FAKULTÄT FÜR !NFORMATIK
Faculty of Informatics

Agent-based simulation in a business strategy game: Evaluation and integration

DIPLOMARBEIT

zur Erlangung des akademischen Grades

Diplom-Ingenieurin

im Rahmen des Studiums

Wirtschaftsinformatik

eingereicht von

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an der
Fakultät für Informatik der Technischen Universität Wien

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Wien, 20.01.2016

(Unterschrift Verfasser) (Unterschrift Betreuung)

Agent-based simulation in a business strategy game: Evaluation and integration

MASTER'S THESIS

submitted in partial fulfillment of the requirements for the degree of

Diplom-Ingenieurin

in

Business Informatics

by

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Registration Number 0925335

to the Faculty of Informatics
at the Vienna University of Technology

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Vienna, 20.01.2016

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Abstract

Business simulations are defined as serious games in which attendees play the role of managers or firm owners competing to sell their goods to the consumers against other companies on the market. Business games are widely used for the development of individual decision making or organization capabilities in universities and companies. Such business simulation games also provide an extensive view of the complexity of a business situation and allow players to get a multidimensional insight of the real-life business process and problematic. A business strategy game is a more special case of a business simulation or business game. With such a type of game, different types of markets can be simulated, to force the participants of the game to develop or test different strategies like cost leadership, differentiation or focus and make appropriate strategic decisions. The problem, of modeling the marketplace or buyers' market for the game, is perhaps the most central and unavoidable issue of a business simulation game. The algorithms that are responsible for calculating the market and firm demand have been evaluated as the most complex and important algorithms of a business simulation game. In this thesis an agent-based model approach is used to model the market at a consumer detailed level for the implementation of a web-based strategic business game. The flexible composition of the market, which results from the usage of the agent-based model approach allows simulating different scenarios in the strategic business game and overcomes the lack of flexibility of the standard models. The results of the implemented artifact in this thesis provided some evidence to sustain the hypothesis that an agent-based model can provide additional information and advantages in a strategic business simulation game. Moreover, the agent-based model approach allowed the modeling of different market compositions on a micro-level compared to other standard models, allowing the investigation of the market and strategic alignment of the participants in the game.

Keywords: Business game, realism, agent-based approach, strategic business game, neoclassical theory of choice, demand model, consumer utility.

Kurzfassung

Ein Wirtschaftsplanspiel oder Unternehmensplanspiel ist ein seriöses Spiel, in dem die Teilnehmer die Rolle von Firmeninhaber einnehmen und ihre Produkte, im Wettbewerb mit den anderen Teilnehmern, den simulierten Konsumenten am Markt anbieten. Diese Planspiele sind weit verbreitet und dienen der Weiterentwicklung der individuellen Entscheidungsfindung und/oder Organisationsfähigkeit der Teilnehmer. Sie werden daher hauptsächlich im Umfeld von Universitäten und Unternehmen eingesetzt. Unternehmensplanspiel bieten den Spielern hierbei einen umfassenden Blick auf die Komplexität des Marktes und des Geschäftsumfeldes und ermöglichen eine mehrdimensionale Sicht auf den Ablauf von Geschäftsprozessen im Zuge des Spielablaufs. Ein Strategiespiel (business strategy game) ist ein Spezialfall eines Unternehmensplanspiel (business game) beziehungsweise einer Wirtschaftssimulation (business simulation). Mit einer solchen Art von Spiel, können verschiedene Marktkonstellationen simuliert werden, um die Teilnehmer des Spiels dazu zu bewegen, verschiedene Strategien, wie Kostenführerschaft, Differenzierung oder Fokussierung zu testen respektive anzuwenden und eigene entsprechende strategische Entscheidungen zu treffen. Das Hauptproblem bei solchen Anwendungen ist die Modellierung des Marktes insbesondere des Käufermarktes welcher das zentrale und unvermeidbare Problem in der Entwicklung eines Unternehmensplanspiel darstellt. Die Algorithmen, die für die Berechnung der Marktnachfrage verantwortlich sind, werden als die komplexesten und wichtigsten Algorithmen eines Wirtschaftsplanspiels gesehen. In dieser Arbeit wird ein agentenbasierter Modellansatz verwendet, um den Markt auf Konsumentenebene für die Umsetzung eines web-basierten strategischen Planspiels zu modellieren. Die flexible Zusammensetzung des Marktes, die durch die Nutzung des agentenbasierten Modellansatzes ermöglicht wird, erlaubt es verschiedene Szenarien des Konsumentenmarktes im Planspiel zu simulieren und damit die mangelnde Flexibilität von Standardmodellen zu vermeiden. Die resultierenden Ergebnisse aus der Umsetzung des Artefakts zeigen, dass der Einsatz eines agentenbasierten Modells zusätzliche Informationen und Vorteile in einem strategischen Unternehmensplanspiel aufweisen kann. Darüber ermöglichte es der agentenbasierte Modellansatz die Modellierung von verschiedenen Markt-Zusammensetzungen auf einer detaillierteren Ebene zu realisieren. Im Vergleich zu anderen Standardmodellen ermöglichte es den Teilnehmer des Unternehmensplanspiel eine strategische Ausrichtung an Hand des untersuchten Marktes vorzunehmen.

Schlagwörter: Geschäftssimulation, Realismus, agentenbasierter Ansatz, strategische Geschäftssimulation, Theorie der rationalen Entscheidung, Nachfragemodell, Nutzenfunktion.

Contents

CHAPTER 1

Introduction

Business simulations or business simulation games are specified as serious games in which attendees play the part of firm owners competing to sell their products to the market of consumers against other competing companies on the market [1]. These business games are primary used for the improvement of an individual's decision making or participants' management skills in universities and firms [2]. Such business simulation games also provide an expanded view of the intricacy of a particular business situation and allow the participating players to achieve a wide perspective of a simulated real-life business process and scenario [3]. There is a big offer and variety of diverse games with different goals and intentions but most of these available games have the primary focus on the teaching of accounting skills [4]. A business strategy game is a special case of a business simulation or business game focusing on a specific area. With such a type of game, different market situations can be simulated, to force the participants of the game to develop or test different strategies like cost leadership, differentiation or focus and make appropriate strategic decisions to support the chosen strategies [5]. Focusing on this area, the business simulation game should help participants that play such a game to gain skills or develop available ones in the management field by providing a system that covers basic functionality and characteristics of the targeting area.

1.1 Terminology

A business simulation, business game or a business simulation game is defined as a serious game in a certain business environment, in that attendees play the part of firm managers or owners that are competing against other participants on the market to sell their products to the available buyers on the marketplace [1]. Even simpler explained, a business game is a game which simulates a competitive industry in which attendees are able to manage business firms [6]. The terms business game, business simulation and business simulation game are equivalently used in that context. The word game is often associated with a time wasting activity that is taking things not too seriously or is a type of application that is mainly designed for fun by entertaining the user. In the connection and relation to the term business game, the word game should not be linked with that sort of definition. A more universal definition for a game that is in that context more appropriate is, that a game is played when one or more players or participants cooperate or compete for profits based on an accepted set of rules [7]. This definition puts the focus on the communication and competition between two or more participants of a game. A simulation on the other hand is according to Banks et al. [8] a reflection of an execution of a particular real-life process or an existing system over time. It seems at first glance as if these two concepts do not supplement each other. According to Lainema [9] a simulation is also defined as an defined set of activities and/or actions that are executed to reach an optimum outcome for specified problems. Usually this is not the aim of an educational game. So analogously to Lainema [9] the concept of simulation gaming offers therefore a more appropriate mix and balance between these two terms. Aldrich [10] additionally added the educational aspect to business simulations to distinguish serious simulation games from simulation games that are designed to primary entertain the participants. Business simulation games or economic simulation games are therefore a more specific term for simulation games that describe the particular environment in that the game is taken place. Because of the applied business environment, these games are used to coach the business skills of attendees and/or evaluate the participants' quantitative and qualitative performances in such a game [11]. The different terms that are used to define a serious business simulation game are shown in Figure 1.1 with their overlapping relationship in a Venn diagram.

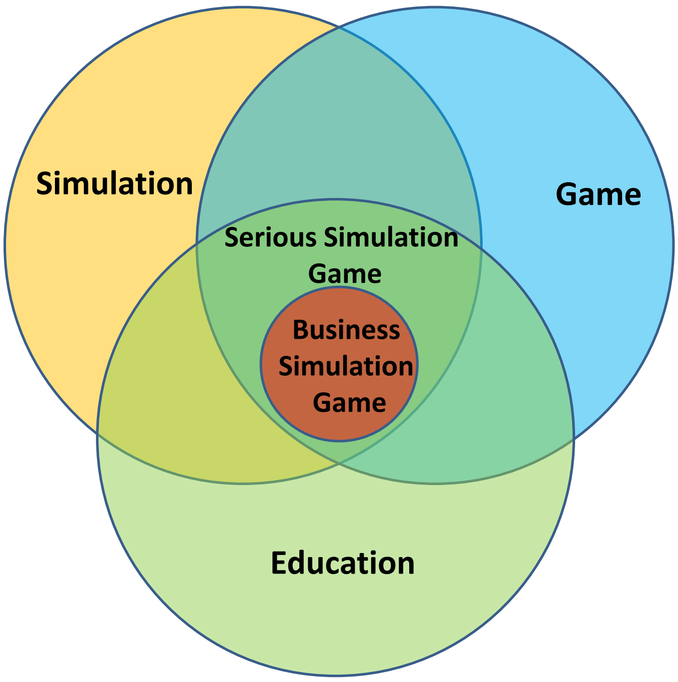


Figure 1.1: Venn diagram of the relationship between simulation, game, education and business simulation game.

There is a big offer and variety of business simulation games on the market but many of them have the focus on the teaching of accounting [4]. Business games are mostly dealing with the decision making processes that are typically involving actions like setting prices, promotional budgets, research & development expenditures, and sometimes evaluating quality and product attributes for each round of the simulation [12]. A business strategy simulation game is an even more specialized term for the already defined business simulation game. Such a type of game is focusing more on decisions that are necessary for the development and support of different strategies on a simulated market like for example cost leadership, differentiation or focus strategy [5] [12]. Additionally, the participants in such games are challenged to initially find and formulate a strategy for a company and then make the decisions that are supporting their primary chosen strategy in the simulated environment [13].
Although there are a variety of different names for business simulation games none of these terms imply the method that is used to model the underlying market of consumers or buyers in this game. The different possibilities that are used to model the market of buyers or demand side in such game implementations are explained shortly in Section 1.4 and in detail in Section 2.2 and Section 2.3.
The term *agent-based model* that is used in the further sections is one type of computational models that are used for simulating the system. Agent-based models are a special type of micro scale model that are used to simulate an amount of parallel actions and interactions of defined agents in a system [14]. The main purpose of this kind of simulation is the ambition to re-establish and predict the presence of emerging complex phenomena in a system [14]. The realization of the emergent behavior of systems from the lower (micro) level, resulting from parts of the system, to a higher (macro) level is the major intention behind this type of simulation [14]. Individual agents that are representing this micro level are typically rational acting in terms of their own interests like economic benefit, social status or reproduction [15]. To realize this kind of behavior for agents in an application they are using heuristics or a defined set of simple decision making rules for their actions [15]. The concept of agent-based modeling was developed as a rather simple approach in the late 1940s [16]. Since this model approach requires computation intensive processing, it was not in the center of interest until the late 1990s [16].

1.2 Evolution of business games

Although business simulation games are mostly used to teach and improve management skills and competences of the players in a simulated business environment, business simulation games are successors of war games that were developed a long time before business simulation games even existed [11] [17] [18].
One of the first direct forerunners of the recent business simulation game in Europe can be traced back to the year 1932 and was developed by Mary Birshstein. Birshstein was an eminent employee in the Bureau for the Scientific Organization of Work in 1929 in the city Leningrad when it was combined with the Leningrad Institute of Engineering and Economics. While teaching at the Institute, Birshstein developed the idea to use the concept of war games in the business sector. She developed her first business simulation game in 1932. This business game was simulating the assembly process of a typewriter factory and was used to teach managers how

to handle various available production problems. Because of the achieved benefit and positive feedback of this first business simulation, Birshstein and her team additionally developed more than 40 similar exercises that were focusing on the simulation of the production and distribution processes for various types of businesses from 1932 to 1940. [19] [17]
In North America especially the United States, the first modern business simulation was developed in 1955. In that year, RAND Corporation in Santa Monica developed the so called 'Monopologs' simulation that was used to simulate a supply system for the Air Force to enhance the skills of their military staff in the role as inventory managers [20] [21]. One year later in 1956, the 'Top Management Decision Simulation' was implemented as the first business game, by the American Management Association for the usage in management seminars [22]. This was proceeded in 1957 by the implementation of an additional business simulation game that was known as 'Business Management Game' [23]. It was developed by Greene and Andlinger for the consulting firm of McKinsey & Company [23]. In the same year the 'Top Management Decision Game' was the first known business simulation game that was used in a course at the University of Washington in 1957 [24]. From this point, the spreading and usage of business games has risen sharply. For years after the first use of the 'Top Management Decision Game', it was approximated that there are more than 100 business games available in the area of the United States and that these games approximately had been used by more than 30,000 executives and numerous students [25].
More than 40 years later in 2004, an e-mail survey of 14,497 business faculty members from various disciplines of the American Association of Collegiate Schools was accomplished to evaluate the actual business simulation game usage. From 1,085 survey respondents of the survey, 30.6% of the respondents were currently using business simulations, while another 17.1% of the participators of the survey were past business game users. [26]
In the course of evolution of business games the first developed games were very simple according to the number of decision variables that were available in the game, the number of participants that could accommodate as well as the number of markets and products including the amount of feedback available to the participants. This limitation was necessary cause of the fact that models in the game had to be simple and uncomplicated since the results of the executed simulation games were hand scored. As business schools and universities had finally access to mainframe computers, the business games began to migrate to the newer platform and allowed realizing a higher complexity for such games. Nowadays business simulation games run of course on personal computers or on web servers allowing the participants of such games a quick and easy input and a more dynamic and flexible business environment. Additionally, the possibility of a graphical output on a personal computer allowed offering the attendees a more detailed overview of their result in the game. [27]
The technical evolution of business games from initial hand scored applications to modern games that are running on personal computers, is described by Wolfe in 4 steps [28]. Faria [18] added a fifth layer to the original layers of Wolfe [28] that can be seen in Table 1.1.

Phase	Period	Development
I	1955 - 1963	Creation and growth of hand-scored games
II	1962 - 1968	Creation business games on the mainframe and distribution of commercially published games
III	1966 - 1985	Time of the fastest growth of mainframe games and significant accretion the complexity of business games
IV	1984 - 2000	Growth of PC-based games and evolution of decision making tools to guide business games
V	1998 - now	The growth of the availability of business games on the internet that run on central servers

Table 1.1: Phases in the Development of Business Gaming [18] [28]

1.3 Motivation

Business games are often used for the improvement of an individual's decision making or organization managing in universities and companies [2]. In a course, each student can manage a fictive company in a simulated market or industry in order to accomplish a deeper insight of management issues or various business structures [2].How this simulation is realized in a business game depends on the model and the modeling approach that is used for the game. Since Goosen [29] first introduced a generalized algorithm for a business simulation game, several modeling paradigms such as the equation-based [30], interpolation-based and statistical-based [31] approaches have been examined as techniques to simulate the market demand in a business simulation game. Accordingly much effort has been then devoted to increase the validity and edibility of the concrete proposed models [32]. Another approach that is not yet broadly applied to the modeling of consumer behavior in business simulation games is the agent-based modeling approach [32]. Although various scholars arguing about the benefits of agent-based modeling over equation-based modeling, very few agent-based models have been realized in the field of business simulations [1]. Because of the demand in the field of strategic management for a business strategy game, to teach the different strategies by means of 'learning-by-doing', a new game with a dynamic buyers market is going to be created. The business strategy game should enable the lecturers of a course to simulate different market compositions based on the consumers, which have different preferences regarding their buying decisions. It should be possible that the market composition can be changed during the game to force the participants to investigative and act reactive to changes in order to perform well in the game. Additionally, it should be guaranteed that the game is accessible in a simple way for the participants and require no special software to be installed and use it without any barriers. To satisfy these requirements the agent-based model approach was chosen to evaluate and analyze the practicable usage for a web-based strategic business game that should run in all common web browsers. The possible shortcomings or advantages of the agent-based model approach have to be compared and evaluated to the standard models from the perspective of the participants and operators of the game. The major motivation of this thesis is to provide a dynamic web-based business game to improve and test the learned theories in the field of strategic management by means of 'learning-by-doing'.

1.4 Problem Statement

Machuca [33] stated that the missing transparency in common business games has given them the standing of 'black boxes'. The concealment of the models that are used in the games was argued to be one of the major causes for the inability of the participants to perceive cause-and-effect relationships within the game [33]. In developing such business strategy games there are several possibilities to implement and describe the dependencies of the underlying system. There are different types of computer simulation approaches that can be applied to model the system [32]:

- Equation-based: mathematical equations are describing the industry and firm-level demand [30].
- Interpolation based: the interpolation method determines the graphs of industry and firm demand functions [31] .
- Statistical: the fraction of customers which consume a given product is evaluated using probability distributions for the purchase [31] .
- Agent-based: the complexity of the marketplace is modeled using a bottom-up approach, modeling the behavioral rules of each consumer [32].

Regardless of the type of computer simulation that is chosen to build the model, simpler models have the advantage that participants more likely recognize the consequences of their actions compared to more complex models that have more interdependence [34]. In return, the more complex and detailed models are often seen as more realistic. Goosen et al. [34] stated that the difficulty to construct a realistic and comprehensible model originated from the 'dilemma of simplicity versus real-world complexity'. It is argued that the agent-based technique provides the advantages of a natural description of the system and derives its macro behavior therefore as an emergent phenomena from the individual agent interaction and the goals and beliefs of this agent [32]. It is also argued that this modeling technique provides a new way to understand data and is therefore a way for businesses to understand and anticipate the likely effects of their decisions [35]. In the following subsection the shortcomings of the standard models will be discussed that should be resolved by applying the agent-based model approach in this thesis.

1.4.1 Lack of realism in business games

Faria and Wellington [26] who started a survey back in the year 2004, discovered that only 13.6% of the students that applied in this survey considered business simulation games as a realistic exercise. A similar survey from Bruhn and Mozgira [36] in the year 2007 achieved a similar result. More than 88% of the participating students responded that business simulation games do not provide a realistic perspective of the business environment. The perceived realism depends of course on the functional area that the business simulation game is trying to cover. As already stated in the beginning of Section 1.4, there is a trade-off between the simplicity and the achieved realism.

1.4.2 Lack of understandability of business games

In the beginning of Section 1.4 it was already explained that on the one hand simpler models have the advantage that participants more likely comprehend the consequences of their actions and decisions compared to more complex models with more interdependence. On the other hand, the more complex and detailed models are assessed as more realistic [34].
The missing understanding and ability to perceive these cause-and-effect relationships is often related to the veiling of the model that is used for the simulation [33]. With the application of the agent-based model approach the aim is to provide a model for a strategic game with an utility function that consists of at least three parameters that influence the decision of a consumer for a specific good. Explaining the relevant parameters of a consumer to the participants of a game, it should be avoided that the aggregated market behavior or the individual consumer decision is perceived as a black box during the game.

1.4.3 Lack of level of details in business games

The equation-based, interpolation based and statistical simulation modeling approach describe the market in the games in form of their macro behavior. Such macroscopic simulators model the flow of the system using high-level mathematical models [37]. The macroscopic view of this model approaches do not allow distinguishing between different customers on a micro level. The decisions, actions and properties of diverse buyers could not be modeled with these approaches because of the missing microscopic support that is provided by these models. Baptista [32] argued that the additional information of individual consumer decisions and information about them plays an important role in increasing the understanding of the attendees that are playing such a game.

1.4.4 Lack of flexibility on the market

As already mentioned in Subsection 1.4.3 the equation-based, interpolation based and statistical simulation modeling approach using mainly high-level mathematical models. The use of these mathematical models hardly allows a simple parametrization to simulate different market situations. Additionally, the use of this parametrization often requires mathematical understanding of the underlying equations in the applied model. So these approaches do not overcome the underlying problem of finding a flexible demand function for describing the market demand. [32]
According to Bazghandi [37] the flexibility of agent-based modeling can be argued with following examples. Adding more consumers or agents to the model is on possibility within game and easy to implement manage. Also the implementation of various behavior of subgroups of agents and single agents, as well as the aggregation of agents can be easier realized and is therefore a more natural description of the system than in the other models [37].

1.5 Aim of the work

The aim of this thesis is the creation of a web-based business strategy game with a transparent and dynamic configurable buyers' market based on an agent-based model approach with a high degree of realism. The first point in this work is the integration of the game in the lecture Strategic Management. The operator of this game should be able to configure the market composition based on different consumer types with different buying preferences and a defined behavioral decision process. The changes of the market composition should be possible for every single game instance and should be applicable during the game. This enables the operator to create, before or during the game, different market scenarios for the participants. This should force the participants to investigate the market, develop strategies and react to changes on the market. As second point it should be analyzed and described if there are possible advantages of an agent-based model implementation approach in the business strategy game compared to the stated standard models from the perspective of the operator and the participant. The hypothesis posed is that *agent-based models are a practicable approach to model a dynamic buyers' market in a web based business strategy game*. Due to the massive effort to cover all functional areas of a business, this game is focusing on the area of strategic management with the specific aim of enabling the participants to apply Porter's generic strategies [5].

1.6 Methodological approach

For this thesis the *'design science'* research methodology is used that is according to Hevner et al. [38] defined as a result based research methodology for the area of information technology. This methodology offers definite instructions for evaluating various research projects [38]. According to Hevner et al. [38] this research methodology is especially in the information systems discipline one of the leading research methods. The goal of the design science paradigm is to increase the borders of human and organizational capacities by creating a new and innovative artifact that is then used and evaluated within this thesis [38]. The artifact in this research paradigm is the developed web-based strategic business simulation game that will be integrated in the lecture and evaluated with a questionnaire based survey. The seven guidelines that Hevner et al. [38] presented for the design science research for the discipline of information systems will be explained in more detail in Section 3.1.

1.7 Structure of the work

This chapter gave an overview of the used most important terminology that is used in the further thesis as well as a historical perspective of the evolution of business simulation games. After a brief overlook over the domain problem and the illustration of the goal in this thesis, the used methodological approach that is applied in this work was described.

In Chapter 2 the major microeconomics models (Section 2.1), that will be the fundamental basis for this work, will be covered in detail as well es the standard models (Section 2.2) that were already shortly mentioned in the previous sections. Following this, the newer agent-based model (Section 2.3) approach will be explained in detail and how the microeconomics and behavioral

theories can be applied to this model approach (Section 2.4. It is argued how the connection between the microeconomics theory and the relatively new modeling approach could potentially provide a more realistic business game in the area of strategic management with a more dynamic market composition.
Chapter 3 will be dealing with the details of the used methodological approach (Section 3.1) as well as the basic requirements and the concept of the game (Section 3.2). Additionally, the used development method (Section 3.3) and the evaluation method for the created artifact is explained (Section 3.4).
The following Chapter 4 explains the various implementation details of the artifact including amongst other things the technological architecture (Section 4.1), the consumer simulation implementation (Section 4.3), the used mathematical model (Section 4.4) and some graphics of the concrete implementation (Section 4.5).
In the Chapter 5 an overview of the taken survey is provided including the obtained and evaluated results of the survey. A summary is given of the detected advantages and disadvantages of the applied agent-based model approach for the web-based business strategy game.
As last Chapter 6 in this thesis, a summary is provided with an outlook of further topics of interest. The outlook should supplement the thesis with additional points of improvement of the actual implemented artifact and discovered topics of interest that could enhance the realism of the current application.

CHAPTER 2

State of the Art

Modeling the consumer market is a central aspect of developing a business simulation game and one of the main challenges and unavoidable issues someone is confronted with during the implementation [34]. As it was already shortly mentioned during the introduction, there are several available models that are used in business games already. These simulation models are mainly used to simulate the market and therefore the overall market demand as well as the individual market demand for a firm or specific product. Depending on the simulation model and the algorithm that is used for simulating, the ability to perceive cause-and-effect relationships between the actions and the resulting demand of firms can be higher or lower. Goosen [34] already stated that the demand algorithm in a business simulation game is one of the most complicated and important algorithms in such a game.

The complexity of such demand algorithms correlates with the number of variables that are used, like for example the price, advertising, number of participants and number of products. With the use of these variables, the algorithm calculates the demand for each company in the game based on the overall demand on the market that is also derived. The importance of this algorithm follows from the fact that the calculated demand should correlate and be comprehensible with the decisions that have been taken in the game from the participants. One of the difficulties is, to compare decisions between companies in terms of their quality. Such demand models of business simulation games are based primary on the well known classical economic demand theory. [31]

To provide a fundamental basis for the understanding and development of such demand models in a business simulation game, an introduction to the necessary economic theory in the following sections is given.

2.1 Microeconomics Theory

Microeconomics theory is a branch of economics that is used to study and model the behavior of individuals and firms. It is dealing with the process of making decisions as well as the allocation

of limited resources. Typically the microeconomics theory applies to markets in that goods or services can be bought or sold. Microeconomics provides the fundamental basics to understand how decision and behavior of consumers affect the supply or the demand for these products or services on the market. The resulting supply and demand determines consequently the prices on the market that in turn evaluate the quantity supplied and the contrary quantity demanded of those goods and services. [39]
Summarizing these definitions, the aim of microeconomics is to examine the market mechanisms that assemble relative prices between goods and services and allocate limited resources over many alternative uses. Microeconomics includes of course a lot of diverse areas like [40]:

- Model of supply and demand
- Theory of perfect competition
- Rational consumer behavior (consumer choice)
- Elasticity
- Production theory
- Cost-of-production theory of value
- Monopoly
- Oligopoly
- Market structure
- Game theory
- Labor economics
- Welfare economics
- Information economics

According to Zernik [41] the main goal of business simulation games is to allow the participants to use the learned theoretical concepts in a more complex and difficult real life situation to provide a challenge and a feedback using these models. Also relying on the microeconomics theory for the implementation of the business simulation game, three theories proposed in microeconomics are explained in more detail in this section cause of their relevance regarding the implementation of the agent-based consumer market.

2.1.1 Model of supply and demand

The *model of supply and demand* is a fundamental research topic in the fields of microeconomics that is dealing with markets. Markets are defined as an aggregation of buyers and sellers that determine the prices and quantities of diverse goods and services traded on the market through the interaction between them [39]. The model of supply and demand is used to understand how prices and quantities for products and services are established in a market. This model explains this process of price and quantity building with the help of the *demand curve* and the *supply curve* focusing on the buyer and the seller perspective. Demand is in that context the quantity of a product or service desired by all consumers in the market dependent on the price of the good. The already mentioned demand curve is therefore a graphical representation of the relation between quantity and price for a given market and product or service. The demand curve is a downward slopping curve and follows the law of demand that denote the fact that the demanded quantity for a product or service rises as the price of this product decreases [39]. An example for a demand curve can be seen in Figure 2.1 that shows the relation of the willingness to pay for a pizza slice according to the quantity of pizza slices available on the market.

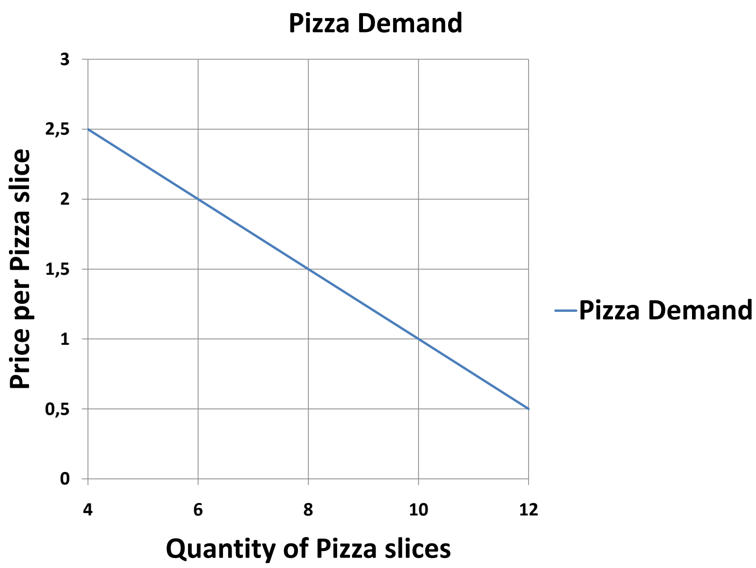


Figure 2.1: Demand curve that shows the quantities of pizza slices demanded for specific prices on the market (adapted from [39])

A reason for downward slopping demand curve is that the customers expect a benefit when buying a product or service. A reasonable customer will buy a good only if the expected benefit of this purchase will exceed the costs of it. If the price for a product rises the benefit will decrease for the customers until no more customers are satisfied by the cost benefit of the purchase. There are of course other factors next to the price that influence the demand of consumers like the income that can be a restriction for buying a good as well as the taste of consumers, prices of substitutes and complements on the market. The demand curve of a market is of course affected

by these factors and can be formulated as a *demand function*. Preferences or tastes of consumers for a product can of course be influenced and changed by the use of marketing campaigns of businesses that are commonly resulting in a overall higher willingness to pay. As well as the preferences the expectations of consumers can also affect the demand curve for example if the consumers expects a higher income or that prices of a given product will increase or decrease in the future. But the main factors that influence the consumers in making their decisions will treated later with the behavior model. [39]
Considering the supplier perspective there is the *supply curve* that follows the same principle as the demand curve. The supply function is on the contrary to the demand function a rising curve that shows how many products a vendor is willing to produce and sell for a given selling price of the product. The supplier will only produce if he is able to sell the product to a price that compensates at least the production costs and time he invested. The higher he could sell a product, the higher is the profit for a sold product and the willingness to produce additional products. This can be seen in Figure 2.2 with the same pizza example on the supplier side. [39]

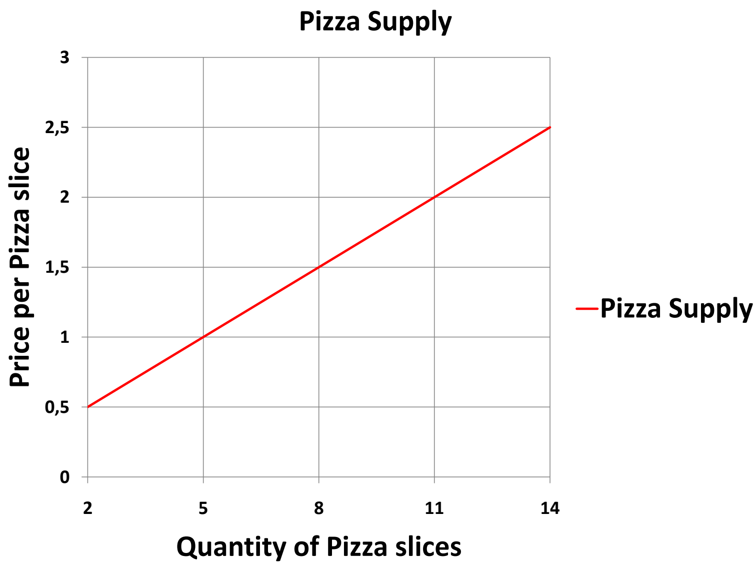


Figure 2.2: Supply curve that shows the quantities of pizza slices a supplier is willing to produce for a specific selling price (adapted from [39])

Another explanation for the rising quantity is the substitution from other suppliers that are switching because of the rising price. The producer can for example decide to produce pizza instead of hamburgers if he has a higher benefit when selling pizzas. [39]
Using the demand curve of the consumers and the supply curve of the suppliers for a given product it is possible to describe the *equilibrium quantity and price* for this product on the market. The equilibrium quantity and price is the price-quantity pair at which buyers and sellers are both satisfied. According to the demand and the supply curve it is the price-quantity pair at which these two lines intersect. [42] The resulting equilibrium from the demand and supply curve of the pizza can be seen in Figure 2.3.

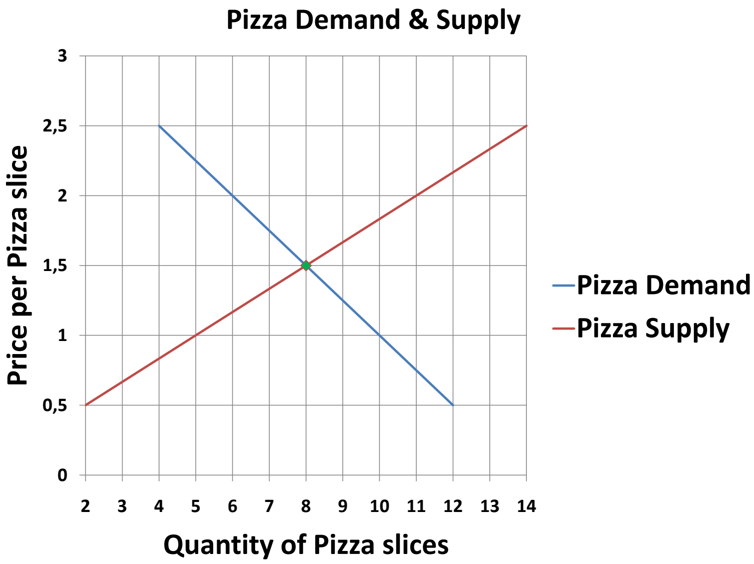


Figure 2.3: Resulting equilibrium of the demand and supply curve on the crossing point of the two lines (adapted from [39])

If the pizza slices would we bought to another price than the equilibrium price either buyers or sellers, or both, would be dissatisfied. The theory of market demand and supply also considers the market structure that is influencing the form of the demand and supply curve. The two main types of market structures used in microeconomics are the *perfectly competitive* and the *imperfectly competitive* markets [42]. The market used for the explanation is the competitive market that will be explained in Section 2.1.2. Another important analytical concept that is of major interest for the demand and supply model is the concept of *price elasticity of demand*. The price elasticity of the demand is defined as measure of the responsiveness of the demand for a product to a change of the price of the same product. The elasticity is given as the percentage change in the quantity of a demanded good that is resulting from a change in the price [42]. The formula to calculate the demand price elasticity can be seen below in Equation 2.1 where ε is the resulting elasticity, P is the current price of a good, Q is the demanded quantity at that price, ΔP is the change in the price and ΔQ the resulting change in the demand.

$$\varepsilon = \frac{\Delta Q/Q}{\Delta P/P} \tag{2.1}$$

The price elasticity is always a negative value because the price changes always move in the opposite direction from changes in quantity demanded. The demand for a good is elastic to the price if the resulting price elasticity is less than -1. The demand for a good is inelastic with respect to price if its resulting price elasticity is greater than -1. If the elasticity is exactly -1 it is defined as unit elastic. The three categories of elasticity can be seen in Figure 2.4.

The resulting price elasticity depends highly on the number of substitutes on the market. If the consumer can easily choose another alternative product the demand curve is normally

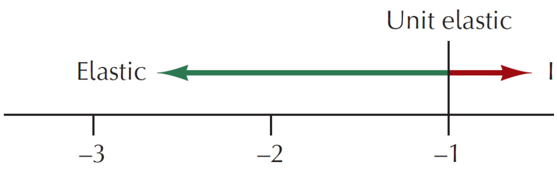


Figure 2.4: Three categories of elasticity [42, p. 112]

more responsive to price changes of the original product. The steeper the demand curve is, the less elastic is the demand for the product at any arbitrary point on the given demand curve and therefore reacts weaker to changes in the price.

2.1.2 Theory of perfect competition

The theory of demand and supply is using the concept of perfectly competitive markets that results in the theory of perfect competition. The concept of the demand curve, the supply curve and the resulting elasticity of demand assumes that the underlying market satisfies four elementary conditions to fulfill the criteria for a perfect competitive market [42].

- **Standardized products:** There are standardized and homogeneous products or services on the market that have no differences in the quality and characteristic between different suppliers. In a perfectly competitive market, the product sold by one company is considered to be perfect substitute for the product sold by any other.
- **Firms are price takers:** Firms are behaving as price-takers and no single participant gut influence the price of a product it buys or sells and there are no present entry or exit barriers on the market. A market price is therefore not affected by a singly firm regardless of how much output it produces on the market.
- **Perfect factor mobility:** There exists a perfect long-run mobility of factors or production on the market, allowing flexible and cost-free long term adaptations to changing market conditions and there are no costs in the exchange of the goods. Additionally, there are no entry or exit barriers in the market that hinder participants to join or leave.
- **Perfect information:** All firms and consumers on the market possess perfect knowledge of the prices, utilities and the quality of products on the market. The information is accessible without any barriers or time limits and allows therefore a fast reaction to changes that happen on the market.

Because of the fact that in prefect competition products are homogeneous on the market, the consumer uses the price as parameter to choose if and what product he is going to buy. With the price as the only utility value the consumers and suppliers of the market are able to communicate with each other. Following the fact that one firm or consumer on the market is relatively small in comparison to the whole market, the presence or absence has no significant effect on the equilibrium price. Due to the perfect information of consumers and suppliers on the market the changes in the previous defined demand and supply curve will be communicated in a short period of time forcing the suppliers to change their prices until all participants will agree to the equilibrium price. Additionally, there is no need to invest in advertising, because there is perfect knowledge of all the products and firms on the market. Of course these conditions can hardly be found on real market regardless of the type of industry. Nonetheless, this is used to generate useful insights in economic models even if the model assumptions are only partly satisfied. [42]

2.1.3 Theory of rational consumer behavior

The theory of the rational consumer behavior is also known as choice theory or rational action theory. It describes and adds up all individual choices that are made from a consumer when buying a product on the market. The sum of all these individual decisions on the market results in the demand curve of the market. Rational choice theory assumes that all consumers that enter the marketplace have existing well defined preferences of the offered goods. Consumers try to portion their available budget to satisfy their own preferences in the best possible way. [42]
To fulfill this task, the consumer has to define the different combinations of goods he wants to buy and is able to buy. These combinations depend on the available budget of the individual consumer as well as the prices of the goods on the market. Accordingly the buyer has to describe his preferences of all feasible combinations in forms of a ranking. These combinations are also called product bundles. This step assumes that the buyer posses perfect information of the market. The idea behind this theory is that the consumers will always act rational in his decision and buy the most preferred bundle of goods that is on the same time the highest ranked bundle for the consumer on the market. [42]
A concrete product bundle B_1 consist of several products that can be represented as B_1=(a_1,a_2,...a_n) in which a_i represents the quantity of a particular good in the bundle. The limited budget *b* of a consumer restricts the possible bundles that are available to choose. Therefore the sum of all prices p_i times the amount for the product a_i where *i* indicates the particular product/amount combination cannot exceed the budget *b* of the consumer and is the budgetary constraint with its formula in Equation 2.2 below. [42]

$$a_1p_1 + ... + a_np_n <= b \tag{2.2}$$

To make those bundles comparable depending on the individual preferences of each customer the *utility value* is calculated with the *utility function*. With this approach, for each possible and affordable bundle of goods a number is calculated that is called *utility value* and represents the satisfaction of the customer with the specific bundle. The utility function is calculated with the particular amount a_i of the different goods depending on how important the amount of one good is compared to another. The specific utility value *u* is therefore calculated with the function *U* depending on the amounts a_i of the different goods. In Equation 2.3 the equation for the utility value calculation value can be seen. [42]

$$u = U(a_1, a_2, ..., a_n) \tag{2.3}$$

The higher the utility value u is the more preferred is one bundle to the customer than another one. All bundles with the same utility value are equal in terms of their benefit for the buyer. The concept of utility allows the ranking bundles of goods for individual user preferences. A consumer always tries to maximize his utility and chooses therefore the bundle that is affordable to him with the highest utility value. Preferences among various consumers can of course differ and result therefore in different utility values for the same bundle of goods. The concept of utility is therefore only applicable to compare bundles for a specific customer (or customers with the exact same preferences) and not to compare utility values of different bundles between consumers with diverse preferences. [42]

2.2 State-of-the-art models in business games

As already mentioned in the introduction of this work there are different and older algorithms next to the newer agent-based modeling approach that are used to model the demand in a business simulation game. According to Gold and Pray [31] who reviewed articles that are representing algorithms for business simulation games, the most important algorithms beside the agent-based modeling approach used in business simulation games can be categorized in:

- **Equation based models:** The industry demand and the firm demand are modeled as two functions in the game. [43]

- **Interpolation based approach:** The interpolation approach uses self-designed functions based derived from graphics. [44]

- **Statistical based approach:** This approach uses a probability distribution to model the purchase proportion on the market. [45]

Each of the following three algorithm approaches will be explained in detail in this section, explaining their principle of modeling the market as well as their advantages and disadvantages when implemented in a business simulation.

2.2.1 Equation based models

One approach that was thoroughly reviewed and described by Gold and Pray in 1982 to 1984 [46] [43] [47] was the equation based modeling approach. Gold and Pray [46] reviewed several computerized business simulations and compared the internal algorithms used to calculate the demand and sales in the simulations. In the following two years Gold and Pray [43] have built on the acquired knowledge and developed a multiplicative mathematical functional form to create market- and firm-level demand for business simulations. In a further paper of Gold and Pray [47] they extended their mathematical functional model and described how non-price factors like marketing and research & development of firms can be considered in calculating the demand.
According to Gold and Pray [46], in economic texts the demand quantity (Q) is a function of a

number of independent variables like price (*P*), income (*Y*), price of a related good (P_R), advertising (*A*) or other factors. In their paper in 1982 [46] they stated that in managerial economics there are two main mathematical functions to express the quantity of the demand:

1. $Q = a + bP + cA + dY + eP_R$
2. $Q = a + P^b A^c Y^d P_R^e$

Equation (1) describes a linear model that is according to Gold and Pray [46] most often used in econometric analysis because of the following reasons:

- Experience indicates that most of the demand relationships are nearly linear over the available data.
- This model is easier to estimate with the least squares method.
- The impact on the total demand is more independent to a slight change of any other demand variables.

Equation (2) is a power function or log-linear model that is according to Gold and Pray [46] the second most popular econometric functional form to calculate the quantity of demand. The reasons for choosing this functional form are the following statements:

- It is like the linear model also easy to estimate with the log-linear regression techniques.
- It gives good econometric results with according to the goodness of fit.
- The impact on the total demand due to a slight change of a single variable is argued to be more realistic compared to the linear model.

In the following paper of Gold and Pray in 1983 [43] they come up with further suggestions how to exactly implement an equation-based model for the market demand based on the analyzed games in their foregone paper. They noted four concepts that have to be considered in order to implement a stable equation-based demand function using the independent variables price (*P*), marketing (*M*) and R&D (*R*) expenditures.

1. The harmonic mean should be used to calculate the average market price.
2. Exponential smoothing should be used on all demand variables to capture the inter-temporal effects.
3. A generalized multiplicative market demand function should be used to allow variable elasticities.
4. A generalized multiplicative method should also be applied to calculate the firm level demand which has variable firm level elasticity and is constrained by the total market demand.

The harmonic mean (1) is used in the demand function to calculate the average market price. The lower prices will be weighted relatively more than the higher prices. Gold and Pray [43] claimed that due the fact that low priced products/firms generate a higher demanded quantity than high prices products/firms. The harmonic mean price *P* for the industry is calculated with the help of the number of firms in the industry *n* and the price of the product produced by firm *i* as p_i. The formula for the harmonic mean can be seen below in Equation 2.4 [43].

$$P = \frac{n}{\sum_{i=1}^{n} \frac{1}{p_i}} \tag{2.4}$$

Exponential smoothing (2) is considering the past values of the independent demand variables as well as the current ones. The current and past expenditures of different variables impact on the potential demand quantity of a firm. The exponential smoothing technique allows specifying how important the historic value is in comparison to the current one with an exponential smoothing coefficient for each independent demand variable. A larger value for the smoothing coefficient put more weight on the current value whereas a small value put more weight on the historical value. The exponential smoothing for a demand variable *V* is calculated with the period-aid smoothed value V_o, the mast current mean value V_n and the smoothing coefficient *a*. The formula of the exponential smoothing for the independent demand variables can be seen in Equation 2.5. [43]

$$V = aV_n + (1 - a)V_n \tag{2.5}$$

To calculate the market demand (3) and the firm demand (4) Gold and Pray [43] recommended to use a multiplicative market demand function (power function) due to the fact that it allows variable elasticity. The market demand consists according to Gold and Pray of three variables. The exponentially smoothed harmonic price, the exponentially smoothed R&D expenditures and the exponentially smoothed marketing expenditures that were used with constants in the multiplicative market demand power function. The market demand *Q* is therefore calculated with the exponentially smoothed harmonic price *P*, the exponentially smoothed R&D expenditures *R*, the exponentially smoothed marketing expenditures *M* and the constant parameters g_i as shown in Equation 2.6. The constant parameters g_i that are used in the market demand formula are depending on the designer's specification concerning the elasticity values specified for the demand. [43]

$$Q = g_1 P^{-(g_2 + g_3 P)} M^{(g_4 - g_5 M)} R^{(g_6 - g_7 R)} \tag{2.6}$$

The firm demand is a weighting function that determines the proportion of demand for each firm depending on the total market demand. As already mentioned the firm demand function is like the market demand function also a multiplicative function. To calculate the weight of the total market demand for each firm the firm demand function uses the price, the marketing expenditures and the research and development expenditures for each firm. The firm demand weighting w_i for firm *i* is calculated with the price of firm i p_i, the marketing expenditures for firm i m_i, the research and development expenditures for firm i r_i and the constant parameters

k_i. The parameters k_1, k_4 and k_7 are necessary to prevent the resulting weight from being zero. Equation 2.7 shows the weighting function formula with its parameters. [43]

$$w_i = [p_i + k_1]^{-(k_2+k_3*p_i)}[m_i + k_4]^{+(k_5-k_6m_i)}[r_i + k_7]^{[k_8-k_9r_i]} \tag{2.7}$$

Based on the calculated overall market demand Q and the firm demand weighting w_i, the firm level demand q_i can be derived as shown in Equation 2.8 [43].

$$q_i = w_iQ \tag{2.8}$$

2.2.2 Interpolation based models

As an answer to the equation based models, Goosen [44] criticized in 1986 that designers of simulations are often have to define the functional relationships in systems with less knowledge of the theory and practice behind it. Consequently, the game designers have problems in developing such equations that provide a desirable result for a broader range of decision variables. Goosen [44] argued that there is a lack of flexibility to simulate a broad set of demand characteristics in equation-based models because a game usually includes a number of diverging functional relationships for that the precise functional behavior is not prescribed in theory or implied by empirical data. Goosen [44] presented with the interpolation based methodology an approach that should overcome the mentioned problems.

The interpolation based approach is a graph-based model that demands the game designer to define the desired relationships in the simulation game in a graphically way. The graphical representation of the specific relationship can consist of multiple inflection points and minimum and maximum points if needed by the game designer. An inflection point or point of inflection is a point on a curve at which this curve changes its form from being concave to convex or the other way round. These points are used in functions to model for example increasing and decreasing returns. Aim of the interpolation based model is to obtain the dependent variable values for every independent variable value that is used in the game. To determine the dependent variable as output from independent variables, that are often used as decisions values, functional equations are used. The resulting conditioned value of the variable is either an output that is used as statement or the input for another functional equation. [44]

Goosen [44] argued that if a business relationship has to be realistic the relationships that have been found in reality had to be also considered within the business simulation game. Like in the equation based model there are a number of values like price, advertising, research & development, wage rate, credit etc. that have to be recognized as independent variables in the game. The main point in defining a functional relationship is the theory that supports the specific relationship as well as the minimum, maximum and inflection points for a specific relationship. The goal of the interpolation based method is to approximate functional equations based on minimum and maximum values or points on inflections that are given by the designer. [44]

To construct such a functional equation there according to Goosen [44] four steps necessary within the interpolation method to receive the mathematical function. The four steps are:

- **Prepare graph:** A graph has to be prepared with the required calibrations and the detailed outlined curvilinear functional relationship.

- **Select points:** Different points have to be selected in constant intervals based on the drawn relationship in order to deduce the interpolation schedule.
- **Prepare schedule:** The schedule is going to be calculated based on the specific coordinate values of the points that have been selected. These ordered paired values of the coordinates are called range values.
- **Compute missing values:** For any autonomous value of a specific variable that is not listed in the table of range values the missing dependent value is computed by using the interpolation equation presented in a paper by Goosen [44].

In Figure 2.5 that is taken from the original paper from Goosen [44], the illustration of the interpolation algorithm can be seen with the functional relationship between the two variables wage rate and production rate per hour and the interpolated values that are computed from the curve with the interpolation algorithm.

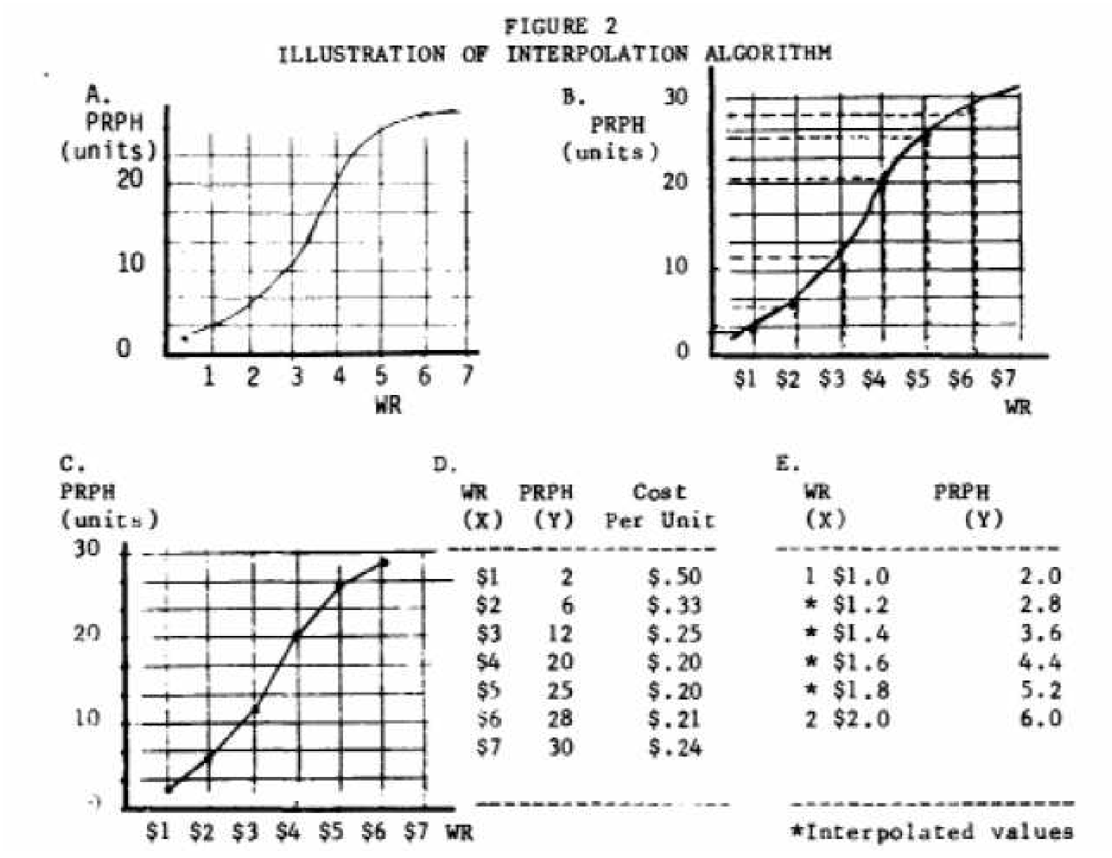


Figure 2.5: The functional relationship between wage rate and production rate per hour and the resulting table resulting with the resulting interpolated values. [44, p. 250]

In comparison, with the equation based model this approach gives the simulation designer more control over the favored results without the need to compute the needed parameters of equations on his own like in the example of Gold and Pray [43]. This approach offers an abstraction for the simulation designer and helps him to focus on the game itself and not on the parameters of the complex mathematical equations used in the system. Gold [48] criticized in 1993 the interpolation based approach because it does not consider interactive effects between the dependent and independent variables which are embodied in most business relationships. Gold [48] argued that in sophisticated demand, production, or cost functions it should be possible to implement interactive effects to exist between the independent and dependent variables. An interactive effect is available when the relationship between two variables is influenced by the level of a third variable. These interactive effects can be linear but are mostly non-linear.

2.2.3 Statistical based approach

As a third approach to model the demand market in a business simulation game, Carvalho [45] proposed the statistical-based approach in 1995. Carvalho criticized that the already available approaches did not explicitly model the essential element of a marketplace: the consumer. In his statistical based approach he uses a gamma probability distribution to simulate the different preferences of the consumers on a market. Carvalho [45] uses the equimarginal principle for the market demand in the simulation of his model that build upon the marginal utility of the utility function that was already introduced in Subsection 2.1.3.
The marginal utility for a certain good measures the resulting rate regarding the change of the total utility from an increase or decrease of the consumed quantity of that good. The concept of marginal utility is helpful to explain how a consumer will decide on a given bundle of goods with different quantities. The equimarginal principle states that a consumer reaches the equilibrium when the proportion between marginal utility (*UM*) and price (*p*) is the same for all goods on the market. In this state of equilibrium the consumer maximizes its total satisfaction causing that the last monetary unit bought of each good (*p*) results in an equal amount of marginal utility (*UM*). The equimarignal principle states that all ratios of marginal utility for a product UM_n to the price P_n are equal for each good on the market like it is shown in Equation 2.9. [45]

$$\frac{UM_1}{P_1} = \frac{UM_2}{P_2} = ... = \frac{UM_n}{P_n} = \text{UM per monetary unit} = \pi \tag{2.9}$$

The marginal utility depends in fact on the utility function, that differs from consumer to consumer based on the preferences of each them. As a consequence of this, each buyer has of cause another marginal utility per monetary unit (π). Carvalho used a gamma distribution function to model the probability distribution of π for the whole market. The consumer demand market was modeled with this gamma distribution function that is depended of the two parameters α and β. The two parameters are defined as shape parameter (α) and the rate parameter (β) of the distribution function and are shown with two examples of distribution curves in Figure 2.6

Each product on the market has according to these model a particular ratio between marginal utility and price (π_p). The marginal utility of this product was in Carvalho's model directly related to the two variables quality (*Q*) and price (*P*) of the particular product. The product marginal utility/price ratio (π_p) for the product (*p*) is calculated with the product's price (P_p),

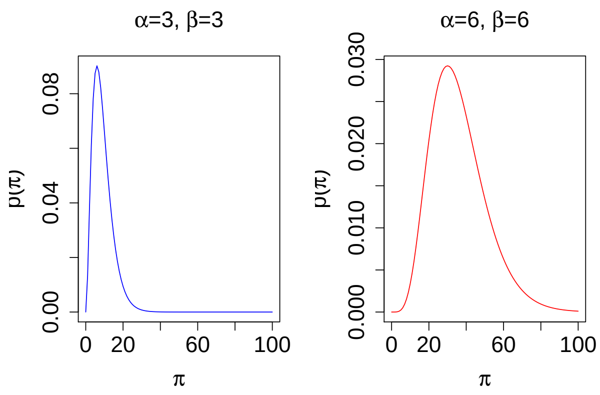


Figure 2.6: Two different possibilities of purchase probability functions of a market with the parameters α and β and the resulting probability $p(\pi)$ based on the marginal utility per monetary unit π

research & development expenditures (*R*) for the company, the marketing expenditures (*M*) for the company and the various constants (k_i) as it is shown in Equation 2.10. [45]

$$\pi_p = k_1 + \frac{k_2 - P_p}{k_2 * k_3} + \frac{R - k_4}{k_4 * k_5} + \frac{M - k_6}{k_6 * k_7} \text{ ,with } k_i = 1....7 \epsilon \Re \tag{2.10}$$

A product is going to be bought on the market if $\pi <= \pi_p$. The proportion of the consumers on the market buying the specific products offered, is calculated with the density function from 0 to π_p as shown in Equation 2.11. [45]

$$F(p) = \int_0^{\pi_p} p(\pi) d\pi \tag{2.11}$$

Carvalho's model was supported by Gold and Pray [49] who had also the opinion that the individual consumer should get more attention when modeling the demand model. The two parameter α and β that are used to model the shape and the rate of the distribution can be changed in the game to simulate changes in the income, taste or number of consumers on the market. Although Gold and Pray [49] supported the idea of modeling the individual consumer, they also criticized some limitations of this model. They argued that the distribution parameter values (α and β) are difficult to control for a game designer. The relation of these parameters to the income, taste and market dimension was not clearly defined within this model. Additional to that point of critique Gold and Pray [49] mentioned that in this model there is no explanation provided how the firm demand is calculated in detail. The use of the distribution function just calculates the market demand but did not provide a solution to determine the proportionate firm level demand for each company on the market [49]. Similarly to the interpolation approach, this sort of model never became as favored as the equation-based models.

2.3 Agent-based modeling approach

Agent-based modeling (ABM) approach is compared to the other simulation models a relatively new paradigm to model the market that started its notable expansion in the 1990s [50] [1]. Like the already presented statistical based approach the agent-based modeling approach focuses on the individual consumer on the market.
The concept of agent-based modeling is a form of simulation that consists of different agents in a simulation with simple rules of behavior the agents are using to make their decisions. Through the fact that these agents are individual in their behavior, the rules or parameters they are applying can change from agent to agent. When they individual agents are simulated in the game the aggregated rules of behavior for all individual agents can result in complex systems dependent on the different simulation situations. [51]
An agent in an agent-based simulation is defined as an autonomous object with its own characteristics and particular behavior. In order to apply the agent-based modeling approach to a game, the game designer can concentrate on defining the properties and behaviors for each individual agent type in detail and the possible interactions with other agents or the environment in the simulation. By creating an amount of such heterogeneous consumer agents that have different properties an artificial heterogeneous market can be defined and simulated. [52]
Rand and Rust [51] argued that the biggest advantage of the agent-based modeling approach is the fact that none of the mentioned definitions requires knowledge of macro-dynamics theory from the designer. The game designers focus on the implementation of the micro-rules of behavior and measure the result on the macro level after the simulation finished. This bottom-up approach allows to understanding the emerging result of a complex system based on simpler individual decisions of the individual agents. It is often used to search for an analytical insight into the overall behavior of agents that are just following simple rules in a system. Agent-based modeling is an approach that combines different elements like complex systems, game theory, computational sociology, emergence, evolutionary programming, and multi-agent systems. [51]
Although agent-based modeling provides a new approach that can help solving the problems of the three already mentioned modeling techniques for business simulation games, the agreement and publication of this approach in the highest-level journals has been slow [51]. This results mainly due to the lack of wide accepted standards of how agent-based modeling is used rigorously. Additionally, through the fact that the agent-based modeling approach is a computationally intensive form of simulation, its application was depended on the growing computing power [53]. Rand and Rust [51] supported this statement and argued that this computational simulation method will become more and more powerful and applicable as time goes on.

2.3.1 Models in ABM

Agent-based modeling follows the key notion that simple and elementary behavioral rules are able to generate a complex behavior of the total system. They are also following the tenet that: 'The whole is greater than the sum of the parts'. Agents are typically characterized as bounded rational and following their own interests using simple rules or heuristics to act or even learn and adapt during a simulation [15]. One of the difficulties resulting from this explanation of agent-based modeling is to capture the adequate level of detail of the different agents in the simulation. [54] According to Bonabeau [54] agent-based models are composed of:

- numerous agents of different types specified at various scales
- decision-making heuristics or rules based decision support
- rules for learning or adaptive processes
- a topology for interaction within the simulation
- a non-agent environment to interact with

Agent-based models are typically implemented as computer simulations. This can be either realized as custom software, or with toolkits and frameworks that support the implementation and test. They also support the designer to see, how adjustments of single behaviors will affect the total emerging behavior of the system. [54]
The level of detail that is used to model the agents for a simulation depends according to Twomey and Cadman [55] on the system that is being modeled as well as the questions that are being asked in that context. Hood [56] distinguished the accurateness of the representation into three different categories with following definitions:

1. **Low fidelity:** This means that all agents that are within the model have the same behavior and attributes. There are no different types of agents that can be differentiated in the simulation. These kind of low detailed agents are of interest for problems where the statistic of a collection of entities is the primary focus for the modeling like in many physic and chemistry simulations. Because of the simple agent design there are normally much higher numbers of agents used than in usual agent-based models. [56]
2. **Medium fidelity:** This level uses an observed distribution of the agents' behavior for the model. This level of detail is useful for models where the ending of the distribution needs to be observed. It is possible to retain some of the observed characteristics of the different agents without having to reveal the internal mechanisms of the agents. [56]
3. **High fidelity:** This is the most complex level of detail for agent-based models that tries to unveil the internal mechanisms of the agents. Among other thing the goal is to model the beliefs, the individual desires and the intentions of the agent. The agent has also the ability to adapt and learn during the simulation so that the agent's behaviors and characteristics evolve over time. The agents are enabled to learn about their own environment and observe what actions and decisions lead to success or failure. This level of fidelity leads to the idea of a mentalist or cognitive agent. [56]

Particularly the high detailed agents need some theoretical basis in order to explain the used determined processes of human behavior to model a consumer market. Until know there are no consistent attempts present that offer a integrative model that combines the different psychological theories together in a form that it could be applied in agent-based model [55]. Twomey and

Cadman [55] stated that until know the attempt of Jager and Janssen [57] [58] [59], to provide a multi-theoretical conceptual model combining different theories of behavior that are relevant for describing the consumer behavior, is the most promising one in the field. Their aim was to observe the significant processes of decision making and relate this to available empirical data from psychology in the social field in order to implement a rule-based multi-agent model from the derived knowledge. This multi-agent model consists of behavior rules from a multi-theoretical model of consumer behavior. Jager and Janssen [57] [58] [59] stated that each consumer could get involved in different cognitive processes while deciding which product to choose on the market depending on their minimum level of satisfaction and their limit for uncertainty. The two dimension satisfaction and uncertainty are used to classify four possible modes of cognitive processing in their model [57] [58] [59]:

1. **Repetition:** In this mode the consumer has a high degree of satisfaction and a low uncertainty. There is this state there is no urgent to look around for other satisfying goods and the consumer know what he gets when he buys the product. The consumer will just repeat the previous behavior order to remain satisfied. [58]

2. **Deliberation:** This mode is present when there is a low satisfaction with a good so that the urge to look for other goods on the market increases. But of the fact that the consumer possess a high level of certainty of outcomes it is not necessary to look at what other consumers are doing on the market. [58]

3. **Imitation:** This mode appears with a high level of satisfaction from a good but because of a present high level uncertainty about the outcome the consumer is more likely to follow other consumers on their decisions suggesting that imitating others' behavior may be beneficial. [58]

4. **Social comparison:** Similar to the imitation mode the consumer is highly uncertain and is looking around at what other are doing on the market. Cause of the low level of satisfaction in this mode agents are trying to deviate some additional information about the good from the interest other agents have for the p. In that mode people have a drive to evaluate the behavior of similar others when they feel uncertain about which behavior/decision to perform/choose. [58]

Jager and Janssen [57] [58] [59] argued that these factors at the micro and macro level are needed because they steer the consumption behavior and the linked cognitive processes of the single consumer. Therefore their created conceptual model combines theories and variables from these two levels. At the macro-level of their conceptual model they differentiate between economical, demographic, technical, institutional and cultural developments. On the micro-level they differentiate between the needs of the consumer, the possible goods that can be consumed and the capacities the consumer has as to consume it. The two basic variables of this conceptual model are the representation of the two dimensions level of needed satisfaction (*LNS*) and the uncertainty (*Unc*). Jager and Janssen [57] [58] [59] used four needs in their conceptual model to calculate the total level of needed satisfaction (*LNS*). The total level of needed satisfaction (*LNS*) is calculated as weighted sum of the individual needs. The four needs in the model of Jager and Janssen [59] are:

1. **Need for identity:** The level of gratification for the need identity (*LNS1*) depends on the amount of agents that consume the same product.
2. **Personal taste:** The personal taste is an personal characteristic of an agent and is the satisfaction for personal taste (*LNS2*) for a specific good.
3. **Leisure to the price:** The need satisfaction for leisure (*LNS3*) is related to the costs of the products, by expecting that goods with lower costs need less time to generate income.
4. **Subsistence:** The individual sensitivity to pollution determines the individual level of satisfaction for the specific need subsistence (*LNS4*) and is related to the rate of pollution of a good.

As already mentioned, the second dimension in the conceptual model is the uncertainty (*Unc*), which is used to define the mode of cognitive processing. Jager and Janssen [59] defined that the uncertainty of a consumer can be calculated as the discrepancy between the expected level of needed satisfaction and the actual level of needed satisfaction. In their model it is assumed that the expected level of needed satisfaction is equal to the detected experienced level of needed satisfaction in the last period. Based on the derived level of needed satisfaction (*LNS*), the level of uncertainty (*Unc*), the defined minimum level of needed satisfaction (*LNSmin*) and the maximum tolerable uncertainty (*Uncmax*) the according cognitive processing is chosen [59]:

1. **Repetition (Unc<Uncmax, LNS>LNSmin):** If the individual agent is satisfied but not uncertain, it will purchase the same product as in the period before.
2. **Deliberation (Unc<Uncmax, LNS<LNSmin):** The agent will control all feasible solutions and select the best feasible solution.
3. **Imitation (Unc>Uncmax, LNS>LNSmin):** In this case, the agent inherits the behavior of the consumers that build the majority on the market.
4. **Social comparison (Unc>Uncmax, LNS<LNSmin):** The agent will choose that good which has been purchased the most by consumers with similar characteristics in the last period.

The model can evolve differently according to the level of the maximum tolerable uncertainty (*Uncmax*) and the minimum level of needed satisfaction (*LNSmin*) that is configured. This concept model considered the micro as well as the macro level and different modes of cognitive processing. Unfortunately there is no explicit consideration for the marketing and promotion expenditures as well as the costs of the products in the original model of Jager and Janssen [58]. This lack of variables makes in the conceptual model not suitable for our implementation. Figure 2.7 shows the illustration of the conceptual model of consumer behavior

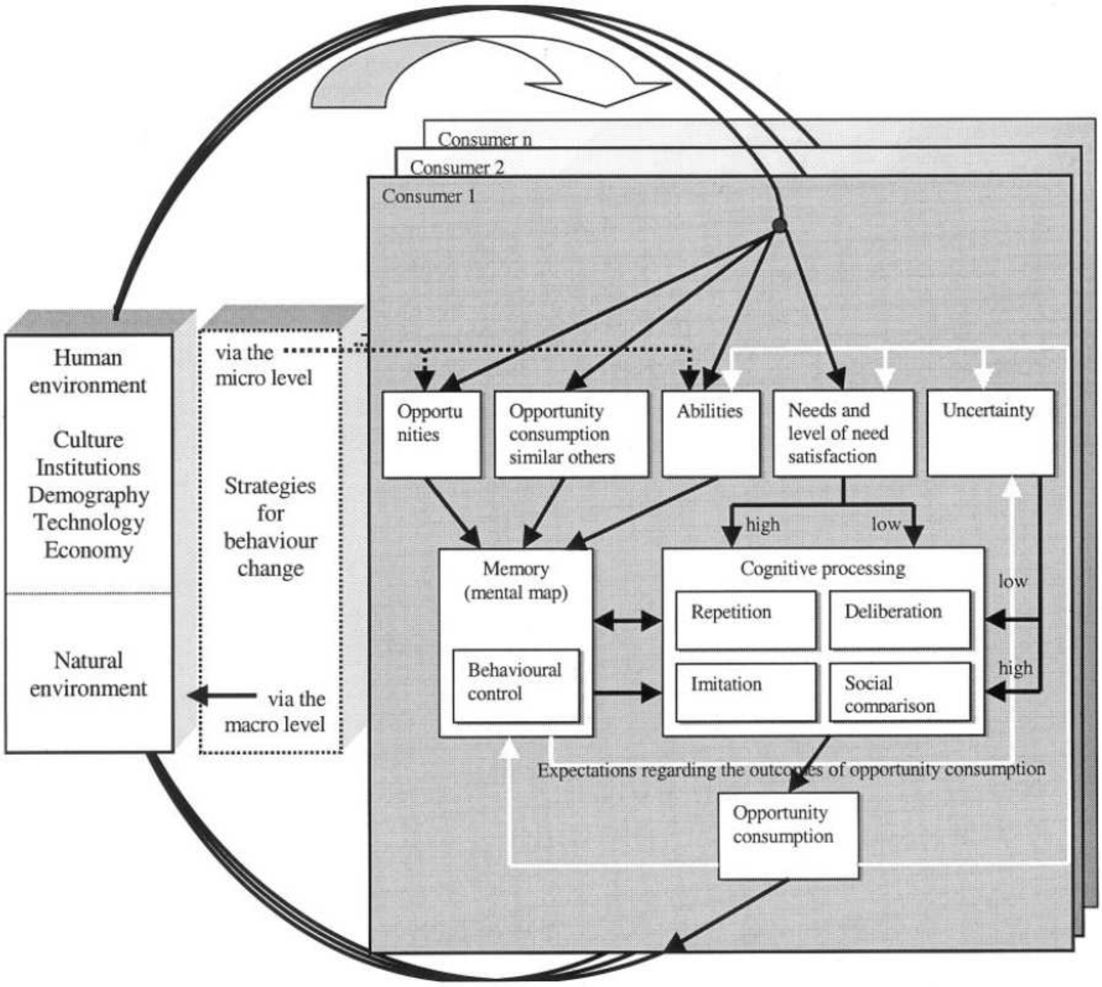


Figure 2.7: The conceptual model of consumer behavior. [57, p. 97]

2.3.2 Advantages of the agent-based modeling approach

As already stated in the previous sections there are many advantages that arise with the usage of the agent-based modeling approach. Twomey and Cadman [55] and Hood [56] summarized the advantages of agent-based modeling compared to the most modeling techniques:

- **System assumption:** One of the main strengths of agent-based modeling is the fact that the system in total is not regulated to a particular behavior within the system. There are no assumptions of linearity or equilibrium in the model that are mostly found in the older top-down modeling approaches. The emerging behavior of a system that results from the micro-level is normally one of the most interesting outputs the agent-based model can provide. [56]
- **Realism:** The agent-based modeling approach is a more realistic approach because it is

like the real world a system of interacting entities that can be individually modeled. [56]

- **Natural representations:** Compared to other model definitions the agent-based modeling approach is easier to understand through the fact that it use simple and structural rules on a micro-level of the system. The rules that are applied are mostly more intuitive and simpler to understand than a system of complex mathematical equations that simulate the demand on the macro-level. [55]

- **Heterogeneity:** With the use of different agent types in a model it is possible to introduce a high degree of diversity (heterogeneity) in a population of agents. Traditional models that use mathematical models often assume homogeneous actors in their models. The use of agent-based modeling allows applying different rules and different attributes to agents that leads to an increasing heterogeneity of the system's composition and population. [55]

- **Bounded rationality:** Agents can be modeled with bounded rationality based on the rules that are applied to the different agent types. Limited abilities and limited information to process information can be considered in the internal models of each agent type and there is no need to assume perfect rationality in the model if not required. [55]

- **Communication and social networking:** Another advantage of agent-based modeling is the ability to implement communication between agents. This enables the agents to share data or imitate other agents that are in the population. That level of fineness can be usually not provided with the use of traditional mathematical models because of the too high rising complexity of the needed equations that have to be applied to them. [55]

- **Object-orientated analysis, design and programming:** The agent-based modeling approach can be combined well with an object-orientated analysis, design and the programming approaches through the fact that each agent can be represented as an object in the defined model. [55]

- **Maintenance and refinement:** The extension of the model with new types of agents that consists of new attributes and behavior is easy manageable without reformulating the whole existing model and without destroying the definitions of old agent types. [55]

2.3.3 Disadvantages of the agent-based modeling approach

Like in each other model there are of course also disadvantages that could occur cause of the use of agent-based models. The additional flexibility of agent-based modeling approach can lead to problems and difficulties that Twomey and Cadman [55] stated in their paper.

- **Data problems:** One of the major problems of this approach is the missing sufficient data. Most quantitative research until now concentrated mainly on variables and their correlation. That is not suitable with the process-based simulation approach that is characteristic for agent-based modeling. Twomey and Cadman [55] argued that cause of this lack new theories are needed that consider and support the potentialities of agent-based simulation.

- **Identifying rules of behaviors:** Capturing the needed rules or mechanisms that are used to model the agents' behavior can be depended from the application and the level of fidelity a time-consuming task. [55]

- **Programming skills:** Any advanced agent-based model implementation requires in most cases a programming language in order to implement the rules and behavior or even the whole agent. This causes a shift in the sense that programming skills got more important for modeling than mathematical skills. There are of course agent-based software frameworks available that help social scientists or business analysts abstracting, to build a system with agent-based modeling without requiring special programming skills. [55]

- **Computational time:** Agent-based models are, depended from their level of fidelity, computationally much more intensive than the traditional approaches. Although the computing power nowadays allows the use of agent-based modeling there are still limits in sense of the level of detail and the amount of agents that can be run in a simulation within a reasonable amount of time. [55]

- **Unrealistic model expectations:** Twomey and Cadman [55] mentioned the possible danger that new users of the agent-based model approach may expect too much from the model in case of the predictive power. In a model it is certainly the case that to much complex adaptive patterns result in a chaos, which make any long-term predictions practically impossible. Twomey and Cadman [55] also argued that the agent-based modeling approach can in that case also be used to discover. With experimenting for example it can be discovered that the linkage of two apparently unimportant behaviors can drive the system into a different direction. [55]

- **Lack of prescriptive ability:** Hood [56] already stated in 1998 that agent-based modeling approach usually provides no mechanism to regulate or steer the total system from one state to another. That means that it is on the one hand possible to repeat a simulation run under differing scenarios with the desire of achieving a particular outcome but on the other hand it is not possible to invert the model to obtain what interactions of the agents are necessary for a particular observed property to come up. [56]

2.3.4 Economic theory supporting ABM

Another reason and motivation to use the agent-based modeling approach is due to various relatively new economic theories that support this type of simulation approach. The shift of diverse economic theories to concentrate more on the individual actor on the market than on the aggregated behavioral models is one of the causes to use other simulation approaches. Especially the (1) Austrian School of economics and the heterodox school of economics with the emerging field of (2) evolutionary economics support the choice of agent-based modeling for the consumer market.

(1) The Austrian School of economic idea is using the idea of methodological individualism.

This economic school is arguing that social phenomena are a result from the actions and motivations of individuals [60]. The origins of the Austrian School relate to Carl Menger [60] and his book 'Principles of Economics' that was first published in 1871 and reformulated the economic field and discussed the theoretical failures of the old classical school. The Austrian School evolved further in the late-19th and early-20th century in Vienna based on the work of additional popular representatives next to Carl Menger like Eugen von Böhm-Bawerk, Friedrich von Wieser, Ludwig von Mises and others [61]. Fritz Machlup [62] who was a student of Wieser and Mises, is another representative of the Austrian school and summarized the 6 typical tenets of Austrian economic thinking as:

1. **Methodological individualism:** To explain economic phenomena the individual actions of individuals or groups have to be observed.

2. **Methodological subjectivism:** To explain economic phenomena the choices of the individuals based on their knowledge, believes and expectations and their perceived consequences of their actions have to be observed.

3. **Tastes and preferences:** Subjective assessments of products/services/goods on the markt determine the demand and therefore the price.

4. **Opportunity costs:** Costs with which economic actors on the market calculate, reflect the alternative possibilities that must be gone ahead.

5. **Marginalism:** All economic decisions are determined by the marginal utility.

6. **Time structure of production and consumption:** The decision to save or to consume are caused by the subjective time preference.

The theory behind the Austrian School is that subjective choices of individual actors on the market like personal knowledge, expectation, time and other factors are the reason for the arising economic phenomena. They try to understand the economy by investigating the social influence of the individual choice of different actors. This approach is known as methodological individualism. The different between this approach and that from other schools of economic thought is that they focus more on the aggregated variables, equilibrium analysis and social groups rather than individuals. [61]
Therefore the Austrian School supports the use of agent-based modeling that also focus on the individual consumers on the market with their own preferences, budgets, decisions processes and expectations.

(2) Evolutionary economics is a part of the heterodox school of economic thought which is mainly influenced by the existing field of evolutionary biology. Evolutionary economics is dealing with the investigation of processes that mainly influence and therefore change the economy through the operations of diverse agents on the market. There is no intention of obtaining an equilibrium state for the market or company. A permanent competition between products, services, business forms and even economic systems ensures that only those competitors can

continue to exist that adapt to the constantly changing competitive conditions based on the prevailing environmental requirements. [63]
Nelson and Winter [64] [65] that are one of the leading figures of evolutionary economics argued that economic change need mechanisms that offer selection, create variation and establish self-replication. They use the term 'steady change' regarding the field of evolutionary economics to point to the evolutionary aspect of the economic processes involved. This should distinguish them from the classical economics with their popular concept of 'steady state' economics. Nelson and Winter [64] [65] are arguing to rely on available evidence on learning and behavior at both the individual and organizational levels. Actors on the market following behavioral processes assuming bounded rationality to perform actions in the economic environment. Evolutionary economics argues that the surviving actors on the market are the ones who are having routines and resulting actions that get along best with the environment. Also this economic theory supports the use of the agent-based modeling approach cause of the existing focus on individuals and their actions on the market. The existing bounded rationality and imperfect knowledge stated in this economic theory that combines with individual preferences are factors that suggests the agent-based modeling approach to model the consumer market. [64] [65]

Agent-based computational economics (ACE) evolved from the above mentioned economic theories and is therefore the area of computational economics that studies economic processes based on modeled evolving systems of independent behaving and communicating agents. Agent-based computational economics is in that case a specialization to economics that uses computational methods to analyze available complex economic systems that are often also adaptive. Therefore the agent-based modeling approach is already used attempting to replace the known theoretical assumption of mathematical optimization in the equilibrium. This is realized with the help of the less limited agents with bounded rationality that could adapt dependent on the prevailing environmental state. [66]
Tesfatsion [66] mentioned that in current research in the field of agent-based computational economics the most addressed topics are:

- Learning and the embodied mind
- Evolution of behavioral norms
- Bottom-up modeling of market processes
- Formation of economic networks
- Modeling of organizations
- Design of computational agents for automated markets
- Parallel experiments with real and computational agents
- Building ACE computational laboratories

The use of agent-based computational economics models should help researchers in the field of economic to support experimental testing based on the theory and data from different fields of social and economic science [66]. The economic theories that were described in this section based on the Austrian School of economics and the evolutionary economics as well as the introduced concept of agent-based computational economics encourage the motivation to use an agent-based simulation approach for the implementation in a web-based strategy game.

2.4 Architecture of consumer behavior

Like in the conceptual model of Jager and Janssen [57] [58] [59] that provide a conceptual multi-theoretical model connecting different theories of behavior that are relevant in the context of consumer behavior, there are of course other theories of consumer behavior available. These theories can be applied of course to build a new conceptual model that simulates the internal behavior of an agent.
Because of the relevance for this work and the reputation of this model, the BDI (Belief-Desire-Intention) architecture of Bratman et al. [67] will be presented in this section as a basis to build a conceptual model from it. This model represents an abstraction of human thoughts based on available theory of rational actions in the human cognition process that is using the concept of practical reasoning. In the BDI architecture agents have to perform reasoning and weight alternatives of their actions against each other. Agents are of course resource bounded in a way that they are not able to perform optionally extensive computation tasks in a constant time. An agent in this architecture is selecting an action based on the own expected utility of the results. The expected utility is in that context a function of the single agent that is conditioned based on the agent's beliefs and desires. If there would be no bounds of the available resources, an agent could compute any time the best action from out all alternatives form himself by maximizing its expected utility for the options. The beliefs, desires and intentions of an individual agent are providing the variables for an utility function to calculate the best choice that satisfies his goals. [67]
Shen et al. [68] developed a technical architecture on top of the theoretical BDI (Belief-Desire-Intention) architecture of Bratman et al. In this technical architecture every internal condition of the agent is described by a collection of three reasonable elements (beliefs, desires and intentions) that the particular agent uses to plan and calculate the actions and decisions it will perform. The architecture uses following elements to represent the internal planning system of the agent [68]:

1. The **beliefs** are the information an individual agent has of the world. The beliefs of an agent could be about his internal state or about his environment. Beliefs are dynamic and cause the model therefore to have a dynamic process to update beliefs during the simulation.

2. The **desire** of an agent represents his striving for something. This can be for example the desire to buy a product.

3. The **intentions** of an agent are the aims that an agent has engaged to achieve. Intentions are associated with a plan with descriptors. The agent will commit to that goal that guarantees the maximum utility outcome.

4. **Plans** are used from agents achieve the intentions and represent a sequence of actions.

5. **Goals** are group of competing beliefs that are consistent with the current desires of an agent. Goals that are generated from beliefs and desires are required to be steady, and feasible in this model.

Based on these elements defined by Shen et al. [68], the process of the internal decision making can be modeled including the following steps an agent has to perform:

1. If the agent on the market has a *desire* to consume a good, it is going to build a list of all feasible combinations of goods according to his *beliefs* of the product. Feasible means in that context that the agent is able to buy the bundle of goods. For each bundle of goods an *intention* is resolved for the agent.

2. The agent selects from the list of feasible *goals* that one which maximizes is individual utility function and commits to it. This *intention* is the basis to generate a *plan* to consume these goods from the specific stores on the market.

3. The consumer is trying to realize his *plan* by performing a step of actions. After each performed action the *beliefs* of the agents are updated instantly. If an action is not able to be fulfilled by the agent a new *plan* has to be generated.

In Figure 2.8 the overall process of the BDI architecture can be seen with the basic aspects of the process and how they are related to each other.

The planning process is executed for each agent independently from other agents in the model and relates to the internal state and the beliefs of the agent. Based on the continuous updates of the beliefs of an agent when performing an action, the intentions of an agent can adapt over time. In that case an agent can be influenced indirectly by the choices of other firms and consumers that are affecting the environment. Although there are many benefits of the BDI architecture like the imperfect information, separation between the intention and the successful action and the influence agents have on each other there is still critique on the architecture. One point of critique of the BDI model was given by Georgeff et al. [69] who mentioned that it is not an appropriate solution for certain types of behavior. To be more specific, the basic BDI model seems to be inappropriate for implementing systems that have to learn and change their behavior over time. Such kinds of systems are becoming more and more popular. Additionally, it was criticized that the basic BDI model gives no detailed consideration of the implementation of the agents in form of communication between agents or effects of different social groups of agents. [69]

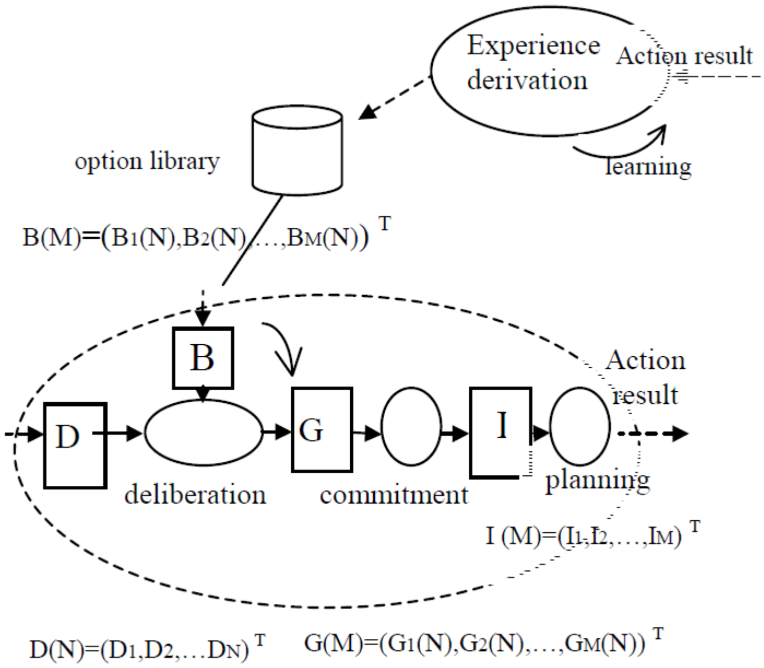


Figure 2.8: BDI model with beliefs *B*, desires *D*, goals *G* and the intentions *I*. [68, p. 1026]

2.5 Conclusion

As it was shown in this chapter, there are a lot of different models and architectures available to model the market for a business simulation game. The older standard models (equation-based, interpolation-based and statistical approach) focus on the demand calculation on the macro-level. These kinds of models are not able to include the behavioral theory like it can be used in the agent-based modeling approach. Agent-based modeling provides the possibility to model on a micro-level the single consumer and therefore integrate behavioral processes to make decisions on the market. Compared to the standard models the agent-based model approach offers an interesting flexible alternative to model the demand in a business simulation game. The option to model and present the single consumer in the market can improve the quality of information for the participant as well as the realism of the game. Participants of such games will more likely understand the cause-effect relationships and see the consequences of their decisions.
Because of the additional information of the agents on the micro-level, the representation of this information has influence on the understanding of the participant. The representation of individual agents or groups of agents directly corresponds with the investigation possibilities of the market. How the different preferences of a customer and his beliefs or uncertainty can be visualized to the participant is one of the main questions for the implementation of such a game with an agent-based consumer model. Additional to representation another focus in this thesis is to evaluate the flexibility that the agent-based model can provide to change the market composition within the game, to force participants to explore the market. Changing the preferences, beliefs

or still the number of agents in the simulation can lead to new emerging result.
The model of consumer behavior with the belief-desire-intention architecture provides an useful base to build the conceptual model for the decision finding process of the agent. Starting with the simple theory of the belief-desire-intention architecture a more powerful model can be implemented that includes additional decision factors and even add agent interaction to the model. In comparison, with the standard models the new agent-based model approach allows adding behavioral theory to the simulation. Different behavioral approaches can applied to agents and tested to find out how they will affect the emerging market results. The web based business simulation game should therefore be easy extendable to change, adapt and extend the behavioral rules of agents easily. This should guarantee an enhancement of different forms of agent types in subsequent developments that support even more recent complex economic and behavioral models.

CHAPTER 3

Methodology

This chapter will illustrate and describe the chosen methodology that was used for this thesis with respect to the objectives of this work. As such the concrete game concept, the development method for the game implementation as well as the data model and the used analysis method are covered in this chapter.

3.1 Methodological approach - Design Science

According to Hevner et al. [38] there are two paradigms that are mainly used for the research in the area of information systems. The first is the behavioral science that seeks to develop and justify theories that explain or anticipate human or organizational behavior. This is done with the systematic analysis and investigation of behavior. Investigation can be realized with controlled or naturalistic investigation and sophisticated scientific experimentation. On the other hand the second research paradigm is the design-science paradigm that seeks to extend the limits of organizational and human capabilities by implementing new and innovative artifacts. Both of these paradigms are primary to the information systems discipline because of the junction of organizations, people and technology. [38]
The difference to behavioral science is that the design-science paradigm includes the design of a novel or innovative artifact and the following analysis of the use and/or performance of such an artifact for a specific problem domain, to enhance and understand the behavior of the facets of the information system. The created artifact has to be evaluated in order to assure that this artifact either resolves an issue that has not yet been solved, or is a more effective solution for a problem in a specific problem domain. [70]
Due to the fact that a new strategic business simulation game with dynamic agent-based buyer's market is developed to answer the research question, if agent-based models are a practicable approach to model a dynamic market with individual consumers in a web based business strategy game, the design science paradigm is used to evaluate this newly created artifact. Based on the created artifact the evaluation will be performed with participants that are using this new

Guideline 1: Design as an Artifact	Design-science research must create an applicable artifact as construct, method, model or instantiation.
Guideline 2: Problem Relevance	The aim of design-science research is to implement technology-based solutions to relevant business problems.
Guideline 3: Design Evaluation	The quality, utility and efficacy of a design artifact must be accurately demonstrated with well-performed evaluation methods.
Guideline 4: Research Contributions	Effective design-science research must create a valid contribution in the areas of the design foundations,design artifact and/or design methodologies.
Guideline 5: Research Rigor	Design-science research is basing on the application of accurate methods in both the implementation and evaluation of the artifact.
Guideline 6: Design as a Search Process	The search for an effective artifact need utilizing available instruments to reach desired goals while satisfying regulations in the problem environment.
Guideline 7: Communication of Research	Design-science research has to be presented effectively both to management-oriented and technology-oriented audiences.

Table 3.1: Design-Science Research Guidelines by Hevner et al. [38]

artifact that is integrated in the course. Through the fact that the usage of this artifact can either be as a participant or as operator of the game there have to be two viewpoints considered in the evaluation of the artifact. Advantages or disadvantages of the approach used for the artifact can either arise for the participants or for the operator. Hevner et al. [38] have presented a set of seven guidelines of design science research within the discipline of information systems that are listed in Table 3.1.

To comply each of these guidelines there will be different activities or achievements in the thesis that will be processed or fulfilled. The seven steps that will be performed to satisfy each guideline are listed in the Table 3.2 below and match with each guideline from Table 3.1.

Activity 1:	A web-based business strategy game, based on an agent-based model for the market of consumers, will be implemented.
Activity 2:	There is a need for a business strategy game in the field of strategic management to teach the different strategies by means of 'learning-by-doing'.
Activity 3:	To evaluate the resulting artifact there will be a functional test in the course that will show if the agent-based model approach is a successful implementation for a strategic business game.
Activity 4:	The contribution of the design-science research is the artifact itself, which is the business game itself.
Activity 5:	The rigor is derived from the effective use of the knowledge base so there will be different accepted methodologies like iterative procedure models with feedback cycles that will be applied in the construction/implementation phase of the artifact.
Activity 6:	The design science is per se iterative and is a process that has often cycles which will match with above mentioned iterative procedure model of guideline 5.
Activity 7:	In the implementation phase there will also be such cycles to find the best features for the artifact.

Table 3.2: Activities or achievements to meet each of the design-science guidelines

The investigation of the resulting artifact will be performed with at least 40 participants which play the designed and developed web-based business strategy game. The game will last for 10 rounds with a changing consumer market during the game. After the completion of the game, a questionnaire is performed and evaluated. The collected data is used to identify the advantages and disadvantages from the perspective of the participants and verify the hypothesis of this thesis. Following the seven guidelines and the steps to satisfy each of these guidelines within this thesis, the design-science research approach is obeyed clearly and the results of this thesis are comprehensibly determined.

3.2 Game concept

The requirements that were placed for the business simulation game in the specific field of strategic management were given by the advisor of this work with the goal of implementing it in the lecture 'Strategic-Management'. The implemented game should enable the participants of this course to consolidate or even improve their skills by means of 'learning-by-doing'. Goal of the application is to help the participants to deepen their understanding in 'Strategic Management' and offer them a possibility to apply their gained knowledge within the course. The objective was therefore to develop a web-based strategic business simulation game for strategic management that allows the participants to play games as competing companies for a consumer market that is focusing on a specific product category.

3.2.1 Game aspects

To give an approximate overview of the key aspects/requirements that have to be considered during the implementation of the game, the aspects that should be covered are listed below:

1. **Flexibility:** The game should enable the operator to model different types of consumers with various preferences according to the input of the operator. The market composition should be able to vary in terms of amount of the consumers on the market as well as the preferences of the consumers. It should be possible to model different types of consumers (agent types) whereas consumers of the same type have similar preferences according their purchase decision. During the game the operator should have the possibility to change the market composition by changing the amounts of different agent types, the attributes of the agent type or even a single agent that represents a potential consumer on the market.

2. **Accessibility:** The participants and the operator should be able to access this game anywhere with a standard browser and without additional software that has to be installed. It should be realized as a boarder free online game to keep the motivation to participate on a high level. The participants have to be able to log into the application with a private user name and password in order to see their personal settings and decisions for their specific game they are participating. The up-time of the game should be kept high for the participants in order to take their decisions for their company anytime during the day.

3. **Expandability:** In terms of implementation the business simulation game should be developed to consider further extensions of the decision model in the future. The behavior of the consumer that is realized with a decision process has to be implemented in a modular way to extend the behavior of the agent in future work with for example additional behavioral theories. In this context the behavior or decision process is also described as decision strategy in the implementation. The expandability is ensured with the used strategy pattern for the agent behavior implementation. Additional to the expandability of the agent behavior, it should also be considered in the implementation that additional preferences and decision variables could be added in further developments of the game.

4. **Transparency:** The transparency of the consumer purchase decision should be provided in the application. The operator (and in certain conditions also the participant) should be possible to see what product each agent has chosen at a specific point of time in the simulation game. This information has to be provided in the game and historically saved for subsequent evaluations of the game.

5. **Comprehensibility:** In addition to the transparency of the chosen product of the consumer, the preferences of each consumer should also be accessible. This should guarantee the comprehensibility of the decision of a consumer for a particular product with its specific characteristics based on the individual preferences of the specific consumer.

These rough requirements of the game that provide the backbone of the whole game implementation are explained in more detail in the following subsections. The following description of the functionality provides list of requirements used to implement the game.

3.2.2 Participant's perspective

A game should consist of a specific number of rounds that are simulated within a game instance. The participants that represent a company owner have to make each round decisions for their fictive company in order to perform well on the market. Software agents represent the consumers on the market using a specific decision process to decide for a product. The decision of a consumer in a simulation round depends on the actions, decisions and performance of the companies on the market as well as the individual preferences of the consumer. A simulation round is in that context a period of time in that the participant can choose specific decisions that are explained in this section. After the time for a simulation round is expired the decisions of all consumers on the market are going to be simulated, resulting in the sales volumes for each company for the offered products.

The participants are acting as retailers in the market and have to choose their product portfolio they offer based on the products the available producers are offering on the market for a specific price and quality. On the other side there are the software agents that represent the consumers on the market with their specific decisions process that is used to determine which product is bought. Products that are offered have different **qualities** that are rated on scale from 1 to 10. The participant should be able to choose their different products from the producers on the market in order to draw up their own product portfolio with the intention to perform well on the market. The amount of products in a portfolio is therefore limited, that with an increasing portfolio the logistic costs are increasing as well and will cause higher additional costs for the participants company.

The participant chooses and sets the **selling prices** of the products in his portfolio that are used as the second main criteria for the software agents in the decision process. Participants are not able to see the selling prices of other competitors in the same round but they should have the possibility to perform market analysis that cover this information depending on how much a participant is willing to invest in a market analysis report. More expensive reports should even include consumer details that can be used to decide if the chosen strategy and product portfolio fits to the market or it has to be adapted or reformulated.

Participants should have different decision options additional to the composition of the product portfolio that the company is offering to the consumers. Further the participants are able to invest in marketing activities, research & development expenditures or personal development in each simulation round. These possibilities to invest are the potential **company image** increasing expenditures of a participant in this game.

These three investment possibilities were chosen additional to the sales volume of a company as the main influencing factors for the company image. According to Siano et al. [71] there are of course more actions in real life that are influencing the development of a company image. To restrict the complexity of the game for the initial development, the three actions marketing investment, research & development investment and personal development investment were established additional to the sales volume. The expenditures are increasing the quality of service as well as the image of the company on the market additional to the realized sales volume of a round. The investments are a monetary amount that can be chosen for each of the three categories. Compared to the other expenditures of the competing companies on the market and the weighting of the importance of the expenditures, the investments can be more or less effective

on the market. Additionally, the sold products on the market in relation to the other competitors' sales volumes can influence the image of the company on the market positively or negatively. The mathematical model behind the image calculation is treated in Section 4.4.
As already mentioned the functionality to perform a market analysis to investigate the market composition and the customer preferences should be provided. This should enable the participants to align the product portfolio if necessary. Depending on the money amount spent for the market analysis the resulting report includes more or less data and different levels of investigation. The market analysis should include, dependent from the amount that was spent, the following information:

1. General information about the amount of potential consumers and the competitors on the market.

2. Performance based information about the sales.

3. Competitor specific information about their investments and their offered products on the market with the belonging price and their sales performance of the last period.

4. Consumer related information about the preferences of particular competitors in order to perform a market analysis.

Based on the scope of the market analysis that correlates with the investment for it, the participant can use this information to analyze the market and make more appropriate decision if necessary.
In order to keep the simulation game simple for the initial development, the requirements are, that there are no storage costs for products and no delivery charges considered. The assumption for this simplifying requirement was that the producer of the product is delivering on demand if a consumer decides to buy this product from the portfolio of the participant (retailer). In further developments of the game this can of course be implemented in order to increase the complexity and realism of the game. Interest payments however are required to be implemented in order to charge an indebted company. The interest rate for the games should also be configurable from the operator.
Based on these requirements the necessary functionality for the investigation of the market and strategic decisions are considered for the participants.

3.2.3 Operator's perspective

The operator/administrator of the game should have, like the participant, the possibility to log into the application. A list of all running and finished games should be present in order to choose one of them to either configure or analyze it or create a new one. In addition to this functionality the operator should also be possible to configure the overall settings for all games that are used for the calculations of the performances as well as individual game settings like the starting budget of companies.
When a new game is needed the operator should be able to configure a game and add/remove participant accounts to this game. The game consists of a defined amount of rounds where each

of them that starts and ends at a specific time the operator can set. Within this time slot the participants can make their decisions. After a round's deadline is exceeded the operator can simulate the round with the configured consumer market. The results of the simulation should be visible directly after the simulation.
The consumer market can be configured for each round in order to ensure the flexibility of the market composition. It is required that various types of consumer can be modeled with a specific amount and the mean preferences for price, quality and company image. According to the defined consumer types the configured amount of agents are going to be generated with normal distributed preferences where the mean preferences from the configured consumer type is used. During the decision process each consumer agent is using a weighted utility function to determine which product on the market satisfies his preferences most. According to the utility value the consumer will decide to buy a product or not. If he decided to buy a product that is available on the market it will be bought without any restrictions or barriers. The operator is able to configure a minimum utility for all consumers that have to be fulfilled to buy a product. This represents a minimum requirement for a product that has to be fulfilled for a customer.
For each game the round wise and overall values should be visible in tables to analyze the game. This includes the budget, investments, company image, agents and all decisions that have been made. The performance of the different participants of a game should be provided in a tabular or graphical form to evaluate the different occurrences on the market.

3.3 Development method

The development of the business simulation game is realized with an iterative and incremental development process. This development approach is a combination of an iterative design or iterative method and an incremental build model for the software development. This approach is widely suggested and used for larger development projects. The iterative and incremental development approach are used in different models like the Rational Unified Process, Extreme Programming, Scrum or several other agile software development frameworks [72]. This development process is similar to the plan-do-check-act cycle of business process improvement that also includes cycles [72].
The cycles of the incremental and iterative techniques consists of pieces evolved from the known Waterfall model. The process of the Waterfall model is repeated in smaller pieces of the total project scope throughout the whole development lifecycle. These smaller pieces will be handled like with its own waterfall process beginning with analysis, followed by design, implementation, and finally testing. These cycles/iterations are repeated until the whole project scope is implemented so the result can be delivered. [73] [74]
Figure 3.1 shows the graphical representation of the iterative and incremental development process with its different activities according to Philippe Kruchter [74].

This agile approach was chosen because the implementation is more agile. According to Cohen et al. [73] the iterative development deals better with changes because the only complete requirements that are the ones for the current iteration. There have to exist of course provisional requirements for the next iteration but this could be changed until the analysis phase of the next cycle [73]. The uncertainty of the extent of development was therefore the main reason

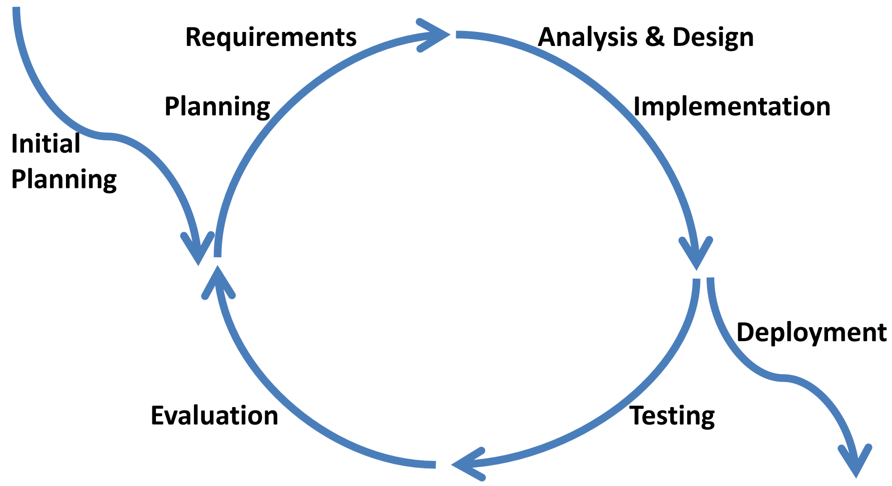


Figure 3.1: Iterative and incremental development process adapted from Philippe Kruchter [74].

why the iterative and incremental development process was chosen to implement this business simulation game. The flexibility of the model to change the scope and the requirements and get early feedback after a finished iteration was also one of the decisive factors for this model.

3.4 Evaluation & analysis method

The game will be performed with participants that have taken the lecture 'Strategic Management' and attenders that did not participate in this lecture. The participants will compete in different games where each game consists of four to six competing companies on the market. A game is lasting for ten rounds where each round lasts for about one day. Within this time slot the participants can make their decisions for the particular round.
The attenders are not informed about the starting consumer composition of the market or about changes on the market. There is neither the information how the preferences of the consumers are distributed on the markets nor how many potential consumers there are on the market. The players are of course able to investigate the market during the game with investments in marketing analysis. All of the players will receive the same starting-budget for their company in order to be able to make investments for their company. The market composition will change two times and simulate a shift of the consumer preferences during a defined time horizon. The three phases with the different market compositions of the agent types throughout the simulation are listed below:

- Round 1-3:

20% of the agents on the market prefer lower priced products

50% of the agents on the market prefer products with relatively high quality

30% of the agents prefer products from companies with a relatively high image

- Round 4-7:

  35% of the agents on the market prefer lower priced products

  40% of the agents on the market prefer products with relatively high quality

  25% of the agents prefer products from companies with a relatively high image

- Round 8-10:

  50% of the agents on the market prefer lower priced products

  25% of the agents on the market prefer products with relatively high quality

  25% of the agents prefer products from companies with a relatively high image

After the simulation has been completed the players fill out a questionnaire that provides the basis for the strategic business game evaluation. The questionnaire consists of seven constructs with different questions. The constructs covered in the questionnaire with their superordinate issues are:

1. **Agent behavior:** How comprehensible was the behavior of the consumers?
2. **Agent information:** Are the preferences of the agents clear to the participants?
3. **Segment identification:** Was it possible to identify the consumer segments on the market?
4. **Strategy adaption:** Did the investigation of the market influence the participants decision?
5. **Address segments:** Was it possible for the participants to align their product portfolio for a consumer segment?
6. **Game comparison:** Has the game been more or less accepted than other already played simulations?
7. **Game experience:** Did the participants perceive the participation as a challenging and interesting experience?

The questions that are allocated to these constructs are evaluated based on a five point Likert scale. The Likert scale that is named after the psychologist Rensis Likert [75] is a psychometric scale that is often used in research that uses questionnaires. It is the most common used approach to scaling responses in survey research. The answer to a question on a Likert questionnaire specify their level of agreement or disagreement on a symmetric agree-disagree scale for a series of statements. [75] Based on this evaluation the advantages or disadvantages of the agent-based modeling approach for a strategic business simulation game will be analyzed for

the participants' perspective.
Due to the problem to evaluate the operators' perspective on the basis of empirical data there will be an analytical argumentative approach used in order to describe the advantages or disadvantages discovered during the simulation. The lack of empirical data for the operators' perspective is reasoned in the missing opportunity to test the game with a moderate amount of different operators in order to provide an established questionnaire.

CHAPTER 4

Implementation

This chapter will deal in detail with the technical decisions and implementation of the web-based strategic business simulation game. The details of the architecture used for the application are stated including the applied concepts of technical development. Additionally, the integrated frameworks, algorithms and equations that will be applied are explained as well. The crucial points in the implementation of the agent-based modeling approach in the application are described in detail to make the technical decisions taken comprehensible.

4.1 Technological architecture

The technological architecture will be separated into two parts. The web application architecture in Subsection 4.1.1 will give an overview of the taken decisions for the deployment architecture and provides a static view of the run-time configuration of the processing nodes. In Subsection 4.1.2 the used software architectural pattern for implementing the user interfaces and the according business layer will be stated.

4.1.1 Deployment architecture

A deployment diagram is used in this section to describe the run-time architecture of the system, including the software installed on the different components that are used. It gives an overview of the applied components of the system and the middleware that is used to connect the different components. To make the deployment architecture more comprehensible the different components used for the system implementation are described briefly. [76]
The web-based business strategy simulation game will be implemented with the programming language Java that is running on a web server that hosts the application. MySQL will be used as database that interacts with the application and provides the data delivery and persistence. The whole application will be deployed on an Apache Tomcat, that serves as web server and servlet container for the Java based web application. This configuration was chosen, in order to

guarantee a lightweight and easy architecture for the application and to allow running it on different environments without having any license costs. Additionally, the replication of the game to run multiple instances can be realized without having much effort. Java was chosen as the programming language to implement the application because of its different advantages that are listed below [77]:

1. **Agent representation:** The class-based and object-oriented characteristic of Java supports the agent-based modeling approach where each agent is represented as an object with individual characteristics.

2. **Portability:** Programs that are written for a Java platform run also on any combination of hardware and operating system with the necessary runtime support. Java realizes this kind of portability by compiling the Java language code to an intermediate code form that is called Java bytecode, instead of directly compiling it to the relevant architecture-specific machine code for the platform [77].

3. **Popularity & Spreading:** In 2015 Java is reported as one of the most popular programming languages in use. This popularity should guarantee that further development of the existing implementation need no specific knowledge and is coded in a well-defined and documented programming language [78].

4. **Licensing:** The Java Development Kit (JDK) is under the GNU General Public License (GPL) that is the most often used free license type for software, which guarantees the users of it (organizations, companies, individuals) the right to run, modify, share, and study the software [77].

As relational database management system (DBMS) a MySQL database was chosen to persist and deliver the data for the application. MySQL is an open-source relational database management system. The database is only used as a back-end database that is accessed by users only indirectly through the strategic web based business simulation application. The users of the application are therefore not able to connect directly to the database itself and manipulate the data. The architectural reasons for choosing the MySQL database are listed below.

1. **Popularity & Spreading:** MySQL is the most popular Open Source SQL database management system available and largely met the compliance with the well-known SQL standard. Due to the fact that it is also well documented and uses the common SQL standard, the possible extensibility is also ensured for the DBMS component of the application [79].

2. **Performance:** MySQL Server is an appropriate choice for fast processing applications and heavy-load production systems as well as for embedding it into mass-deployed software. MySQL was originally designed to work with medium-sized databases (10-100 million rows, or about 100MB per table) on small computers systems but can nowadays handle also terabyte-sized databases and is therefore sufficiently performing for the web application to meet the requirements. [79]

3. **Licensing:** MySQL can be used as an Open Source product under the terms of the GNU General Public License (GPL) like the Java Development Kit that was mentioned above [79].

The web server and the database are communicating over the Java database connectivity technology (JDBC) interface to receive and write data to the relational database. This technology is an API provided for the Java programming language that defines how a client can access an existing relational database. The API provides methods to perform different operations on the database like querying and updating data sets. The database addressed in the system architecture is only via this API interface accessible from the application and provides the data for the application. It is used to save the results of processes or user changes back into the database. The user is communicating with the web server via web interface that is secured with the Transport Layer Security (TLS) protocol, which ensures the secure communication between the user and the web server over the network. The HTTPS protocol is used in order to protect the privacy and integrity of the exchanged data between the user and the application. The application is deployed on an Apache Tomcat server that serves as an open-source web server for the implemented application.
The overall deployment architecture with its interfaces and components is shown in Figure 4.1 and gives an overview of the already mentioned components and interfaces that have to be provided to run the strategic web-based business simulation game.

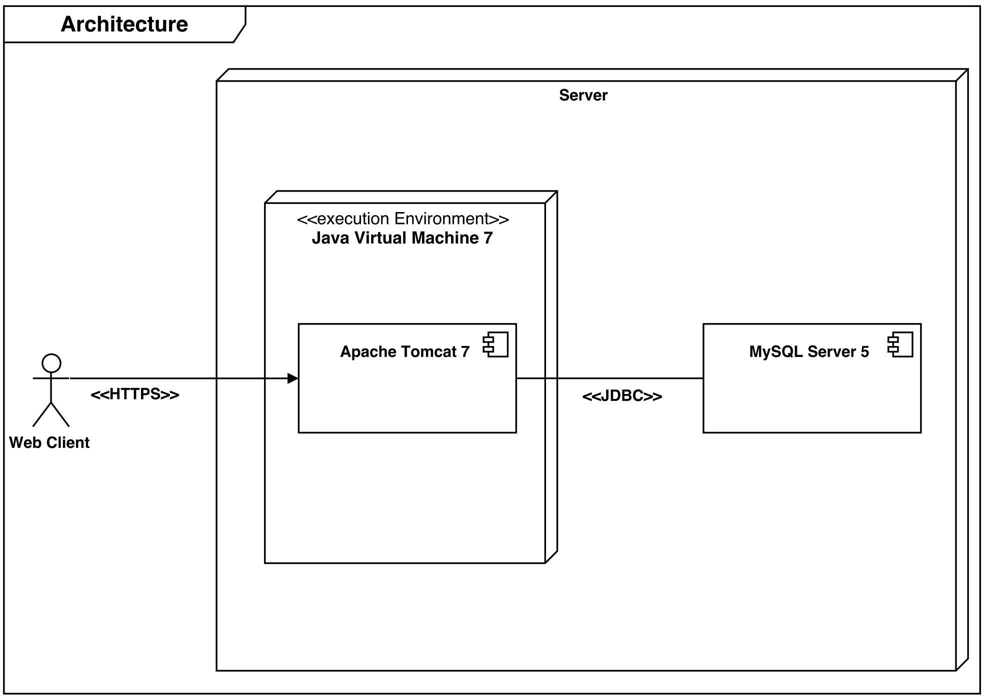


Figure 4.1: Deployment diagram of the strategic web-based business simulation game.

For reasons of simplicity and limited resources the web server and database are running on the same server. For scalability and reliability of the web application, the web server and the database can be separated and spread among different instances. At the time of development, testing and deployment, the performance of the application was on average under 1.5 seconds for answering a request depended from the network connection.

4.1.2 Model-View-Controller pattern

For implementing the user interfaces and the business logic of the application the Model-View-Controller (MVC) software architectural pattern is used. It is applied to separate the software application into three components that are interconnected. The application of this pattern allows splitting the internal representation of the information from the manner how it is represented to the user through the interface. Modeling the user interface of an application should be separated from the behavior of the application based on its problem domain. The model that is responsible for representing the behavior of the application manages therefore the data, logic and rules of it. Traditionally the Model-View-Controller pattern was used for the implementation of desktop graphical user interfaces but this architecture has become also popular for the designing of web applications. It is applied nowadays as a de facto standard for the design of much complex software systems. [80]
The three occurring components of the Model-View-Controller pattern are [80]:

1. **Model (carries data):** The model is an object representing the data of a domain-specific software that is fetched according to commands from the controller. The realization of the model can be a plain integer (representing the model of a counter) or a string (representing the model of a text editor) or an even more complex object that is an instance of a defined class.

2. **View (shows user interface):** The view component generates the output that is presented to the user based on the changes that occurred in the model. It is therefore some form of visualization of the prevailing state of the model that has changed during the processing of the application based on data, logic and rules that have been applied.

3. **Controller (handles processing):** The controller is the component that connects the associated model and view components. This component is responsible to send instructions to the model. As reaction to this the model updates its state or informs the associated view, which the presentation of the model has changed.

The separation of these three components should provide a more detailed overview of the different tasks the web application has to handle during the execution. Further developments in one of the three components can be done without influencing the other two components. This allows focusing on one component if improvements are needed or lacks of this component are discovered without influencing the others. The internal business-logic of the web application is therefore strictly delimited from the representation of the processed data. An overview of the interdependence of the three components among themselves and the interacting user is shown in Figure 4.2.

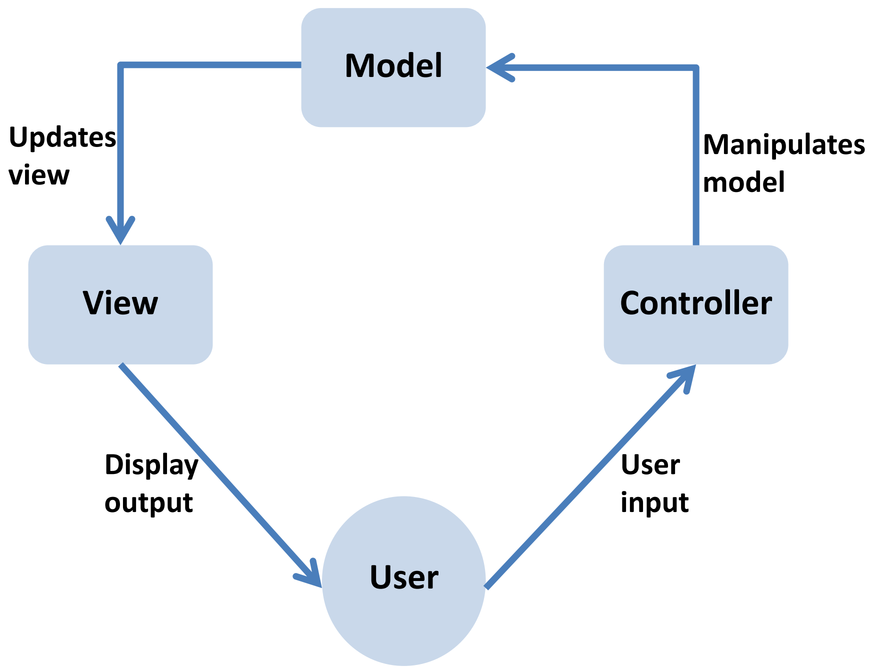


Figure 4.2: Model-View-Controller dependencies (adapted from [80])

The Model-View-Controller pattern is applied through the usage of JavaServer Faces (JSF) which is a Java framework for building web applications. This framework provides a component-centric approach for developing web applications with Java and simplifies the overhead for the developer in integrating the Model-View-Controller pattern. JavaServer Faces ensures that the web application increases its maintainability by integrating the established Model-View-Controller architectural design pattern into the overall architecture. The use of the JavaServer Faces framework separates the components according to the Model-View-Controller as it is shown in Figure 4.3. [81]

The user-interface code that represents the View component is clearly separated from the application data and the business logic that is represented from the Model component. The Controller component handles all user interactions and provides the application data access for the pages and restrict unauthorized or improper access of the pages. The compliance with the guidelines for the Model-View-Controller pattern is therefore guaranteed during the implementation of the application with the usage of the JavaServer Faces framework, which is integrated in the web application. Additionally, the JavaServer Faces framework enables the use of different available components for the implementation of a state-of-the-art web interface. JavaServer Faces provides, based on the used component library, a compilation of different open source user interface components, which can be used for the implementation of the view component. The user interface components are mainly used to provide a graphical presentation of the achieved results of the different performed simulations to the operator of the game.

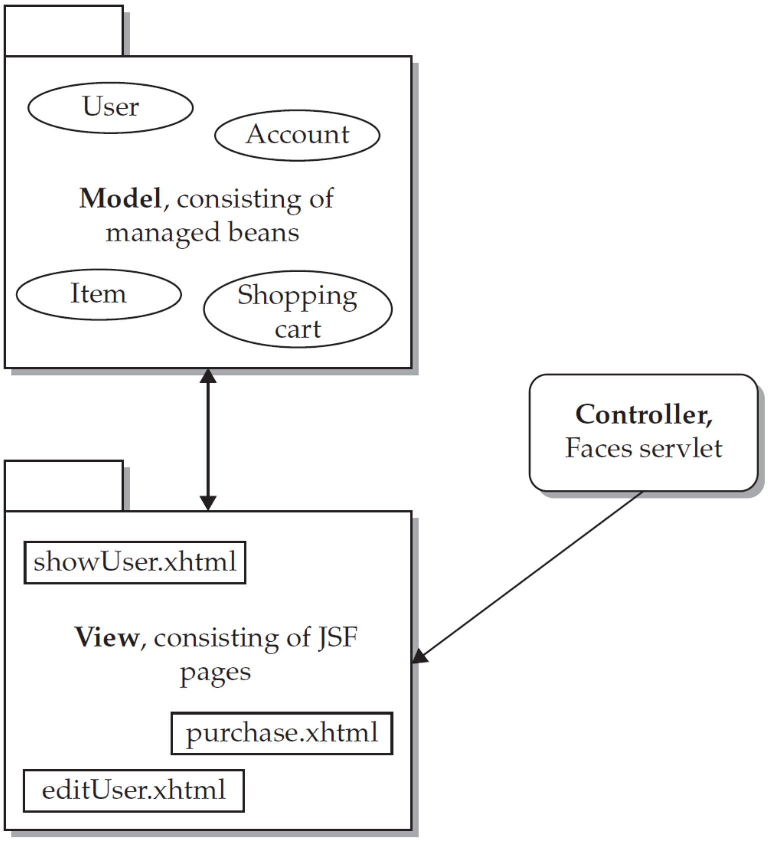


Figure 4.3: Model-View-Controller implementation in JavaServer Faces [81, p. 12]

4.2 Data model & access

In this section the constructed Entity Relationship Model will be discussed including the implementation of the data access to provide the data in an efficient way in the application. The reasons that have been taken in the choice of specific implementations are explained as well as the different entities occurring in the data model. These sections provide therefore and extensive insight into the basic elements of development.

4.2.1 Entity Relationship Model

The entity relationship model (often shortened as ER model) is used to describe the data and information aspects of the business domain. It was developed based on the initial requirements and expanded incrementally within the development cycles of the implementation process. The entity relationship model is used to visualize the needed business data and provide the basis for the implementation of the relational database used in the application. The analyzed requirements, including the necessary data for the implementation, result in twelve different artifacts that have been observed. These identified artifacts are modeled as entities in the model with the necessary relationships. The twelve entities discovered in the analysis of the requirements are:

- **Game:** The game entity is one of the central parts of the business domain that holds all relevant information. This includes the available suppliers, products, agents, rounds and the different round information.

- **User:** The user, that is at the same time the company, is the second central entity in the application. It represents the data of the participant in the application including the status data of the company during the game. Additionally, there are also users that have the privileges of an administrator to manage the application and the games.

- **Round:** Each game consists of different rounds that represent a period in the game. In each period the decisions of the companies are taken to simulate them with the actual consumer market.

- **AgentType:** Each round consists of different agent types that are describing a specific group of agents. The type includes the mean preferences and the amount of the agents that are going to be created according to these definitions. The agent type is used to declare a group of consumers with similar preferences.

- **Agent:** The agent is an instance of the agent type with concrete preferences and represents an individual consumer on the market. Each of these agents will run through a decision process using its own preferences to decide for a purchase option.

- **CompanyRoundDecisionAndResult:** For each round and company this entity is created to save the decisions taken during the round including the resulting outputs of the simulation. This entity is mainly used to save the historical decisions and changes throughout the whole game.

- **Supplier:** This entity represents a simple supplier that provides products to the participant in the role as a retailer. The participant is able to choose products from a supplier for his product portfolio.

- **Product:** The product is a good from a supplier with a name, quality level and price that can be chosen for the product portfolio.

- **CompanyProduct:** The company product is a product that is related to the product portfolio of an user. It has the same quality level as the product from the supplier but can of course differ at the price because of the profit marge the user added to it.

- **Report:** The report entity is the result of a market analysis. It can differ in the level of depth and detail according to the type of market analysis.

- **News:** The news entity is used to send messages to the users of a game to notify them about important events or to deliver just further information within the game.

- **Setting:** The entity settings is not related to any other entity. It saves the application wide parameters for the simulation, agent creation and initialization of the game. Only users with an administrator role are able to change these parameters.

The relations of the entities that are described above can be seen in Figure 4.4. It includes all entities and relations of the relational data model. The detailed attributes with their data type of the separate entity is provided in the Appendix A.

4.2.2 Data Access

The data access in the application which provides the simplified access to the data stored in the entity-relational MySQL database is realized with the Hibernate object-relational mapping framework. The framework is used in the Java environment to provide a mapping of a traditional relational database scheme to and object-oriented domain model in the application. It persists the data stored in the object-oriented domain model to the database and provides the loading mechanism from the database to the object-oriented domain model that is used in the application in the model component of the Model-View-Controller architectural pattern. The framework allows also performing native SQL statements that are also used in the application for the statistical analysis. [82]
The reasons for choosing the Hibernate framework in the application are [82]:

- **Efficiency:** It reduces the development effort that would otherwise be increased with additional manual data handling in SQL and JDBC [82].

- **Object support:** It offers the support for generating an object-oriented domain model that can be directly used for the business logic in the application [82].

- **Abstraction:** The framework encapsulates the vendor-specific SQL code and automatically translates the result sets from a tabular representation of the database to an object based in the Java environment [82].

- **Flexibility:** The framework supports the object mapping for the creation of the domain model to work with the Java objects as well as native SQL statements. Because native SQL statements are necessary for an effective statistical evaluation of the game based data, the possibility to use both is of great importance. [82]

- **Readability:** The source code has less overhead code and is therefore more efficient and shorter. The use of the object-oriented domain model and the use of objects increases the comprehensibility of the code compared to native SQL methods. [82]

- **Expandability:** The extension of the domain model results in less overhead because of the abstraction of the relational-database to the object oriented domain model. New dependencies can be added with less effort by including new objects simply to the domain model. [82]

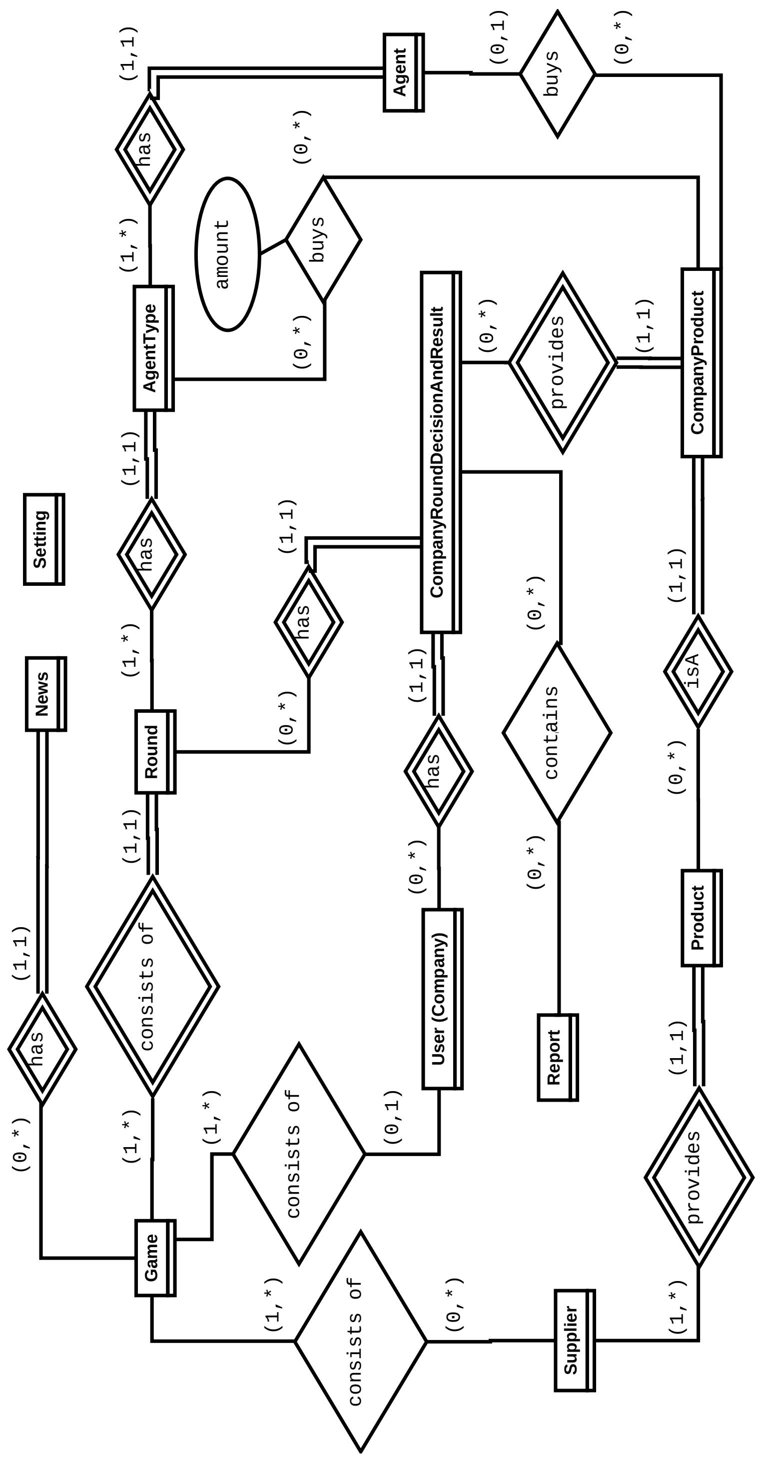


Figure 4.4: ER Diagram

Following these arguments, the Hibernate framework suites the present requirements and was therefore the primary decision to be implemented for the data access layer in the application.

4.3 Consumer Simulation Implementation

For the simulation of the consumer market a separate Java toolkit was used, enabling the agents to be simulated and providing further methods for the simulation. The discrete-event multi-agent simulation toolkit MASON was chosen for the technical implementation of the market simulation. MASON provides a free, fast, easily extensible and discrete-event multi-agent simulation toolkit that is written in Java and is developed to be used as basis for a wide area of multi-agent simulation applications. The framework allows the clear separation between the model and the visualization of the simulation. Models can be dynamically attached to visualizers that are responsible for the representation of the simulation results.
MASON is a joint project between the GMU Center for Social Complexity and the Evolutionary Computation Laboratory of the George Mason University. It was designed and implemented by Luke et al. [83]. It is oriented on the following four main design goals that are of important significance for the implementation of the web-based simulation game:

- The framework should be based on a small, fast, easily understood, and easily modified core.
- The recreation of identical results should be guaranteed independent of the platform.
- There should be an efficient support for up to a million agents without visualization.
- It should be possible to easy embed the framework into larger existing libraries.

MASON is written in Java in order to guarantee its portability and multi-platform compatibility. The toolkits architectural design provides three layers that separates the complexity and increases on the same time the flexibility of it. The three layers are the utility layer, the model layer, and the visualization layer that are described below [83]:

- **Utility layer:** The utility layer includes classes that can be used for general purpose. The classes include a random-number generator, data structures, various GUI widgets, and movie- and snapshot-generating facilities.
- **Model layer:** The model layer is a collection of classes including a discrete event schedule and schedule utilities that are the basic core of the toolkit. These components are needed to run simulations on the command line.
- **Visualization layer:** The visualization layer provides a set of GUI-based visualizations and possibilities to manipulate the model.

The interaction of the relating basic objects in the model and visualization layers can be seen in Figure 4.5 showing an UML diagram of the basic classes in MASON including the model and the visualization layer.

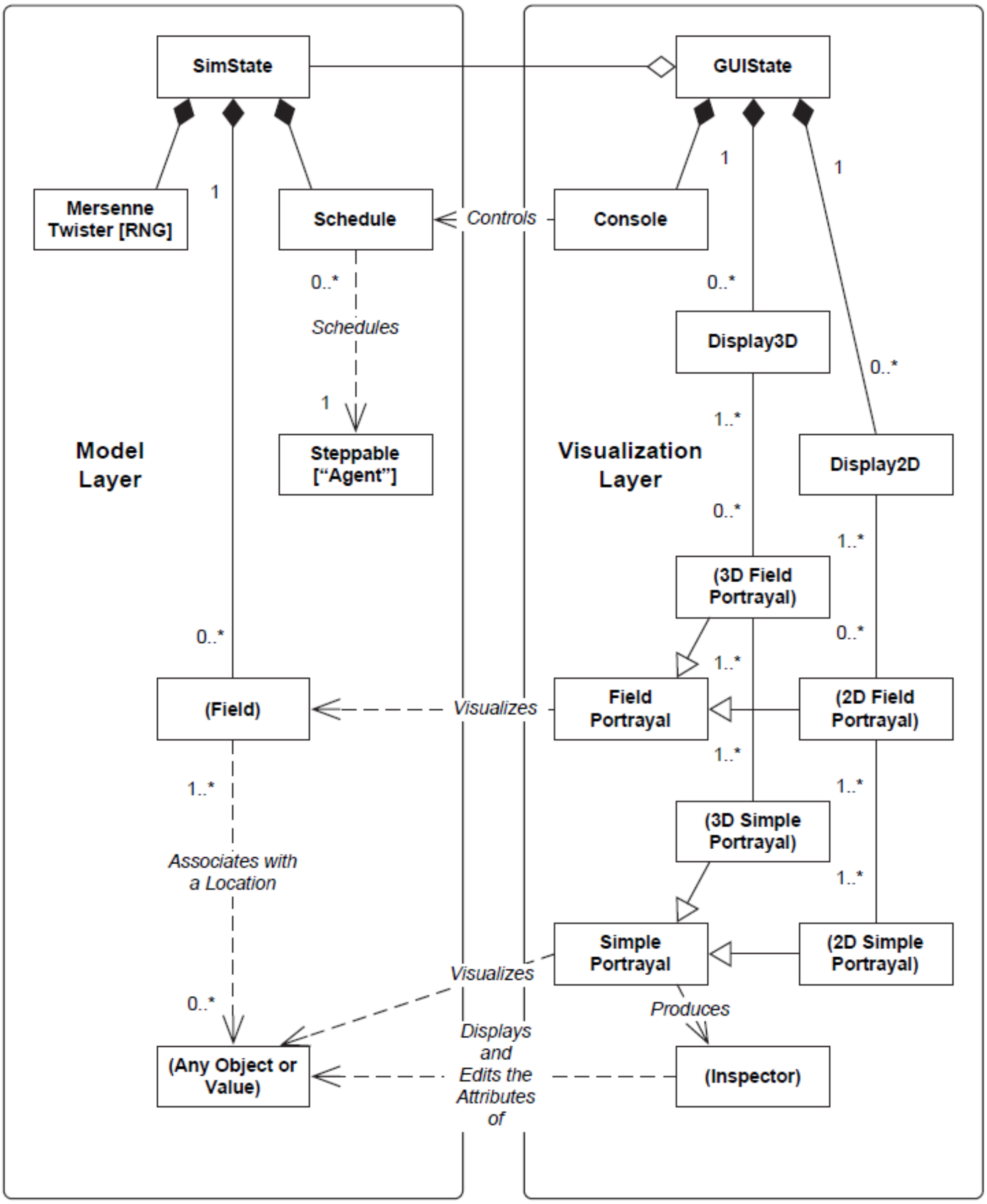


Figure 4.5: UML diagram of MASON including the model and visualization layers [83, p. 3]

The crucial element in the model layer is the 'Steppable' interface that was used to implement it into the agent object. It represents the consumer behavior within the application. The implemented method 'step' is processed during the simulation of the market. It contains the different behavior and decision processes of the individual agents representing the consumers in the market. During the simulation for each agent in the market, which is allocated to the round that is going to be simulated, the 'step' method is invoked. This method includes the decision process that is responsible for the purchase decision of the agent.

4.3.1 Decision process

The decision process is the process that is triggered by the agent to decide for one of the offered products on the market. This decision process includes several steps like investigating the market, collecting all offered products, evaluating the product alternatives and ranking them based on the own preferences. Based on the implementation and limitations of the different steps, a consumer's decision process can be more or less effective in terms of finding the product that fits best to the preferences. The steps used in the decision process used in this implementation are shown in Figure 4.6.

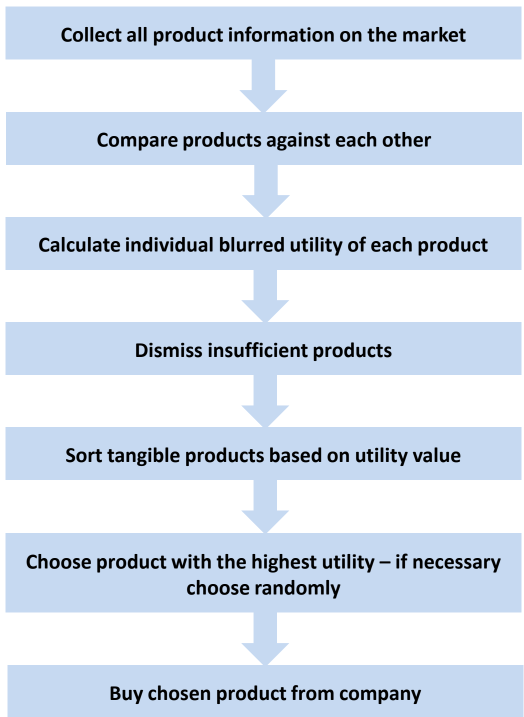


Figure 4.6: Decision process for an agent with its actions.

A more detailed description of the different steps of Figure 4.6 are described below and give an insight in the actions that each consumer has to perform to decide for a product.

1. The agent collects all the available products on the market from all companies including the necessary information for his decision. For this game there were no limited resources considered in collecting all the information about the products. There are no limitations,

so that a consumer is able to find all products offered on the market. The gathered information includes the selling price of the product, the quality level of the product and the image the company has on the market.

2. Based on the collected information of each product, the agent compares the different factors of relevance to each other. This step is necessary to evaluate for example how much better or worse the quality of a specific product is in comparison to the product with the best quality on the market. Therefore the dimension index is used, that is described in detail in Subsection 4.4.3, to calculate the compared performance for the selling price, the quality of the product and the image of the company on the market.

3. The agent calculates the utility value for each product based on the own preferences it has and the calculated dimension index of the different factors. The exact declaration of the preferences will be explained in Subsection 4.4.1. Using the calculated dimension index and the preferences of the agents, an utility value is calculated based on the equation that is described in detail in Subsection 4.4.4. The calculated utility value that ranges between 0 and 1 is then blurred based on the settings of the operator, which are provided in the overall game settings. Blurring the utility value means that it is rounded to a specific decimal place. This is simulating that the absolute correct utility value on any arbitrary number of comma places is not realistic and a consumer cannot distinct between to products that are so close in their utility. The blurring mechanism possibility can be changed anytime by the operator to make distinctions of products, based on the utility, more or less precisely.

4. Dependent from the settings the operator defined in the application, the agent rejects products with an utility value that is under a defined minimum satisfied utility limit. This limit is, according to the requirements of the game, equal for all agents and not defined per agent type. If this minimum utility limit is set to 1, each product can be a tangible choice. The setting of this limit was implemented to allow agents the decision to buy no product in a round, if their preferences are not satisfied enough with the products on the market. This could be the case if there are just high priced goods on the market with high quality but the specific consumer just prefers cheap products and do not consider the quality at all in his decision.

5. After rejecting the non-tangible products, the remaining products are ordered based on their utility value. The ordering of the utility values results in a transitive relation between the different utility values where a higher utility value is always preferred against a lower one.

6. The ordered list of products, according to their calculated utility values, is the basis for the final decision of the product. The product with the highest utility value is taken from the ordered list and represents the chosen product from the specific agent-based on its preferences. If two or more products have the highest utility value at the same time, the product is chosen randomly out of the equally ranked products. The brand loyalty was according to the requirements not taken into account for the decisions process.

7. The chosen product is then bought by the consumer. This means that the selling price of the product is credited to the participant that offered that product on the market. The chosen product is then saved as the customer choice to the agent and the decision process for the agent is done.

Each of the implemented steps is a modular action in the decision process that can be extended to add additional steps or change the selections criteria. Therefore the decision process can be easily improved, using additional theories of cognitive processing and implementing them as further step in the process.

4.4 Applied mathematical models

Although the agent-based modeling approach does not need as much mathematical effort as the traditional models, there is of course a minimum demand for mathematical formulation for dependencies, behaviors and market mechanisms. Calculating the utility value of a certain good or comparing the attributes of products on the market are just a few examples that are needed in the application. In the following subsections the equations that are of main interest for the development are described in detail to provide a comprehensible insight to the mathematical methods used in the application.

4.4.1 Preference distribution

The agents for the simulation are created based on an agent type definition that groups the agents with similar preferences. The agent type contains therefore the number of agents that have to be created for the defined group. Additionally, the agent type contains the definition of the mean preferences for the selling price, product quality and company image. The values for the preferences are standardized for each attribute and are ranging between 0 and 1. The value 1 for a preference means that this decision factor is important to the agent whereas a value of 0 means that he did not care for this preference at all. The different preferences with the respective characteristics based on the value are:

1. **Price:** A value of 1 states that the agent highly prefers products with low prices whereas the value 0 means that the agent did not care for the price of the good. A value of 0 is means therefore that a relatively high price is not necessarily and exclusion criterion for a specific product.

2. **Quality:** A value of 1 states that the agent highly prefers products with a high quality whereas the value 0 means that the agent did not care for the quality of the good. The value of the preference is inversely proportional to the price values.

3. **Image:** A value of 1 states that the agent highly prefers products where the company selling those products has a relative good image on the market whereas the value 0 means that the agent did not care for the image of the company at all. Like the quality the image is also inversely proportional to the price values.

Based on these three characteristic values and the amount of the agents, a concrete agent type is defined. The individual agents are created based on this definition with normal distributed preferences. The preferences of the agent type are therefore the mean values for the distribution. This requirement allows the creation of heterogeneous agents to an agent type definition. The normal distributed preference for a specific created agent is calculated with Equation 4.1 where μ_p is the mean preference of the agent type for one of the three preferences, σ the standard deviation of the distribution that the operator can define in the application, y_r a normal distributed random variable and z_p the resulting random normal distributed preference value for the specific agent that is created out of the agent type definition.

$$z_p = \mu_p + y_r * \sigma \tag{4.1}$$

The operator of the game is able to manually overwrite the created normal distributed preferences of a concrete agent to create more concrete consumer markets. This allows the operator to create for example just homogenous agents that have all the exactly same preferences.

4.4.2 Weighted preferences

In order to put the generated normal distributed preferences of a specific agent into relation, the relative share of the total values of the preferences are calculated. Therefore each preference is divided through total sum of preferences to get his relative importance to the other preferences. The equation to calculate the weighted preferences is shown in Equation 4.2 where p_p is the preference for the selling price, p_q the preference for the product quality, p_i the preference for the company image on the market, p_{sum} the total sum of all preferences of the agent, p_{wp} the weighted preference for the selling price, p_{wq} the weighted preference for the product quality and p_{wi} the weighted preference for the company image on the market.

$$\begin{aligned} p_{sum} &= p_p + p_q + p_i \\ p_{wp} &= \frac{p_p}{p_s um} \\ p_{wq} &= \frac{p_q}{p_s um} \\ p_{wi} &= \frac{p_i}{p_s um} \end{aligned} \tag{4.2}$$

The weighting method was chosen to guarantee that the resulting value of the utility function is ranging between 0 and 1 independent of the used characteristics that are included in the equation.

4.4.3 Dimension index

The dimension index is a value that describes how well or poorly values of a characteristic are in relation to other values available for that characteristic. This method is used to compare the selling prices, product qualities and the images of the different companies on the market. The dimension index compares the actual amount of a variable to the minimum and maximum values

that are discovered for the characteristic value. [84]
The formula to calculate the dimension index for a specific value v can be seen in Equation 4.3 and is adapted from [84, p. 178] in which v_{act} is the actual value for that the dimension index is calculated, v_{min} is the minimum value occurring for that characteristic, v_{max} is the maximum value occurring for that characteristic and d is the resulting dimension index.

$$d = \frac{v_{act} - v_{min}}{v_{max} - v_{min}} \tag{4.3}$$

Through the fact that the price preference is inversely proportional to the product quality and the company image preferences, this value has to be subtracted from 1. The Equation in 4.4 is similar to Equation 4.3 and differs only in that case that the dimension factor for the price d_p is the equation for the dimension factor subtracted from the value 1.

$$d_p = 1 - \frac{v_{act} - v_{min}}{v_{max} - v_{min}} \tag{4.4}$$

Calculating the dimension index for every characteristic of a product allows comparing the characteristics to each other. Like the weighted preferences in Subsection 4.4.2, the dimension index also ranges between 0 and 1 whereas the maximum value of a characteristic results always in a dimension index of value 1 and the minimum value result to a dimension index of value 0. To use the dimension index, the minimum and the maximum value of a characteristic have to differ from each other. If this is not the case, this would result in a division by 0. This case is possible if there is only one product on the market or all products on the market have the same value for a characteristic like the price. In the application this is checked by applying the dimension index 1 to a characteristic if the minimum and maximum values are the same. This would state that it is the best alternative, cause of the fact that there is no alternative on the market that is worse for the given characteristic.

4.4.4 Utility calculation

The calculation of the utility value for a specific agent and product need the weighted preferences of the agent for the selling price, product quality and company image. Additionally, the dimension indexes of the specific product attributes are also needed. The additive utility function is used to calculate the utility value. In the additive utility function every attribute is independent from the others and the resulting utility value is therefore a weighted sum of attribute utilities. [85]
For each characteristic the dimension index is multiplied with the weighted preference and summed up to get the utility value. The Equation 4.5 shows the formula to calculate the utility value where d_p is the dimension index for the selling price, d_q the dimension index for the product quality, d_i the dimension index for the company image selling this product, p_{wp} the weighted preference for the selling price, p_{wq} the weighted preference for the product quality, p_{wi} the weighted preference for the company image and u as the resulting utility value.

$$u = d_p p_{wp} + d_q p_{wq} + d_i p_{wi} \tag{4.5}$$

The resulting utility is always a value between 0 and 1. This calculated value is then blurred based on the settings of the operator in the application. The blurring factor specifies on how many decimal places the resulting utility value should be rounded. The method of blurring simulates that the customer cannot distinct clearly between to products with a very similar utility value. So the blurring factor allows optionally specifying how precise the calculated utility value should be rounded and therefore how well a customer can distinct between two given products.

4.4.5 Image calculation

The calculation of the changing corporate image of the participant's company involves several steps in the current implementation of the business simulation game. Different factors were chosen to calculate the company image, following the suggestions of Siano et al. [71] who wrote about the main drivers influencing the corporate image and reputation. To restrain the complexity of the initial development of the business game, the decision was taken to implement four of these potential corporate image drivers in the game. The main factors chosen for the actual implementation of the game are:

- **Marketing:** The actions of the company to communicate the value of a product, service or brand to the customers or consumers for the purpose of promoting or selling that product.
- **Research & Development:** Involves actions of the company to improve the research and development of new innovations.
- **Personal development:** Includes educational activities to improve the skills of the employees of the company.
- **Sales volume:** The quantity of products or goods sold by the company to the customers in a specific fiscal period.

The first three factors can be controlled by the participant/company owner with optional investments decisions he can take. The sales volume factor depends on how well the product portfolio of a company is performing on the market and how good the competitors are in relation. The higher the relative sales volume on the whole market the better is the reputation for the company in the next period. As it can be seen in Equation 4.6, for all investment possibilities and the sales volume the relative share compared to the investments and sales volume of the whole market is calculated. In this equation N is the number of all participants firms, MI_i is the marketing investment for participant i, RMI_i is the relative marketing investment for participant i, RDI_i is the research & development investment for participant i, $RRDI_i$ is the relative research & development investment for participant i, EI_i is the educational investment for participant i, REI_i is the relative educational investment for participant i, S_i is the sales volume of participant i and RS_i is the relative sales volume of participant i.

$$
\begin{aligned}
RMI_i &= \frac{MI_i}{\sum_{i=1}^{N} IM_i} \\
RRDI_i &= \frac{RDI_i}{\sum_{i=1}^{N} RDI_i} \\
REI_i &= \frac{EI_i}{\sum_{i=1}^{N} EI_i} \\
RS_i &= \frac{S_i}{\sum_{i=1}^{N} S_i}
\end{aligned}
\tag{4.6}
$$

The calculated values in Equation 4.6 are relative values based on the total investments or sales volume. Using these four relative values, a weighted average value is calculated. Equation 4.7 shows the weighted relative company investment RCI_i for each company i based on the weighting factors w_1, w_2, w_3 and w_4 that add up to 1.

$$
\begin{aligned}
RCI_i &= w_1 * RMI_i + w_2 * RRDI_i + w_3 * REI_i + w_4 * RS_i \\
1 &= w_1 + w_2 + w_3 + w_4
\end{aligned}
\tag{4.7}
$$

The weighting of the four different relative investment/sales values allows the operator to set difference preferences on the market. Participants are therefore challenged to find the most effective action to invest into beside to the relative sales volume. For every participant i the weighted relative investment/sales values are calculated. Based on each of these values the average relative investment RAI for the market can be calculated as seen in Equation 4.8 where N is the number of all participants in the game and RCI_i the relative company investment for the concrete participant with index i in the game.

$$
RAI = \frac{\sum_{i=1}^{N} RCI_i}{N} \tag{4.8}
$$

Using the calculated average relative investment it can be now compared if the relative company investments are above or below the market average. Using the exponential smoothing technique, the new image for a company can now be calculated using the deviation from the average relative investment. In Equation 4.9 the calculation of the new image I_r for the actual round r can be seen using the image of the previous round I_{r-1}, the deviation d and the applied smoothing factor α that can be configured by the administrator of the game.

$$
\begin{aligned}
d &= RCI_r - AIS \\
I_r &= \alpha * I_{r-1} + (1 - \alpha) * (I_{r-1} + d)
\end{aligned}
\tag{4.9}
$$

The different steps of the image calculation allow the operator to change the impact of the various factors by changing the used weighing parameters or the smoothing factor to simulate more complex situations for the participants. For the empirical tests that were performed, the weighting factors are set equivalent and the smoothing factor was set to 0.5 so that the previous round and the actual round are weighted equally.

4.4.6 Logistic costs

To hamper the participants making to large assortments of different products with different prices, the logistic cost curve is implemented in the game. The logistic cost curve allows the operator to set an amount of free products in the portfolio that require no additional logistic costs to pay. For every additional product that a participant is going to add to his portfolio, additional logistic costs will be charged. The logistic cost curve is implemented as an exponential growth function. The goal of the logistic costs function is to restrict the size of the offered goods from a participant and provide a trade-off situation for increasing the size of the assortment. The Equation 4.10 shows the logistic cost function where p_t is the total amount of products in the assortment, p_f is the amount of products that are not charged with logistic costs, p_a is the amount of products that will be charged with logistic costs, r is the rising factor of the logistic cost function, c_u is the logistic cost factor for an additional product and c_l as the resulting logistic costs that will be charged to the participant.

$$\begin{aligned} p_a &= p_t - p_f \\ c_l &= e^{p_a/r} * p_a * c_u \end{aligned} \tag{4.10}$$

The variables r, p_f and c_u are configured by the operator to restrict the amount of products in the assortment or make a steeper logistic cost function. This means that each additional product is more expensive for the total logistic costs. An example of a realization of the logistic cost curve is shown in Figure 4.7.

4.5 Visualization of decisions and market information

Trying to give an overview of the implemented application, the user interfaces of main interest for the participants and the operator of the game are shown and explained in this section. This should provide an overview of the game including a short description of the interfaces. Additionally, the main functions are explained for each of the shown interfaces to provide a detailed insight into the developed application.

4.5.1 Participant View

For the perspective of the participant the functions of primary importance are the decision possibilities including the investment decisions and the market analysis function to investigate the consumer composition of the market. This subsection will cover therefore the graphical user interfaces that are relevant for the participants in the game. Figure 4.8 shows the menu structure with the different decision possibilities for a participant. The menu structure includes the different decision possibilities for the participant for a specific round. Additionally, the actual round

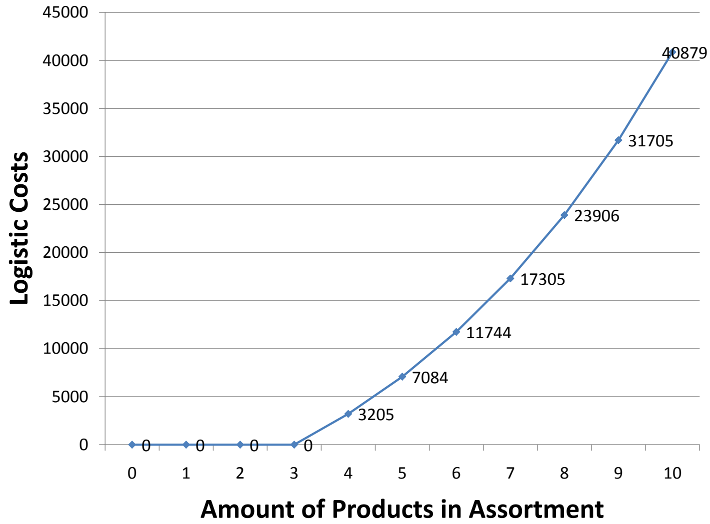


Figure 4.7: Example of a logistic cost curve with p_f=3, c_u=2900 and r=10

can be seen and the time until decisions can be taken from the participant for this round. It is the general menu the participants are seeing if they log into the application and allows them to instantly take their decisions.

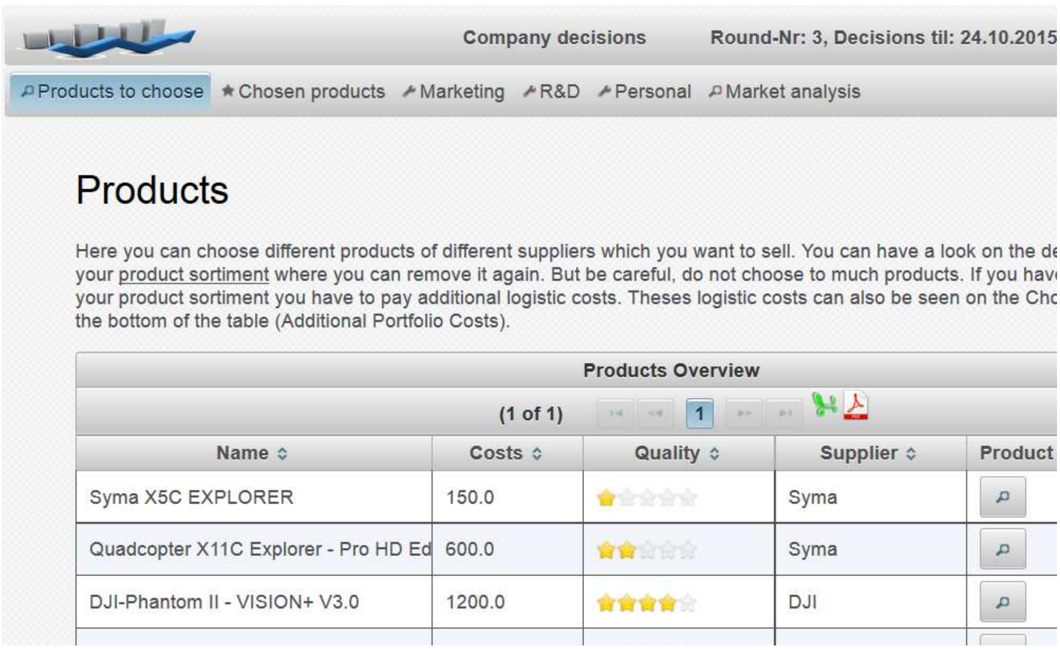


Figure 4.8: Menu structure

Figure 4.9 shows the product portfolio of the participant. This product portfolio includes the relevant information of all offered products of the participant's company including the selling price that can be changed by the participant. If a participant decides to add a new product to his portfolio he has to set the selling price for the product. This is the price the consumers are seeing on the market and using as part of their purchase decision. If the portfolio is above a defined size there are additional logistic costs that are shown in the portfolio table below. The logistic costs are calculated with the logistic cost curve that was already mentioned in Subsection 4.4.6. The portfolio can be dynamically changed as long the current round is not expired. Decisions can be changed as often as desired within a round.

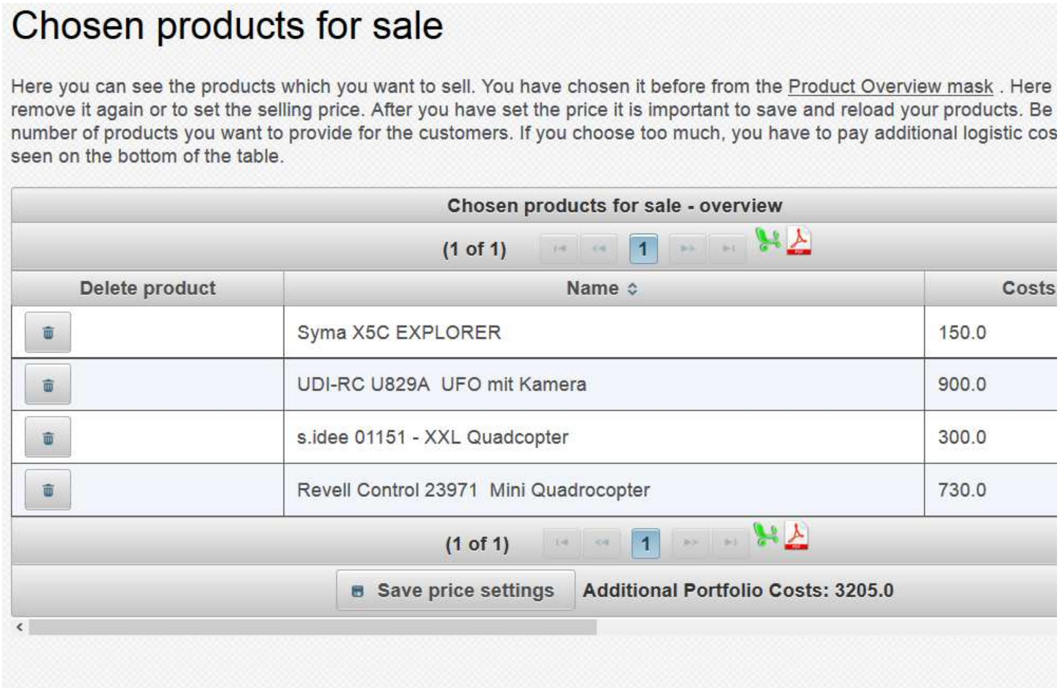


Figure 4.9: Product portfolio

Figure 4.10 shows the investment possibility for the marketing of the company. It is similar structured for the R&D and the personal investments and allows the participant to choose and investment amount for the specific field. The investment is ranging between 0 and the maximum defined amount according to the settings of the operator. The participant is able to see his past investment decisions for each of the categories. Additionally, the evolution of the investment spending curve can be seen as additional feedback. As already mentioned, the user is not aware of the related effectiveness of the different investment possibilities. The operator is able to change the impact of the different investments in the overall settings. All of the investments are optional and are taken over from the previous period to the next round after the simulation of a round is successfully performed. This feature was implemented to increase the usability and allow the participant to adapt the investments decisions easier according to the inputs of the last round.

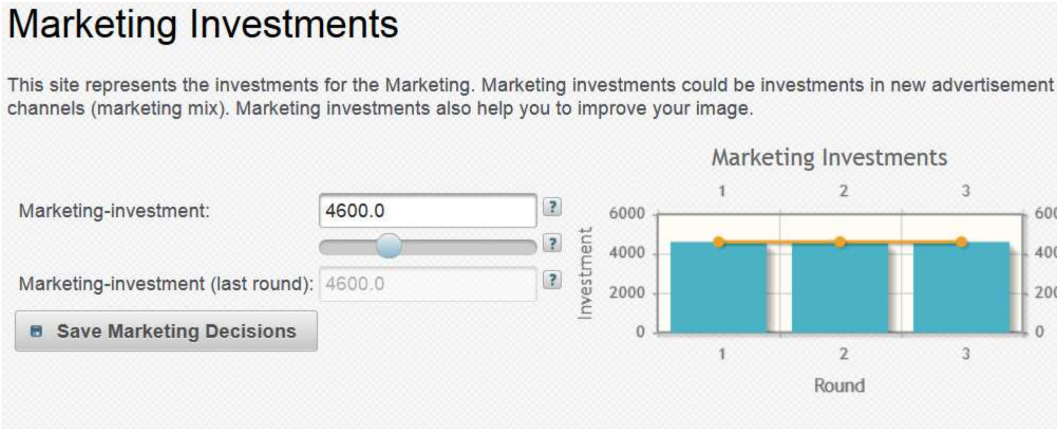


Figure 4.10: Marketing investment

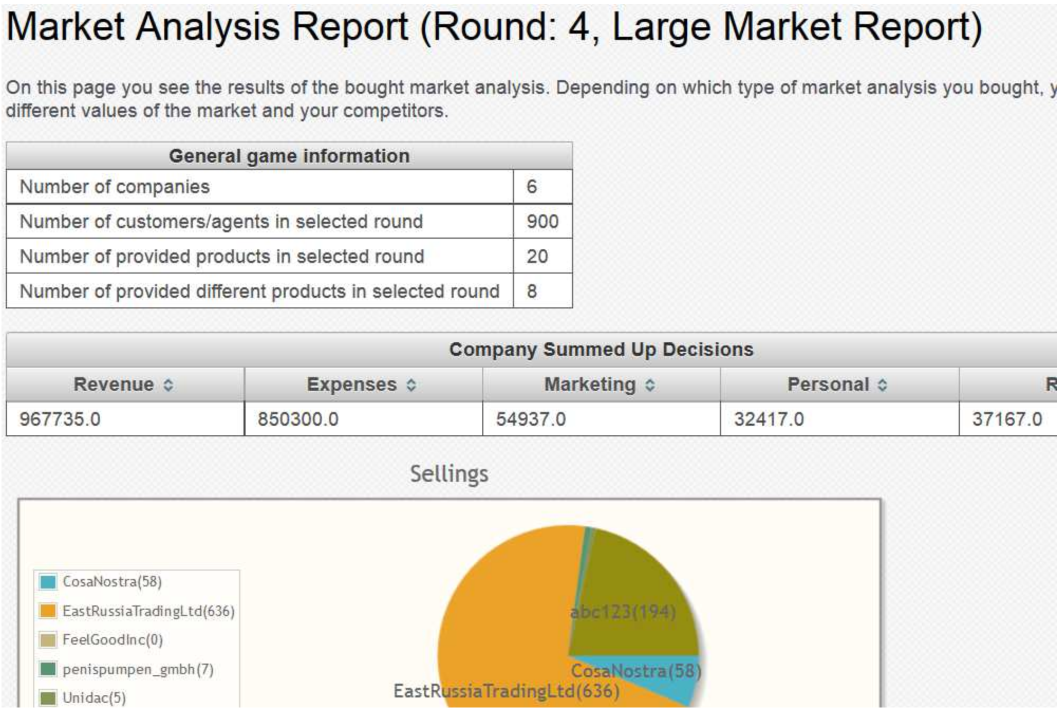


Figure 4.11: Market report

The participant is able to choose between three different market reports in a period. The result of a report will be available in the next period and presents the results from the round when the report was bought. The three report possibilities differ in their investment costs for the participant. The higher the costs for a market analysis report the more information is provided for the participant and allows a more detailed market investigation. The market report decision possibility allows investing into market analysis of different quality levels. Figure 4.11 is showing the first part of a received large report. The first half of the resulting report includes a general market overview, the own decisions taken in the previous round and the distribution of the sales volumes according to the different companies on the market.

Figure 4.12 shows the second half of the ordered market report. In this section there are not only the own decisions of the last round shown, there are also the decisions of the different competitors on the market. Additional to the information of the competitors the participant who ordered the report gets an insight of the agents preferences on the market. A defined proportion of all consumers are presented to the participant including their preferences. This data can be exported as PDF or Excel file to use it for further analysis. This supports the participants to investigate the composition of the market and the general preferences of the available consumers. The proportion of the provided competitor and agent data depends on the type of report that was chosen.

Company Results And Decisions (All Companies)

(1 of 1) 1

Company	Round	Revenue	Expenses	Marketing	Personal	R&D	Image
Unidac	4	7750.0	7250.0	4000.0	2500.0	5000.0	0.456
CosaNostra	4	98600.0	86950.0	14600.0	5150.0	5250.0	0.514
EastRussiaTr	4	752960.0	664200.0	13337.0	13337.0	13337.0	0.617
abc123	4	105485.0	89800.0	10000.0	6000.0	6000.0	0.516
FeelGoodInc	4	0.0	0.0	7000.0	3000.0	3000.0	0.448
penispumpen	4	2940.0	2100.0	6000.0	2430.0	4580.0	0.449

(1 of 1) 1

Agent Preferences (All Agents)

(1 of 90) 1 2 3 4 5 6 7 8 9 10

Quality preference (0-1)	Price preference (0-1)	Image preference (0-1)	Chosen pr
0.13	0.664	0.072	s.idee 01151 - X
0.367	0.747	0.178	s.idee 01151 - X
0.207	0.348	0.706	s.idee 01151 - X
0.779	0.028	0.147	DJI-Inspire 1 - T600 Quadrocc

Figure 4.12: Market report (continued)

4.5.2 Operator View

For the operator or administrator of the game there are various different possibilities that allow setting the parameters for a specific game instance. Of primary importance for the administrator are the setting possibilities for the market composition based on the agent type configuration and the statistical outputs of the results in the game. Additionally to those two game specific possibilities there is also opportunity for the operator to set application wide parameters that will be applied to all game instances and simulation runs. Figure 4.13 is showing the agent

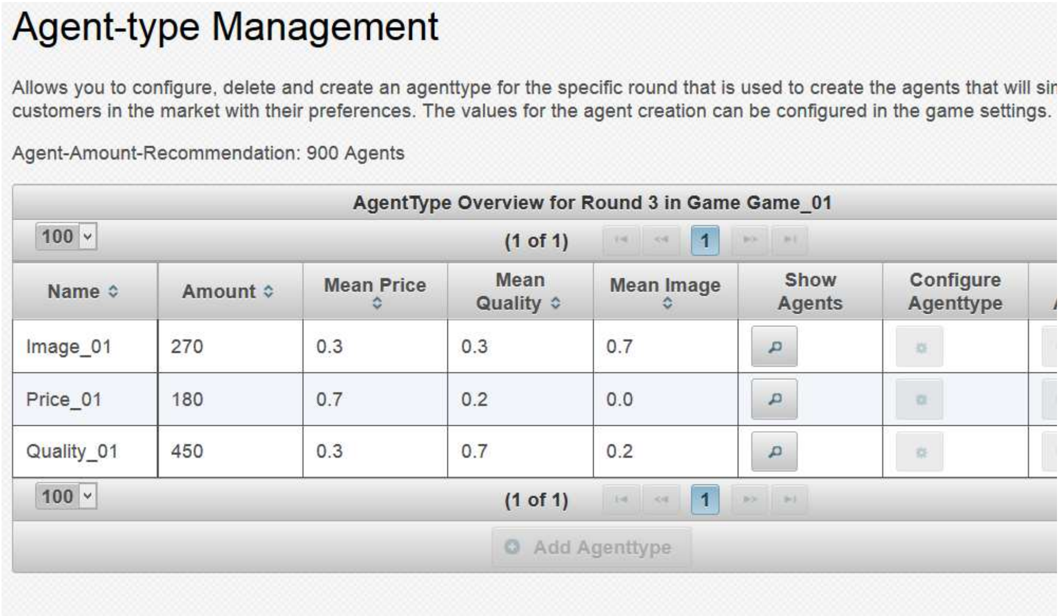


Figure 4.13: Agent type management

type configuration possibility including three different agent types with their mean preferences and their amount of agents for a specific round. Each of the agent types can be named to make the distinction for the operator easier. It can be seen that these three agent type definitions are contrary according to their configured preferences. Each of these agent groups is either more interested in the quality, the price or the image of a company. The composition is a result of the defined amount of the agent type that declares how many agents of the specific type are going to be generated for this round.

Figure 4.14 shows the generated agents for a specific round based on an agent type configuration with the normal distributed preferences. The normal distribution of the preferences is controlled with the configured mean value of the concrete preference type and the variance that can be configured in the operator's settings mask. With the help of these parameters there will be a random value generated for this preference. For each agent a preference value is generated according to this setting to provide an individual agent instance. The generated individual agent instances with their preferences are listed for each agent type and can be overwritten and saved. A generated agent can be overwritten as long as the simulation for this round, to that the agent is dedicated, is not executed. The generated agents are also copied automatically to the next round after a round was simulated successfully. This should avoid additional configuration overhead for the operator when using the agent-based model approach. Only changes of the actual market composition have to be adapted in the agent type definition for the specific round. If the composition should remain constant there is no additional configuration necessary for the operator.

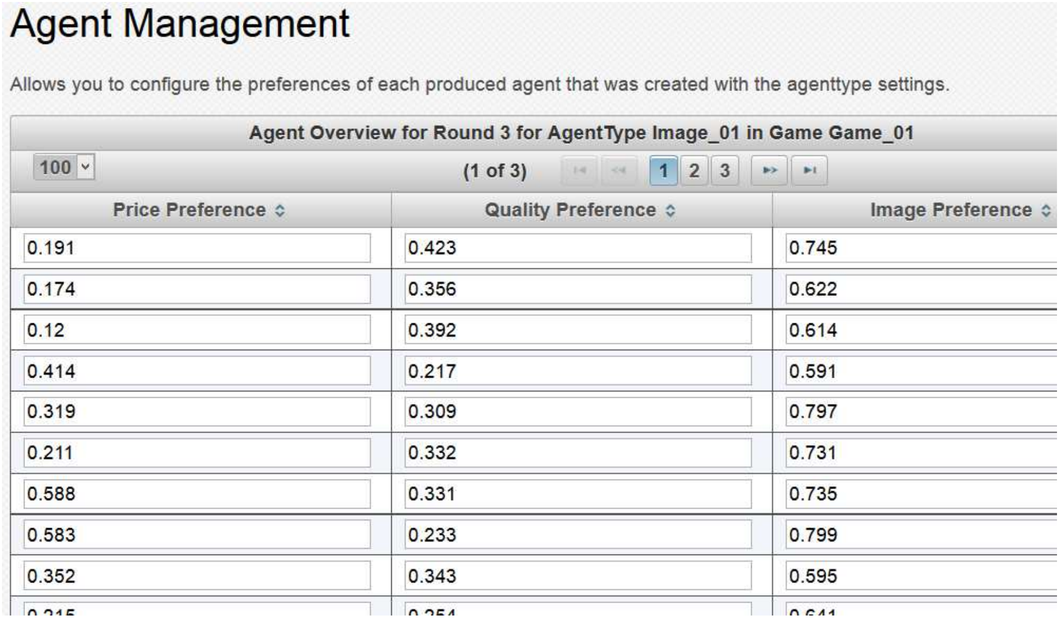


Figure 4.14: Generated agent instances

The results and ongoing developments of a game instance can be seen by the administrator in two different ways. There is the possibility to either see the statistical results in a graph in form of line/bar diagrams or in a tabular form.
Figure 4.15 shows the budget development of the different participating companies for a specific game. This type of graph based output can be used by the operator to give a quick overview of company based evolutions in different fields like budget, image, selling volumes and others. It is also possible to see the market shares of the top-selling products and the actual configured portfolio cost function. The development of different categories like budget, image and others are shown for each company and each round to follow the development of a company in a specific category of interest. This type of chart should help the operator to retrieve the changes of the performance after a market composition change occurred during the game. Additionally, the graph based output should enable the operator to provide an overview to the participants, to show them their developed performance after the game is finished.
Figure 4.16 shows the tabular output for the decisions of the participants. The tabular output can be filtered and allows the operator to get a more detailed insight in the different decisions of the participants and agents during the game. The tabular view also allows exporting the received data as PDF or CSV file format to allow the operator to perform analysis offline. The tabular form provides more information to the operator for a more detailed insight into the decisions of the game for each round. The statistic function whether as a graph or as a table can be used anytime by the operator for a specific game. It only requires the administrator to be logged in and choose a game for that the statistic output should be generated.

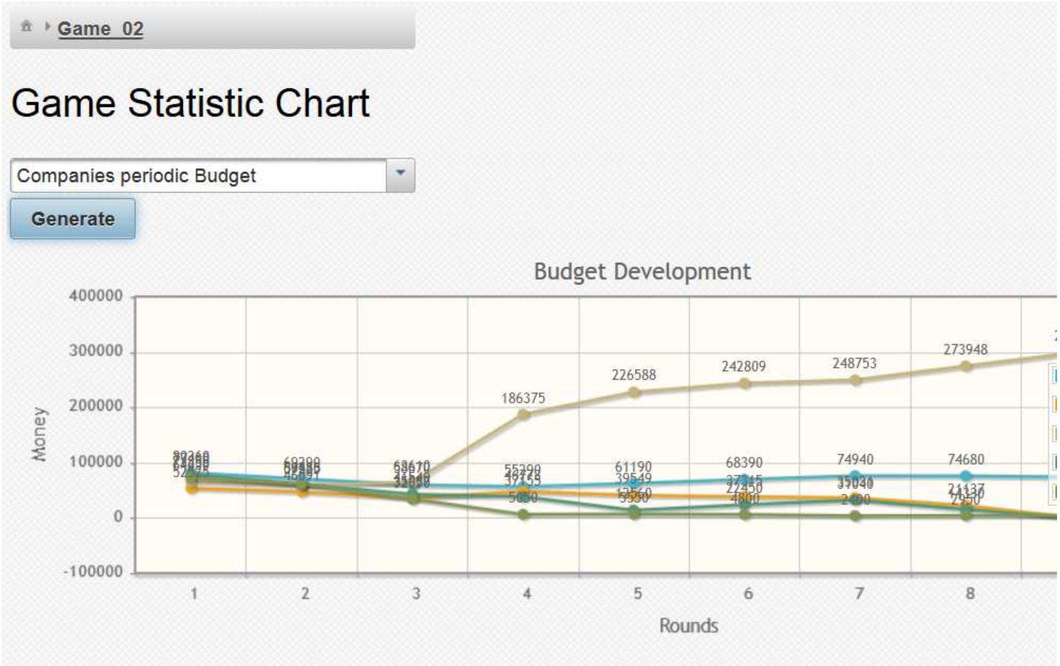
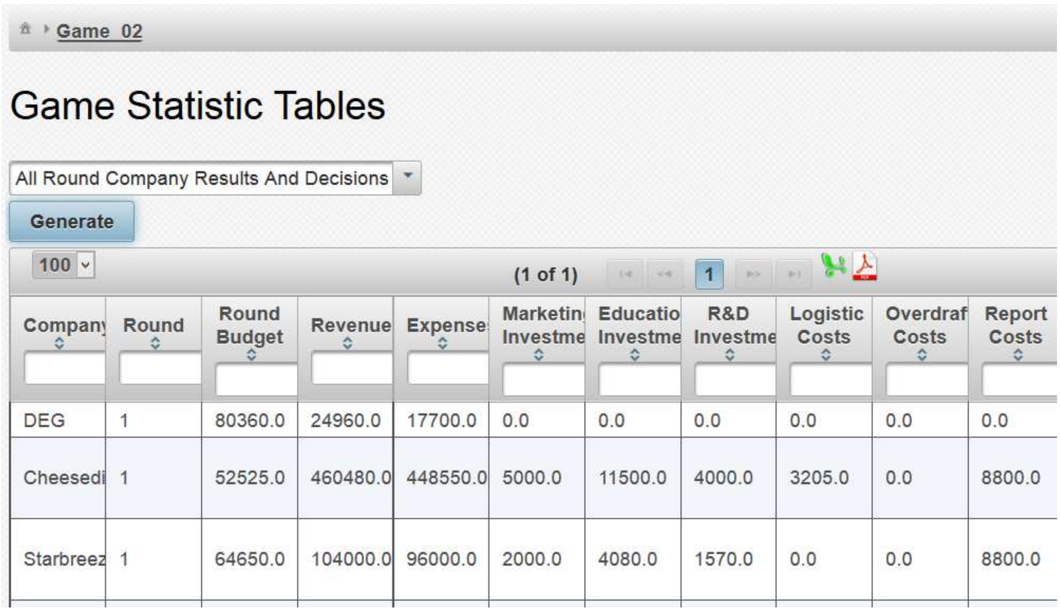


Figure 4.15: Graph based output



Company	Round	Round Budget	Revenue	Expense	Marketin Investme	Educatio Investme	R&D Investme	Logistic Costs	Overdraf Costs	Report Costs
DEG	1	80360.0	24960.0	17700.0	0.0	0.0	0.0	0.0	0.0	0.0
Cheesedi	1	52525.0	460480.0	448550.0	5000.0	11500.0	4000.0	3205.0	0.0	8800.0
Starbreez	1	64650.0	104000.0	96000.0	2000.0	4080.0	1570.0	0.0	0.0	8800.0

Figure 4.16: Tabular based output

One of the most important interface for the operator can be seen in Figure 4.17, showing the overall settings mask that is used to configure the settings that are valid for all game instances within the application. They are primary used for the initial settings for the participants, the agent preference distribution and the calculations during the decisions process. Contrary to the agent configuration for each round, this mask is changed less often and is therefore a stable setting throughout the game. The overall setting is divided up into six sections that are:

- **Image Calculation Setting:** Includes the weighting factors for the image calculation.
- **Company Setting:** Contains the settings for the starting image, portfolio cost curve, smoothing factor, and the starting budget for a company.
- **Market Setting:** Contains the interest rate for the debts on the market.
- **Agent Setting:** Includes the minimum consumer utility, the preference variance, the agents per company factor for recommendations and the utility precision.
- **Game Initialization:** Contains the factors that are used to calculate the different costs occurring in the game.
- **Game Initialization Investment:** Defines the maximum costs for the investments.

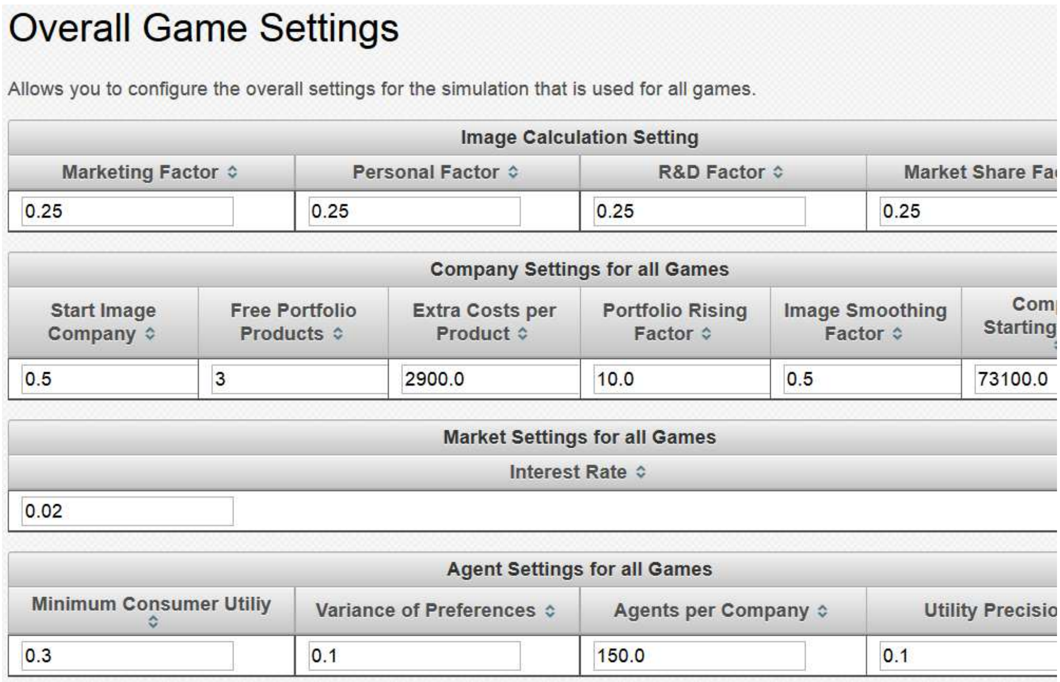


Figure 4.17: Overall game setting mask

4.6 Summary

This chapter summarizes the various implementation details used for the implementation of the web application. The deployment architecture was explained briefly including the reasoning for the decisions taken for specific components. Based on the software architectural overview, the data model was presented, giving information about the used data elements in the game and how they are related. The entities occurring in the game are explained in detail, to provide the overview of the essential objects implemented in the game.
The frameworks for the data access and the simulation within the application are also mentioned as one of the core elements in the application. The simulation framework MASON was explained in detail to understand how the simulation framework is interacting with the object-mapping framework Hibernate in the application. This should provide an insight in the implementation possibilities of the simulation framework to a web application with a relational database as back-end data storage.
Additionally, the decision process that was used to simulate the cognitive behavior of the agents is described in detail. The actions an agent is going to perform during the execution of the decision process are described. These actions explain in detail how the agent gets to a decision during the simulation. The decisions process is performed by each agent during the simulation run of a round. The performed mathematical models used in the different steps of the decisions process are explained briefly to allow the re-engineering of them. The process should additionally provide a more intuitive way of describing the market based on the individual behavior rather than the macro-economic view.
As last part of this chapter the different visualizations of the existing data in the application are shown. The interfaces of main interest were described from the participant's and operator's view. Through the fact that the possibilities to see the data and decisions of an individual agent are discovered as one of the main points of interest in the implementation, they are described in detail and presented in this thesis.
The implementation chapter should provide an insight into the developed application that is used as artifact for the design science approach. It describes in detail a possible way of implementing the agent-based modeling approach to a web-based application. Additionally, it is shown how the behavior of an agent can be implemented and changed during the game. This chapter should therefore provide a technical basis and reference according to future work in this field.

CHAPTER 5

Results

The evaluation of the proposed solution had to take place on an experimental level and on an analytical level. To answer the research question if agent-based models are a practicable approach to model a dynamic market of consumers in a web based business strategy game and what are the advantages or disadvantages, the created application had to be assessed from the view of the participants of the game as well as the operator who administers it. For the perspective of the participants, the application of the agent-based model is evaluated based on an experimental setting for the participants. This setting was tested with a survey for the participants to evaluate the performance and the acceptance of the created artifact in the business environment. The perspective for the operator is evaluated based on an analytical analysis that summarizes the discovered qualities of the artifact and the drawbacks of the usage of the agent-based model approach in this application.

5.1 Experimental evaluation for participants

The utility, quality, and suitability of the designed artifact is evaluated for the participants based on an experimental setting of the artifact that is integrated in the lecture. The participants are divided into groups of four to six people that are performing as competing companies against each other on the market. As in advance explained in Chapter 3, each of these groups perform in an own instance of a game and will be facing the same settings as the other groups to ensure the comparability of the different groups in the evaluation. A game for the applying participants in a group is lasting for ten rounds where each round lasts 14 hours. In each round the participants were able to take their decisions within that period of time.
Each group was facing the same market composition of consumers and the same settings in the game instance. During the simulation two changes of the market composition occurred. The first change was applied after round three and the second one after round seven. These changes should challenge the participants to investigate the market and adapt their product portfolio to react to the transformation of the market.

The performance of the individual participants of a group is measured based on their achieved budget for their company in the end of the game. The survey took place after the game was completed and covers seven different fields of interest. Each field is addressed with at least two questions/statements to evaluate the performance of the developed artifact for this construct of questions based on a five point Likert scale. The survey also allows the participants to omit questions/statements if the answers are not suitable. The 5-point Likert-scale was used with 1 representing strong disagreement, 2 disagreement, 3 adequate, 4 agreement and 5 strong agreement for the statement and the option to omit the question/statement. The seven questions constructs that are evaluated for the implemented artifact are:

1. **(C1) Agent behavior:** How comprehensible was the behavior of the consumers?
2. **(C2) Agent information:** Are the preferences of the agents clear to the participants?
3. **(C3) Segment identification:** Was it possible to identify the consumer segments on the market?
4. **(C4) Strategy adaption:** Did the investigation of the market influence the participants decision?
5. **(C5) Address segments:** Was it possible for the participants to align their product portfolio for a consumer segment?
6. **(C6) Game comparison:** Has the game been more or less accepted than other already played simulations?
7. **(C7) Game experience:** Did the participants perceive the participation as a challenging and interesting experience?

For the evaluation of the developed strategy game, 47 contestants participated in the game. To provide a representative group of participators for the evaluation of the simulation game, 22 of the 47 participators did not attend the lecture 'Strategic Management' in this semester. The other 25 participators attended the lecture before participating in the game.

5.1.1 Construct validation

To provide the validity of the different constructs of interest the collected data resulting from the questionnaire was tested with the Cronbach's alpha test. The Cronbach's alpha function is used to test the expected correlation of the responses of two or more questions/statements that are assigned to the same construct. If the internal consistency is at least acceptable, the average correlation of a set of items can be used as an accurate estimate of the average correlation of all items that pertain to a certain construct. The reliability for a construct is given if the resulting reliability for the Cronbach's alpha test provides a value that is at least 0.7 for this construct of questions. Therefore the Cronbach's alpha value is calculated for each of the seven constructs to test if the internal consistency of all constructs is at least acceptable.

Construct	Occurring questions per construct	Calculated α-value
(C1) Agent behavior	3	**0.70**
(C2) Agent information	3	**0.66**
(C3) Segment identification	2	**0.12**
(C4) Strategy adaption	2	**0.52**
(C5) Address segments	2	**0.02**
(C6) Game comparison	2	**0.62**
(C7) Game experience	2	**0.50**

Table 5.1: Resulting values for the Cronbach's alpha per construct

In the following Table 5.1 the calculated Cronbach's alpha for each construct of questions is given, including the number of questions occurring in the specific construct.

Based on the calculated Cronbach's alpha values for the constructs, only one construct of questions/statements fulfilled the criteria to be used as an acceptable construct by providing a satisfying correlation of the responses. As a consequence of this result, the questions/statements for each construct in the survey have to be evaluated separately to assess the applicability of the agent-based modeling approach for a web-based business strategy game.
Each of the 16 questions/statements was therefore evaluated individually, including all 47 participants that take part on the survey after playing the strategic simulation game. For each statement in the questionnaire the distribution of the Likert-scale values is shown including the calculated mean value for all not omitted answers. Additionally, the mean of the best performing half and the mean of the worst performing half of the participants, based on the achieved budget, are also presented for each question. The distinction of these two resulting parts should indicate if there are main differences in the answers, dependent of the achieved results in the game. This should state if responses to questions are mainly influenced based on the achieved results of the participants.
The results of the 16 separately evaluated questions are presented in Figure 5.1 to Figure 5.16 including the question and the originally assigned construct. Additionally, the amount of not omitted answers for these questions/statements is given as well as the mean for all valid answers, the mean of the 50 percent top performers and the mean of the 50 percent worst performing participants in the game. The amount of responses per Likert-value is given as an absolute value on the y-Axis of the figures. The distributions provide a quick overview of the different questions and the tendencies of the participants to the different questions and are used for the evaluation in the following Subsection 5.1.2. The detailed questions are additionally provided in the Appendix A with their relating construct.

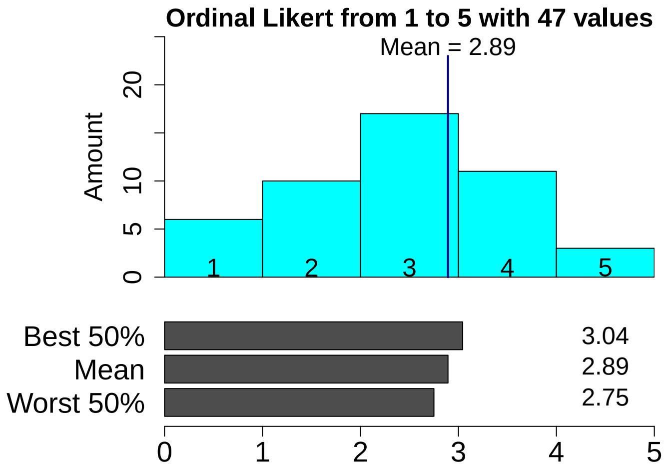


Figure 5.1: **Q1** Agent behavior: I think that the selection of the products by the consumers was comprehensible.

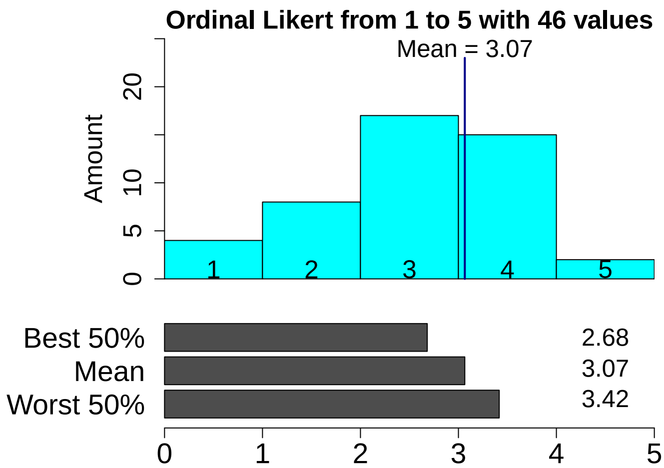


Figure 5.2: **Q2** Agent behavior: I think the consumers behaved randomly when they bought a product.

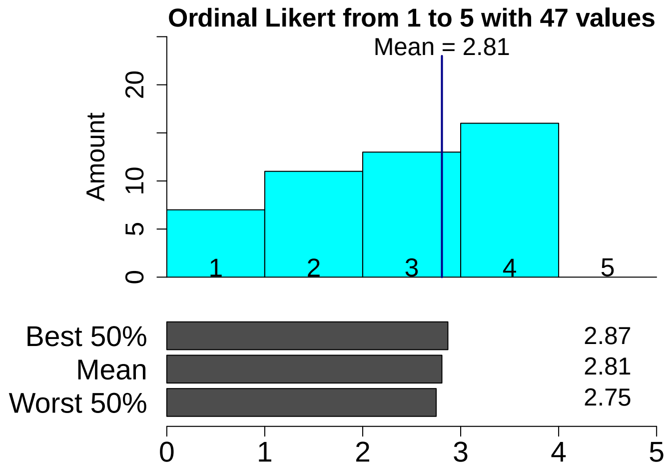


Figure 5.3: **Q3** Agent behavior: In my opinion the criteria which were used for the decision-making of the customers were clear.

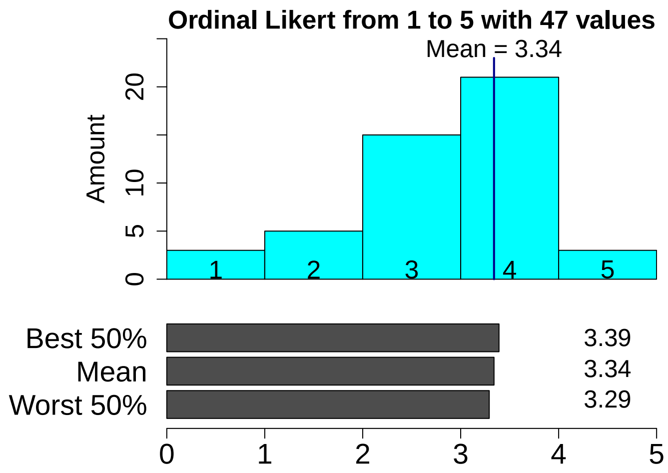


Figure 5.4: **Q4** Agent information: I perceived the possibilities in the game to explore and visualize the consumers and other competitors as understandable.

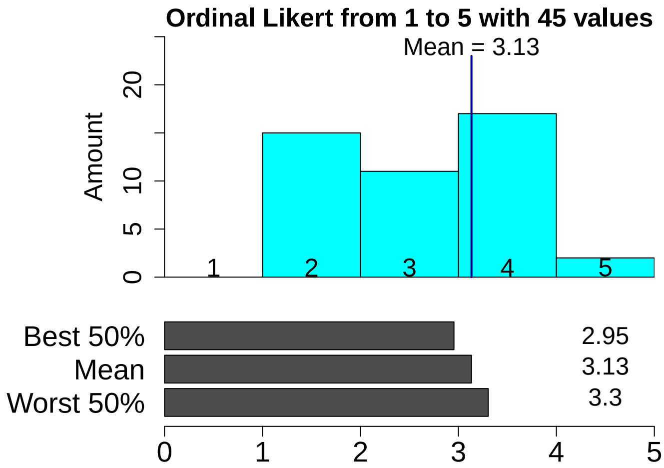


Figure 5.5: **Q5** Agent information: I think that the representation of the consumers in the business strategy game was confusing.

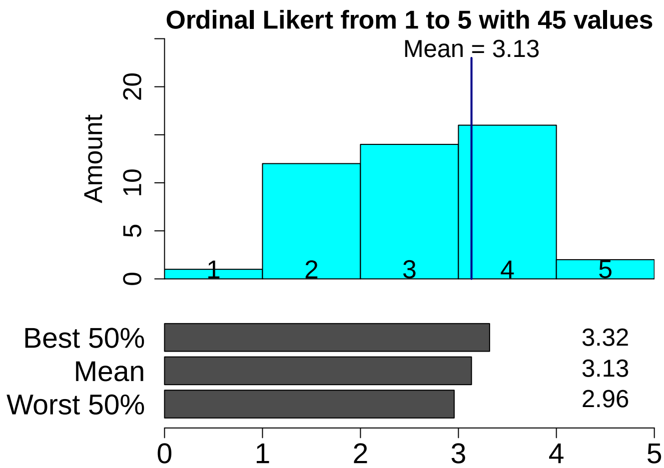


Figure 5.6: **Q6** Agent information: The representation of the individual consumers helped me to recognize the consumer segments.

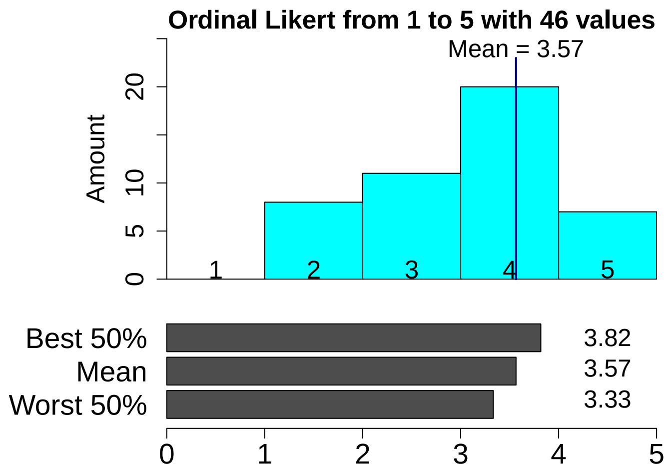


Figure 5.7: **Q7** Segment identification: I perceived it as a challenge to identify customer segments and their size on the market.

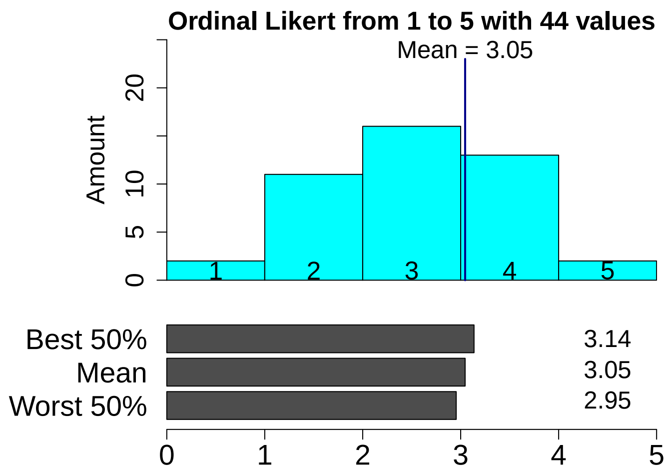


Figure 5.8: **Q8** Segment identification: In my opinion the opportunity to explore the consumers at a detailed level was realistic.

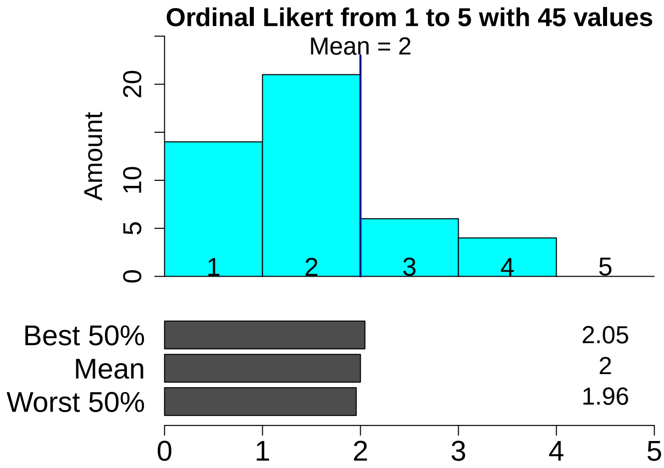


Figure 5.9: **Q9** Strategy adaption: I did not need to change my strategy during the game.

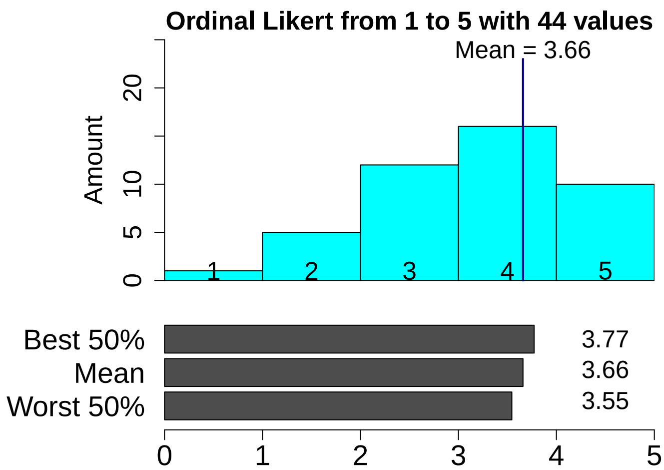


Figure 5.10: **Q10** Strategy adaption: The investigation of the consumer market influenced my strategy.

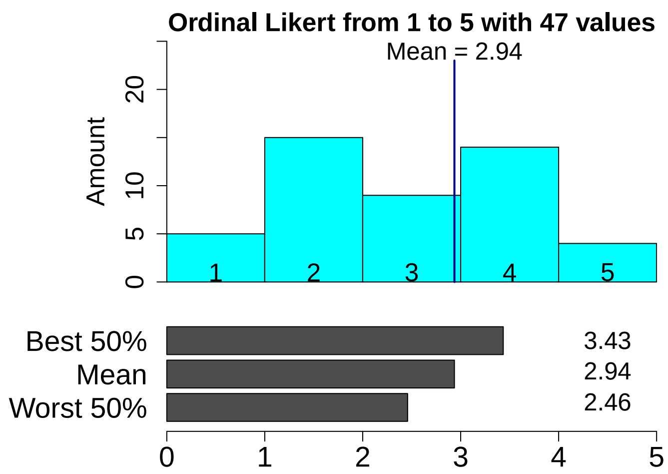


Figure 5.11: **Q11** Address segments: In my opinion it was easy positioning my product portfolio to the consumer segments.

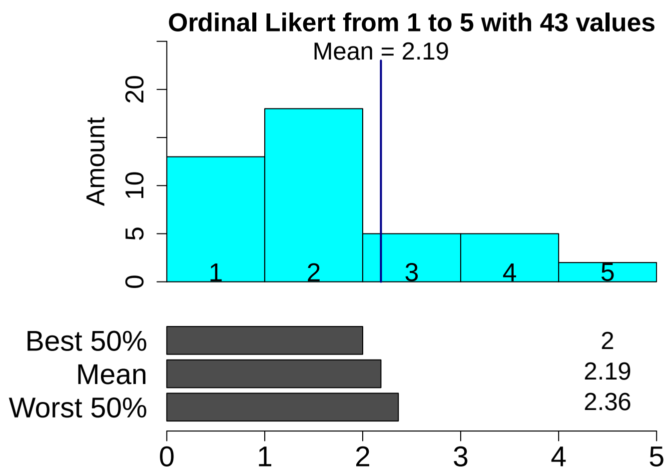


Figure 5.12: **Q12** Address segments: It was not necessary for me to discover the market.

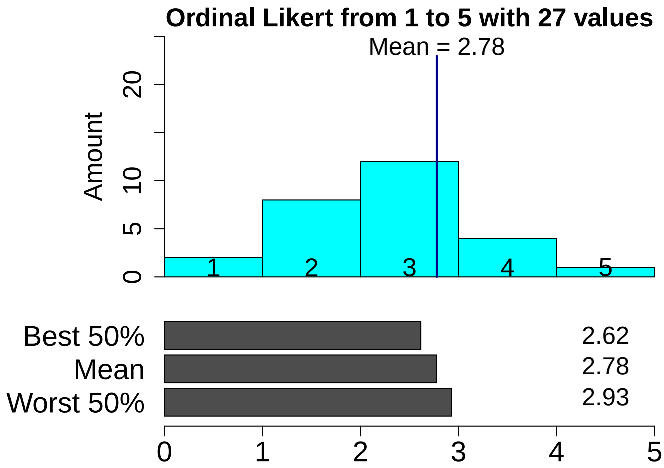


Figure 5.13: **Q13** Game comparison: I think that the consumer market in this game felt more realistic than in other business games I played.

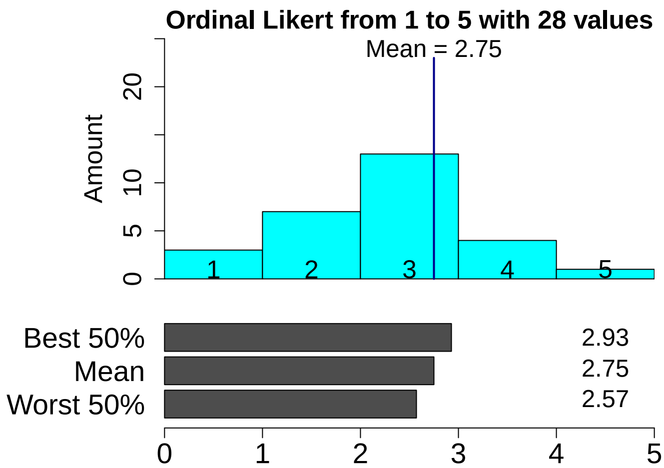


Figure 5.14: **Q14** Game comparison: In my opinion this game had fewer possibilities to explore the market than other business games I played.

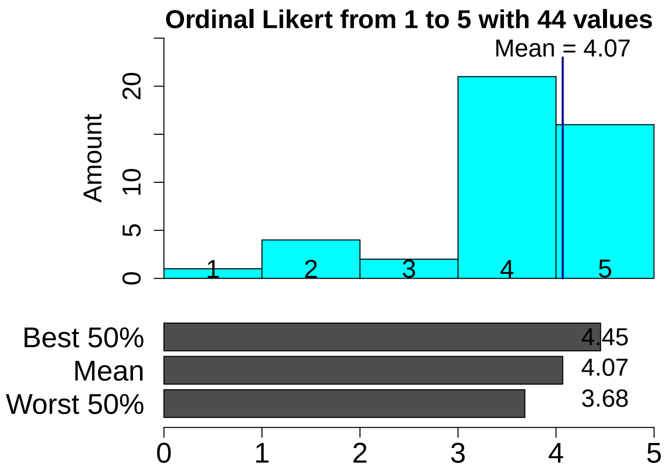


Figure 5.15: **Q15** Game experience: In my opinion the business simulation game was interesting.

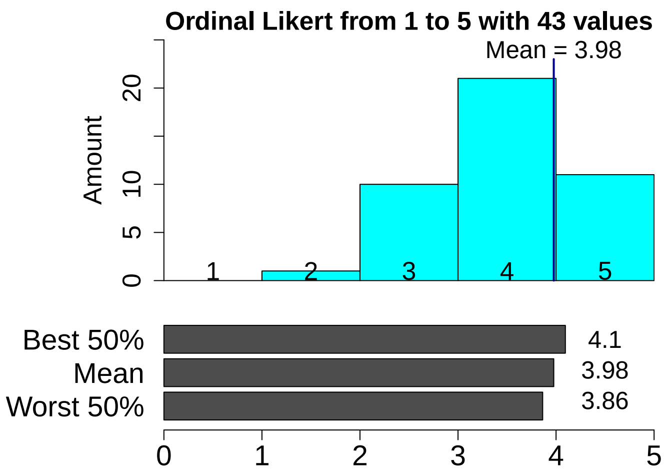


Figure 5.16: **Q16** Game experience: I perceived playing the game as challenging.

Question	Construct	Framing	Observations	Mean	Median	p-value
Q1	Agent behavior	positive	47	2.89	3	0.002
Q2	Agent behavior	negative	46	3.07	3	<0.001
Q3	Agent behavior	positive	47	2.81	3	<0.001
Q4	Agent information	positive	47	3.34	4	<0.001
Q5	Agent information	negative	45	3.13	3	<0.001
Q6	Agent information	positive	45	3.13	3	<0.001
Q7	Segment identification	positive	46	3.57	4	<0.001
Q8	Segment identification	positive	44	3.05	3	0.002
Q9	Strategy adaption	negative	45	2.00	2	<0.001
Q10	Strategy adaption	positive	44	3.66	4	<0.001
Q11	Address segments	negative	47	2.94	3	<0.001
Q12	Address segments	negative	43	2.19	2	<0.001
Q13	Game comparison	positive	27	2.78	3	0.017
Q14	Game comparison	negative	28	2.75	3	0.013
Q15	Game experience	positive	44	4.07	4	<0.001
Q16	Game experience	positive	43	3.98	4	<0.001

Table 5.2: Overview of the responses for all questions

5.1.2 Interpretation

The responses of each question/statement were tested with the hypothesis that the performance for this question is above the average. To test this hypothesis for all questions and to find out if the mean is a meaningful measure, the responses of all questions were tested with the Shapiro–Wilk test to identify if the values are normally distributed. The null hypothesis of the Shapiro–Wilk test is that the population is normally distributed whereas the alternative hypothesis states that the sample data is not from a normally distributed population.
Testing with a chosen alpha level (significance level) of 0.05 the null hypothesis is rejected if the resulting p-value is less than the chosen alpha level indicating that there is a evidence that the responses are not normally distributed. Table 5.2 provides an overview of the different responses to the questions of the previous subsection including the main statistical parameters of the responses. The table includes the number of the question, the construct to that this question belong, the information if the question is positive or negative framed, the amount of observations, the resulting mean of all responses, the resulting median of the responses and the resulting p-value of the Shapiro–Wilk test.

On the basis that there is a relative small amount of observations (<= 47) for each question and the fact that there is an ordinal nature of the data, it was decided to use the median as the primary location parameter to evaluate the performance based on non-parametric statistical hypothesis tests. Jamieson [86] stated that for ordinal data one should employ the median or mode as the measure of central tendency. This is argued due the fact that response categories in a Likert scale questionnaire have a rank order, but the intervals between two possibilities cannot be presumed equal. To evaluate the median as the main measurement of central tendency the questions were therefore framed positively including the resulting responses to get the framed median for the responses. To test the one-sided hypothesis that the performance for this question is above the average, the sign test and the Wilcoxon signed-rank test are used to see if the positive framed median is greater than the average hypothetical performance of 3. The two non-parametric statistical tests were chosen through the fact that based on the results of the Shapiro–Wilk test there could be no assumptions made about the distribution of the data.

The sign test is a statistical method that can be used to test for consistent differences between pairs of observations. Given pairs of observations for each response, the sign test determines if one value of the pair tends to be greater than (or less than) the other value of the pair. The sign test can therefore also be used to test the median of a collection of numbers. By applying a one-sided test, it is checked whether the median is greater or less than a given hypothetical value. Specifying a significance level for the one-sided test for the received responses, the sign test determines if the median is significantly greater than a specified median of 3.

The Wilcoxon signed-rank test is like the sign test also appropriate for this case if the observations can be ranked, and each observation in a pair is a random sample from a symmetric distribution. This test is used when comparing two related samples to determine if their population mean ranks differ based on a given significance level. The responses of the questionnaire are therefore compared with a second sample that is a vector consisting of the reference medians with the value 3. Based on this setting it can be determined with a one-sided test, like in the sign test before, if the responses of a questions are significantly greater than a specified median of 3 based on a given alpha level.

For the two statistical tests the one-sided null hypothesis is formulated that the median is equal or lower than 3, stating that there is no performance above average, whereas the alternative hypothesis states that there is an performance above average for these questions. If the null hypothesis is discarded on the desired alpha level, the alternative hypothesis is left as the inly possibility, indicating the over-average performance for this statement.

Like the Shapiro–Wilk test that was used before the sign test and the Wilcoxon signed-rank test are also evaluated with and alpha level of 0.05. The null hypothesis is therefore rejected if the resulting p-value is below the desired alpha-level of 0.05 meaning that the alternative hypothesis is left. The Table 5.3 provides an overview of the statistical tests that were applied for the responses of the positively framed questions.

			p-value	
Framed question	**Construct**	**Median**	**Sign test**	**Wilcoxon signed-rank test**
Q1	Agent behavior	3	0.708	0.768
Q2	Agent behavior	3	0.868	0.644
Q3	Agent behavior	3	0.696	0.912
Q4	Agent information	4	0.004	0.016
Q5	Agent information	3	0.804	0.833
Q6	Agent information	3	0.237	0.174
Q7	Segment identification	4	<0.001	<0.001
Q8	Segment identification	3	0.425	0.384
Q9	Strategy adaption	4	<0.001	<0.001
Q10	Strategy adaption	4	<0.001	<0.001
Q11	Address segments	3	0.436	0.356
Q12	Address segments	4	<0.001	<0.001
Q13	Game comparison	3	0.941	0.892
Q14	Game comparison	3	0.151	0.095
Q15	Game experience	4	<0.001	<0.001
Q16	Game experience	4	<0.001	<0.001

Table 5.3: Overview of the statistical results for all positively framed questions

According to Table 5.3 for 7 questions out of 16 the null hypothesis is rejected which suggests that for these statements there is an above average performance corresponding to the responses. The above average performance was achieved for the statements Q4, Q7, Q9, Q10, Q12, Q15 and Q16. To detect if one of the other statements is not under average the both tests were also performed with the changed null hypothesis that median is equal or greater than 3 and the alternative hypothesis that the median is less than 3 with the same alpha level of 0.05. For none of the statements the null hypothesis could be rejected indicating that there is no evidence that based on those test there is a under average performance of one of these questions.
Summarizing these results, none of the responding answers indicating an under average performance and 7 are above average. According to question **Q4** the results of the created artifact succeeded to provide the participants comprehensible possibilities to explore the market and visualize the consumers and the competitors on the market. The responses of question **Q7** indicated that the consumers perceived the identification of the customer segments and their affiliated size as a challenging task in the game. According to question **Q9**, the majority of 78% of all participants agree that they had to change their strategy at least at once during the game do align to the market. Question **Q10** confirmed supplementary that 59% participants agreed that the investigation of the market influenced their decided strategy on the market. A majority of 72% of the participants admitted that it was necessary for them to investigate the market in the game according to question **Q12**. In retrospect, the participants who have played the simulation perceived it as an interesting and challenging exercise agreeing with a total of 84% and 74% according to the question responses of question **Q15** and **Q16**. The implemented strategic business simulation game succeeded therefore in 7 out of 16 questions that were put as a target

for the initial implementation. Although there are positive results for most of the constructs that have been defined as relevant for the game there are some responses which have lagged behind the desired goals that were set for the construction of the artifact.
Although there is no evidence that there is a under average result for any of the statements there are some constructs that could not achieve a positive result in any of their statements. The questions **Q1** and **Q2** could not achieve a positive result for the construct that defines the behavior of the consuming agents. The purchase behavior of the agents was therefore not evaluated above average to be a comprehensible and rational behavior to the consumers in the game. Additionally to the behavior, the criteria which were used for the decision-making of the consumers was not clear for 38% of the participants according to question **Q3** that was also assigned to the construct that defines the behavior of the consuming agents. Also the construct that was evaluating the performance of the game compared to other games with the questions **Q13** and **Q14** could not achieve an overall significant advantage of this implemented artifact. Therefore the representation of the customers and their preferences should be considered as one of the main points of improvement for the further development. In addition there should also be improvements of the consumer purchase behavior to increase the comprehensibility for the participants.
The participants had also the possibility to optionally give additional feedback to the game in the form of open statements. This was used as additional source of feedback for further improvements of the artifact. The possibility to play against other human actors on the market was seen as an advantage over other games that let the participant act in a simulated environment against virtual competitors. It was seen as an additional motivation to compete against other participants within the game instead of artificial competitors. As a point of improvement the participants suggested adding an image for each product available on the market to increase the realism of the game and the distinction of the products. Two responses of participants even suggested implementing more possibilities to analyze the customers and the competitors of the game. Considering this feedback and the evaluated questions it arises that more focus has to be placed on the visualization of the analysis and results for further developments to generate a higher comprehensibility of the actions and acceptance of the participants.

5.2 Analytical results

For the view of the operator an empirical analysis based on a survey could not be realized within this thesis. As already mentioned in Chapter 3 the lack of empirical data for the operator's perspective is reasoned in the missing opportunity to test the game with a moderate amount of different operators in order to provide an accepted questionnaire with a satisfying sample size. Therefore the observations that have been made during the use of the artifact as an operator will be discussed and evaluated. This argumentative approach will result in a list of experienced advantages and disadvantages which have arisen during the application for the view of the operator. Based on this list the advantages and shortcomings of the usage of the agent-based modeling approach for the operator are present and should provide an input for further developments.

5.2.1 Argumentative approach for the operator

The operators' view is structured into four parts that will be considered and discussed in this section. The first one is covering the complexity of the configuration of a game instance and the effort that the operator has to put into it. As second point the possibility to configure a concrete market situation and examine the results on a detailed level will be discussed for the artifact. The third point is focusing on the simulation performance for a round in the game. And as last point the understandability of the parameters that are used and configured in the game is evaluated.
As first point of the analysis the complexity and the effort of the configuration for a game is observed. Configuring the initial setting for a game results, depending on the level of detail of the agent configuration, in a quite time consuming part for a specific game instance. Modeling each agent separately and renouncing the help of the agent type definition results in a time consuming activity. Renouncing the normal distributed preferences of agents, provided by the agent type definition, needs a redefinition of the preferences for the specific agent instances. This can result, depended from the amount of agents in the market, in a quite demanding task if a lot of agents are affected from the redefinition of their preferences. In the actual version of this simulation game there are three preferences used that have to be set manually for each agent, if the configured agent type definition wants to be overwritten. This is necessary for the operator to model a concrete market composition for the participants to test their reactions and strategic behavior for certain cases on the market. Another observed difficulty resulting in the use of the agent-based modeling approach is the configuration of the consumer amount. Like for the equation-based, interpolation-based and the statistical approach there is also a configuration of the central parameters necessary. The amount per agent type is one of the most important values that have to be configured to achieve a desired market behavior. The total amount of agents, resulting from the amount in the agent type definition, affects the potential sales volume on the market and therefore the turnover for the companies. A market that only consists of agents that are interested in cheap goods will therefore generate a lower potential turnover for the companies than the same amount of agents that are interested in high quality goods that are more expensive. The parameterization of the amount is therefore necessary and need some considerations of the operator through the fact that this value needs to be adapted depended of the amount of users that participate in a game to avoid too low sales volumes.
Focusing the second point of the questions, the artifact shows that the more general modeling of a concrete market situation can be realized through the definition of different agent types in a round. Using opposed settings for the preferences allowed the operator to model the different groups of agents with different behavior. The implemented normal distribution of the preferences supported a faster configuration of concrete market situations with resulting heterogeneous agents. This allows modeling more intuitive market scenarios which were needed to model different market compositions forcing the participants to adapt their strategies and react to the changes on the market. The possibility to narrow the behavior of an agent down to three preferences simplified the configuration of a group of agent. The opportunity to divide the market into different groups of consumers was observed as one of the most important advantages of this modeling approach in the game for the operator. After simulating the round the operator could discover the purchase decision of each agent for the simulated rounds and therefore perceive on a detailed level the actions of the simulated consumers. The ability to investigate the

purchase decision of different agents increased therefore the comprehensibility for the operator and allowed to reconfigure the market based on the observed results of a simulated round.
Although the higher computation power is considered as one of the disadvantages against the older standard models, the performance of the implemented artifact is satisfying and did not exceed the limitations given by the requirements during the execution. Through the fact that the simulation had to be started manually by the operator after a round is expired, the requirements demanded that the simulation should not take longer than two hours for a configuration of 1000 agents and six companies with a total of 25 products offered on the market. The limitation of the simulation time was chosen to have the possibility to perform a second and third simulation run if problems occur during the first run. The simulation of that combination took about five minutes on the server and was therefore 24 times faster than the maximal allowed time for the simulation. The server that was running the application and the database according to the deployment architecture in Chapter 4 was a 64bit Windows operating system with a 3 Ghz dual-core processor and 8GB main memory. Apart from the duration of the simulation this configuration was capable of performing four different game instances parallel with four to six participants per game. The higher processing power of the agent-based modeling approach was therefore no exclusion criterion for the given requirements.
The comprehensibility and understandability of the created artifact was considered as the main argument choosing the agent-based modeling approach against the other introduced modeling approaches. The more intuitive parameters that are used for the configuration of the market, especially the agents that represent the market, provide a more natural and therefore understandable way of configuring the central aspect of the game. The preference attributes and the amount of the agents per agent type are considered as the main parameters of configuration next to the other parameters like the product portfolio function, the minimum consumer utility limit, the utility precision, the maximum investments and the variance of the preference distribution. Additionally, the factors that are calculating the initial budget for the companies and the limitations for the investments can be changed. These initial settings however have not been changed during the execution of a game instance. Characterizing the market based on the distribution of different groups of agents with different behavior was perceived as a more intuitive and realistic opportunity than to configure parameters in an aggregated demand equation. Like already mentioned in the second point the possibility to see the purchase decision of each agent increases the insight and therefore the comprehensibility for the operator of the game. The detailed overview and the possibility to allow the participants to perform an analysis based on the agent preferences was considered as one of the main advantages next to the heterogeneous market configuration.
Summarized one can say that agent-based approach offered new possibilities and an intuitive way of modeling a market on a micro-level in a strategic simulation game but did also require a judicious configuration of the market by the operator of the game. The risk of misconfiguration regarding the amount of agents and/or their preferences can lead to starvation of the companies in term of their sales volume and the resulting turnover. Although the agent-based model approach provides a more intuitive and straightforward model of the consumer market there is nonetheless a potential of misconfiguration. This deficit can be softened during the application with the provided detailed actions and results that can be observed. This provided feedback can be used to correct the misconfiguration of the agents for further executions.

CHAPTER 6

Discussion and outlook

This chapter summarizes the main findings of this thesis and covers the drawn implications of applying the agent-based approach to model the market of consumers for a web-based business strategy game. Within this chapter the open issues of the applied model approach are going to be discussed in detail, including the potential of covering these issues in future work. Related literature is given to provide a fundamental basis for future work and should provide a further outlook of this topic and related fields of science.

6.1 Summary of the results

Summarizing the results of Chapter 5, the agent-based modeling approach allowed implementing functionality into the strategic simulation game that enables the participants to perform analysis on a micro-level and make decisions on the market traceable on a consumer detailed level. This characteristic of the game allowed the participants to adapt or align their business strategy based on the perceived preferences/behavior of the consumer agents in the game. The possibilities to investigate the market mixture, identify the consumer segments, address the consumer segment with an aligned product portfolio and the available investments were evaluated as the most important advantages occurring with the use of the agent-based modeling approach. The need to adapt the used strategy based on the changes in the consumer market was evaluated as the main approved functionality and justifies therefore the use of the game in the lecture 'Strategic Management'.
Based on the results of the survey the participants considered the behavior of the agents as well as the representation of the consumers in the game to be enhanced. The decision as result of the cognitive process of an individual consumer is therefore not considered as fully comprehensible to the participants. If they parametrization of the cognitive process should be improved or the cognitive process as a whole has not been observed in this thesis and can therefore not be answered. In addition to the consumer behavior the representation of the consumers in the market was also criticized in the survey of the game. The representation of the detailed agent information should therefore get more focus for the further development. Alternative representations of

the preferences of the agents in the market should be considered to overcome this deficit of the currently implemented and studied artifact.
Although the enumerated deficits were observed in the evaluation of the constructed artifact, the participants did not perceive that the artifact has major drawback against other business games that they are already participated in. Additionally, the web-based strategic management game was assessed by the participants as an interesting and challenging enrichment of the lecture. The participants also liked that they were able to test the learned theories and improve their skills in this field with the help of this game.
Summarized the created artifact succeeded clearly in 7 out of 16 questions that were set as goals during the requirement phase of the implementation. Important new possibilities, like the investigation of the consumer market, could be provided in the game with the help of the agent-based modeling approach for the consumer market. Although there are some shortcomings detected in the evaluated artifact, the agent-based modeling approach provide nevertheless major advantages especially for the development of a strategic management game that consists of a flexible consumers market.

6.2 Discussion

Based on the achieved results in Chapter 5 the agent-based modeling approach was considered as a potential modeling approach in the strategic management field. Although this positive result of the application there are some drawbacks discovered in the evaluation and during the execution of the simulation. Due to the fact that there are lacks discovered in the representation of information and the cognitive processing, there is a need for additional developments to overcome the identified deficits. Solving these issues will ensure that this approach is going to be a superior alternative for the older standard simulation models in a business simulation game for the topic of strategic management.
The simulation of the cognitive processing of an individual consumer and the representation of the total agent population as well as the single agent are points that are discovered as topics for potential improvements in further developments. Respectively the representation of large quantity of information comprised in the agent-based models need a more effective way of presenting it to the user to enhance the understanding of the game for them. Also the representation of the preferences of an individual agent was criticized to be presented in a more self-explanatory way to increase the acceptance of the agent-based modeling approach.
Despite some shortcomings of the implemented artifact, the use of the agent-based modeling approach did provide a solution for a flexible market modeling with an increased level of details, focusing on the individual consumer representation. Although the behavior of the agent was evaluated as not completely comprehensible for the majority of the participants, the modeling approach did succeed in providing an overview of all executed purchase actions on the micro level. According to Baptista [32] this knowledge plays a major role in enhancing the understanding of the participants for the dependencies occurring in the game. Also the lack of the flexibility in the market that was mentioned by Baptista [32] could be coped with the agent-based approach. The evaluated results stated the participants perceived the change of the market composition and had to adapt their strategies to remain successful in the ongoing competition

with the other participants. Additionally, a vast majority of all participants evaluated the game to be an interesting and challenging exercise in the lecture that allowed them to apply the learned theory.
Answering the underlying research question of this thesis, if the agent-based modeling approach is a practicable solution for modeling the market in a strategic business game, the results in this thesis showed that the agent-based modeling approach offered an applicable and new way of modeling the consumers' market for a management game in the field of strategic management. It could be successfully applied in an interactive web-based strategic simulation game, enabling participants to compete against each other in the role of a company on a flexible structured consumer market. The goal to provide a flexible and configurable market composition that forces the participants to investigate the market and adapt their strategies was achieved successfully. This result was therefore discovered as a main advantage of the usage of the agent-based modeling approach for the field of strategic management. There are although some shortcomings discovered in the representation of the generated data of the agents which should be extended in further developments of the game, to improve the realism and the comprehensibility of the agents' decisions that are treated in more detail in Section 6.3.

6.3 Outlook

To overcome the challenges which encounter on the creation of such an artifact, the model of consumer behavior used for the decision finding process was kept simple for the initial development. The goal was the simulation of a realistic market that consists of numerous heterogeneous agents with different buying preferences. The model was mainly inspired by the classical economy theory of consumer behavior. Based on this theory the consumer has a perfect information of all goods on the market, act perfect rational dependent of his preferences and take an independent purchase decision each time the consumer had to decide [42]. Improvements in the realism of the implemented cognitive decision process can be realized by using a variety of approaches that could be implemented additionally to the existing decision process. According to Bonabeau [54] and Twomey and Cadman [55] following aspects have been considered as enrichment of the agent-based modeling approach to increase the realism:

1. Bounded rationality
2. Influence by other consumers (social imitation)
3. Adaptive processing & learning
4. Imperfect information

Bonabeau [54] argued that human agents usually are characterized by their potential irrational behavior, subjective choices and their complex psychology that includes soft factors that are usually difficult to quantify, calibrate, and sometimes justify. Twomey and Cadman [55] also advised that bounded rationality realized as limited information and limited abilities to process information should be explicitly incorporated into the model followed by the possibility of social

imitation of other agents.
Said et al. [87] presented a more complex modeling of the behavior of agents that is party affected by their social surroundings. The social surrounding of an agent was suggested as interaction between the consumers in the environment in the form of recommendation, disqualification and rumor. This model presented a more complex environment allowing the agents to communicate among themselves. Like the company image that is used in the developed cognitive process in this thesis, the model of Said et al. is also considering the brand of a company. Said et al. however uses additional indicators like the publicities, innovations and recommendations to define the brand. Although this model introduced a new perspective of the behavioral process including a new external stimulus for the agents, the paper did not provide a model descriptive enough to be implemented in this thesis for the behavior of the agents.
A more descriptive source for improvements is the already introduced model of cognitive processing of Jager and Janssen [57] [58] [59] that included the indicator of uncertainty that could be used in further developments to implement some of the listed points. The uncertainty of a decision is used in this model as a variable to indicate if the agent should behave independently or follow other consumers on their decisions. Uncertainty is discovered if the expected level of needed satisfaction for a product is below the received level of satisfaction of that product. This change of satisfaction level can therefore cause the agent to adapt his process and change his behavior for the ongoing simulation.
There are a variety of possibilities to extend the agent's model of cognitive processing and introduce new indicators that influence the behavioral processing of an agent and potentially increase the realism and acceptance of the simulation. Despite this number of possibilities to advance the model and increase the realism there are hardly descriptive models which one can build on. Choosing a descriptive model you can build on is mainly depended on the kind of simulation that is tried to be implemented. Therefore the necessary character of the problem has to be extracted to model it with the help of the agent-based modeling approach. Improving the model and therefore increasing the complexity of an advanced process or model should nevertheless meet the requirements that are facing the operational simulation run-time to make it a feasible solution for the application. The 'dilemma of simplicity versus real-world complexity' mentioned from Goosen et al. [34] is also present for the modeling of the cognitive processing of the agent.

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APPENDIX A

Appendix

A.1 Entities

The following tables describe the occurring entities of the developed entity relationship model in detail. They include all the attributes that are used in the respective entity with their particular data type.

Game	
Attribute	**Data type**
name	String
initDate	Timestamp
startDate	Timestamp
roundTime	Integer

User	
Attribute	**Data type**
nickName	String
password	String
email	String
admin	Boolean
budget	Double
imageValue	Double
marketingBudget	Double
employerEducationBudget	Double
rdBudget	Double
salt	String

Round	
Attribute	**Data type**
roundNumber	Integer
startDate	Timestamp
endDate	Timestamp
played	Boolean

AgentType	
Attribute	**Data type**
agentName	String
amount	Integer
meanQuality	Double
meanPrice	Double
meanImage	Double

Agent	
Attribute	**Data type**
preferenceQuality	Double
preferencePrice	Double
preferenceImage	Double

CompanyroundDecisionAndResult	
Attribute	**Data type**
revenue	Double
expenses	Double
marketingInvestment	Double
employerEducationInvestmetn	Double
rdInvestment	Double
overdraftCosts	Double
logisticCosts	Double
newImage	Double

Product	
Attribute	**Data type**
productName	String
qualityFactor	Double
productCosts	Double
active	Boolean

CompanyProduct	
Attribute	**Data type**
sellingPrice	Double
amountSold	Integer

Report	
Attribute	**Data type**
reportTypeName	String
reportType	Integer
reportLongText	String
reportPrice	Double

News	
Attribute	**Data type**
text	String
header	String
newsDate	Timestamp

Setting	
Attribute	**Data type**
portfolioExtraCostsPerProduct	Double
startImageForCompanies	Double
interestRate	Double
minimumConsumerUtility	Double
maxFreePortfolioProducts	Double
startBudgetForCompanies	Double
factorMarketing	Double
factorPersonal	Double
factorRD	Double
factorMarketShare	Double
factorMarketShare	Double
newsDate	Timestamp
newsDate	Timestamp
newsDate	Timestamp
newsDate	Timestamp
preferenceVariance	Double
portfolioFactor	Double
exponentialSmoothingFactor	Double
agentAmountCompanyFactor	Double
tradeMargin	Double
factorCostMarketing	Double
factorCostRD	Double
factorCostPersonal	Double
factorReportSmall	Double
factorReportMiddle	Double
factorReportBig	Double
factorReportSpy	Double
factorLogisticCosts	Double
factorStartBudget	Double
maxCostsMarketing	Double
maxCostsRD	Double
maxCostsPersonal	Double
utilityPrecision	Double

A.2 Survey questions

(C1) Agent behavior
Q1: The selection of the products from the consumers on the market was comprehensible.
Q2: I think the consumer behaved randomly when they bought a product.
Q3: In my opinion the criteria which were used for the decision-making of the customers were clear.

(C2) Agent information
Q4: I perceived the possibilities in the game to explore and visualize the consumers and other competitors as understandable.
Q5: I think that the representation of the consumers in the business strategy game was confusing.
Q6: The representation of the individual consumers helped me to recognize the consumer segments.

(C3) Segment identification
Q7: I perceived it as a challenge to identify customer segments and their size on the market.
Q8: In my opinion the opportunity to explore the consumers at a detailed level was realistic.

(C4) Strategy adaption
Q9: I did not need to change my strategy during the game.
Q10: The investigation of the consumer market influenced my strategy.

(C5) Address segments
Q11: In my opinion it was easy positioning my product portfolio to the consumer segments.
Q12: It was not necessary for me to discover the market.

(C6) Game comparison
Q13: I think that the consumer market in this game felt more realistic than in other business games I played.
Q14: In my opinion this game had fewer possibilities to explore the market than other business games I played.

(C7) Game experience
Q15: In my opinion the business simulation game was interesting.
Q16: I perceived playing the game as challenging.