and the news mechanism of LDM.

Market Operation During the runtime of the decision market, the market organizer supervises the decision market. If participants are allowed to propose new decision options and the options are to be checked by designated participants, these participants then check these proposals and subsequently accept or decline them.

Furthermore, the market organizer may have devised a bonus scheme for granting additional money in the preparation step. During market runtime, the market organizer checks the criteria for this bonus scheme, determines the amount of additional money for each participant and grants the bonuses accordingly.

In the preceding preparation step, the market organizer may have planned to employ market perturbations for learning on the intentions of the participants in the decision making effort. These market perturbations are realized by executing one or more specific trading actions. Currently, these trading actions are executed by a designated participant using one or more dedicated user accounts in LDM. The respective market actions that the designated participants execute during the runtime of the decision market should then follow the perturbation plan devised in the preparation step.

Market Close Finally, the decision market is closed by disabling trading. The decision market may be closed at a predetermined point in time that is also communicated to the participants. This, however, may lead to last minute speculation and price rallies. Closing may also be done at a random point in time, communicated only as a time span. In this way, last minute speculation may be diminished [58].

4.5.4 LDM Evaluation

The results of the LDM application are then evaluated after the market has been closed. The first aspect is the determination of the winning decision option or options. Prior to the market execution, the market organizer has determined the number of winners, n, that is sought for. The first n options of the ranked list are hence considered the winning decision options of the pending decision.

LDM also includes the concept of market perturbations. In the evaluation phase, the impact of the executed market perturbations is evaluated. Criteria for interpreting the reactions of the other traders are given in Section 3.9. Basically, if traders are easily swayed by the additional trading actions, the participants are considered to mainly exhibit profit-oriented trading behavior and the market result is deemed to be of limited use for a good decision.

Participants in LDM may also comment on the trading actions as well as the available decision options. Furthermore, these comments may also be rated. The main goal of these comments and rating is to encourage interaction and to provide additional insights during the trading phase of the decision market. However, in the evaluation of the market result, these comments and rating may also be considered in the utilization of the market result or in case of any disagreements.

CHAPTER 5

The Liquid Decision Making Software Prototype

In the preceding chapters, we introduced the foundations as well as the system concept of LDM. In addition to the development of these contributions, we implemented a software prototype for LDM. This software prototype served to investigate the pertinence of the LDM approach in different case studies. In this chapter, we highlight general considerations in the implementation of this software prototype.

5.1 General Considerations

A key aspect of LDM is the utilization of the market metaphor for decision making. In Section 4.3, we highlighted requirements for realizing this market metaphor in LDM. In the following, we consider the characteristics of the market metaphor and derive general requirements for designing a software prototype that preserves these characteristics. The market metaphor allows for a continuous participation of a large and heterogeneous number of people. This large number of people also does not necessarily have to be situated in the same location nor does it have to participate at the same time. Rather, the market metaphor provides for participants being distributed geographically and over time. Also, the market metaphor offers a promptly feedback on the single trading actions due to its price mechanism. The aforementioned characteristics of the market metaphor should be preserved in the design of the software prototype of LDM. Hence, the prototype for LDM should provide for accessibility, compatibility, and maintainability.

Accessibility Participants in LDM may be distributed geographically and may trade at different points in time. Therefore, the LDM prototype should allow for a distributed access in a continuous fashion. Furthermore, people should participate repeatedly in order to advance the decision making. Therefore, the LDM prototype should also have a low entry barrier and should be easy to use.

Compatibility In their geographical distribution, participants are likely to utilize different hardware and operating systems. The LDM prototype should therefore support a range of platforms as wide as possible.

Maintainability The implementation of the LDM system is in the status of a software prototype due to its research focus. Due to this prototypical nature it is likely to be frequently updated with features and bug fixes. Therefore, the software prototype should require a low effort for deployment, maintenance, and software updates.

We also devised some non-functional considerations for LDM including performance, portability and adaptability.

Performance The market metaphor offers immediate feedback to participants on their contributions and in this way a real-time observation of the decision making status. To ensure this immediate feedback, the LDM software prototype is required to efficiently process the single orders of the participants and to update the book keeping in a timely fashion. Even in times of heavy trading, participants should not experience major performance issues during their navigation in the software prototype as well as during the contribution of their opinions through trading.

Portability While some LDM installments may be realizable as publicly accessible systems, others may have to be operated in closed environments such as in companies for example for reasons of intellectual property rights. For such cases, the LDM software prototype should be deployable on standard hardware and software without the need for proprietary or specialized hardware and software.

Adaptability The LDM approach is based on the market metaphor for decision making. It uses the concepts of markets and stocks for identifying the most favored decision options. While this can be generalized over several decision making situations, it may be required to adapt certain aspects of the LDM software prototype to the specific decision making situation at hand.

5.2 Platform Selection

In the previous section, we identified general requirements for the design of the software prototype of LDM. Basically, the software prototype may be implemented as a web-based application or as a desktop-based application. Given the aforementioned considerations, we opted to implement the software prototype as a web-based application. This allows us to address the considerations effectively. First, a web-based solution is easily accessible by using the standard browser as found on any PC. This contributes to a low entry barrier for participation. Next, the realization over the Web allows for a participation from any location with reasonable Internet connectivity at any time during the runtime of a given decision market. Web-based applications that utilize standard Web technologies also ensure compatibility across different browsers and operating systems, hence contributing to compatibility and accessibility. From a user's point of view, web-based applications are always up-to-date as they are retrieved from the Web server each time they are used. From a developer's point of view, the software has to be maintained and updated only on the central Web server, but does not need to be maintained on several client installations.

For implementing a web-based application, both an implementation from scratch or the utilization of an existing Web framework are conceivable. We wanted to be able to focus on the implementation of the core functionalities of the LDM system without having to deal with the intricacies of Web application development. Therefore, we decided to employ a Web application framework. The goal of such Web frameworks is to provide web application developers with elementary functionalities concerning user interface components, page navigation, separation of user interface definition and business logic, transaction safety as well as data storage. We therefore used the following selection criteria for choosing a Web framework.

User Interface Traders interact with the software prototype of LDM by entering various inputs such as proposing decision options, triggering market orders, and commenting. Furthermore, participants review the results of their interactions via listings on decision statuses, stock prices, and rankings. Thereby, the entered as well as the presented information mostly consists of textual data and key figures. For an easy handling of these input and presentation tasks, standard components should be available in the selected Web framework.

Navigation The LDM system provides for defining multiple decisions and decision options. Furthermore, participants may inspect accompanying market data and market overviews. These functionalities are likely to be provided on different Web pages of the software prototype, thus requiring navigation between those Web pages. These navigation paths between the single Web pages should be flexibly definable.

Business Logic The goal of implementing the software prototype of LDM has been to test the pertinence of the market-based decision making approach as well as the impact of the market perturbations. The functionalities of LDM implemented in the business logic of the prototype. We wanted to be able to focus on the implementation of these functionalities without the need to implement large parts of additional supporting functionalities. Therefore, the Web application framework should allow to focus on the core functionalities of the software prototype.

Transactions The results of LDM emerge from the trading actions that participants execute during the runtime of the market. The software prototype therefore needs to handle these trading actions in the correct chronological order and without interference between them. The Web application framework therefore should offer a transaction-safe handling of the single trade actions.

Data Storage LDM consists of several entities including decisions, decision options, markets, stocks, share holdings, transactions, comments, and ratings. These entities need to be stored for the retrieval and manipulation in user interactions.

Therefore, the Web application framework should provide for a easy to manage data storage of these entities.

Tabbed Browsing A decision is typically associated with multiple decision options. Participants in LDM may want to keep an eye on more than one decision option at a time and trade in it. Current Web browsers offer to open Web addresses in separate so called *tabs* and to switch back and forth between them quickly. These tabs are a usual way of keeping track of multiple items on a Web site, for example different hotels in hotel booking or different decision options in decision making. A Web application, however, has to support this tabbed browsing of multiple items appropriately and to associate actions on the single tabs to the proper items. Therefore, the Web framework should be able to handle multiple browser tabs correctly.

In the engineering of software applications, the model-view-controller pattern is often utilized for separating the concerns of data modeling, handling user interactions and executing the requested business logic. For Web applications, this translates into persisting and managing the entities of the application's data model, modeling the user interface using HTML and Javascript, handling the interactions of the user with the graphical user interface, and executing the requested functionalities of the business logic.

Based on the aforementioned considerations, we decided to use the Seam[1] Web application framework for implementing the software prototype of LDM. The Seam framework combines separate frameworks for presentation, business logic and persistence into a unified approach. The Seam framework requires a Java application server for execution. The recommended server for the Seam framework is the JBoss Application Server[2]. Therefore, the JBoss server was employed in the studies of this thesis. In the following, we highlight the different technologies that are integrated by the Seam framework. Note that for this software prototype Seam version 2 has been utilized.

User Interface Seam incorporates Java Server Faces (JSF)[3] as its view technology. JSF provides a life cycle model for handling user interactions with the user interface and offers a rich component library for the realization of elementary functionalities such as data input, input validation, and data presentation.

Business Logic The Seam framework provides for the use of Java Enterprise Edition (JEE) as the programming language for the business logic.

Data Storage Data storage is realized by the persistence layer of the Seam framework. This storage includes data of all users, decisions, decision options, comments, prices, and transactions. The Hibernate[4] object-relational mapping framework is utilized by Seam for persistent storage as well as handling of data.

[1] http://www.seamframework.org
[2] https://www.jboss.org/jbossas
[3] http://www.oracle.com/technetwork/java/javaee/javaserverfaces-139869.html
[4] http://www.hibernate.org

5.3 Architecture

The software prototype of LDM is implemented using the Seam Web application framework [63]. The LDM system provides for different functionalities concerning the decisions, trading, and users (see Section 4.3). These functionalities are grouped in the components of the architecture of the LDM software prototype. As introduced before, the LDM software prototype employs a model-view-controller approach that is realized in the three tiers of presentation, business logic and persistence. This architecture is depicted in Figure 5.1.

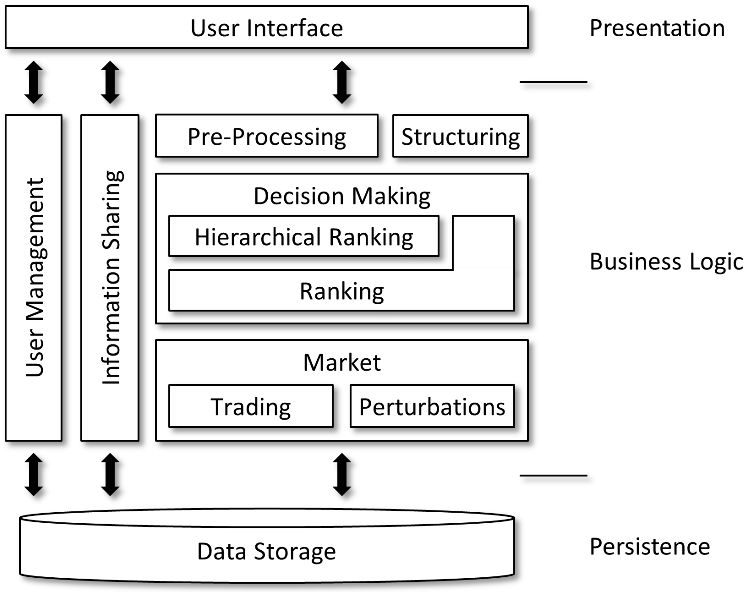


Figure 5.1: The architecture of the LDM software prototype

User Interface The user interface is responsible for displaying the requested information as well as for receiving the user interactions with the LDM software prototype.

Pre-Processing The pre-processing component is responsible for accepting decision option proposals from participants, for adding them to the processing queue, and for handling the processing decisions of the market organizers. As a result, proposals are added to the respective decision as new decision options, or are dismissed.

Structuring The structuring component deals with the structuring mechanism as described in Section 4.4.5. That is, the component keeps track of the current effective structure, proposals for alternative structural parts, the resulting conflicts between competing proposals, and the winners of the respective conflicts.

Ranking The ranking component handles the decisions, decision options, and their rankings. For this, the component maintains a mapping of the decisions and decision options to markets and stocks of the market and retrieves the respective prices. Based on these prices, a ranking of the decision options is formed.

Hierarchical Ranking The hierarchical ranking component extends the ranking component with a hierarchical ranking capability. In this component, the relationships between the single decision options at the different hierarchical levels are maintained. The hierarchical ranking component also determines the way in which the prices of the hierarchical decision options are calculated (see Section 4.4.4).

Trading The trading component is responsible for accepting the trading orders of the participants, checking their validity, and finally for executing them. There, the new prices are calculated and the involved stocks are updated accordingly. Furthermore, the share holdings and available cash of the participants are updated as well.

Perturbations LDM includes the approach of market perturbations for learning on the intentions of participants and on the quality of market results. The perturbations component handles these market perturbations. This includes the differentiation between a trading action that is executed by a regular trader and a trading action that is executed by a user who is entitled for perturbations.

Information Sharing The information sharing component processes the additional information that is contributed by participants besides their trading actions. In the current software prototype, this includes the commenting mechanism and the voting mechanism for the helpfulness of the comments.

User Management The user management component handles user-related functionalities including user registration, authentication, password changes, and user profile information handling.

5.4 Discussion

In this chapter, general considerations for the design of the LDM software prototype have been presented. Furthermore, the realization using the Seam Web application framework has been highlighted. This Web framework deemed suitable for meeting the criteria that we devised in this chapter. However, minor shortcomings have also been identified in the course of the studies that we conducted accompanying this research. Especially when it comes to real time requirements of the software prototype concerning the currentness of information on the Web pages it was noticeable that the Seam Web framework has not been designed for such requirements. The asynchronous nature of the Web infrastructure and the architecture of the framework do not provide for true real time updates of prices. As such, price updates may not be immediately available to all participants in their Web application instances of LDM, especially in an environment with high trading volume in a short duration of time, such as in a laboratory. However, we argue that the advantages of installation-free operation and low entry barrier make up for these inconveniences.

CHAPTER 6

Evaluation of Liquid Decision Making

Accompanying to the development of LDM, we employed four case studies so as to investigate the research questions outlined in Section 1.2. In the following, we highlight the research approach, summarize the overall results, and provide details on the case studies. The following evaluation is based in part on previous reports concerning the results of the case studies [62, 65].

6.1 Overview

6.1.1 Case Study Approach

The goal of this research was to investigate the application of the market metaphor to decision making. To this end, we defined specific research questions, developed LDM to address the research questions, and investigated the pertinence of LDM. For the latter task, different approaches seemed worth considering, including controlled experiments in a laboratory and in the field, as well as case studies.

Controlled experiments serve to investigate the impact of defined changes in one or a few independent variables to a range of dependent variables in well-defined and controlled circumstances. Furthermore, control groups of people are used which are not subjected to the independent variables but are identical to the treatment group in every other aspect to serve for comparison. Such experiments allow to precisely investigate cause-effect relationships and the answering of detailed hypotheses. To this end, they require a laboratory environment, a large enough pool of people for random sampling of the treatment and control groups, and the object of study to be amenable to an investigation in an artificial lab setting. Field experiments aim at alleviating this by investigating experimental outcomes in a more natural setting. However, they also rely on an experimental approach including the randomization of participants and the use of treatment and control groups.

Case studies in contrast are employed with the goal of exploring and understanding multiple facets of a phenomenon in its context, of exploring behavior of individuals through interventions, and to evaluate settings of situations [107]. Yin there discerns three types of case studies, namely exploratory, descriptive, and explanatory case studies [107]. Exploratory case studies target the exploration of situations or interventions for which the phenomenon or outcome have not yet been clearly defined. Descriptive case studies focus on describing the details of a phenomenon in its real-life context. The goal there is primarily to learn to know the phenomenon and the context it occurred in as a basis for the refinement of problem statements and hypotheses. Lastly, explanatory case studies attempt to explain a given situation and its phenomena, that is, to increase the understanding of cause and effect in a given situation.

We wanted to investigate the use of the market mechanism and of the functionalities of LDM for decision making as well as the impact of the design principles and the market perturbations on the trading behavior of participants in the context of natural decision making situations. To this end, the execution of case studies to explore, learn to know, and explain the impact of the devised LDM approach were deemed more appropriate than controlled experiments which are targeted at detailed hypothesis testing. Furthermore, participants do not act independently in markets, rather, their trading behavior is influenced by the actions of the other participants. For observing precise correlations in experiments, however, independent subjects and their individual actions have to be considered. Thus, a challenge in the investigation of the market metaphor is that the subject of observation is not the single participant but rather the whole market. For observing the impact of a change in a single independent variable, a whole market has to be executed, requiring several randomly selected people to continuously participate in a market over a longer time. For statistically significant conclusions, several such observations, that is, markets, are required. This, however, was not feasible for the investigation of the LDM approach. We thus decided to collect qualitative data in case studies. Case studies provide a good means for collecting qualitative data while at the same time being practicable from a cost and effort point of view. Furthermore, case studies can be conducted together with existing decision making efforts.

Case studies allow to use multiple data sources for investigating the respective case [107]. For evaluating LDM in our case studies, we wanted to gather data from the trading actions of the participants, their online as well as offline comments, and feedback surveys. The trading actions allowed us to interpret the acceptance of the market approach of LDM through their quantity as well as to gauge the effectiveness of the design principles and market perturbations through their qualitative properties. These evaluations were supported by analyzing the comments that participants make in the commenting mechanism as well as in discussions accompanying the case studies. User surveys provide an easy to administer and cost-effective way to gather answers on questions regarding attitudes. We conducted user surveys subsequently to each market exercise among the participants of the CREATE study, the laboratory study, and the scenario building study. For the symposium study, we gathered the feedback of the participants orally in the closing session of the symposium. In the conducted user surveys, we utilized a Likert scale for the rating of the single aspects of the case studies [66]. The purpose of the Likert scale is to gather the level of negative or positive attitude of participants towards given survey statements. The Likert scale of the case studies ranged from 1 (does not apply) to 5 (fully applies). Values given in the following refer to this Likert scale. The user surveys were conducted anonymously for encouraging participants to provide honest and accurate answers.

6.1.2 Case Studies Overview

We investigated LDM in four case studies in this research. Table 6.1 highlights their setup regarding the decision, their decision options, their participants and their duration.

	CREATE	Laboratory	Symposium	Scenario Building
Decision	Ranking of air transport ideas	Selection of a concept for further research	Ranking of research topics	Selection of the 10 most influential factors
Decision Options	107 aeronautics innovations	5 aircraft concepts	21 research topics	30 influencing factors
Participants	28 people from academia and industry	7 and 10 students in 2 sessions	17 people from the aerospace industry	9 students and 11 researchers
Duration	53 days	4 trading rounds a 20 min	2 days	36 days including 3 dedicated trading sessions

Table 6.1: Overview on the executed case studies

The CREATE Study The first study was conducted accompanying the EU-funded project Creating Innovative Air Transport Technologies for Europe (CREATE)[1]. The CREATE project was concerned with the generation and selection of innovative ideas for the future of aeronautics. LDM was utilized as an alternative means for ranking the generated ideas for future air transportation. The decision options consisted of 107 aeronautics innovations that were ranked by participants from both industry and academia over a period of 53 days. For more detail see Section 6.2.1.

The Laboratory Study The laboratory study was executed in a university laboratory and comprised the selection of an aircraft concept for further research. 7 and 10 students participated in 2 sessions, respectively, and ranked 5 aircraft concepts using LDM. 4 trading rounds were executed with a during of 20 min each (see Section 6.2.2).

The Symposium Study The symposium study accompanied the annual partner symposium of Bauhaus Luftfahrt. There, research proposals are reviewed and selected for further research. 17 participants from the aerospace industry utilized LDM to rank 21

[1]http://innopedia.wikidot.com/create

research topics. During the two days of the symposium, the provided LDM market was open for trading. For details see Section 6.2.3.

The Scenario Building Study The scenario building study was conducted together with a scenario building seminar at the Technische Universität München and dealt with the selection of influencing factors for the generation of scenarios for the future of personalized mobility. 9 students and 11 researchers selected 10 influencing factors from a total of 30 factors using LDM. For details on the case study that lasted 36 days including 3 on-site trading sessions, see Section 6.2.4.

6.1.3 Revisiting the Research Questions

In this section, we revisit the research questions and highlight the case studies and their respective share in answering them. The research questions focus on the general applicability of the market metaphor to group decision making, on the required functionalities for a market-based decision making system, on incentives for people to participate, and on suitable scenarios for actually applying the LDM approach. Below, we restate the research questions.

RQ 1 How can the market metaphor be applied to group decision making?

RQ 2 Which functionalities are appropriate for market-based group decision making?

RQ 3 Which incentives encourage the contribution of sincere opinions by participants?

RQ 4 Which scenarios favor the achievement of a decision that is predominantly based on sincere opinions?

A double plus symbol in Table 6.2 indicates a focus on the respective research question, a single plus symbol denotes that this research question has also been dealt with in the respective case study, and in case studies market with a zero symbol, the respective research question has not been addressed.

	RQ 1	RQ 2	RQ 3	RQ 4
CREATE	++	+	+	0
Laboratory	+	++	++	0
Symposium	+	+	+	+
Scenario Building	++	+	++	+

Table 6.2: Contribution of the case studies to answering the research questions

The CREATE study was concerned with the selection of innovative ideas for the future of aviation and addressed research questions 1, 2, and 3, with a focus on the general applicability of LDM. The laboratory study related to the investigation of research questions 1,2, and 3 in a laboratory environment. In the laboratory study, we focused on the functionalities and the incentives provided to participants. With the symposium study, we inspected all four research questions with an equal focus. The last case study was executed in conjunction with a scenario building seminar and concerned the generation of pictures of the future of personalized mobility. There, LDM was utilized for selecting the most influential factors for these pictures of the future. We also addressed all four research questions in this case study, with a special focus on the application of LDM and the incentives for participants.

6.1.4 Results

Overall, the results of the case studies suggest that the proposed application of the market metaphor to group decision making is a viable approach, that the virtual market model adequately depicts the participants' behavior, that the devised design principles support the achievement of good market results, that the market perturbations can support the identification of the motivations of the participants, that the identified application scenarios are feasible for the utilization of LDM, that the functionalities are appropriate for the market-based approach of LDM, and that the LDM software provided a suitable implementation of the devised functionalities. In Table 6.3, we summarize the contributions of LDM and their share in addressing the single research questions.

Contribution	Description	RQ
Foundations		
Market Approach	Correspondence between the elements of decision making and of the market metaphor	1
Virtual Market Model	Impact factors on the behavior of participants	1,3
Design Principles	Guide to the design of decision markets to ensure the achievement of a good decision	1,2,3,4
Market Perturbations	Means for learning the trading intentions and the quality of a decision market result	1,2
Application Scenarios	Scenarios based on the factors of result utilization, stakes, and incentive objectives	4
Application Steps	Steps for the set up of a decision market	1
System Concept		
Conceptual Architecture	Architecture of the LDM system applying the ranking capability of the market metaphor to decision making and its application in different domains	1
Functionalities	Functionalities in the categories of decision making, market trading, user handling, information exchange, and market perturbations	2
Software Prototype	A web-based software prototype realizing the functionalities, providing a low entry barrier, easy deployability, and maintainability	1,2

Table 6.3: Contributions of this work

RQ 1: How can the market metaphor be applied to group decision making?

In LDM, a market corresponds to a decision and a stock refers to a decision option. This correspondence was well received by the participants in all executed case studies. The functionalities that the LDM system provides to traders were deemed useful by the participants in the joint selection of decision options. The functionalities for executing market perturbations were deemed adequate by the market organizers and the artificial trades were deemed to have stimulated further trading actions by the other participants.

In the application of the market metaphor to decision making, the characteristics of a continuous participation, of a promptly feedback, and of the revision of one's opinion can be retained for the market metaphor. These characteristics were rated by the participants to be advantageous of LDM in making a joint decision.

In LDM, the MM approach is used for determining stock prices. Participants thought the price determination by this market maker to be easily understandable. In the case studies, the design steps were employed for designing and executing the single decision markets. These design steps were deemed useful in the preparation and execution by the organizers of the case studies.

The collaborative decision principle was realized in all case studies by phrasing the decision accordingly. Generally, participants indicated to have engaged in both competitive trading and trading based their sincere opinions. In the laboratory study, two different wordings were used in phrasing the decision. In the competitive wording, participants reported to have been trading competitively to a larger degree than in the collaborative wording. In the scenario building study, the ranking of participants according to their portfolio worths was removed from the user interface. In this way, participants were not able to easily compare their rankings and were expected to engage less in competitive trading. There, participants reported to have engaged in sincere trading to a higher degree than in competitive trading.

The user involvement principle was realized in the case studies to different degrees. In the CREATE study and the laboratory study, the personal involvement could be established to a low degree, in the symposium study to a medium degree, and in the scenario building study to a high degree. This is also reflected in the mixture of competitive and sincere trading that was reported by the participants.

The dual incentives principle was implemented in all case studies. In the user surveys, participants reported that the means for realizing the dual incentives, the e-mail digest and the dashboard, encouraged them to participate and to return regularly to the mechanism.

The impact of market perturbations was investigated in the laboratory study, in the symposium study, and in the scenario building study. The findings of the case studies point to the ability of market perturbations to give an indication on the trading intentions of the participants.

Taken together, the findings of the case studies suggest that the market metaphor can successfully be applied for group decision making by employing the proposed correspondence between the market elements and the decision making elements, by following the devised design principles as well as the application steps, and by utilizing the concept of market perturbations.

RQ 2: Which functionalities are appropriate for market-based group decision making?

In Section 4.3, we identified relevant functionalities for LDM and categorized them according to decision making, market trading, user handling, information exchange, and market perturbations. In the LDM software, we implemented the functionalities prototypically. In the CREATE study, the focus was on the market maker functionality, the price chart, and the e-mail digest. Participants rated the market maker functionality to be easily understandable, the price chart to be helpful for following market activities, and the e-mail digest to be informative on the current market status.

The laboratory study was concerned with the overall usability of the LDM software as well as with the informativeness of the price chart and of the dashboard. Participants rated the overall LDM software to be useful, the page navigation to be intuitive, the provided information to be beneficial for following the market activities, and the price chart to be useful for following the price development. Participants furthermore stated that the dashboard provides an appropriate amount of information on the current market status. The functionalities for executing market perturbations deemed also useful to the organizers in the laboratory study.

In the symposium study, feedback was gathered orally on the provided functionality of LDM. Notable from this study is that one participant reported difficulties in understanding the price formation entailed by the utilization of the market maker mechanism. This points to the need of properly introducing the utilized market maker mechanism.

The usability of the LDM software and the commenting mechanism were addressed in the scenario building case study. There, participants rated the LDM software to be easy to use. The commenting mechanism was also rated to be helpful for providing insights to the other participants and for understanding the rationale of others. In conclusion, the results of the case studies point to the appropriateness of the decision making, market trading, user handling, information exchange, and market perturbation functionalities that have been selected and implemented for LDM in this thesis.

RQ 3: Which incentives encourage the contribution of sincere opinions by participants?

A market result of LDM is deemed to be of good quality if trading occurred predominantly based on sincere opinions. Incentives in LDM should therefore encourage the contribution of such sincere opinions. In the CREATE study, we provided two kinds of incentives. On the one hand, participants were told to select the ideas that they truly favor for the future of aeronautics. On the other hand, they were promised a reward for the highest portfolio worth. This mixture of incentives was reflected in the trading behavior. Participants reported both to have been following market trends in speculative efforts and to have been trading according to their sincere opinions on the available decision options.

In the first trading session of the laboratory study, participants were told to trade profitably on the decision market whereas in the second session, they were told to collaboratively identify the most promising decision option. No direct incentives were provided, rather, the incentives consisted of the obligations that participants felt towards the organizers. Participants in the competitive setting rated the influence of portfolio maximization on their trading actions higher than in the collaborative setting. Furthermore, three participants also reported their perception of a mismatch in the competitive setting between jointly determining the best decision option and individually maximizing their portfolio worths.

In the symposium study, the provided ranking of the participants according to their portfolio worths created a competitive perception among them. Furthermore, the general setup of the case study provided for a collaborative setting and for user involvement. Participants reported in the feedback session to have traded mostly according to their corporate backed interests. The ranking of the portfolio worths, however, encouraged two participants to also strive for optimizing their portfolio worths and hence for improving their ranks among the other participants.

In the scenario building study, the collaborative decision principle and the user involvement principle were implemented comprehensibly as the participants had to actually work with the selected decision options in the scenario building effort. Also, the LDM software did not provide a ranking of the participants' portfolio worths. In this setting, participants reported to have been contributing sincerely to the selection of the decision options and they also accepted the selected decision options for further utilization in the scenario building effort.

The findings of the case studies indicate that competitive incentives can encourage competitive trading behavior, for example maximizing one's portfolio worth. Such trading behavior, however, is likely to bias the achievement of a good decision. Therefore, we conclude that those incentives encourage the contribution of sincere opinions that de-emphasize competition among participants, that instead focus on the achievement of a good decision, and that involve participants in the final decision.

RQ 4: Which scenarios favor the achievement of a decision that is predominantly based on sincere opinions?

As highlighted in Table 6.2, the fourth research question has been dealt with in the symposium case study and in the scenario building case study. The symposium case study corresponded to Scenarios 3 and 4 of the identified scenarios. There, the market result did not directly determine the selected decision options, but rather was deemed to have some influence on the external decision, participants had some stakes in the decision outcome, and they were provided with incentives based on both their portfolio worth and their contributions. The feedback of the participants suggests that the incentive based on portfolio worth actually led some participants to maximizing their portfolio worths. Such market behavior, however, has been identified to be likely to produce biased market results of inferior utility for the market organizers. This result points to the importance of the applicability check of the application steps as well as to the suitability of the identified application scenarios.

The fourth research question was also addressed in the scenario building case study. The setup of this case study corresponded to Scenario 8 of the scenarios highlighted in Table 3.3. In this case study, the market result was directly utilized as the decision on the selected decision options, the participants had stakes in the market result as they had to work with the outcome, and the incentives were set for a contribution of their sincere opinions. This setup in compliance with Scenario 8 proved beneficial in obtaining a useful market result. This is highlighted by the good rating of the produced decision options by the market organizer as well as by the participants, and by the meaningful scenarios of the future that were produced by the scenario building effort.

In conclusion for research question four, the findings of the symposium study and of the scenario building study suggest that the identified influencing factors are relevant for the determination of the suitability of a given decision making situation for the application of LDM and that the derived Scenarios 4 and 8 favor the achievement of a good decision when using LDM.

6.2 The LDM Case Studies

In this section, we present the design, execution, and result of the case studies that we executed to investigate the research questions of this work.

6.2.1 The CREATE Study

The acronym CREATE refers to a research project of the Seventh Framework Program of the European Union and stands for Creating Innovative Air Transport Technologies for Europe [3]. In the aeronautics industry, development of technologies mainly occurs as evolutionary changes to existing technologies. This evolutionary development is however often hardly able to meet ambitious goals for example set forth by the strategic agenda Flightpath 2050[2]. Project members of CREATE had thus realized that new processes should be developed for furthering innovative ideas for air transportation to enable step changes in this sector. The goal of the CREATE project was hence to devise and realize a process for gathering and evaluating ideas for the future of air transport. In this project, five means for addressing these needs were designed: a creative workshop, a discussion process based on Innopedia[3], a process for watching technological opportunities called Technology Watch, a portal for assisting idea contributors called Idea Portal, and an assessment process for reviewing the contributed ideas. The CREATE process allows for the participation of multiple people in the contribution and development of innovative ideas. LDM also provides for the participation of a large and heterogeneous group of people in the evaluation of decision options. Therefore, the CREATE project provided a good opportunity to test LDM.

Objectives, Setup and Execution

The Strategic Prioritization and Planning Process (SP2) has been adapted for the assessment of ideas in CREATE. SP2 is a qualitative and structured assessment method devised by Kirby et al. for the strategic planning of future technology portfolios [55]. The first step of the CREATE process consists of so called *creative workshops*. Such a creative workshop has been held in Duxford with the goal of generating innovative ideas for the future of air transport. There, the participants produced 107 distinct ideas. The next

[2] http://ec.europa.eu/transport/modes/air/doc/flightpath2050.pdf
[3] http://innopedia.wikidot.com/create

step in the CREATE process was to evaluate and rank these ideas using the adapted SP2 approach. In addition to SP2, we tested the ranking of these ideas using LDM.

Objectives In the CREATE case study, research questions one, two, and three were addressed by investigating the market approach of LDM (RQ1), the provided functionalities (RQ2), and the virtual market model (RQ1, RQ3). The market approach refers to the overall applicability of LDM. In the focus of the functionalities were the price formation using the market maker, the price chart, and the e-mail digest. As highlighted in the virtual market model in Section 3.3, incentives play a key role in influencing the trading behavior of participants. Therefore, a goal of this case study was to gain experience on the impact of incentives on the trading behavior. To this end, participants were provided with two incentives. The first incentive consisted in the request by the organizers to determine the most appropriate ideas for the established questions. This aimed at creating a moral obligation for complying with the request of the organizers. The second incentive comprised a material reward for the highest portfolio worth to be determined at the end of the market exercise. As the CREATE project originated in the aerospace domain, the material reward consisted of a short sightseeing flight at the site of the respective winner. The investigation of market perturbations was not part of this case study.

Setup LDM was used for selecting the most promising ideas for the future of aviation. This selection was subdivided into four questions regarding the technological challenge, environmental friendliness, level of impact on the aviation industry, and the time frame of the realization of the gathered ideas. This subdivision was based on the categories emphasized by the Flightpath 2050 agenda. The LDM installment was set up as follows. The four sub-questions represented the decisions to be made and the 107 ideas corresponded to the decision options. For each of the four decisions, all 107 decision options were tradeable independently. That is, trading in a decision option of one decision did not influence the price of the identical decision option of another decision. This has been chosen to avoid cross influences between the single decisions. The contribution of additional decision options, that is, ideas, was not allowed in this LDM installment. Eligible for participation in this market exercise were all participants of the Duxford creative workshop and additionally employees of the CREATE project members. The audience originated from both industry and academia, and had a diverse knowledge background. The market exercise was started directly after the workshop for taping the insights that participants gained during the workshop. As people participated mostly besides their regular work duties, we decided to run the market exercise for about one and a half months. This provided participants with enough time to reconsider the ideas and to contribute their opinions. We did not announce the exact end date for avoiding last-minute speculative behavior, rather, we decided to close the exercise within a time span of one week after the one and a half months. The participants received an initial endowment of $5000 virtual play money for trading. This amount of money was deemed to be large enough to allow for trading in multiple decision options, yet small enough to discourage ill-considered spending. Furthermore, we devised a scheme for granting additional play money to the participants. This was targeted at further encouraging trading during the market runtime. The scheme provided for granting the amounts of $5000, $2500, and $1500 at intermediate points in time during the market. We decreased the amount of money to encourage participants to focus their trading on their most favorite decision options towards the end of the market exercise. Following the market maker approach, the prices of the decision options started at $50 each. The virtual play money was not redeemable for real money.

Execution At the beginning of the market exercise, we invited the 50 people of the previously determined audience to participate in LDM for the evaluation of the generated ideas. These participants received a written tutorial that introduced them to the market-based approach of LDM for ranking the gathered ideas. The market exercise was then started at September 1st, 2009. The tasks of the participants included the ranking of the ideas regarding the four sub-questions as well as participating in the discussion of these ideas. During the runtime of the market exercise, participants were granted additional play money three times according to the devised scheme. The first grant was given after 7 days of trading and consisted of an additional amount of $5000 of virtual play money. After 21 days, the amount of $2500 was granted to the participants. The last subsidy was granted after 42 days of trading with an additional amount of $1500. The points in time were selected based on the trading activity of the participants. For encouraging participation during the runtime of the market exercise, a newsletter was sent on a daily basis, containing a summary of the market activities and the recipient's respective market status. The market exercise was planned to last for about one and a half months and to be closed within one week after that period. After 53 days of trading, the market exercise was then closed and the three highest ranking ideas were determined as winners for each of the four questions. Subsequently, we gathered feedback from the participants by means of an online survey.

Results and Discussion

The objectives of this first case study concerned the market approach of LDM, the provided functionalities, and the virtual market model. Overall, 28 of the 50 invited people actively participated in this market exercise following the Duxford workshop. The participants completed a total of 681 single trades with a maximum of 120 trades, a minimum of 1 trade, and a mean value of 24 trades per person. For each of the four questions, 107 ideas were tradeable, resulting in a total of 428 stocks. 109 of these 428 stocks were actually traded during the market exercise. The following results refer to the post-market survey and the utilized Likert scale, ranging from 1 (does not apply) to 5 (fully applies).

Market Approach Regarding the market approach of LDM, we focused on the general applicability of LDM in a group decision making effort. Participants regularly made trades in the four decision markets, embracing the continuous nature of the LDM approach. Figure 6.1 depicts this in the number of trades per day. There is fluctuation discernible, but overall trading continued until the end of the market runtime. In the user survey, 83% of the participants indicated their willingness to participate in another market-

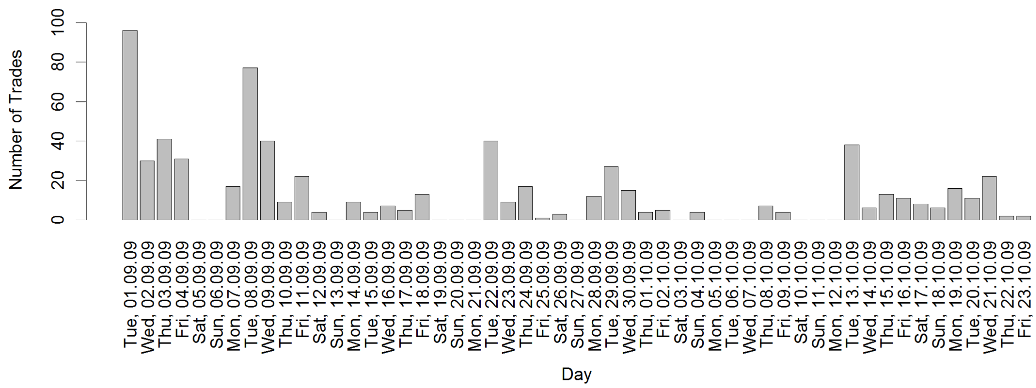


Figure 6.1: Number of trades per day during the CREATE study

based idea assessment exercise. Participants also reported to recommend this market-based approach with a mean value of 3.2. Furthermore, participants thought that the application of LDM provided additional value to the idea selection process of the CREATE project with a mean value of 3.4. 56% of the participants also estimated the capabilities of aggregating diverse opinions as well as of incorporating a large user basis to be key discerning factors of the LDM approach.

The high percentage of people willing to engage in another market effort can be interpreted that the market approach is unlikely to have general impediments that would deny further applications. Consent to the additional value of the approach and to the recommendation of the approach was 0.9 and 0.7 points above average. This slightly positive rating and the aforementioned general willingness suggest that LDM was successfully employed overall. The lack of a more pronounced positive rating could have resulted from the market having been an add-on to the actual CREATE process. As an add-on, the benefits from participating in the market may not have been well perceived by the participants given the additional work load. This may also be reflected in the fact that just about half of the participants recognized the key discerning factors of the market approach in this case study. For further studies, a stronger focus may be put on the emphasis on the key discerning factors of the market approach as well as on a more relevant integration in a decision making process.

Functionalities The second aspect of this case study concerned appropriate functionalities for a market-based decision making effort. Participants were asked to evaluate three distinct features in the post-market survey. For the first feature, the market maker mechanism, participants reported it to be easily comprehensible with a mean value of 3.1. In this case study, short selling was allowed. This feature, however, was rated as too difficult to understand with a mean value of 3.8. The next feature that was surveyed was the price chart that allowed the participants to follow the price developments of the single ideas. Participants rated this price chart as helpful for following market activities with a mean value of 3.7. Lastly, an e-mail digest was sent on a daily basis to all participants. 63% of the participants reported that they were motivated by the newsletter at least once to participate, with 28% even having been motivated at least once a week. The newsletter was also thought to have kept traders up to date with a mean value of 3.5.

The above average ratings of the functionalities (0.6 and 1.2 points) indicate that the functionalities in general are not likely to pose general impediments to their application. As the market maker mechanism has been reported to be easily understandable in literature [58], the slightly positive rating of 0.6 points above average of our use of the market maker mechanism may be the result of a too coarse introduction to it. A more detailed introduction should probably help in understanding it better in further applications. The rating of short selling (1.3 points towards too difficult) suggests that some participants did not completely understand its implications and that it might need to be introduced more thoroughly or that it might be favorable to omit short selling. To reduce sources of confusion with the market approach, we opted to omit short selling in applications of LDM with a predominantly novice audience. Overall, the functionalities were deemed appropriate to be employed in further studies, with a more detailed introduction to the market maker mechanism.

Virtual Market Model We investigated the impact of incentives on the trading behavior by providing two incentives. The first incentive aimed at encouraging sincere behavior whereas the second incentive targeted speculative behavior. Participants reported in the post-study survey to have been following both incentives to varying degrees. We determined speculative behavior by asking for the prediction of other's behavior and the creation of trends. 11 of the 18 survey participants reported at least one attempt to create a market trend, with 5 traders attempting this at least 3 times. The winner of the material reward also reported that he tried to predict the most likely winning ideas, that is, joining in a Keynesian beauty contest, in order to maximize his portfolio worth. However, the first incentive – the moral obligation to provide one's sincere opinion – was also respected by the participants. 67% of the participants ranked *personal belief* highest among the criteria that were relevant for their trading behavior. These results point to a mixture of trading behavior exhibited by the participants. In Section 3.5.2, we highlighted that maximizing one's portfolio worth in a decision market by engaging in a Keynesian beauty contest does not necessarily lead to the identification of the best decision option. Results from this case study indicated that participants responded to the provided incentives by corresponding trading behavior. Hence, the virtual market model seemed to properly model the impact of incentives on trading behavior. Therefore, it seemed worthwhile to further investigate the impact of incentives with respect to the achievement of a good decision.

6.2.2 The Laboratory Study

Case studies may be executed both in the field and in the laboratory. An execution in the field allows for a more realistic application of the subject in question in its intended surroundings whereas a laboratory allows for more control of factors that influence the behavior of participants [105]. For investigating the impact of the collaborative decision principle as well as the concept of market perturbations, we decided to execute this study in a laboratory [62]. In this way, we were able to explore the behavior of participants in the laboratory more closely as it allowed a better monitoring of the participants while at the same reducing external influences. Furthermore, we were able to gather direct feedback from all participants right after the laboratory sessions.

Objectives, Setup and Execution

Objectives The objectives of this case study focused on the market approach of LDM (RQ1), the virtual market model (RQ1, RQ3), the design principles (RQ1, RQ3), the concept of market perturbations (RQ1, RQ2), and the provided functionalities (RQ2). The collaborative decision principles stipulates that a collaborative setting should be favorable for the achievement of a good decision. To test the impact of the perceived settings, we framed the two decision making sessions differently to the participants. The introduction of the first session aimed at creating a competitive setting whereas for the second decision making session, a collaborative perception was targeted.

Setup The setup of the laboratory study was as follows. Two decision making sessions were held in the laboratory, each with one market round without discussion among the participants and one with discussions being allowed. The second round with discussion aimed at examining the interplay between face-to-face discussions and the market-based approach as well as for checking for reactions to the market perturbations. Participants for these two decision making sessions were recruited among students of the Ludwig-Maximilians-Universität München by means of a mailing list and an invitation during a university lecture. As the laboratory was equipped with 11 laptops, we randomly selected 11 students from the interested candidates. Each student was given a separate login.

For this laboratory study, the decision making situation was chosen from the aerospace domain. Due to the affiliation of the author, decision options and their characteristics were readily available for this domain. For the decision to be made, participants were to imagine to be members of a committee for choosing the most promising innovation from a list for further funding and research. The decision options referred to five future aircraft concepts, namely a box wing aircraft, a modular passenger container aircraft, a super sonic aircraft, a blended wing body aircraft, and an airship. LDM was used to determine the most promising concept. Participants were endowed with an amount of $5000 of virtual play money for trading and the prices of the decision options started at $50, following the MM mechanism. Rewards based on portfolio performance were not offered for not over-emphasizing competitive trading. Rather, the students received a small real money allowance for their participation.

Execution The two decision making sessions were executed as follows. After introducing the participants to the overall event, the task of making a joint decision using LDM was presented to them. Furthermore, the rationale of trading shares for indicating approval or dissent, the price mechanism of the market maker, and the interpretation of the resulting prices for the final ranking were explained. The participants were then given a walk-through of the LDM software, highlighting the functionalities and displayed information. The participants then traded in a test market for approximately ten minutes to familiarize themselves with LDM. In this test market, a different decision as well as decision options were used compared to the actual study market and participants were also given a separate budget that was not transferred to the study market. Then, the participants were presented with the actual decision to be made and the decision options. Written information on the decision options was provided for the students and they informed themselves on the decision options for about 15 minutes. Subsequently, participants completed a survey on their individual ranking of the single decision options. Then, the first market round was started with participants not being allowed to talk to each other. This market round lasted for about 20 minutes. The end of the market round was announced three minutes before the market was stopped. After a short pause, the market results as well as the budgets were reset and the second market round was started. In this second round, participants were allowed to talk to each other. The duration of this second round was also around 20 minutes, with the end having been announced three minutes earlier. After the two trading rounds, the participants completed a feedback survey. Overall, each decision making session lasted for about two hours.

We executed the market perturbations manually by monitoring the market status during each trading round and performing trading actions according to the steps highlighted in Section 3.9. For the execution of the market perturbations, we waited for about ten minutes for prices to form during the trading rounds. During the first trading round of session one, we executed two market perturbations for the decision option *Box Wing*, as highlighted in Figure 6.2. We chose the second highest decision option for checking the reactions of participants to a perturbation that did not involve the highest ranking decision option. In the second trading round of session one, the highest ranking decision option, *Blended Wing*, was chosen for market perturbations (see Figure 6.3). We executed the second market perturbation there to stimulate further trading. In the first trading round of session two, we executed two perturbation actions for the decision option *Box Wing* (see Figure 6.4). Lastly, in the second trading round of session two, we executed market perturbations for the two decision options *Blended Wing* and *Box Wing* as they were involved in a head-to-head race for the first rank.

Results and Discussion

The laboratory study had the objective of investigating the behavior of the participants in different market settings, the reactions of the participants to market perturbations, and the overall LDM approach. Seven students participated in the first trading session and ten students participated in the second trading session, with eleven candidates having been invited. Overall, lively trading formed in both trading sessions, joint decisions were identified from the view of the participants, and the market perturbations were successfully executed [62]. Also, the LDM software was well accepted. The following results are based on the post-market survey, using a Likert scale ranging from 1 (does not apply) to 5 (fully applies).

Market Approach Participants rated the market approach in the lab study was rated with a mean value of 4.1 for its suitability. They also perceived the market approach to have helped them in identifying the best innovation with a mean value of 4.1. The satisfaction with the market result was indicated with a mean value of 4.0. Participants rated the possibility for an independent and equal contribution of their opinions with a mean value of 4.0 and also liked the continuous nature with a mean value of 4.2. Furthermore, the immediate feedback by the price mechanism was highly valued with a mean value of 4.4.

Compared to the CREATE case study, the overall market approach has been rated with higher mean values in the laboratory study. In the lab study, participants were given a more thorough introduction to the market mechanism and they were able to trade in a test market prior to the actual decision market. Following the higher ratings, these measures may have served to create a better understanding of the overall market approach. This is likely also reflected in the better reception of the discerning market capabilities by the participants. Overall, participants accepted the market-based approach well.

Virtual Market Model and Design Principles An objective of the laboratory study was concerned with the impact of the incentives and of the perception of the decision making situation on the trading behavior. Therefore, the sessions were presented as a competitive and a collaborative settings, respectively. For determining the impact of these settings, participants were asked to rate the factors that influenced their trading behavior. For the competitive session, participants rated the influence of personal belief with a mean value of 4.1 and of portfolio maximization with a mean value of 4.4. In the collaborative session, participants indicated personal belief to be influential with a mean value of 4.2 and portfolio maximization to be influential with a mean value of 3.7. While the ratings of personal belief differ only by a value of 0.1, the ratings of portfolio maximization are lower for the collaborative session by a value of 0.7. These results suggest that in these two sessions, the different settings of the sessions may have favored different weightings of trading behavior among participants regarding the weighting of portfolio maximization. This points to the virtual market model appropriately modeling the impact of market design, especially incentives, on the trading behavior of participants. These findings also indicate that the collaborative decision principle contributes to the achievement of a good decision, that is, a decision based on sincere opinions.

Market Perturbations A second goal of the laboratory study was the examination of the approach of market perturbations. There, market perturbations were successfully employed in both trading sessions [62]. In each trading session, a stock was selected and artificially lowered in its price by means of an additional trader account. Considering the feedback at the end of the sessions, participants did not suspect the exogenous introduction of such artificial market dynamics. In trading round one of session one, we executed two market perturbations for the decision option Box Wing (see Figure 6.2). The first market perturbation put the decision option from the second rank to the bottom of the ranking. This perturbation was corrected by two traders about 10 seconds and 20 seconds later. They raised the perturbated decision option to the fourth rank. The second market perturbation again lowered the decision option to the bottom of the ranking. This was corrected by four traders within the next minute and the decision option ranked second again for a short period. However, the decision option finished the trading round on the fourth rank.

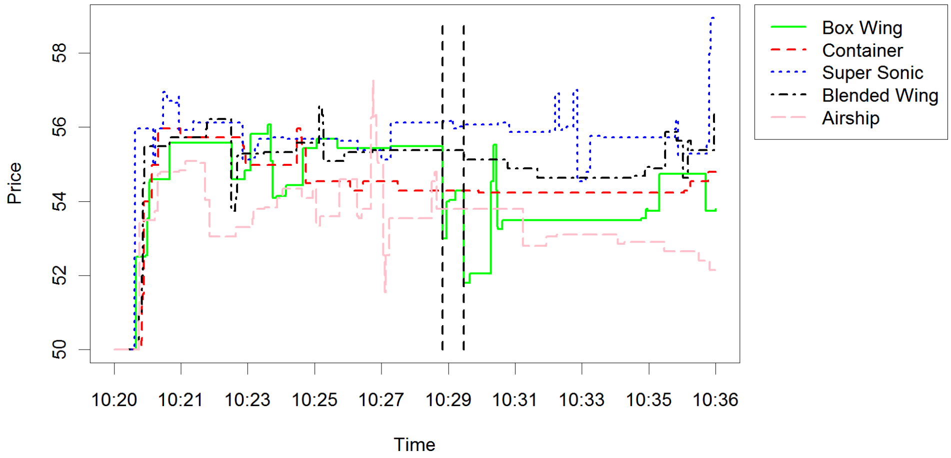


Figure 6.2: Price developments in the first trading round of session one. Market perturbations are highlighted by the vertical dashed lines.

First of all, it can be noted that further trading actions in the perturbated stock followed shortly after the extreme market perturbations. These trades are likely to have been reactions by the other traders as they seem to correct for both of the perturbations. In this trading round, discussion were not allowed among the participants. The only clues the participants had on the opinions of the others were their trading actions. Prior to the two market perturbations, the decision option Box Wing ranked second, afterwards it finished fourth in the trading round. This may have been due to not all participants having sincerely favored this decision option. This result suggests that market perturbations could have been able to uncover decision options that participants were not willing to vouch for. This missing support may have been due to them not trading based on their sincere opinions.

During the second trading round of session one, two market perturbations were executed for the decision option Blended Wing, as indicated in Figure 6.3. The first

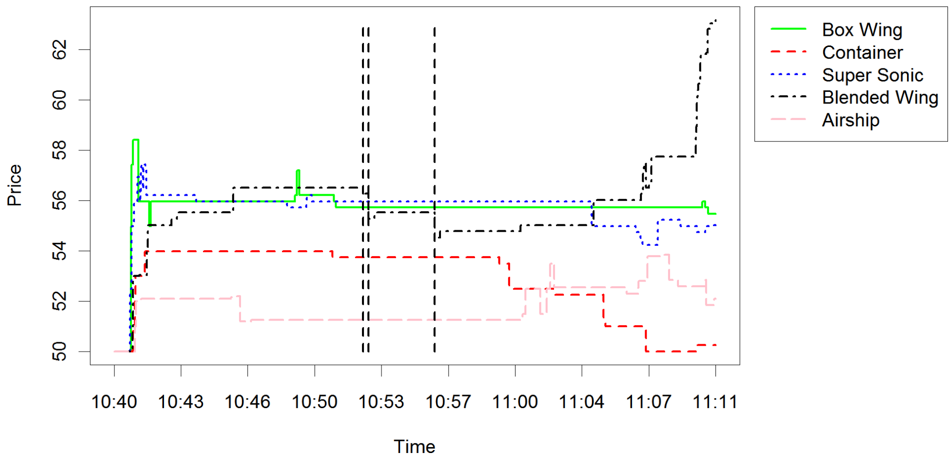


Figure 6.3: Price developments in the second trading round of session one [62]. Market perturbations are highlighted by the vertical dashed lines.

market perturbation consisted of two perturbation actions and lowered the decision option to the third rank. 20 seconds later, another trader raised this decision option but did not change its rank. As no further trades were executed during the next three minutes, we performed another market perturbation for the decision option Blended Wing to stimulate trading. This, however, had only a minor effect as only one participant made a small trade in the perturbated decision option right after the perturbation action, but did not change its rank. At the end of the trading round, the perturbated decision option finished first among the five options. Please note that in this trading round, discussions were allowed among participants. That is, participants were able to communicate their opinions directly and to strive for consensus in this way. The observation of the discussions of this trading round suggests that participants had formed sincere opinions on the decision option Blended Wing. The price development suggests that the participants were not swayed by the market perturbations. These results point to the ability of market perturbations to identify trading based on sincere opinions [62].

In the first trading round of laboratory session two, a head-to-head race emerged for the two decision options Box Wing and Blended Wing (see Figure 6.4). We executed a market perturbation for decision option Box Wing to influence this head-to-head race. As equilibria hardly occurred for these two decision options, we freely selected one decision option for perturbation. We lowered its price below the second highest decision option. Within 5 seconds after this market perturbation, another trader sold a large amount shares, further lowering the price of this decision option. 15 seconds later, three other traders started to correct the market perturbation. For the remainder of the trading round, the head-to-head race continued and the perturbated decision option Box Wing finally finished first.

In this trading round, participants seem to have favored both Box Wing and Blended Wing but were not able to reach a consensus using LDM. The market perturbation was also not able to resolve this head-to-head race. However, participants did mostly not follow the downtrend created by the market perturbation. This may have been the case

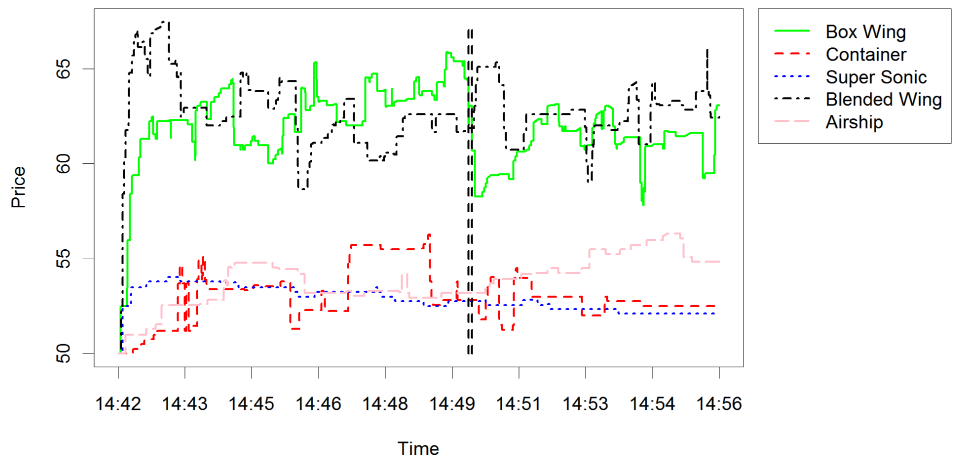


Figure 6.4: Price developments in the first trading round of session two [62]. Market perturbations are highlighted by the vertical dashed lines.

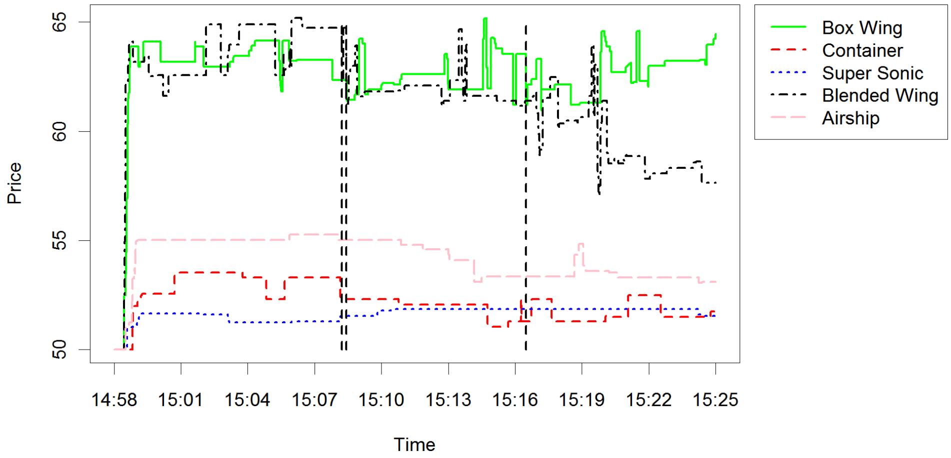


Figure 6.5: Price developments in the second trading round of session two. Market perturbations are highlighted by the vertical dashed lines.

because participants sincerely supported this stock. For this case, the results suggest that the market perturbation was able to point out this sincere trading [62].

During the second trading round of session two, the two decision options Blended Wing and Box Wing were both chosen for a market perturbation as there formed a head-to-head race (see Figure 6.5). The first market perturbation was executed for the decision option Blended Wing as it was the highest ranking stock then. After this first market perturbation, both top ranking decision options saw a short spike of increase in prices but remained lower for about four minutes. Then, the head-to-head race started again. We then selected the decision option Box Wing for a market perturbation as it prevailed in the head-to-head race for about five minutes. Almost immediately after this perturbation, the lowered price was corrected by another trader and the head-to-head race started once more. At session end, decision option Box Wing prevailed for about five minutes and also finished first.

As in the previous trading session, participants did not follow the downtrend that was started by the market perturbations. Rather, they again engaged in the head-to-head race. Discussions during the trading session indicated that both decision options were equally favored among the participants. This suggests that they formed sincere opinions on the options. In this case, the results suggest that the market perturbations could indicate these sincere opinions on the perturbated decision option. Participants agreed on decision option Box Wing in the discussions of this second trading round during the last five minutes. There, the head-to-head race stopped and the agreed-upon decision option rose while the other decision option was sold.

Looking at the trading actions of the participants in the two sessions, different trading patterns can be discerned. These patterns comprise buy-and-hold, head-to-head race and random. The buy-and-hold pattern is characterized by a relatively short buying phase at the beginning of the decision market and a subsequent hold phase without further trading. Participants exhibiting such a buy-and-hold pattern are not very likely to change their portfolio composition because of market perturbations. However, only one of the ten participants of session two followed this pattern which is highlighted in

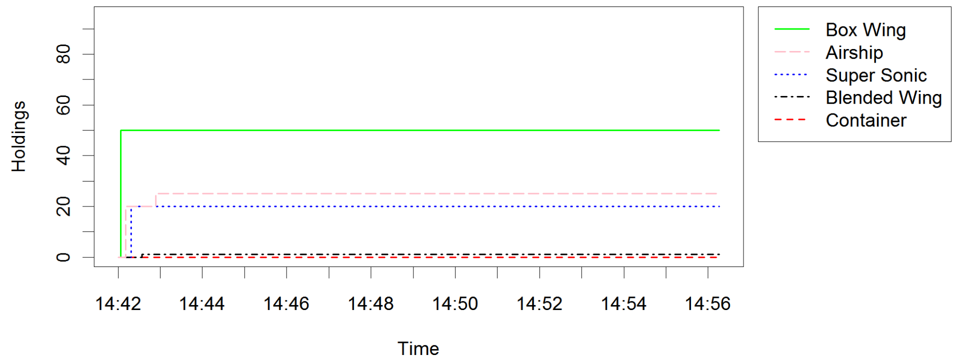


Figure 6.6: Buy-and-hold trading pattern

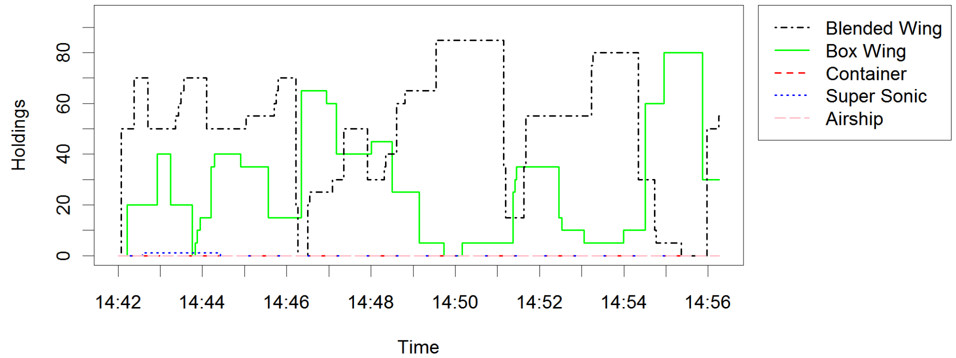


Figure 6.7: Head-to-head race trading pattern

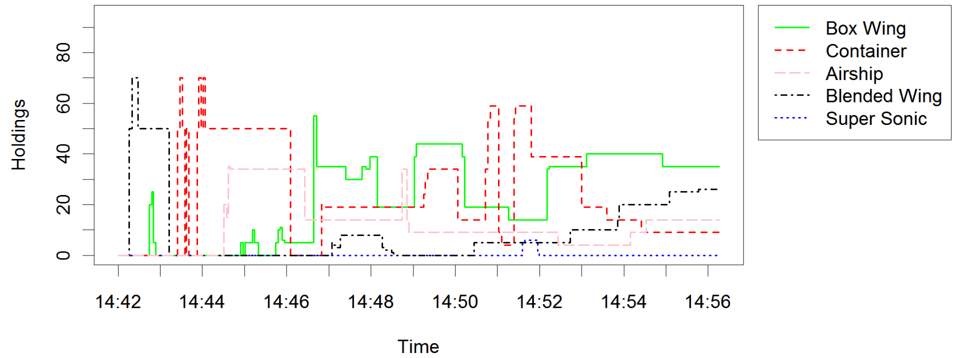


Figure 6.8: Random trading pattern

Figure 6.6. With the head-to-head race pattern, the respective participant heavily traded on his favored decision options in order to position them at the top of the decision option ranking. In Figure 6.7, the participant apparently has two favorites which he tries to support in turn. Two participants followed this pattern. Such participants should be more likely to follow a market perturbation. The random pattern refers to the fact that the trading behavior seems more random without knowing the exact favorite or goal of the respective participant. Figure 6.8 depicts such a random pattern. There, the trader finally holds most shares of his favorite, but also trades actively in other stocks. Market perturbations should be able to influence a sufficiently large portion of such traders.

Functionalities and Software Prototype The provided functionalities and the software prototype were also investigated in this case study [62]. Participants were provided with a price chart for following the price developments during the trading sessions. This price chart was rated with a mean value of 2.9 for its helpfulness in following the market situation. Furthermore, a dashboard provided participants with information on the current stock prices, the latest trading actions, and their respective share holdings. This dashboard was rated with a mean value of 4.1 for the suitability of the provided information. Overall, participants rated the software to be easy to use with a mean value of 4.9 and the page navigation to be intuitive with a mean value of 4.3. The slightly above average rating of the price chart (0.4 points) may be attributable to the utilized technology which reloaded price chart images using Asynchronous Javascript and XML (AJAX). This occasionally caused a flickering effect in the images. The relatively high levels of the other ratings point to the overall appropriateness of the provided functionality and of the software prototype.

Further Results In this laboratory study, further notable insights were gathered. Some participants clearly noticed a conflict of goals between maximizing one's portfolio worth and contributing one' sincere opinion in situations in which actions to achieve those goals differed. This was expressed during the trading sessions and in the subsequent feedback round. This pointed to the relevance of the collaborative decision principle as well as the user involvement principle for designing installments of LDM and it thus deemed worthwhile to investigate the design principles in further studies.

The two trading sessions both had two trading rounds each, one round without discussion and one round with discussion being allowed between the students. In the rounds with discussion being allowed, we noticed that the groups switched between two "modes" of activities multiple times. The first mode was concerned with trading in the decision options while the second mode related to the actual discussion activity. In the survey, participants reported their impression that the discussions influenced the market activities with a mean value of 4.0, but the reverse influence of the market on the discussion only with a mean value of 2.8. Some students perceived this influence of the direct discussion to be negative as it may impact the personal opinion and may lead to a market result that may be stronger aligned with the groups dominant opinion.

Figures 6.9 and 6.10 both highlight this switching between the two modes of activities. In these figures, the summarized available cash of all participants is shown with respect

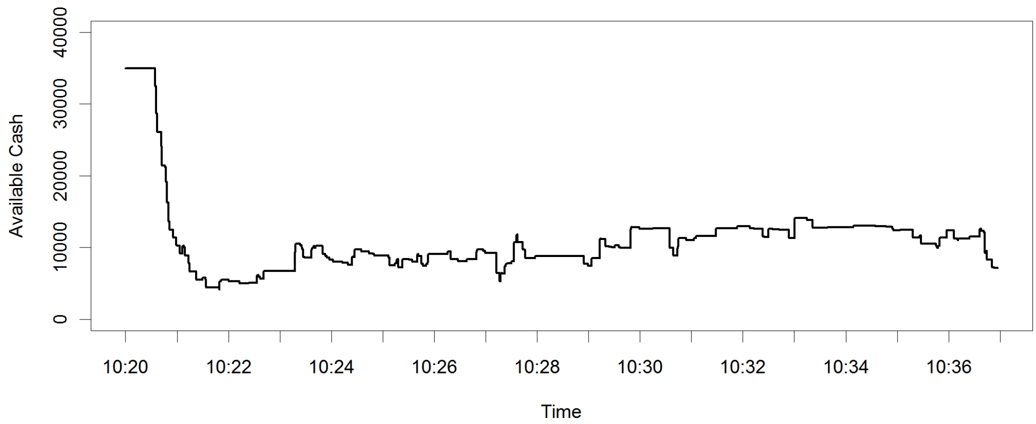


Figure 6.9: Development of the available cash without discussions allowed

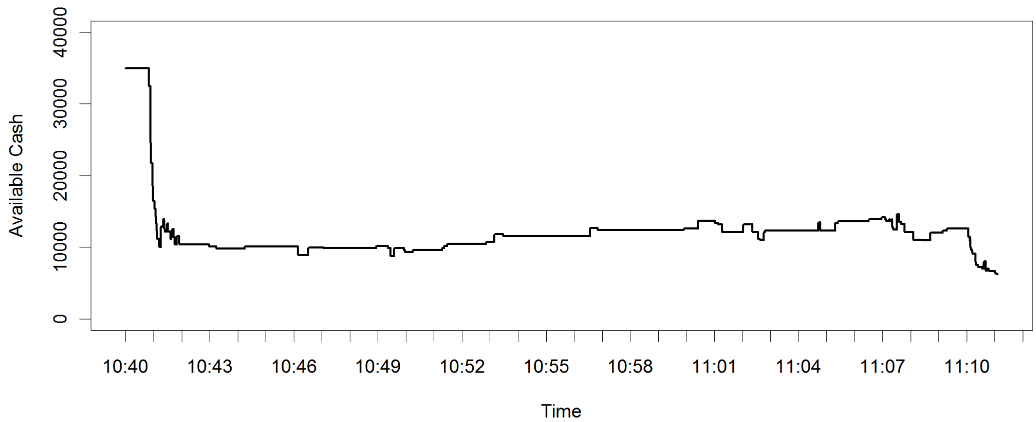


Figure 6.10: Development of the available cash with discussions allowed

to the trading time of the respective trading rounds. In Figure 6.9, the available cash of participants changes frequently, indicating an ongoing trading activity. In this first round of trading, no discussions were allowed. In contrast, Figure 6.10 shows longer phases without changes in available cash, indicating that participants did not trade during these phases. Apparently, participants ceased trading during these periods of active discussions. These results indicate that the suitability of the LDM approach for real-time and direct group meetings should be further investigated. However, this was not within the scope of this thesis.

6.2.3 The Bauhaus Luftfahrt Symposium Study

Bauhaus Luftfahrt is a public research institute with funding from the companies Airbus Group, IABG, Liebherr Aerospace, and MTU Aero Engines as well as from the Bavarian State. At Bauhaus Luftfahrt, the future of mobility and air transport is considered from different points of view. Annually, representatives of the funding partners gather with Bauhaus Luftfahrt in a meeting termed *symposium*. There, the representatives examine current research projects and coordinate future research topics together with the executives of Bauhaus Luftfahrt. In the course of these symposiums, research proposals are presented for consideration of future research. In this process of coordination, the heterogeneous views of the participants from the different companies need to be reconciled. LDM facilitates such a reconciliation of heterogeneous views from a large group of people. The annual symposium of Bauhaus Luftfahrt was therefore a good opportunity for presenting LDM and for executing it alongside the established process of proposal selection.

Objectives, Setup and Execution

The Bauhaus Luftfahrt symposium of the year 2012 was held at the premises of Bauhaus Luftfahrt. This provided us with the opportunity to test the LDM approach alongside the presentation and selection of the research proposals.

Objectives The objective of the Bauhaus Luftfahrt symposium study was to investigate the market approach of LDM for the selection of research proposals (RQ1), the virtual market model (RQ3), the devised design principles (RQ3), the impact of market perturbations (RQ1) on trading behavior, the validity of the identified application scenarios (RQ4), and the provided functionalities (RQ2).

Setup Approximately 40 people of the funding partners and of Bauhaus Luftfahrt participated in the symposium. They were invited to also participate in the LDM market exercise. For this market exercise, one decision was prepared for the participants. This decision corresponded to the ranking and selection of the most promising research topics. Participants were asked: "vote for the research topics that you recommend for further investigation at Bauhaus Luftfahrt." The decision options referred to the 21 research topics that were proposed by Bauhaus Luftfahrt from its different research disciplines. This list of decision options was not open for amendments during the market exercise as the objective of the symposium was to rank the proposals that had already been prepared.

In this installment of LDM, the design principles of this research were considered as follows. The collaborative decision principle emphasizes the collaborative nature of the decision making effort and of providing appropriate information. Therefore, we introduced the application of LDM to the selection of research topics to the participants as a collaborative effort. Furthermore, the LDM software provided an easily retrievable overview on the currently jointly chosen research topics. The design principle of user involvement facilitates a personal involvement of the participants in the finally chosen decision options, in this case, the research topics. While the standard selection process of Bauhaus Luftfahrt for the research proposals could not be replaced with the LDM approach, participants were notified that the market results would be presented at the end of the symposium and that the result could likely influence the involved stakeholders to a certain degree. The setting of the symposium study corresponded to Scenarios three and four of the identified application scenarios (see Table 3.3). The market result was deemed to influence the final decision, the participants had stakes in the outcome and the incentives were based on performance and contribution. As the Bauhaus Luftfahrt symposium lasted only for two days, the main medium of addressing the prospective participants was by word of mouth during opening sessions and breaks. We furthermore planned to execute market perturbations during the runtime of the market exercise. We scheduled the market perturbations for the second day as we wanted participants to get acquainted with the LDM approach on the first day and prices to develop undisturbed.

Execution The participants received individual logins in their welcome packages for access to LDM. LDM was accessible via three laptops that were provided in the lobby of Bauhaus Luftfahrt. Participants had an initial amount of $5000 of virtual play money at their disposal and prices started at $50 for each decision option. The money was not redeemable for real currency. The decision market was started at the beginning of the symposium. The general idea of market-based ranking of decision options, the functionalities of the LDM software, and their tasks were introduced to the participants in a presentation at the beginning of the symposium. The decision market was then open for trading for the two days of the symposium. For the second day of the symposium, participants were endowed with an additional amount of $5000 of virtual play money to encourage further trading in the decision options besides the other symposium activities.

We scheduled market perturbations for the second day of the symposium study, as highlighted in Figure 6.13. We executed the first market perturbation in the morning shortly after price equilibria had formed among the highest ranking stocks. The then highest ranking stock, *Hybrid-Electric Power Systems*, was perturbated with the goal of lowering the highest ranking stock below the second-highest stock. Another market perturbation was executed at midday when the then highest ranking stock, *Novel Gas Turbine Engine Cycles*, had been in equilibrium since morning. The goal there was also to lower the stock below the second-highest stock.

At the end of the symposium on the second day, the decision market was closed and the resulting ranking was presented to the participants of the symposium during the closing session. Feedback was gathered orally from the participants.

Results and Discussion

The symposium study had the objective of investigating the market approach of LDM, the provided functionalities, the design principles, the application scenarios, and the market perturbations. The symposium had 40 participants, 17 of these participants also logged in to the decision market for trading. Feedback on this application of LDM was gathered orally in the closing session of the symposium in which the market results were presented. Overall, the participants executed 313 trades during the two days of the symposium. The development of prices is depicted in Figure 6.11. As can be discerned in the figure, participants mostly traded during the breaks of the symposium.

Market Approach and Functionalities Overall, LDM was successfully applied to the decision making effort. On both days, participants made a reasonable number of trades, as it is summarized in Figure 6.12. Furthermore, the mapping of the research topics to the stocks as the decision options was reported as appropriate by the participants in the feedback session. Regarding functionalities, the MM mechanism of LDM entails a change in a stock price with every single trade that is executed. However, a given participant is not able to profit from price changes caused by his own trades. This causing of a price increase without the possibility of profiting from it was reported to be confusing by one participant of the symposium study. This phenomenon, however, is inherent with the selected MM mechanism. These results point to the overall adequacy of the market approach of LDM, but also highlight the need for a detailed introduction of participants to the MM mechanism of LDM.

Virtual Market Model and Design Principles The application of LDM was introduced to the symposium participants as a collaborative effort, following the collaborative decision principle. Furthermore, a notion of user involvement was generated by advising the participants on the potential impact of the selected research topics. The intention was to encourage participants to contribute their sincere opinions on the decision options. In the feedback session, participants reported to have traded according to their corporate background and, to a lesser degree, to their personal opinions. The collaborative decision principle and the user involvement principle were hence deemed to have been implemented fairly well by the overall setting of the market exercise. The LDM software also provided a ranking of the traders according to their portfolio worths. This ranking was reported by two participants to have incited their trading efforts to optimize their ranking position. These results indicate the importance of the collaborative decision principle and of the user involvement principle. The findings also point to the impact of incentives on trading behavior, as highlighted in the virtual market model. Furthermore, the results also indicate the requirement for a proper selection of the provided software features. Hence, software features that encourage competitive behavior such as the maximization of one's portfolio worth should be omitted for the benefit of sincere contributions.

Application Scenarios The setup of the symposium study corresponded to application scenarios three and four of the scenarios highlighted in Table 3.3. Scenario four was

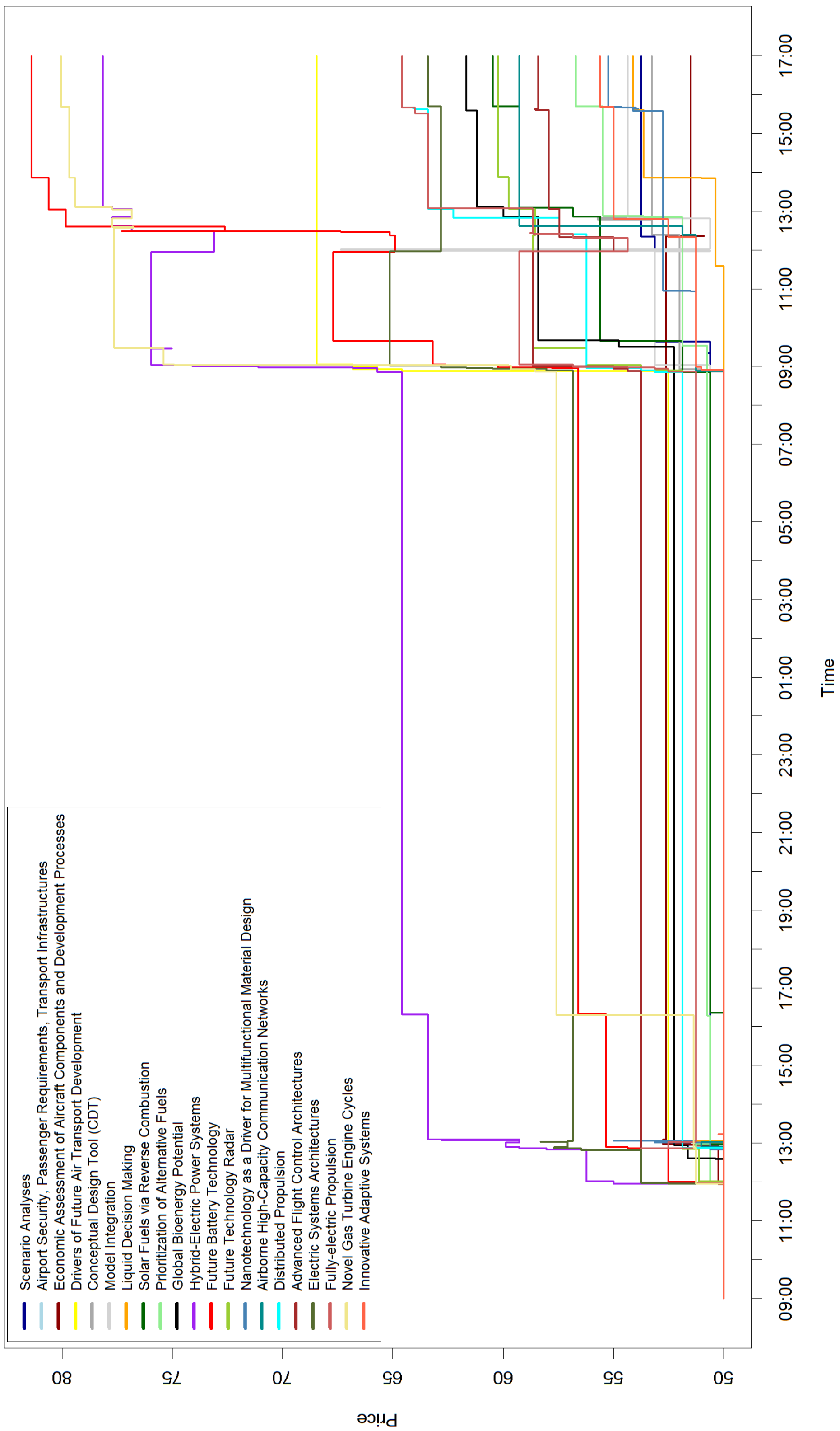


Figure 6.11: Development of prices during the symposium study

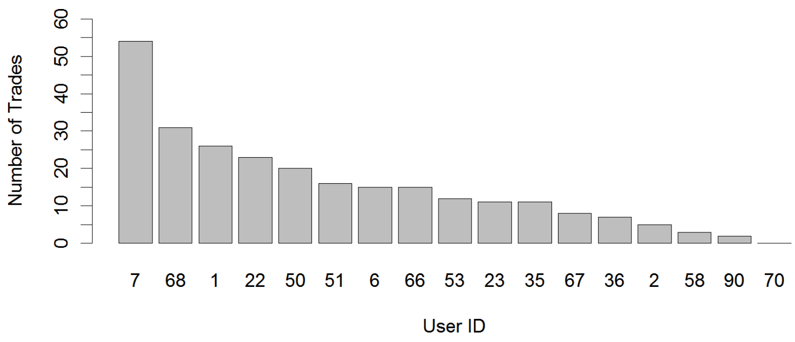


Figure 6.12: Distribution of the number of trades per user in the symposium study

identified as suitable for achieving a good decision as its influencing factors encourage the contribution of one's sincere opinion. This is also suggested by the findings of this study. In this study, incentives based on both performance and contribution were provided, corresponding to scenarios three and four. As highlighted above, performance-based incentives that encourage competitive behavior should be omitted as they bias sincere contributions. This corresponds to application scenario four which contribution-based incentive is deemed to be suitable for the achievement of a good decision.

Market Perturbations We executed two market perturbations during the second day of the symposium study. Both perturbations lowered the respectively highest ranking stock below the second highest stock (see Figure 6.13). According to the concept of market perturbations, traders were expected to react in trend-following and in trend-correcting ways. In the first perturbation situation, traders did not follow the initiated downtrend for the previously highest stock. Rather, the generated downtrend was corrected six minutes later by another trader. The correcting trader was the same trader who initially contributed to the highest rank of this stock. This points to this trader actually caring for this particular stock and its underlying topic. In this case, the perturbation and the following support for the stock can be interpreted to have uncovered a sincere support for the stock. However, the same trader also increased the second-highest stock soon afterwards. This suggests that the trader favored both stocks, but not their exact order.

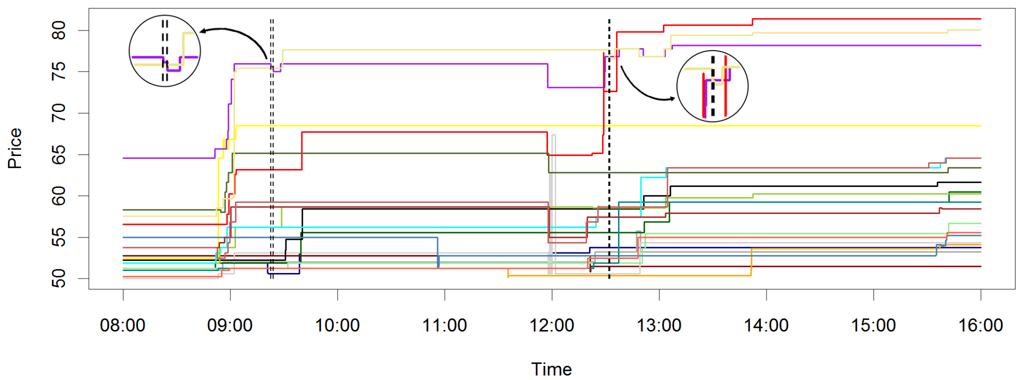


Figure 6.13: Market perturbations (indicated by the dashed lines) during the second day of the symposium study. The highest ranking stocks have been perturbated, respectively.

In the second perturbation situation, traders also did not follow the generated downtrend, but rather corrected it four minutes later. The correction was executed by the same trader as in the first perturbation. Shortly after this correction, however, another stock, *Future Battery Technology*, was increased by a different trader. There, the first trader did not take actions to increase his favored stocks beyond this new highest ranking stock. This is presumably the case because the first trader supported two stocks at the same time and had not enough remaining money for further trade actions. Participants reported to have been trading based mostly on their corporate background and their personal opinion. This is consistent with the results of the market perturbations as the perturbations did not induce trend-following behavior. These results suggest that market perturbations can be able to reveal trading behavior that is based on the outcome of a market, that is, on the contribution of one's sincere opinion.

6.2.4 The Scenario Building Study

The term *scenario building* refers to the development of possible future scenarios regarding a certain topic of interest [52]. The basis of this scenario building consists of factors that influence the setup of the resulting future scenarios. Hence, the methodology for scenario building focuses on the identification of the most influential factors and the generation of potential future scenarios based on these factors. A typical execution of a scenario building effort is as follows. Initially, factor candidates are identified that potentially influence the future of the topic of interest. From these identified factor candidates, the most important factors are selected regarding their uncertainty and impact. The more impact a factor has and the wider its range of possible values is, the more pronounced the resulting scenarios are likely to be. Basic scenarios are then built from the selected factors. Finally, consistent pictures of the future are formulated based on the basic scenarios.

During the building of such scenarios, one has to decide which factors to include in the development of the scenarios. This gathering and selection of factors typically takes some time to accomplish as relevant information on the topic at hand and potential factor candidates need to be collected. Furthermore, scenario building may also profit from the incorporation of multiple participants with different perspectives on the topic at hand. LDM has been devised as an approach for making decisions over longer periods of time and for the participation of multiple people. Hence, the applicability of LDM to scenario building should be worthwhile to investigate.

Objectives, Setup and Execution

This applicability of LDM to scenario building has been tested in a case study accompanying a two week university seminar on scenario building at the Technische Universität München [65]. This university seminar was concerned with the building of scenarios for a personalized mobility in the year 2050. Nine bachelor students participated in this seminar in partial fulfillment of their curriculum. The objective for the students was to learn the scenario building methodology and to utilize the methodology for determining potential scenarios for the future of personalized mobility.

Objectives The objective of this case study was to investigate the market approach of LDM for scenario building (RQ1), the virtual market model (RQ3), the suitability of the design principles for designing this installment of LDM (RQ3), the concept of market perturbations ((RQ1)), the identified application scenarios of LDM (RQ4), and the provided functionalities (RQ2).

Setup In this seminar, the LDM approach was combined with the scenario building methodology as follows. LDM was utilized for making decisions regarding the gathering, assessment and selection of the most influencing factors as an input for the building of the scenarios. The decision was: "which are the most influential factors?" The decision options were represented by the single factors. More specifically, the participants contributed their factor proposals using the proposal functionality of LDM and ranked the factors according to their supposed level of influence using the market functionality. Furthermore, the participants categorized the factors into the predefined categories of society, technology, environment, economy, politics, values, and air transport using the structuring mechanism as introduced in Section 4.4.5.

The design principles that were devised in this thesis (see Section 3.8) were realized as follows. The principle of a collaborative decision was implemented by omitting information on portfolio worths and user ranking based on this. Furthermore, the jointly selected factors were highlighted accordingly. In accordance with the user involvement principle, the decision to be made was chosen such that it carried meaning with it for the participants. That is, the participants had to utilize the selected influencing factors in the generation of their scenarios later on. Lastly, the dual incentives principle was realized by clearly stating the goals within the user interface of the LDM software and by offering up-to-date information to the participants.

Due to the utilization of the market metaphor in this scenario building effort, this application of LDM was termed *Szenario-Börse* (engl. scenario stock exchange) for this seminar. For this installment of LDM, virtual play money was utilized that was not redeemable for real currency. Each participant was endowed with an initial amount of \$10.000 of virtual play money upon registration and the prices of the decision options started at \$50. We furthermore planned to grant the participants another \$5000 at the beginning of the seminar, which was not announced to the participants beforehand. Anonymity was granted as participants were identifiable by others only by their individually selected user names. In previous installments of the scenario building seminar, participants gathered and selected factors over a period of two to three days during the seminar using a different approach. For LDM, however, we wanted the participants to have sufficient time for learning on the topic of future mobility, for gathering information, and for identifying potential factors as well as for forming their opinions using the Szenario-Börse. We therefore decided to open the Szenario-Börse three weeks prior to the scenario building seminar (see Figure 6.14). In addition to the nine bachelor students, we broadened the audience for the three week pre-seminar period to incorporate more diverse knowledge. To this end, we invited eleven additional people from the organizing institutions.

For the scenario building case study, we furthermore planned the execution of market perturbations. We subdivided the case study into three phases (see Figure 6.14). The

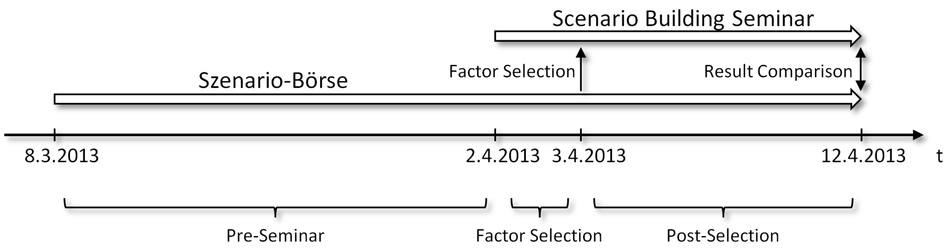


Figure 6.14: Integration of the Szenario-Börse with the scenario building seminar

pre-seminar phase comprised trading prior to the first trading session of the scenario building seminar, the factor selection phase referred to the time span from the beginning of the first seminar trading session to the end of the second trading session and the selection of the factors, and the post-selection phase lasted from the selection of the factors to the end of the scenario building case study. For each of these phases, we planned to perform at least one market perturbation.

Execution The Szenario-Börse was filled with an initial set of 12 factors. In this way, participants could start with ranking these factors right away and thus immediately learn to know the functionalities of LDM. All invited participants received a written tutorial to familiarize themselves with the market approach for decision making as utilized in LDM as well as with the functionalities provided by the LDM software prototype. The Szenario-Börse was then opened for trading three weeks prior to the begin of the seminar. The tasks of the participants have been to contribute additional factors to the existing initial list of factors, to rank the existing factors, and to categorize the factors as well as to make comments and to rate these comments for their helpfulness.

At the start of the actual scenario building seminar, the most influential factors had to be finally selected for the development of the scenarios. We therefore hosted two trading sessions for the nine bachelor students only as they had to work with the chosen factors. These trading sessions were executed on the 2nd and 3rd of April 2013, and lasted for about 45 minutes. We did not announce the exact end of each session but rather a time span to avoid last minute speculative behavior. The additional participants were no longer allowed to contribute. The students were granted an additional amount of $5000 of virtual play money to express their opinions in these two trading sessions. After the second trading sessions ended, the 10 most highly ranked factors were transferred to the subsequent scenario building. The decision market was still open for trading, but was no longer relevant for the selection of the factors. However, at the end of the scenario building seminar, LDM was employed in a third trading session for gathering the insights of participants on the actual relevance of the factors that they gained during the seminar. The overall insights and impressions of the single participants on the application of LDM to the scenario building effort were subsequently gathered in a user survey.

As highlighted in the setup of the case study, we scheduled market perturbations for each of the pre-seminar, factor selection, and post-selection phases of the scenario building case study. During the pre-seminar period, we executed one market perturbation on March 25th, 2013 (see Figure 6.16). We chose to wait for about two-thirds of that period for most participants to have traded at least once in the decision market.

There, *energy storage technologies* was the highest ranking stock and we thus lowered its price below the second highest stock at that time. For the factor selection period, we wanted participants to form a ranking of the factors during the first trading session without market perturbations. Thus, we chose to execute market perturbation during the second trading session as indicated in Figure 6.17. There, we executed three market perturbations. The first market perturbation involved the factor *size of global middle class*. This factor was then ranked in the lower half of the factor ranking and we wanted to check the impact of perturbating such a low ranking factor. The second market perturbation targeted the factor *median disposable income*. This market perturbation consisted of two perturbation actions for making it seem more natural to the other participants. There, we also lowered the highest ranking stock below the second highest stock. The third market perturbation was concerned with the factor *energy storage technologies*, as it was the highest ranking factor at that time. We also lowered its price below that of the second highest stock. The last two market perturbations were executed during the post-selection phase of the case study (see Figure 6.18). There, we performed the perturbations early on in the third trading session for giving participants enough time to react to the perturbations. We first selected *median disposable income* for perturbation as it was among the top ranking stocks and as we already had perturbated it previously. The second market perturbation then targeted the factor *energy price* as it was the highest ranking stock.

Results and Discussion

The market approach of LDM, the identified application scenarios, the design principles, the market perturbations, and the functionalities were in the focus of the scenario building case study. For evaluating these aspects, we conducted a user survey at the end of the scenario seminar among all participants. Basically, participants made a total of 1545 trades during the runtime of the market, with a maximum of 333 trades, a minimum of 3 trades, and a mean value of 71 trades. Ratings in the following refer to the Likert scale that was utilized in the user survey, ranging from 1 (does not apply) to 5 (fully applies).

Market Approach Overall, participants made use of the continuous nature of the LDM approach prior to the start of the seminar on April 2nd, as it is discernible in Figure 6.15. The capability for a continuous participation was also rated as advantageous with a mean value of 3.4. Please note that dedicated trading sessions were held during the seminar on April 2nd, 3rd, and 12th. Also, participants contributed 25 additional factors, 18 of which were accepted for trading. The organizer of the seminar judged the chosen factors to be relevant for the topic of future personal mobility and the produced scenarios to be very conclusive. Participants rated the factors immediately after the selection as valuable and reported their satisfaction with the factors with a mean value of 3.3 in the survey. Furthermore, the promptly price feedback of the market mechanism was rated to be useful with a mean value of 3.5.

The key characteristics of the market approach were rated slightly above average with mean values of 3.4, 3.3, and 3.5, respectively. While these ratings do not point to general impediments in the application of the market approach, they are slightly

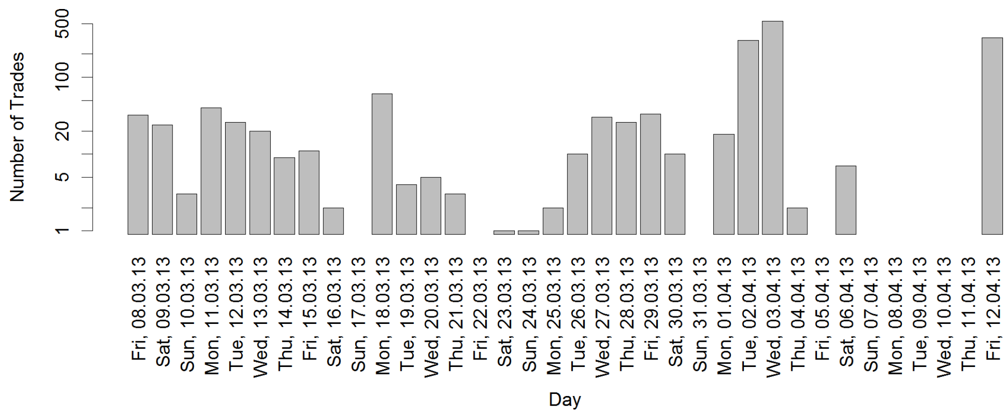


Figure 6.15: Number of trades per day during the scenario building study

lower than those in the lab study. These slightly lower ratings may be attributable to the application of the market approach during the actual scenario building seminar. During the seminar, participants had ample time to discuss the factor selection face-to-face. There, they may not have perceived the key characteristics of LDM to add value to the selection of the factors. Nevertheless, the students participated lively during the pre-seminar phase and during the seminar trading sessions. In the lab study, however, in two of the four trading sessions discussions were also allowed and participants nevertheless rated the market approach higher than in this study. It should therefore be worthwhile to further investigate the impact of face-to-face situations on the perceived utility of LDM.

LDM was furthermore applied as a structuring mechanism (see Section 4.4.5) for categorizing the factors into predefined categories. Participants could propose alternative categories for the factors and trade shares in the respective categorizations. The categorization with the highest price was considered as the valid categorization. In this categorization effort, only 7 trades were executed by the traders, without actually changing a given categorization. This low participation in the structuring mechanism does not necessarily mean that structuring using LDM does not work. Another plausible explanation is that participants rather accepted the predefined categories and did not consider it necessary to spend their money on this categorization. For further studies, the structuring mechanism should therefore be used for a more central aspect of the study.

Functionalities and Software Prototype Regarding the functionalities, we surveyed the helpfulness of the provided market dashboard and of the comments mechanism. Participants rated the information on the current stock prices, the latest trading actions, their share holdings, and the trends of their current share holdings to be helpful for following the market development with a mean value of 3.1. The comments mechanism was rated with a mean value of 2.8 for providing a means to learn on the insights of the other participants. Some participants also reported that they rather wanted to discuss the topics of the scenario building effort in person in the seminar sessions. Furthermore, participants reported the LDM software to be relatively easy to use (mean value of 3.1).

The slightly above rating of the functionalities provided in this case study can on the one hand be interpreted that there was no essential feature missing from the software. On the other hand, participants may have rated the functionalities only slightly above average because they missed some functionality or because the existing functionality had not been appealing to use. This would also be supported by the slightly above average rating of the ease-of-use of the overall LDM software. However, participants may also have been taking these features for granted for a market-based application and thus have rated them only slightly above average. It should therefore be interesting to investigate the fine-tuning of the provided functionalities as well as the impact of omitting one of these features on the rating of the participants.

The average rating of the comments mechanism together with the statements on preferring face-to-face communication can be interpreted that participants may prefer direct communication over the written form of the commenting system if the situation allows for it, for example in face-to-face meetings. The low commenting rate prior to the start of the scenario building seminar could have resulted from participants anticipating the possibility of a direct communication during the upcoming seminar and thus saving the comments for this face-to-face situation. The commenting system could be perceived to be more helpful if it is the only means for sharing information besides trading. It should therefore be worthwhile to investigate the use of the commenting system in a scenario without face-to-face meetings by the participants. Furthermore, more initiating comments by the organizers may also help to encourage participants to use the commenting system.

Application Scenarios In Section 3.6 we identified scenarios four and eight to be most suitable for achieving a good decision with LDM. The scenario building study corresponded to scenario eight, as the result of the decision market was directly utilized as the decision on the selected factors, as participants had stakes in the outcome of the decision market, and as the incentive objective could be set for the contribution of the participants' sincere opinions. The satisfaction of both the market participants and the market organizers with the market results highlights the success of this installment of LDM in the scenario building effort. This success points to the adequacy of the identified scenario 8 for achieving a good decision.

Virtual Market Model and Design Principles In accordance with the collaborative decision principle, LDM arranged for emphasizing the collaborative determination of the most influencing factors rather than the competition for the best individual market performance. The provided information in LDM was targeted at supporting this emphasis and was rated by the participants with a mean value of 3.1 for its relevancy for jointly determining the most influencing factors. Participants also commonly accepted the chosen factors after the selection step as the further input for the scenario building. The common acceptance of the chosen factors can be interpreted that participants did not purely trade following gambling and speculation or that they did not care for the factors and would have accepted any selection of them. However, the latter seems more unlikely as they had to work with the factors afterwards, that is, they had stakes in the outcome.

The user involvement was implemented in that the bachelor students had to work with the factors that they selected with LDM. As the students were interested in producing reasonable scenarios as a result of the seminar, they had a personal interest in selecting the proper factors using LDM. The students rated this resulting personal involvement to have been a motivation for their trading actions with a mean value of 3.2 in the user survey. At the end of the seminar, a third trading session was held for gathering the experience of the students with the factors and their relevance for the scenario building. However, the result of this third trading session had no influence on the generated scenarios. Hence, user involvement was no longer established in this trading session. Accordingly, the students reported in the user survey that they were more drawn to gambling and portfolio optimization in this third trading session. This points to the importance of the user involvement principle for achieving good decisions when using LDM. Likewise, these results suggest that the virtual market model adequately depicts the impact of the market design on the trading behavior of the participants.

Participants in a decision making effort need to be attracted and retained during the runtime of the effort. Thus, in compliance with the dual incentives principle, different incentives were provided. First, a meaningful decision was provided as the students had to utilize the chosen factors. Second, the LDM system provided up-to-date information to the participants in both a pull and push fashion. Participants rated this as an incentive to participate with a mean value of 3.3 and they rated the promptly price feedback with a mean value of 3.3. Over the pre-seminar period, participants repeatedly traded in the market (see Figure 6.15). While participants had stakes in determining the most influencing factors, the slightly above rating of the provided up-to-date information suggested that the repeated participation should in part also be attributable to the second part of the dual incentives, namely the up-to-date information. Hence, the dual incentives principle was deemed to have been successfully realized in this case study.

Market Perturbations Market perturbations were also investigated in the scenario building case study [65]. We executed market perturbations during the pre-seminar, factor selection, and post-selection phases. During the pre-seminar phase, we perturbated the then highest ranking factor, *energy storage technologies*, by lowering its price below the second highest stock, as indicated in Figure 6.16. Subsequently to this perturbation, two notable trading events occurred. After approximately three and a half hours later, another trader sold a large amount of shares of the then highest factor, *people's trust in automated systems*. For the remainder of this trading phase, this stock remained in the middle of the factor ranking. Another two hours later, two different traders increased the initially perturbated factor, *energy storage technologies*, above its previous, non-perturbated level. The perturbation of the stock *energy storage technologies* caused its price to fall and its trend to point downward. This trend was also displayed to the traders in their dashboard. The restoring of the perturbated factor to previous and even higher levels suggests that the traders regarded this factor to be important for the scenario building effort and thus supported it by trading accordingly. This may have been caused by the down trend created by the preceding perturbation. This points to the ability of market perturbations to encourage and uncover trading based on sincere opinions. The large sale of shares of the factor *people's trust in automated systems* in contrast should only be partially attributable to the preceding market perturbation. Rather, this trader might have wanted to cash in on this stock for some money for further trades in other stocks.

The factor selection phase saw three market perturbations. The first market perturbation of this phase concerned the factor *size of global middle class*. With this relatively low ranking factor, we wanted to check the reactions of the participants to market perturbations at the lower end of the factor ranking. Following this market perturbation, two different traders both sold shares of this stock, following the downtrend that was just created by this market perturbation. For the rest of the scenario building case study, this stock remained at the resulting lower ranking. There, the perturbations may have caused the traders to sell their shares in this stock, possibly not to loose money from the downtrend. This points to the ability of market perturbations to identify stocks that the traders are not really convinced of.

The next market perturbations were executed in the factor selection phase, as indicated in Figure 6.17 by the vertical dashed lines. First, we lowered the factor *median disposable income* below the second highest factor. Shortly after this market perturbation, three distinct trading actions were observable. After about 30 seconds, the factor *energy price* was raised to the top of the factor ranking. Another 20 seconds later, the factor *energy storage technologies* was raised to the top of the ranking. About 15 seconds later, the perturbated factor, *median disposable income*, was subject to multiple buy and sell trades, and ranked lower for about 3 minutes. However, it was then raised to the second rank. Towards the end of the trading phase, it ended up on 5th rank overall. The third market perturbation of this phase targeted the factor *energy storage technologies*. Following this market perturbation, the factor *individualization in mobility* was raised above the perturbated factor for a short period. Then, both factors were subsequently lowered and again raised in their prices. Towards the end of this trading phase, none of the top ranking factors had been significantly impacted by the market perturbations. This resilience to market perturbations may have been caused by the traders actually being convinced of these factors. This in turn points to the ability of market perturbations to identify trading based on sincere opinions.

In the post-selection phase, we executed two market perturbations (see Figure 6.18). The first market perturbation concerned the factor *median disposable income*. This factor was not the highest ranking factor at that time but had already been perturbated before. In the two minutes after this perturbation, three distinct traders sold shares of this factor. Ten minutes later, the market perturbation was corrected in part, but the factor remained at a lower rank until the end of the case study. In the post-selection phase, user involvement was no longer given as the factors had already been selected for the scenario building. Participants also reported in the survey that they traded more based on their estimated portfolio worths. The traders following the downtrend may have been influenced by the missing user involvement and by the market perturbation so as to sell their shares of the perturbated factor. This points to the ability of market perturbations to uncover maximization efforts, that is, trading that is not based on sincere opinions.

The second market perturbation targeted the factor *energy price*. This was the highest ranking factor at that time and it was lowered below the second highest factor. About 20 seconds later, the second highest factor, *individualization in mobility*, was also lowered by another trader, effectively restoring the previous order of the two factors. This did then not change until the end of the case study. In this case, traders did not follow the downtrend initiated by that market perturbation. There, participants may have actually been convinced of this factor, or the market perturbation was simply not strong enough to incite selling actions in the traders.

In conclusion, we observed both buying and selling actions in the face of falling prices. This suggests that both kinds of trading actions follow market perturbations, as presumed in Table 3.5. In the scenario building case study, buying actions mostly followed market perturbations of top ranking stocks during the first two phases with user involvement. Selling actions were observed following the perturbation of lower ranking stocks and for stocks in the last trading phase without distinct user involvement. According to our concept of market perturbations, buying actions are interpreted as support for a decision option, whereas selling actions are regarded as the avoidance of losses (see Table 3.6). These results point to the ability of market perturbations to tell trading intentions of participants apart as introduced in Section 3.9.

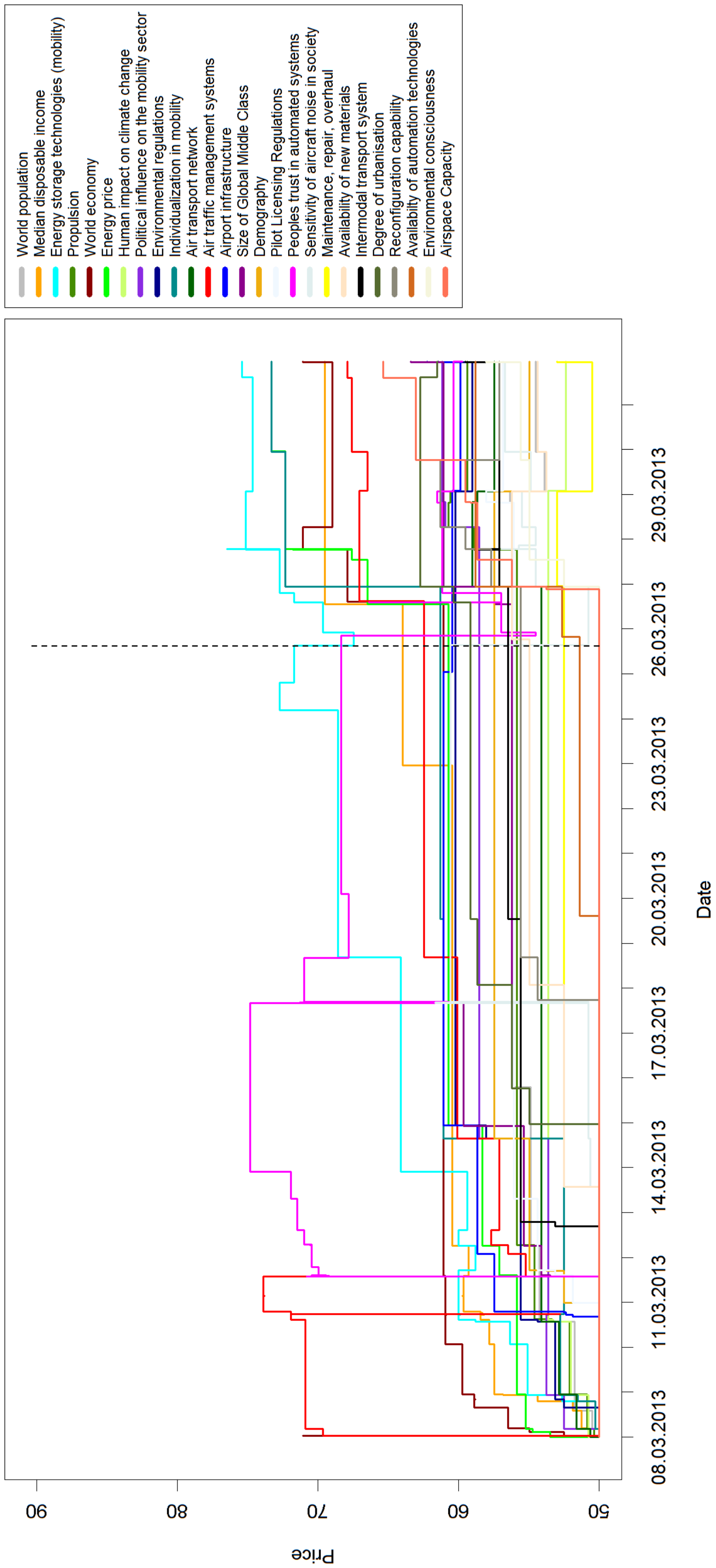


Figure 6.16: Price development during the pre-seminar period of the scenario building study. Market perturbations are indicated by the dashed vertical lines.

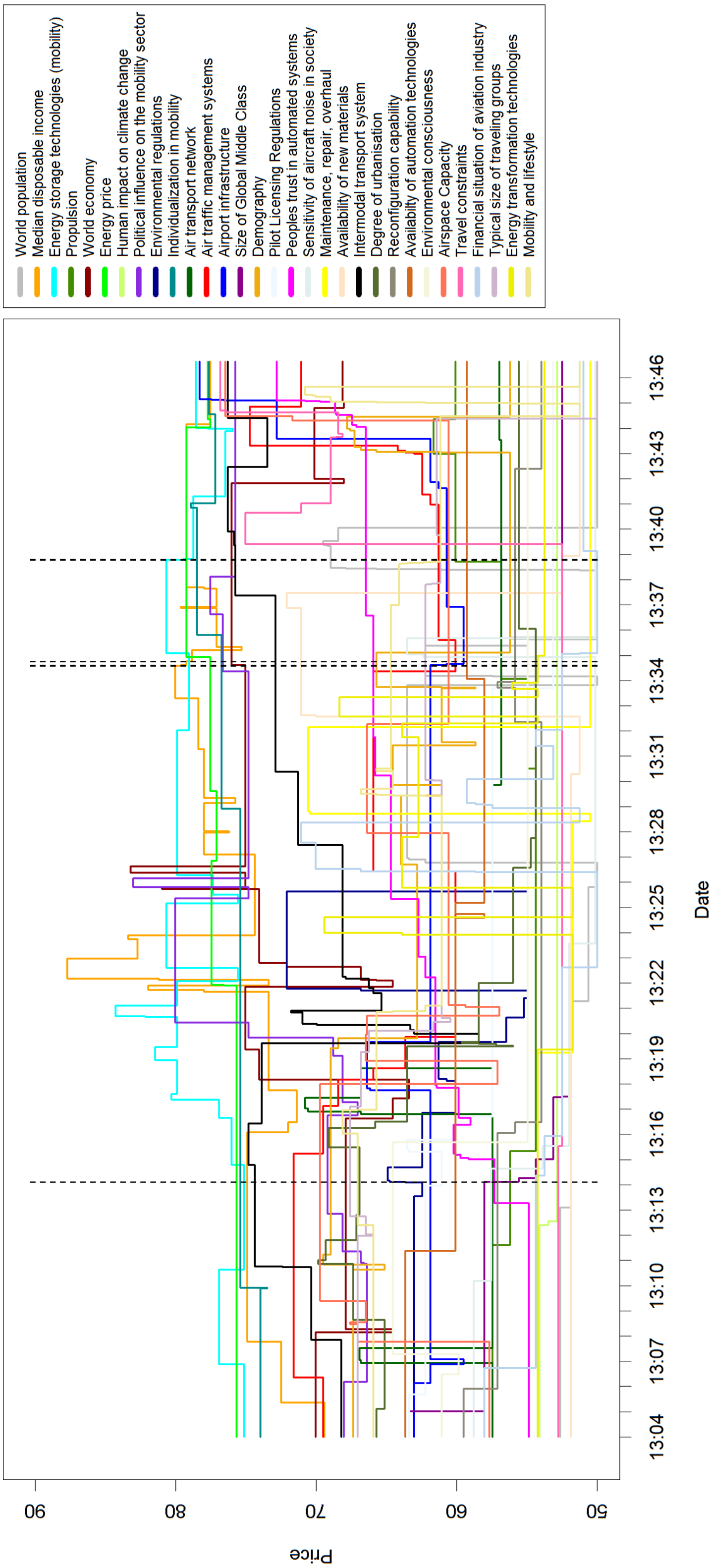


Figure 6.17: Price development during the second trading session of the scenario building study. Market perturbations are indicated by the dashed vertical lines.

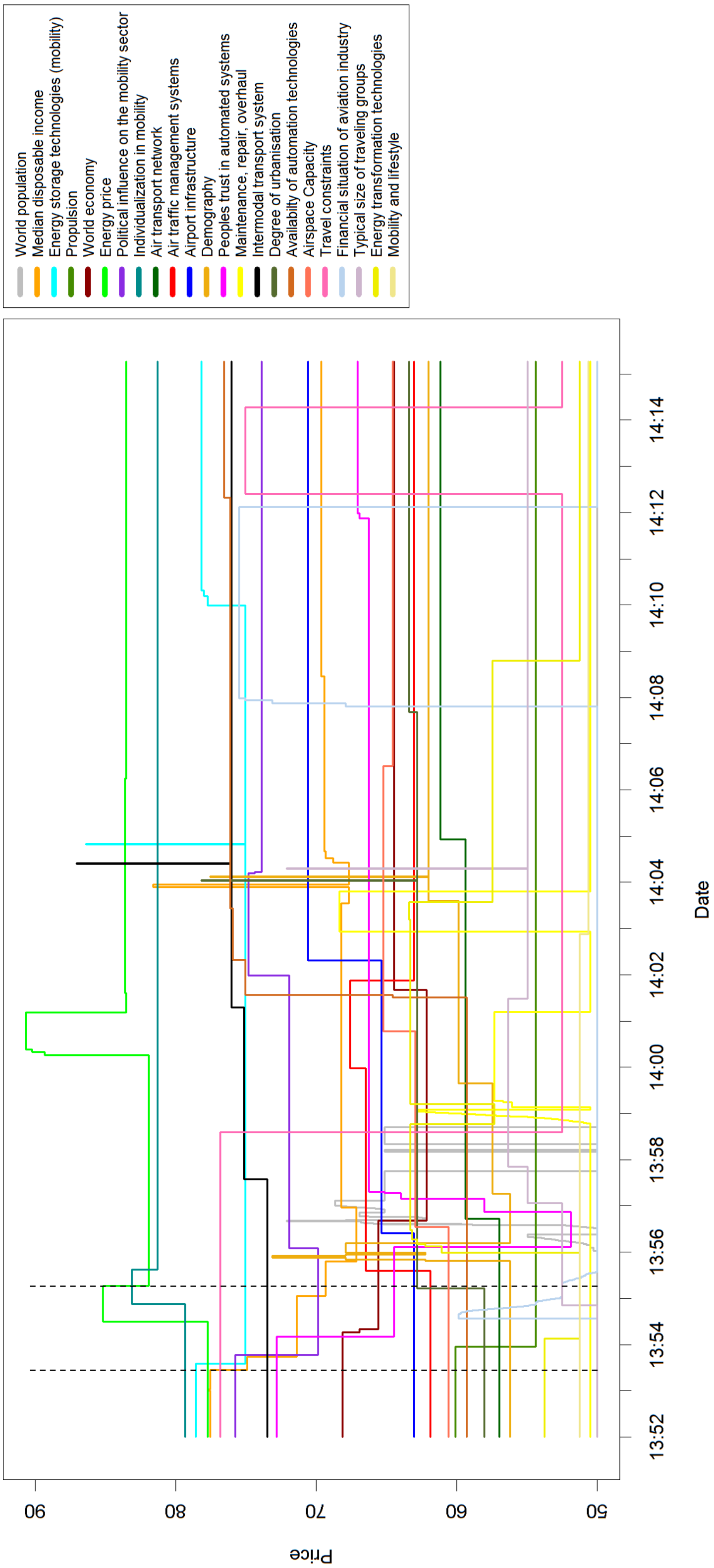


Figure 6.18: Price development during the third trading session of the scenario building study. Market perturbations are indicated by the dashed vertical lines.

Part III

Conclusion

CHAPTER 7

Conclusion and Outlook

In this thesis, we investigated the application of the market metaphor to group decision making. We developed LDM, a market-based approach for decision making and investigated its suitability in case studies. In the following, we summarize the findings of our research, point to further research directions, and provide perspectives on related fields of research.

7.1 Summary

Decision making can benefit from the participation of a large and heterogeneous group of people as they provide different perspectives, background knowledge, and evaluation criteria. The assessments of these people have to be gathered and aggregated in order to form a joint decision. The market metaphor is commonly attributed with the capability of gathering dispersed information from people and aggregating it in an intuitive indicator, the price. In its application to forecasting future events, the market metaphor has been shown to effectively gather individual forecasts from several people and to produce an accurate joint forecast. The main enabler of this capability is the reward that can be provided to participants based on their forecasting accuracy. However, forecasting accuracy is not sought for and cannot serve as a basis for reward in decision making, as the decision has yet to be made. Rather, for a good decision, people should contribute their sincere opinions on the available decision options. We presented LDM in this thesis, a market-based approach for making decisions in large and heterogeneous groups of people. The goal of LDM is to enable the achievement of a good decision in market-based group decision making. In the following, we highlight the contributions of this work, review the research questions that guided the development of LDM, and conclude on the findings of this work.

7.1.1 The Liquid Decision Making Approach

The LDM approach for making decisions in large and heterogeneous groups of people comprises its foundations, the system concept, and the software prototype. In the following, we briefly highlight these components.

Foundations

Market Approach Markets are attributed with the capability of gathering information from a large group of people and of aggregating it into a single indicator, the price. For utilizing this capability for decision making, we determined the correspondence between the elements of decision making and the market metaphor in our market approach. A decision is associated with a market and a decision option corresponds to a stock of that market.

Virtual Market Model The trading behavior of the participants impacts the result of a decision market. We devised the virtual market model for understanding the relationship between the factors of market design and application scenario, the trading behavior of the participants and the market result. This virtual market model forms the basis for the following considerations on the design principles, market perturbations, and application scenarios.

Design Principles We devised the design principles of a collaborative decision, of user involvement, and of dual incentives as design guidelines for installments of LDM. The goal is to guide the behavior of participants towards the achievement of a good decision. The results of the case studies suggest that these design principles are appropriate for that purpose.

Market Perturbations As participants may behave detrimental to the achievement of a good decision, we developed the concept of market perturbations. Market perturbations are targeted to identify the trading intentions of participants. Findings of the case studies suggest that market perturbations pose a promising approach to this end.

Application Scenarios Some application scenarios may be more suitable for achieving a good decision with LDM than others. We identified two scenarios that should be most suitable for LDM based on the factors of result utilization, stakes, and incentive objectives. The results of the case studies point to the suitability of these scenarios.

Application Steps For employing LDM in a given decision making effort, certain steps have to be taken during the setup of LDM. The devised steps of selection, preparation, execution, and evaluation were deemed appropriate based on the findings of the case studies.

System Concept

Conceptual Architecture For understanding how the single parts of decision making based on the market metaphor build upon one another, we devised the conceptual architecture of LDM. It includes the market metaphor, its ranking capability, and decision making. It furthermore highlights potential application domains of the LDM approach such as the scenario building and taxonomy development.

Functionalities Decision making based on the market metaphor requires appropriate functionalities for the participants. We identified such functionalities for LDM in the categories of decision making, market trading, user handling, information exchange, and market perturbations. The results of the case studies suggest that the functionalities are appropriate for a market-based decision making approach.

Software Prototype

LDM also comprises a web-based software prototype. In this software prototype, we implemented functionalities of the aforementioned categories of decision making, market trading, user handling, information exchange, and market perturbations. The findings of the case studies point to the overall usability of the software prototype and the appropriateness of the implementation of the functionalities.

7.1.2 Revisiting the Research Questions

We devised four research questions to investigate the application of the market metaphor to group decision making. These questions concern the utilization of the market metaphor for group decision making, the functionalities as well as incentives that should be provided to users, and suitable application scenarios. We executed four case studies to investigate these research questions. In the following, we summarize our findings.

RQ 1: How can the market metaphor be applied to group decision making? The market metaphor allows for the aggregation of information from a large and heterogeneous group of people. Based on the considerations for devising LDM and on its evaluation in case studies, the market metaphor can be applied to decision making by

- employing the devised correspondence between the elements of the market metaphor and of decision making,
- determining the desired behavior of participants,
- following the devised design principles in the design of the LDM installment, and by
- potentially employing market perturbations.

For the first research question, we conclude that the chosen correspondence between the market metaphor and a pending decision, the devised design principles, and the concept of market perturbations provide a promising framework for applying the market metaphor to decision making.

RQ 2: Which functionalities are appropriate for market-based group decision making? A tool for supporting market-based group decision making has to provide certain functionalities to facilitate such decision making efforts. In this thesis, we identified a set of functionalities for the LDM system that is appropriate for group decision making efforts. Market perturbations were furthermore deemed valuable for identifying the trading intentions of participants. We therefore include market perturbations into the following list of functionalities. We categorize the appropriate functionalities for LDM into

- decision making,
- market trading,
- user handling,
- information exchange, and
- market perturbation functionalities.

These functionalities were deemed appropriate by the participants for making joint decisions in the executed case studies. Thus, we conclude that the aforementioned functionalities contribute to a successful application of LDM in a decision making effort.

RQ 3: Which incentives encourage the contribution of sincere opinions by participants? Incentives motivate people to engage in a certain effort. These incentives should encourage behavior that is beneficial for the goal of the respective effort. For the LDM approach, the goal is to achieve a decision that is predominantly based on the sincere opinions of the participants. Inaptly selected incentives may encourage participants to engage in trading actions that are not based on sincere opinions. An example for such inapt incentives is rewarding the maximization of one's portfolio worth. There, participants are likely to strive for maximizing their portfolio worth rather than contributing their sincere opinions on the decision at hand. Such incentives should be able to encourage the contribution of sincere opinions that

- de-emphasize competition among participants,
- focus on the joint achievement of a good decision, and that
- involve the participants in the final decision.

Findings of the case studies suggest that incentives following these properties can encourage participants to contribute their sincere opinions. The design principles provide useful guidance in the design of such incentives. We conclude that those incentives are feasible which encourage participants to contribute their sincere opinions on the single decision options.

RQ 4: Which scenarios favor the achievement of a decision that is predominantly based on sincere opinions? Some decision making scenarios are likely to be more suitable for the market-based approach of LDM than others. In this thesis, we identified the three factors of result utilization, participants' stakes in the outcome, and the objectives of the incentives to be relevant to determine the suitability of a given decision making scenario for the LDM approach. Based on the scenario considerations presented in Section 3.6, we identified two scenarios to be most suitable for the LDM approach. These most suitable scenarios are characterized by

- a direct or at least supportive usage of the market result in making the decision,

- the existence of stakes on the side of the participants in the pending decision, and
- the possibility to base incentives on contributions, not market performance.

The findings of the case studies point to the adequacy of the identified factors and the suitability of the determined scenarios.

7.1.3 Conclusion

In this thesis, we presented LDM, our market-based approach for group decision making. We identified the following prerequisites for the achievement of a good decision with LDM.

1. The organizer is interested in the sincere opinions of the participants.
2. Participants have stakes in the decision outcome.
3. Incentives for participation and for trading are based on these stakes.
4. Participants perceive the situation as a collaborative rather than a competitive effort.

The following important aspects should hence be considered prior to an installment of LDM for market-based group decision making.

1. Design the incentives properly for encouraging beneficial behavior.
2. Introduce the workings of the market metaphor concisely.
3. Provide appropriate functionality in the market system.

Based on the findings of these case studies, we conclude that the consideration of these aspects makes LDM a promising approach for large and heterogeneous groups of people to make good decisions in the identified scenarios.

7.2 Future Work

In this thesis, we provided LDM and its foundations for market-based decision making, devised design principles for ensuring a good decision, conceived market perturbations for determining the motivations of participants, implemented selected functionalities in our LDM system, and identified suitable scenarios for applying LDM. We envision future work in this area in the directions of further application scenarios and additional functionalities as well as of the foundation and empirical examinations. In the following, we highlight some interesting topics for these directions.

Functionalities and Applications

User Interface Design The different functionalities of LDM are presented to the participants in the respective user interface elements of the software prototype. In the current version of LDM, these elements have been arranged based on simple considerations concerning the main information on the decision and decision options and supplementary information on, for example, the remaining cash or the user currently logged in. Seuken et al. investigate the impact of variations in user interface design on the behavior of participants in economic situations [86]. Such user interface design variations should be interesting to investigate for LDM with respect to their impact on the trading behavior of the participants.

Reputation System The design principles of LDM aim at increasing the engagement of participants with the decision at hand and with the decision making system. Besides the market trading functionalities, LDM currently provides a commenting and rating mechanism for contributing one's insights on the decisions and their options as well as for rating the helpfulness of the comments of others. This functionality may be further extended towards a comprehensive reputation system. Such reputation systems allow their users to create and maintain a reputation as a competent trader among their fellow participants [79]. Striving for such a good reputation may on the one hand increase participation and on the other hand support the contribution of sincere opinions, in line with the goals of the devised design principles. We furthermore highlight in this thesis that rewards based on portfolio performance are likely to bias the achievement of a good decision. It should therefore be interesting to evaluate the impact of rewards that are not related to the portfolio performance of participants. Different metrics will be required for determining such rewards, for example the number of logins, the rated quality of contributed insights, and others.

Automated Perturbation Processing Currently, the LDM system provides for the manual execution of the market perturbations that have been devised in this thesis. The accompanying perturbation process may be automated, for example for large-scale applications that make it difficult to monitor all market activities manually. The decision markets of LDM produce a continuous stream of trading events. Such event streams lend themselves to the treatment with stream processing approaches. Such stream processing approaches allow for the definition of events, conditions, and actions in so called *rules*. These rules are then matched against the event stream and the corresponding actions are executed. Market perturbations could be formulated using such rules in a suitable language such as XchangeEQ [29] and then be evaluated against the incoming trading events.

Ontology Development In this thesis, we presented a simple approach for using LDM for the structuring of topics in taxonomies. There, for each topic at most one association is allowed for a valid structure. That is, for each topic one decision is to be made on which association to accept to form a valid structure. This single decision for each topic can readily be made using the current decision market approach of LDM. Another common approach for structuring topics refers to ontologies. There, a single topic may have several different associations to other topics at once pertaining to different types of relationships. Approaches for building such ontologies collaboratively have already been considered [73]. As LDM is targeted at making decisions in large groups of people, it should be interesting to investigate the general suitability of this approach as well as the modifications that are required for LDM to support such ontology development in groups.

Foundation and Evaluation

Extension of the Virtual Market Model According to the market model introduced in Section 3.3, the design of the virtual market and the respective application scenario impact the trading behavior of the participants and lastly the market result. For future work, it should be interesting to explore further influencing factors for this market model and the behavior of participants. In this thesis, we assume that participants act myopically, that is, for determining their next trading action they only look ahead one trading step at a time (see Section 3.3.3). Participants in virtual markets may, however, also behave strategically. Rothschild and Sethi investigate trading strategies in prediction markets for presidential elections, for example [83]. That is, participants may strategically plan several trading actions in advance, potentially including some trading actions that may, taken in isolation, contradict their overall goal or that may be designed to mislead others.

Further Studies In this research, we investigated the general applicability of the market metaphor to decision making, the appropriateness of the provided functionalities, the adequacy of the design principles, the impact of market perturbations, and the suitability of certain application scenarios in case studies. These aspects were evaluated based on user surveys that were performed at the end of the respective studies. For the further development of the LDM approach, more detailed insights on these aspects should be gathered in further, more controlled, studies. There, the impact of the variation of a single design variable could be determined more clearly, with all other variables kept the same. For the design principles, it should be interesting to investigate the impact of different levels of involvement on the trading behavior in an otherwise equal decision making situation. Regarding the concept of market perturbations, their frequency and their intensity lend themselves for design variables. There, the impact of the frequency and intensity of market perturbations on the trading behavior of participants could be evaluated for example with respect to the general trading activity, the number of participants, and the number of stocks. As highlighted above, the impact of user interface design variations and of additional functionalities should be interesting to examine in controlled studies.

7.3 Outlook

The LDM approach targets decision making efforts that involve a large group of people and that take a longer period of time for gathering the required information and for expanding one's knowledge on the decision topic at hand. Participants then trade in the decision markets based on this knowledge. That is, participants individually acquire knowledge for making their trading decisions and contribute this knowledge in a condensed form as trading actions to the market. Research on knowledge management practices in organizations deals with ways for codifying, sharing, and applying knowledge that exists within an organization [24]. It should be interesting to investigate the relationship of knowledge creation and utilization in market-based approaches such as LDM with such more conventional knowledge management practices.

In this research, we developed LDM with the goal of achieving a decision that is predominantly based on sincere opinions. In the field of business intelligence, the term *weak signal detection* refers to identifying relevant pieces of information that may hint at imminent challenging events [6]. Data analytics methods are investigated for discerning such information, but also human computation based approaches such as LDM may be suitable. LDM allows for an equal, non-hierarchical, and repeated participation of a large group of people and may in this way allow persons to directly and repeatedly contribute such discerning information. It would then be interesting to detect such contributions, for example from the trade patterns and interactions of the market participants.

The LDM approach provides for the utilization of virtual play money for trading in its decision markets. We chose to utilize virtual play money mainly for avoiding legal issues as well as administrative efforts of managing real money deposits. Furthermore, it would probably have been difficult to recruit participants willing to invest their own money for our case studies. Nevertheless, the utilization of real money is an option also for decision markets and its actual impact should be interesting to study. The emergence of virtual currencies such as Bitcoin[1] might pave the way for market-based approaches using virtual *real* money. A first contender in this area is Predictious[2], an online prediction market that utilizes the Bitcoin currency [16].

The market model introduced in Section 3.3 refers to the concept of the *homo oeconomicus* who is assumed to always act in his best interest for maximizing his utility. However, the field of behavioral finance suggests that other factors may as well impact the behavior of participants in economic situations, such as social and emotional influences. Furthermore, people may only be boundedly rational in their decisions. Simon proposes a model of bounded rationality, considering cognitive, temporal, and informational limitations of people in decision making efforts [88]. Rather than striving for the maximization of their utility, participants are assumed to engage in *satisficing*, that is, trying to find a solution that is good enough. The consideration of the LDM approach with respect to these aspects and their impact on the market results should also be worthwhile.

[1] http://bitcoin.org
[2] https://www.predictious.com

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List of Abbreviations

AJAX Asynchronous Javascript and XML

CDA Continuous Double Auction

CFTC Commodity Futures Trading Commission

CREATE Creating Innovative Air Transport Technologies for Europe

DSS Decision Support Systems

GDSS Group Decision Support Systems

HTML Hypertext Markup Language

HTTP Hypertext Transfer Protocol

JEE Java Enterprise Edition

JSF Java Server Faces

LDM Liquid Decision Making

MM Market Maker

MVC Model-View-Controller

RQ Research Question

SP2 Strategic Prioritization and Planning Process

Bibliography

[1] Macmillan Dictionary. http://www.macmillandictionary.com/dictionary/british/manipulation (accessed 14 Jan 2011).

[2] New York Stock Exchange Price List 2013. https://usequities.nyx.com/sites/usequities.nyx.com/files/nyse_price_list_11_12_13.pdf (accessed 2 Dec 2013).

[3] Create - Creating Innovative Air Transport Technologies for Europe. Final Report, October 2010. http://www.acare4europe.org/sites/acare4europe.org/files/document/Create-Final-Report-October-2010.pdf (accessed 5 Jan 2014).

[4] Michael Abramowicz and M. Todd Henderson. Prediction Markets for Corporate Governance. *Notre Dame Law Review*, 82(4):1343–1414, 2007.

[5] Johan Almenberg, Ken Kittlitz, and Thomas Pfeiffer. An Experiment on Prediction Markets in Science. *PLoS ONE*, 4(12):1–7, 2009.

[6] H. Igor Ansoff. Managing Strategic Surprise by Response to Weak Signals. *California Management Review*, 18(2):21–33, 1975.

[7] Chris Argyris and Donald A. Schön. *Theory in Practice: Increasing Professional Effectiveness*. Management Series. Jossey-Bass Publishers, San Francisco, 1974.

[8] Kenneth J. Arrow, Robert Forsythe, Michael Gorham, Robert Hahn, Robin Hanson, John O. Ledyard, Saul Levmore, Robert Litan, Paul Milgrom, Forrest D. Nelson, George R. Neumann, Marco Ottaviani, Thomas C. Schelling, Robert J. Shiller, Vernon L. Smith, Erik Snowberg, Cass R. Sunstein, Paul C. Tetlock, Philip E. Tetlock, Hal R. Varian, Justin Wolfers, and Eric Zitzewitz. The Promise of Prediction Markets. *Science*, 320(5878):877–878, 2008.

[9] Michael J. Barclay, William G. Christie, Jeffrey H. Harris, Eugene Kandel, and Paul H. Schultz. The Effects of Market Reform on the Trading Costs and Depths of NASDAQ Stocks. *Journal of Finance*, 54(1):1–34, 1999.

[10] Tom W. Bell. Prediction Markets for Promoting the Progress of Science and the Useful Arts. *George Mason Law Review*, 14(1):37–92, 2006.

[11] Joyce Berg, Forrest Nelson, and Thomas Rietz. Accuracy and Forecast Standard Error of Prediction Markets. Working Paper, Departments of Accounting, Economics and Finance, Henry B. Tippie College of Business Administration, University of Iowa, 2003.

[12] Joyce Berg, Forrest Nelson, and Thomas Rietz. Prediction Market Accuracy in the Long Run. *International Journal of Forecasting*, 24(2):285 – 300, 2008. US Presidential Election Forecasting.

[13] Joyce Berg and Thomas Rietz. Prediction Markets as Decision Support Systems. *Information Systems Frontiers*, 5(1):79–93, 2003.

[14] Efthimios Bothos, Dimitris Apostolou, and Gregoris Mentzas. A Collaborative Information Aggregation System for Idea Management. In *Proceedings of the 2008 Third International Conference on Internet and Web Applications and Services*, pages 289–296, Washington, DC, USA, 2008. IEEE Computer Society.

[15] C. Boutilier. Eliciting Forecasts from Self-interested Experts: Scoring Rules for Decision Makers. In Vincent Conitzer, Michael Winikoff, Lin Padgham, and Wiebe van der Hoeck, editors, *Proceedings of the 11th International Conference on Autonomous Agents and Multiagent Systems, Valencia, Spain, 2012*, Richland, USA, 2012. International Foundation for Autonomous Agents and Multiagent Systems.

[16] Vitalik Buterin. Predictious: Prediction Markets Are Coming Back... With Bitcoin. Bitcoin Magazine `http://bitcoinmagazine.com/5710/predictious-prediction-markets-are-coming-back-with-bitcoin` (accessed 3 Dec 2013).

[17] Li Chen, Paulo Goes, Wynd Harris, James Marsden, and John Zhang. Preference Markets for Innovation Ranking and Selection. *INTERFACES*, 40(2):144–153, 2010.

[18] Li Chen, Paulo Goes, James Marsden, and Zhongju Zhang. Design and Use of Preference Markets for Evaluation of Early Stage Technologies. *Journal of Management Information Systems*, 26(3):45–70, 2009.

[19] Yiling Chen, Daniel M. Reeves, David M. Pennock, Robin D. Hanson, Lance Fortnow, and Rica Gonen. Bluffing and Strategic Reticence in Prediction Markets. In Xiaotie Deng and Fan Chung Graham, editors, *Proceedings of the 3rd International Conference on Internet and Network Economics, San Diego, USA, 2007*, WINE'07, pages 70–81, Berlin, Heidelberg, 2007. Springer-Verlag.

[20] Vincent Conitzer. Prediction Markets, Mechanism Design, and Cooperative Game Theory. In Jeff Bilmes and Andrew Ng, editors, *Proceedings of the 25th Conference on Uncertainty in Artificial Intelligence, Montreal, Canada, 2009*, UAI '09, pages 101–108, Arlington, Virginia, USA, 2009. AUAI Press.

[21] Ely Dahan and John R. Hauser. The Virtual Customer. *Journal of Product Innovation Management*, 19(5):332–353, 2002.

[22] Ely Dahan, Anna Soukhoroukova, and Martin Spann. New Product Development 2.0: Preference Markets – How Scalable Securities Markets Identify Winning Product Concepts and Attributes. *Journal of Product Innovation Management*, 27(7):937–954, 2010.

[23] Ely Dahan, Arina Soukhoroukova, and Martin Spann. Preference Markets: Organizing Securities Markets for Opinion Surveys with Infinite Scalability. Working Paper, University of California, Los Angeles, USA, 2007.

[24] K. Dalkir. *Knowledge Management in Theory and Practice*. MIT Press, 2011.

[25] Cary Deck, Shengle Lin, and David Porter. Affecting Policy by Manipulating Prediction Markets: Experimental Evidence. *Journal of Economic Behavior & Organization*, 85(C):48–62, 2013.

[26] Stanko Dimitrov and Rahul Sami. Non-myopic Strategies in Prediction Markets. In Lance Fortnow, John Riedl, and Tuomas Sandholm, editors, *Proceedings of the 9th ACM Conference on Electronic Commerce, Chicago, USA, 2008*, EC '08, pages 200–209, New York, NY, USA, 2008. ACM.

[27] Anhai Doan, Raghu Ramakrishnan, and Alon Y. Halevy. Crowdsourcing Systems on the World-Wide Web. *Communications of the ACM*, 54(4):86–96, 2011.

[28] Gunter Dueck. Bluepedia. *Informatik-Spektrum*, 31(3):262–269, 2008.

[29] Michael Eckert. *Complex Event Processing with XChangeEQ: Language Design, Formal Semantics and Incremental Evaluation for Querying Events*. Ph.D. Thesis, Institute of Computer Science, University of Munich, 2008.

[30] Matthew Einbinder. Information Markets: Using Market Predictions to Make Administrative Decisions. *Virginia Law Review*, 92(149):149–186, 2006.

[31] Dieter Fensel. Ontologies: Dynamic Networks of Formally Represented Meaning. In Isabel F. Cruz, Stefan Decker, Jérôme Euzenat, and Deborah McGuinness, editors, *Position Papers for SWWS' 01, The First Semantic Web Working Symposium, Stanford, USA, 2001*, pages 101–108, Stanford, USA, 2001. Stanford University.

[32] Robert Forsythe and Russell Lundholm. Information Aggregation in an Experimental Market. *Econometrica*, 58(2):309–347, 1990.

[33] Robert Forsythe, Forrest Nelson, George R. Neumann, and Jack Wright. Anatomy of an Experimental Political Stock Market. *The American Economic Review*, 82(5):1142–1161, 1992.

[34] Cedric Gaspoz, Jan Ondrus, and Yves Pigneur. Comparison of Multi-Criteria and Prediction Market Approaches for Technology Foresight. In *Proceedings of the 13th Conference of the Association Information & Management (AIM), Paris, France, 2008*, Paris, France, 2008. Association Information & Management.

[35] Andreas Graefe. *Prediction Markets versus Alternative Methods - Empirical Tests of Accuracy and Acceptability*. PhD thesis, Institute of Information Systems and Management, Karlsruhe Institute of Technology, 2009.

[36] Kesten Charles Green, J. Scott Armstrong, and Andreas Graefe. Methods to Elicit Forecasts from Groups: Delphi and Prediction Markets Compared. *Foresight: The International Journal of Applied Forecasting*, (8):17–20, 2007.

[37] Robert W. Hahn and Paul C. Tetlock. Using Information Markets to Improve Public Decision Making. *Harvard Journal of Law and Public Policy*, 29(1):213–289, 2004.

[38] Robert W. Hahn and Paul C. Tetlock. A New Approach for Regulating Information Markets. *Journal of Regulatory Economics*, 29(3):265–281, 2006.

[39] Robin Hanson. Issues In Information Market Design. `http://hanson.gmu.edu/infomkts.html` (accessed 23 Mar 2011).

[40] Robin Hanson. Decision Markets. *IEEE Intelligent Systems*, 14(3):16–19, 1999.

[41] Robin Hanson. Combinatorial Information Market Design. *Information Systems Frontiers*, 5(1):107–119, 2003.

[42] Robin Hanson. Logarithmic Market Scoring Rules for Modular Combinatorial Information Aggregation. *Journal of Prediction Markets*, 1(1):3–15, 2007.

[43] Robin Hanson and Ryan Oprea. A Manipulator Can Aid Prediction Market Accuracy. *Economica*, 76(302):304–314, 2009.

[44] Robin Hanson, Ryan Oprea, and David Porter. Information Aggregation and Manipulation in an Experimental Market. *Journal of Economic Behavior & Organization*, 60(4):449–459, 2006.

[45] Friedrich August Hayek. The Use of Knowledge in Society. *American Economic Review*, 35(4):519–530, 1945.

[46] Paul J. Healy, Sera Linardi, Richard Lowery, and John O. Ledyard. Prediction Markets: Alternative Mechanisms for Complex Environments with Few Traders. *Management Science*, 56(11):1977–1996, 2010.

[47] Shaun Hargreaves Heap. *The Theory of Choice: A Critical Guide*. Blackwell Publishers, 1992.

[48] Clyde W. Holsapple. Decisions and Knowledge. In Frada Burstein and Clyde Holsapple, editors, *Handbook on Decision Support Systems 1*, International Handbooks on Information Systems, pages 21–53. Springer Berlin Heidelberg, 2008.

[49] Clyde W. Holsapple and K. D. Joshi. A Collaborative Approach to Ontology Design. *Communications of the ACM*, 45(2):42–47, February 2002.

[50] Cars Hommes, Joep Sonnemans, Jan Tuinstra, and Henk van de Velden. Expectations and Bubbles in Asset Pricing Experiments. *Journal of Economic Behavior & Organization*, 67(1):116–133, 2008.

[51] Leonard M. Jessup and Joseph S. Valacich. *Group Support Systems: New Perspectives*. MacMillan, New York, 1993.

[52] Hugues De Jouvenel. A Brief Methodological Guide to Scenario Building. *Technological Forecasting and Social Change*, 65(1):37–48, 2000.

[53] Gerrit Kamp and Peter A. Koen. Improving the Idea Screening Process within Organizations using Prediction Markets: A Theoretical Perspective. *Journal of Prediction Markets*, 3(2):39–64, 2009.

[54] John Maynard Keynes. *The General Theory of Employment, Interest, and Money*. Macmillan Cambridge University Press, 1936.

[55] Michelle Kirby, Chris Raczynski, and Dimitri Mavris. An Approach for Strategic Planning of Future Technology Portfolios. In *Proceedings of the 6th AIAA Aviation Technology, Integration and Operations Conference (ATIO), Wichita, USA, 2006*. American Institute of Aeronautics and Astronautics, 2006.

[56] Michael Koch and A. Richter. *Enterprise 2.0*. Oldenburg, 2007.

[57] Christina Ann LaComb. GE's Imagination Markets. Technical Information Series 2007PRE027, GE Global Research, October 2007.

[58] Christina Ann LaComb, Janet Arlie Barnett, and Qimei Pan. The Imagination Market. *Information Systems Frontiers*, 9(2-3):245–256, 2007.

[59] Jean-Jacques Laffont and David Martimort. *The Theory of Incentives*. Princeton University Press, Princeton, New Jersey, 2002.

[60] Jim Lavoie. The Innovation Engine at Rite-Solutions: Lessons From the CEO. *Journal of Prediction Markets*, 3(1):1–11, 2009.

[61] John Ledyard, Robin Hanson, and Takashi Ishikida. An Experimental Test of Combinatorial Information Markets. *Journal of Economic Behavior and Organization*, 69(2):469–483, 2008.

[62] Stephan Leutenmayr and François Bry. Liquid Decision Making: An Exploratory Study. In David Taniar, Eric Pardede, Hong-Quang Nguyen, Wenny Rahayu, and Ismail Khalil, editors, *Proceedings of the 13th International Conference on Information Integration and Web-based Applications and Services, Ho Chi Minh City, Vietnam, 2011*, iiWAS '11, pages 391–394, New York, NY, USA, 2011. ACM.

[63] Stephan Leutenmayr, François Bry, Tom Schiebler, and Felix Brodbeck. Work in Progress: Do They Really Mean It? Assessing Decision Market Outcomes. In Hans-Ulrich Heiß, Peter Pepper, Holger Schlingloff, and Jörg Schneider, editors, *INFORMATIK 2011 Informatik schafft Communities, Berlin, Germany, 2011*, Lecture Notes in Informatics, Bonn, Germany, 2011. Gesellschaft für Informatik.

[64] Stephan Leutenmayr, Fabian Kneissl, Sven Ziemer, and François Bry. Gameful Markets for Collaboration and Learning. In Markus Krause, François Bry, and Mihai Georgescu, editors, *Proceedings of Disco 2013, Workshop on Human Computation and Machine Learning in Games at HComp, Palm Springs, USA, 2013*, Palo Alto, USA, 2013. The AAAI Press.

[65] Stephan Leutenmayr, Sven Ziemer, and François Bry. Decision Markets for Continuously Reflected Collective Decisions. In *Proceedings of the 3rd International Conference on Social Eco-Informatics (SOTICS), Lisbon, Portugal, 2013*, Wilmington, USA, 2013. IARIA XPS Press.

[66] Rensis Likert. A Technique for the Measurement of Attitudes. *Archives of Psychology*, 22(140):5–55, 1932.

[67] Stefan Luckner. Prediction Markets: Fundamentals, Key Design Elements and Applications. In *Proceedings of the 21st Bled eConference eCollaboration: Overcoming Boundaries through Multi-Channel Interaction, Bled, Slovenia*, 2008.

[68] Charles F. Manski. Interpreting the Predictions of Prediction Markets. *Economics Letters*, 91(3):425–429, 2006.

[69] Iván Marinovic, Marco Ottaviani, and Peter Norman Sørensen. Modeling Idea Markets: Between Beauty Contests and Prediction Markets. In Leighton Vaughan Williams, editor, *Prediction Markets: Theory and Applications*. Routledge, 2011.

[70] Debrah Meloso, Jernej Copic, and Peter Bossaerts. Promoting Intellectual Discovery: Patents Versus Markets. *Science*, 323(5919):1335–1339, 2009.

[71] Thomas A. Montgomery, Paul M. Stieg, Michael J. Cavaretta, and Paul E. Moraal. Experience from Hosting a Corporate Prediction Market: Benefits Beyond the Forecasts. In *Proceedings of the 19th ACM SIGKDD International Conference on Knowledge Discovery and Data Mining, Chicago, USA, 2013*, KDD '13, pages 1384–1392, New York, NY, USA, 2013. ACM.

[72] John J. Murphy. *Technical Analysis of the Financial Markets: A Comprehensive Guide to Trading Methods and Applications*. New York Institute of Finance Series. New York Institute of Finance, 1999.

[73] Natalya F. Noy, Abhita Chugh, William Liu, and Mark A. Musen. A Framework for Ontology Evolution in Collaborative Environments. In *Proceedings of the 5th International Conference on the Semantic Web, Athens, USA, 2006*, ISWC'06, pages 544–558, Berlin, Heidelberg, 2006. Springer-Verlag.

[74] Abraham Othman, Tuomas Sandholm, David M. Pennock, and Daniel M. Reeves. A Practical Liquidity-Sensitive Automated Market Maker. In *Proceedings of the 11th ACM Conference on Electronic Commerce, Cambridge, USA, 2010*, pages 377–386, New York, NY, USA, 2010. ACM.

[75] Marco Ottaviani. The Design of Idea Markets: An Economist's Perspective. *Journal of Prediction Markets*, 3(1):41–44, April 2009.

[76] Marco Ottaviani and Peter Norman Sørensen. Outcome Manipulation in Corporate Prediction Markets. *Journal of the European Economic Association*, 5(2–3):554–563, 2007.

[77] Charles R. Plott and Kay-Yut Chen. Information Aggregation Mechanisms: Concept, Design and Implementation for a Sales Forecasting Problem. Social Science Working Paper 1131, California Institute of Technology, 2002.

[78] Daphne R. Raban and Dorit Geifman. Designing Online Information Aggregation and Prediction Markets for MBA Courses. *Interdisciplinary Journal of E-Learning and Learning Objects*, 5:247–262, 2009.

[79] Paul Resnick, Ko Kuwabara, Richard Zeckhauser, and Eric Friedman. Reputation Systems. *Communications of the ACM*, 43(12):45–48, December 2000.

[80] Paul W. Rhode and Koleman S. Strumpf. Manipulating Political Stock Markets: A Field Experiment and a Century of Observational Data. Working Paper, University of North Carolina, 2008.

[81] Libby Rittenberg. *Principles of Microeconomics*. Flatworld Knowledge, 2008.

[82] Ricky Robinson. On the Design and Implementation of a Market Mechanism for Peer Review and Publishing. Technical report, Queensland Research Laboratory, St Lucia, Queensland, Australia, 2009. `http://www.nicta.com.au/people/rrobinson/publications/citemine-paper.html` (accessed 1 Oct 2013).

[83] David M. Rothschild and Rajiv Sethi. Trading Strategies and Market Microstructure: Evidence from a Prediction Market. Working Paper Series, Microsoft Research, New York, 2013.

[84] Ognjen Scekic, Hong-Linh Truong, and Schahram Dustdar. Incentives and Rewarding in Social Computing. *Communications of the ACM*, 56(6):72–82, 2013.

[85] Emile Servan-Schreiber, Justin Wolfers, David M. Pennock, and Brian Galebach. Prediction Markets: Does Money Matter? *Electronic Markets*, 14(3):243–251, 2004.

[86] Sven Seuken, David C. Parkes, Eric Horvitz, Kamal Jain, Mary Czerwinski, and Desney Tan. Market User Interface Design. In *Proceedings of the 13th ACM Conference on Electronic Commerce, Valencia, Spain, 2012*, EC '12, pages 898–915, New York, NY, USA, 2012. ACM.

[87] Peng Shi, Vincent Conitzer, and Mingyu Guo. Prediction Mechanisms That Do Not Incentivize Undesirable Actions. In Stefano Leonardi, editor, *Internet and Network Economics*, volume 5929 of *Lecture Notes in Computer Science*, pages 89–100. Springer Berlin / Heidelberg, 2009.

[88] Herbert Alixander Simon. *Models of Man*. Wiley, New York, 1957.

[89] Christian Slamka, Wolfgang Jank, and Bernd Skiera. Second-Generation Prediction Markets for Information Aggregation: A Comparison of Payoff Mechanisms. *Journal of Forecasting*, 31(6):469–489, 2012.

[90] Erik Snowberg, Justin Wolfers, and Eric Zitzewitz. Information (In)efficiency in Prediction Markets. In Leighton Vaughn Williams, editor, *Information Efficiency in Betting Markets*, pages 366–386. Cambridge Unversity Press, 2005.

[91] Erik Snowberg, Justin Wolfers, and Eric Zitzewitz. Prediction Markets for Economic Forecasting. CAMA Working Papers 2012-33, Centre for Applied Macroeconomic Analysis, Crawford School of Public Policy, The Australian National University, July 2012.

[92] Martin Spann, Holger Ernst, Bernd Skiera, and Jan Henrik Soll. Identification of Lead Users for Consumer Products via Virtual Stock Markets. *Journal of Product Innovation Management*, 26(3):322–335, 2009.

[93] Martin Spann and Bernd Skiera. Internet-Based Virtual Stock Markets for Business Forecasting. *Management Science*, 49(10):1310–1326, 2003.

[94] Brian Spears, Christina LaComb, John Interrante, Janet Barnett, and Deniz Senturk-Dogonaksoy. Examining Trader Behavior in Idea Markets: An Implementation of GE's Imagination Markets. *Journal of Prediction Markets*, 3(1):17–39, April 2009.

[95] Hans R. Stoll. Electronic Trading in Stock Markets. *Journal of Economic Perspectives*, 20(1):153–174, 2006.

[96] Koleman Strumpf. Introduction to Special Issue on Corporate Applications of Prediction Markets. *Journal of Prediction Markets*, 3(1):i–viii, 2009.

[97] James Surowiecki. *The Wisdom of Crowds*. Anchor Books, 2005.

[98] Shino Takayama. A Dynamic Strategy of the Informed Trader with Market Manipulation. *Annals of Finance*, 6(2):287–294, 2010.

[99] Paul Tetlock, Robert Hahn, and Donald Lien. Designing Information Markets for Decision Making. Technical Report 05-23, AEI Brookings Joint Center for Regulatory Studies, 2005.

[100] Michael Totty. How to Decide? Create a Market. *The Wall Street Journal*, June 19, 2006. `http://online.wsj.com/article/SB115073365085184192.html` (accessed 27 Aug 2013).

[101] Georgios Tziralis and Ilias Tatsiopoulos. Prediction Markets: An Extended Literature Review. *Journal of Prediction Markets*, 1(1):75–91, 2007.

[102] Gerrit H. Van Bruggen, Martin Spann, Gary L. Lilien, and Bernd Skiera. Prediction Markets as Institutional Forecasting Support Systems. *Decision Support Systems*, 49(4):404–416, 2010.

[103] Helena Veiga and Marc Vorsatz. Price Manipulation in an Experimental Asset Market. *European Economic Review*, 53(3):327–342, 2009.

[104] Christof Weinhardt and Henner Gimpel. Market Engineering: An Interdisciplinary Research Challenge. In Nick Jennings, Gregory Kersten, Axel Ockenfels, and Christof Weinhardt, editors, *Negotiation and Market Engineering*, number 06461 in Dagstuhl Seminar Proceedings, Dagstuhl, Germany, 2007. Internationales Begegnungs- und Forschungszentrum für Informatik (IBFI), Schloss Dagstuhl, Germany.

[105] Claes Wohlin, Per Runneson, Martin Höst, Magnus C. Ohlsson, Björn Regnell, and Anders Wesslén. *Experimentation in Software Engineering: An Introduction*. Kluwer Academic Publishers, 2000.

[106] Areej M. Yassin. Decision Support Markets: An Innovative Business Intelligence Tool. In Robert C. Nickerson and Ramesh Sharda, editors, *Proceedings of the 15th Americas Conference on Information Systems, San Francisco, USA, 2009*. Association for Information Systems, 2009.

[107] Robert K. Yin. *Case Study Research: Design and Methods*. Applied Social Research Methods. SAGE Publications, 2009.