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RIGA TECHNICAL UNIVERSITY

Jana Bikovska

DEVELOPMENT OF A SCENARIO-BASED APPROACH TO SIMULATION GAMES MANAGEMENT

Summary of the Doctoral Thesis

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RIGA TECHNICAL UNIVERSITY
Faculty of Computer Science and Information Technology
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DOCTORAL THESIS PROPOSED TO RIGA TECHNICAL UNIVERSITY FOR THE PROMOTION TO THE SCIENTIFIC DEGREE OF DOCTOR OF SCIENCE

To be granted the scientific degree of Doctor of Science, the present Doctoral Thesis has been submitted for a remote defence at the open meeting of RTU Promotion Council on December 6, 2021 at 14.30 at the following link: *https://rtucloud1.zoom.us/j/98284534733*

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DECLARATION OF ACADEMIC INTEGRITY

I hereby declare that the Doctoral Thesis submitted for the review to Riga Technical University for the promotion to the scientific degree of Doctor of Science is my own. I confirm that this Doctoral Thesis had not been submitted to any other university for the promotion to a scientific degree.

Jana Bikovska ……………………………. (Signature)

Date: ………………………

The Doctoral Thesis has been written in Latvian. It consists of Introduction; 4 Chapters; Conclusions; 75 figures; 15 tables; 3 appendices. The total number of pages is 121, including appendices. The Bibliography contains 58 titles.

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INTRODUCTION

Research motivation

Despite the fact that simulation games have been widely used for training for decades, with the development of new technologies, innovations are also emerging in this field, which makes it possible to significantly expand the functionality of this kind of games and make them more widely available. Nowadays, research is being carried out into the development and use of such games, as evidenced by the active work of several associations, such as ABSEL (*Association for Business Simulation and Experiential Learning*) and ISAGA (*International Simulation and Gaming Association*), which hold international scientific conferences every year, as well as an industry magazine called “Simulation and Gaming”, which has been publishing articles for more than 50 years on the development of simulation / game development and application methodologies. It is worth mentioning the scientists who contributed to the development of new games, the methodology of their use and development technology, for example, Prof. H. Muller (-Malek) from the University of Ghent (Belgium), Prof. R.W. Grubbström from Linköping University (Sweden), Prof. A. Verbraeck from Delft Technical University (Netherlands), Prof. G. Merkurjeva from Riga Technical University (Latvia). Statistics show that revenue from the global game-based learning market will increase from $ 3.5 billion to $ 24 billion between 2018 and 2024, which also indicates a growing interest in this learning approach.

Business studies is one of the areas where simulation games are used very intensively, and they are called business simulation games. Their development today is focused on the use of web and agent technologies that support e-learning and a student-centred learning approach. In addition, a growing number of companies require staff training in accordance with their needs, and in this context, there is a need for games that can be adapted to a specific learning situation, as well as to assess the trainees. Currently, this problem is solved with a wide range of games available on the market, which allows to choose the most suitable, but in terms of cost, the choice does mostly never lead to a cheap solution. Therefore, there is a need to develop methods that allow the same game to be adapted to different situations, i.e. to generate, model, evaluate and manage different game scenarios. One of the existing problems is that there is little theoretical research and practical results in the field of modelling and management of simulation game scenarios. Within this work, an integrated scenario approach is developed, which ensures the diversity of modelled business situations, their management, as well as the adaptability to a specific learning purpose and learner within a single game. The approach can also be used to analyse scenarios for the development of real socio-economic systems.

The goal of the Thesis

The goal of the Doctoral Thesis is to develop an integrated approach for the generation, modelling and management of dynamic scenarios for simulation games, which ensures the governance of simulation games in accordance with the study content.

The tasks of the Thesis

In order to achieve the goal of the Thesis the following tasks were specified:

1) to study the formalization methods of system planning and management scenarios and their use for the governance of simulation games;
2) to develop an integrated approach to the generation, simulation and management of dynamic scenarios for simulation games;
3) to develop procedures, models and methods for the implementation of the simulation games dynamic scenarios approach;
4) to experimentally test the results of the research, using them for the practical development and management of logistics and supply chain simulation game scenarios.

Research object and subject

The research object is business simulation games.

The research subject is the methods of generating, simulating and managing dynamic scenarios of business simulation games, as well as their use in the study process.

Research methods

The following research methods are used in the development of the Thesis: systems analysis, scenario methodology, system simulation, agent technology, decision making theory, mathematical statistics methods, as well as operations management methods and simulation games as a training method.

Scientific novelty of the Thesis

The major scientific innovative elements of the Thesis are as follows:

1. A simulation game scenario concept has been developed, which allows to define an integrated approach to dynamic scenario generation, modelling and management.
2. A simulation game management procedure has been developed for the implementation of a scenario-based integrated approach in accordance with the defined training content and objectives.
3. Modelling and management of simulation game scenarios is based on the multimodel methodology that allows simulating the dynamics of the scenario developments.
4. A set of governance scenarios have been developed for the ECLIPS and ILMG logistics simulation games.

Practical value of the Thesis

1. The results of the research, including the concept of dynamic scenarios and the management procedure, were applied in the development of the International Logistics Management Game (ILMG) training methodology, which is utilized at Linköping University (Sweden), Polytechnic University of Valencia (Spain), and Riga Technical University.
2. The developed scenarios of the ECLIPS logistics simulation game were used in the European Project No. NMP-032378 “Extended Collaborative Integrated Life Cycle Supply Chain Planning System”, demonstrating the importance of research results.
3. The developed simulation game scenario management procedure is used in practical classes within the RTU master's study programs “Information Technology” and “Logistics and Supply Chain Management” – in study courses Management Component Integration and Decision Synthesis Principles and Practice in Logistics.

Approbation of the obtained results

The research results were presented at 14 international scientific conferences:

1. *2019 Open Conference of Electrical, Electronic and Information Sciences (eStream 2019),* Lithuania, Vilnius, April 25, 2019.
2. *Riga Technical University 55th International Scientific Conference*, Latvia, Riga, October 14–16, 2014.
3. "*International Workshop on Applied Modelling and Simulation" (WAMS2010),* Brazil, Rio de Janeiro, May 5–7, 2010.
4. *The 21st European Modelling and Simulation Symposium: Simulation in Industry (EMSS2009)*, Spain, Tenerife, Canary Islands, September 23–25, 2009.
5. *The 4th International Conference on Interdisciplinarity in Education*. Vilnius, Lithuania, May 21–22, 2009.
6. *The 11th International Workshop on Harbor Maritime Multimodal Logistics Modeling & Simulation (HMS2008),* Italy, Campora S. Giovanni, September 17–19, 2008.
7. *The 22nd European Conference on Modelling and Simulation (ECMS2008),* Cyprus, Nicosia, June 3–6, 2008.
8. *Riga Technical University 48th International Scientific Conference,* section "*Information Technology and Management Science"*, Latvia, Riga, October 11–31, 2007.
9. *The 21th European Conference on Modelling and Simulation (ECMS2007)*, Czech Republic, Prague, June 3–6, 2007.
10. *The 20th European Conference on Modelling and Simulation (ECMS 2006),* Germany, Bonn, Sankt-Augustin, May 28–31, 2006.
11. *International Conference on Operational Research: Simulation and Optimisation in Business and Industry (SOBI2006),* Estonia, Tallinn, May 17–20, 2006.
12. *The 19th European Conference on Modelling and Simulation (ECMS2005),* Latvia, Riga, June 1–4, 2005.
13. *Riga Technical University 45th International Scientific Conference*, Section "*Information Technology and Management Science"*, Latvia, Riga, October 14–16, 2004.
14. *Traditions and Innovations in Sustainable Development of Society,* Latvia, Rezekne, February 28 – March 2, 2002.

The results of the Thesis are reflected in 20 papers, including 2 journals papers in "International Journal of Simulation and Process Modeling" (IJSPM) and 16 papers in international conference proceedings (*h-index: 3*):

1. Bikovska, J. Developing an Integrated Approach for the Scenario-Based Management of Simulation Games. In: 2019 Open Conference of Electrical, Electronic and Information Sciences (eStream 2019): Proceedings, Lithuania, Vilnius, April 25, 2019. Piscaway: IEEE, 2019, pp. 96–99. ISBN 978-1-7281-2500-8. e-ISBN 978-1-7281-2499-5. Available: doi:10.1109/eStream.2019.8732163, *(SCOPUS, Web of Science)*
2. Bikovska, J. Scenario Development Approach to Management Simulation Games. Information Technology and Management Science. Vol. 17, 2014, pp. 144–149.

3. Merkuryeva G., Bikovska J., Ören T. An agent-directed multisimulation framework for simulation games management // International Journal of Simulation and Process Modelling (IJSPM), Vol. 7, No. 3. (2012) pp. 184–192, *(SCOPUS), (contribution ~ 30 %).*
4. Merkuryev Y., Bikovska J. Business Simulation Game Development for Education and Training in Supply Chain Management // Proc. of Asia Modelling Symposium (AMS2012), the Sixth Asia International Conference on Mathematical Modelling and Computer Simulation, Indonesia, Bali, May 28–31, 2012, pp. 179–184, *(SCOPUS), (contribution ~ 60 %).*
5. Bikovska J., Merkuryeva G. The International Logistics Management Game: An Innovative Business Environment for Training // Production-Economic Research in Linköping. LTAB Linköpings Tryckeri AB, 2011, pp. 55–72. *(contribution ~ 80 %).*
6. Merkuryev Y., Bikovska J., Merkuryeva G. Supply Chain Dynamics: Simulation-based Training and Education // The 13 International Conference on Harbour, Maritime & Multimodal Logistics Modeling and Simulation, Italy, Rome, September 12–14, 2011, pp. 221–230, *(SCOPUS, Web of Science), (contribution ~ 20 %).*
7. Merkuryev Y., Merkuryeva G., Bikovska J. Simulation-supported Supply Chain Management // International scientific-practical conference “Simulation and complex modelling in marine engineering and marine transporting systems” – SCM MEMTS 2011, Russia, Sankt-Petersburg, May 29–30, 2011, pp. 50–54, *(contribution ~ 30 %).*
8. Merkuryev Y., Merkuryeva G., Hatem J., Bikovska J. Exploiting Simulation in Supply Chain Management: ECLIPS Project Experience // CD Proceedings of the International Workshop on Applied Modelling and Simulation, WAMS2010, Brazil, Rio de Janeiro, May 5–7, 2010, pp. 455–464, *(contribution ~ 25 %).*
9. Merkuryeva G., Bikovska J., Ören T. An Agent-Directed Multisimulation Framework for Management Simulation Games // 21st European Modelling and Simulation Symposium: Simulation in Industry (EMSS2009), Spain, Tenerife – Canary Islands, September 23–25, 2009, pp. 14–21, *(SCOPUS, Web of Science), (contribution ~ 30 %).*
10. Merkuryeva G., Merkuryev Y., Bikovska J., Pecherska J., Petuhova J. Active Learning Logistics Management through Business Gaming // 4th International Conference on Interdisciplinarity in Education, Lithuania, Vilnius, May 21–22, 2009, pp. 181–186, *(contribution ~ 20 %).*
11. Merkuryev Y., Merkuryeva G., Bikovska J., Hatem J., Desmet B. Business Simulation Game for Teaching Multi-Echelon Supply Chain Management // International Journal of Simulation and Process Modelling (IJSPM). Vol. 5, No. 4. (2009) pp. 289–299, *(SCOPUS), (contribution ~ 20 %).*
12. Merkuryev Y., Hatem J., Merkuryeva G., Bikovska J. Business Simulation Game for Teaching Multi-Echelon Supply Chain Management // The 11th International Workshop on Harbor Maritime Multimodal Logistics Modeling & Simulation (HMS2008), Italy, Campora S. Giovanni, September 17–19, 2008, pp. 20–28. (*SCOPUS, Web of Science), (contribution ~ 20 %).*
13. Kononov D. A., Kulba V. V., Bikovska J. Synthesis of Sustainable Development Scenarios of Social Economic Systems // 22nd European Conference on Modelling and Simulation

(ECMS2008) Cyprus, Nicosia, June 3–6, 2008, pp. 139–144. (*SCOPUS, Web of Science), (contribution ~ 20 %).*

14. Bikovska J., Merkuryeva G. Scenario-Based Planning and Management of Simulation Game: A Review // 21st European Conference on Modelling and Simulation (ECMS2007), Czech Republic, Prague, June 4–6, 2007, pp. 578–583. Book: ISBN 978-0-9553018-2-7, CD: ISBN 978-0-9553018-2-4. (*SCOPUS, Web of Science), (contribution ~ 50 %).*
15. Bikovska J., Merkurjeva G., Grubbström R. W. Enhancing Intelligence of Business Simulation Games // Proc. of 20th European Conference on Modelling and Simulation (ECMS 2006), Germany, Bonn, May 28–31, 2006, pp. 641–646. (*SCOPUS, Web of Science), (contribution ~ 40 %).*
16. Merkuryeva G., Bikovska J. Building Intelligence in Business Simulation Games // Internernational Conference on Operational Research: Simulation and Optimisation in Business and Industry (SOBI2006), Estonia, Tallinn, May 17–20, 2006, pp. 268–272. *(Web of Science), (contribution ~ 55 %).*
17. Soshko O., Merkuryev Y., Merkuryeva G., Bikovska J. Development of Active Training and Educational Methods in Logistics // Annual Proceedings of Vidzeme University College: ICTE in Regional Development, Latvia, Valmiera, June 2005, pp. 62–66. *(contribution ~ 25 %).*
18. Grubbström R. W., Merkurjeva G., Bikovska J., Weber J. ILMG: Learning Arrangements and Simulation Scenarios // 19th European Conference on Modelling and Simulation 'Simulation in Wider Europe' (ECMS 2005), Latvia, Riga, June 1–4, 2005, pp. 715–720, (*SCOPUS, Web of Science), (contribution ~ 25 %).*
19. Merkuryeva G., Bikovska J., Grubbström R. W., Weber J. Development of Learning Scenarios for Network-Based Logistics Simulation Game // Computer Science. Information Technology and Management Science. Scientific Proceedings of Riga Technical University, Volume 20. RTU, Riga, 2004, pp. 148–156, *(contribution ~ 25 %).*
20. Merkuryeva G., Muller (-Malek) H., Bikovska J. Management *Simulation Laboratory in High Schools. Management simulation laboratory in High School //* Traditions and Innovations in Sustainable Development of Society. Issues of Competitiveness in Sustainable Economic Development. Proceedings of the International Conference, February 28 – March 2, 2002. Rezekne University, 2002, pp. 231–237, *(contribution ~ 20 %).*

In total 12 publications are included in Scopus / Web of Science databases: 11 in Scopus, 9 in Web of Science.

The results of the work have been delivered and used within the following projects:

1. Latvian Science Council Grant No. 05.1653 "Development and application of training methodology based on simulation modelling in the field of logistics, based on case studies and business games." Project manager: Dr. habil. sc. ing., Prof. J. Merkurjevs, 2005–2008.
2. The 6th Framework Program of the European Union No. NMP-032378 "ECLIPS Extended Collaborative Integrated Life Cycle Supply Chain Planning System". Project RTU coordinator and manager: Dr. habil. sc. ing., Prof. J. Merkurjevs, 2006–2009.

The scientific significance of the developed approach is confirmed by a certificate issued by company Möbius Ltd. (Belgium) for participation in the task "Business Game" and development of game scenarios for the ECLIPS business game within the framework of the scientific project "Extended Collaborative Integrated Life Cycle Supply Chain Planning System".

The ILMG game scenario developed in accordance with the approach proposed in the work was used in the quarterfinals of the simulation game competition "Business 24h" in autumn 2008, organized by the student organization "Future Education Centre" with the support of the Ministry of Education and Science of the Republic of Latvia.

Thesis statements put forward for the defence

1. The formalization of simulation game scenarios ensures the re-use of the game infrastructure according to different training objectives.
2. A procedure for generating, modelling and managing dynamic scenarios should be implemented to improve game management processes.
3. The implementation of the scenario-based simulation game management approach allows integrating business simulation games in different study courses.

Structure and volume of the Thesis

The Thesis includes Introduction, four chapters, Conclusions, Bibliography and three appendixes. The main text of the dissertation is presented on 100 pages and explained with 75 figures and 15 tables. The bibliography includes 58 titles. The structure of the Thesis is as follows.

Introduction includes the substantiation of the topicality of the research problem, the formulation of the aim and tasks of the research, the definition of the research object and subject, as well as description of the research methods used.

Chapter 1 is devoted to the study of the role of scenarios in the context of simulation games. This chapter describes the scenario formalization methods, including the proposed scenario concept.

Chapter 2 contains a review of scenario generation and modelling approaches and methods. The developed general procedure of scenario generation, simulation and control is described, and an integrated approach to simulation game scenario management is offered.

Chapter 3 discusses practical implementation issues, experimental analysis and application of the developed integrated scenario approach in the ECLIPS game. This includes the development of a conceptual model of the supply chain and inventory management algorithms in accordance with periodic and continuous inventory control strategies. Performance indicators are outlined to assess and compare the effectiveness of different scenarios. The developed game scenario management tool is described that works according to a conceptual model and allows modelling and experimental evaluation of scenarios before they are offered to students.

Chapter 4 focuses on the practical application of the developed integrated scenario approach in the ILMG game. It includes a framework for managing ILMG game with agents. A game agent is implemented that provides scenario generation, as well as an agent – a virtual player that provides modelling of the generated scenario and allows evaluating scenarios before they are integrated into the study process within a certain course.

The results and conclusions of the dissertation are summarized at the end of the Thesis.

The work has three appendices. Appendix 1 contains a certificate issued by Möbius Ltd. (Belgium) for participation in the solution of the task "Business Game" and development of game scenarios for the ECLIPS business game within the framework of the scientific project "Extended Collaborative Integrated Life Cycle Supply Chain Planning System"; a report from prof. R.W. Grubbström (Sweden) about the developed ILMG game scenario, and letter of thanks from the organizers of the simulation game competition "Business 24h" regarding participating in the ILMG game. Appendix 2 provides an example of the completed transaction forms filled in by the participants of the ECLIPS game. Appendix 3 presents a description of the ILMG game scenario.

1. A REVIEW OF THE PROBLEM AREA RESEARCH AND PROBLEM STATEMENT

Simulation games have been recognized as an effective training tool, as they provide a virtual environment for the development of practical decision-making skills in various fields. They are widely used for the military, politics, sociology, business and academic purposes. Nowadays, thanks to the development of information and communication technologies, the functionality of simulation games is expanding, which increases their efficiency, bringing the games as close as possible to real life situations.

Within the framework of the Thesis, business simulation games were studied, which, by their nature, suppose integration of theory and practice, acquisition of skills in recognizing business problems, choice of solution methods and adaptation to the problem, acquisition of rapidly changing environment control skills, as well as decision making in groups. All these features indicate that games are part of active learning, which enables all participants to be actively involved in the learning process.

Simulation games allow using theoretical knowledge in practice, as well as acquiring new knowledge by transforming the acquired experience [1], [2]. Game participants can see how the decisions affect the current situation and future events, and can react to these events by making new decisions. In other words, the decision-making process focuses on the business operations model, where participants take on the role of decision-maker.

Simulation games are characterized by the existence of a research process or system simulation model, where certain actions are performed by game participants (people) [3], [4]. Simulation technology provides modelling of various business environment situations, experimentation with management decisions, quantitative assessment of their consequences, modelling of business environment dynamics, as well as time revers, i.e., repeated modelling of the situation. As a result, the use of a simulation model offers several benefits that can be successfully used in the learning process, such as understanding of complex problems, increasing learning motivation, offering an attractive way of learning, providing a risk-free environment for experimental learning and modelling situations, partially closing the gap between theory and reality. As a result, the practical nature of games provides an opportunity for participants to develop and improve their knowledge and skills in various areas of business problems. Practical skills in systems analysis, decision making, problem solving, overcoming uncertainty, critical thinking, management dynamics, etc. are most often developed in this way.

In business simulation games, participants are offered to be managers at different levels of a virtual company. The data that describe the initial state of the system are usually provided to the players, and during the game they receive information, such as market reports, financial reports, etc. that describes the development of the situation. By reacting to different situations or making decisions, participants have the opportunity to practically apply theoretical knowledge and gain experience in solving various problems, share knowledge, receiving support from the teaching staff.

In the general case, the simulation game contains (Fig. 1.1) a dynamic model of the business environment, which allows to simulate a set of processes, providing modelling of sequences of interconnected states on an accelerated time scale. The sequence of situations is realized under the influence of decision-makers and management. Based on their knowledge and experience, decision-makers make decisions and receive the outcomes of the decisions made in the form of feedback. Model performance sometimes requires management effects that adjust the performance of the game model and is called game management, which is needed to plan and control the execution of a game scenario, as well as change planning, which keeps players within the scenario framework and thus helps to acquire the necessary skills. The feedback and time dimension in the game allow to evaluate the impact of decisions made on future events, i.e., to study the consequences of short-term and long-term decisions, reacting to the events caused by making new decisions, and so on.

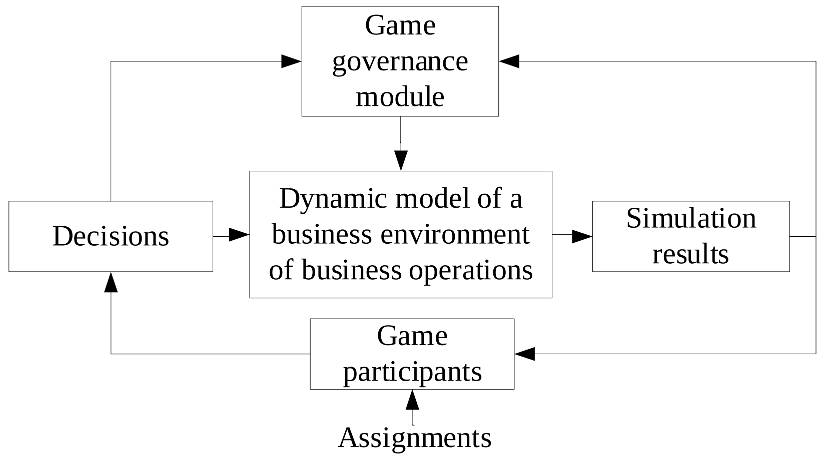


Fig. 1.1. Structure of a simulation game.

The range of business simulation games is very wide and can be classified according to several features [5]. Some of the features that are important in the framework of the Thesis are as follows.

1. Game design principle:
    a. general or functional;
    b. with direct or indirect competition of participants;
    c. with determined or stochastic business environment model;
    d. table or computer games;
    e. individual or group games;
    f. online or offline;
    g. real time or with a turn-based timing mechanism;
    h. with one or several scenarios;
    i. with or without scenario governance.
2. Purpose of use:
    a. study process;
    b. research.

Typically, business games are modelling socio-economic systems, which are characterized by the existence of several development scenarios depending on many objective and subjective factors. Environmental factors that are not directly dependent on human actions can be considered objective, but human decisions that affect the development of the system are considered subjective factors. Since simulation games are only a model that imitates the reality, we cannot talk about completely objective influencing factors, which essentially depend on the developer of the game scenario.

When operating in the virtual environment of the game, the decisions of the participants may lead to situations that change the game scenario so that it is no longer possible to achieve the teaching goals. One way to overcome this problem is to generate and further manage a scenario that will ensure that the goal is achieved. A review of the literature indicates the relevance of this problem as several authors in their research try to solve it in different ways [6], [7], [8].

The use of a scenario approach to training purposes is not new (see Table 1.1). Research on this issue has been carried out, for example, by Kindley [9]. However, currently there are only few methods mentioned in the literature that allow formalizing and further automating the game scenario development and generation process, but research in this direction has already started [10]. Thus, simulation games are one example of the implementation of a scenario-based learning approach.

Table 1.1

Comparison of Traditional and Scenario-based Learning Approaches

	Traditional	**Scenario-based**
Teaching method	Deductive	Inductive
Focus	Learning object or subject	Behaviour of learners
Learning objectives / learning outcomes	Expressed in competences and skills (static)	Depending on the training scenarios (dynamic)
Improving the learning experience	Linear (tasks, correct / incorrect answers, assessment)	Non-linear with feedback (research cases, alternatives, suggestions and guidelines)
Learning process	Prototyping	Action research
Suitability	Simple, well-structured knowledge-based tasks	Complex problems with the interaction of components in a changing environment focused on the integration of knowledge and practice

Simulation games with the ability to generate different scenarios allow choosing the appropriate level of game complexity, which depends on the specific learning objectives and the level of knowledge of the learners. Usually, the process of developing (generating) such a scenario and its subsequent control (management) during the game sessions takes place manually, which, for example, in the case of universal games is both time-consuming and complex, as it requires expert knowledge in various fields [11].

A scenario is a basic element of a simulation game that is predefined. Usually, the scenario shows the general trends of the game and the sequence of factors (events) influencing it over time. Event generation techniques can be different (deterministic, stochastic), but simulation games are characterized by a mixed way of generating events, when the game process follows a certain algorithm, which, for example, depicts the technology of a production process, but the events are stochastic. Knowledge and skills that the learner will acquire depend on the game scenario. If the scenario is well thought out and precisely formulated, as well as relevant for a specific situation, then it fully develops the skills of the game participants and provides new knowledge. If the scenario does not correspond to the situation or is inadequate, then there is a risk that the game will not have the right training effect.

When generating a scenario, it is necessary to determine a set of variables that characterise the development of the modelled process within the modelled time period. Model variables are divided into trends, events and activities [12]. A trend is a variable that reflects the development of a system in a time series format. Trends have a major impact on the processes that take place in a system. Each trend can be assigned a change over time. An event is a variable that influences the dynamics of a particular trend or other events through its implementation or non-implementation. External activities affect both trends and events. The structure of the general scenario is shown in Fig. 1.2.

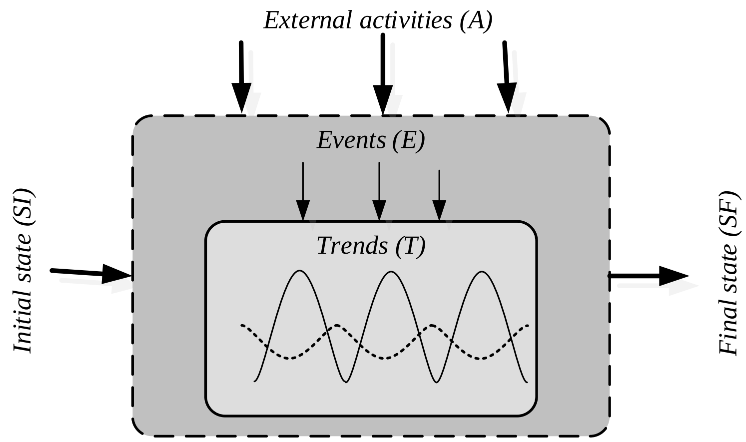


Fig. 1.2. Scenario concept.

In general, a scenario can be interpreted as a description of the system transformation process from the initial state to the final state, following its development trends, which are influenced by both internal events and external influences.

It can be presented by the following 5-tuple:

$$\langle SI, T, E, A, SF \rangle,$$

where

SI – system initial state,

T – predefined system development trends,

E – internal events,

A – external activities,

SF – system final state.

Trends T_i introduced to model system dynamics over time *t* are defined by different functions, e.g.,

$$T_i = f_i(t), T_i \in T .$$

Patterns of these trends depend on the type of function and its parameters.

All internal and external influences depend on the current system state. Any internal and external influences lead to short-term or long-term changes in the pattern of trends, i.e.,

$$f_i^E : E \rightarrow T_i \text{ and } f_i^A : A \rightarrow T_i .$$

The System Initial State (*SI*) is defined by the system structure as well as by value of the trends' functions at the moment when the system investigation starts:

$$SI = T_i(t_0),$$

where t_0 defines the initial time instant.

In terms of the management simulation game, the scenario specifies the initial state of game's business environment and determines the development of the game situation over time according to predefined trends, as well as contains a list of important events taking place during simulation. Events are indicated by the game manager and can affect trends. Participants make their decisions, in other words, take actions that can affect both trends and events. Trends may be configured according to the teaching goals by changing appropriate parameters available in the game.

Considering the structure of the simulation game (Fig. 1.1), the scenario can be defined as follows: the game scenario determines the initial state of the game model as well as its development over time and allows making necessary changes to the current situation during the game (Fig. 1.3).

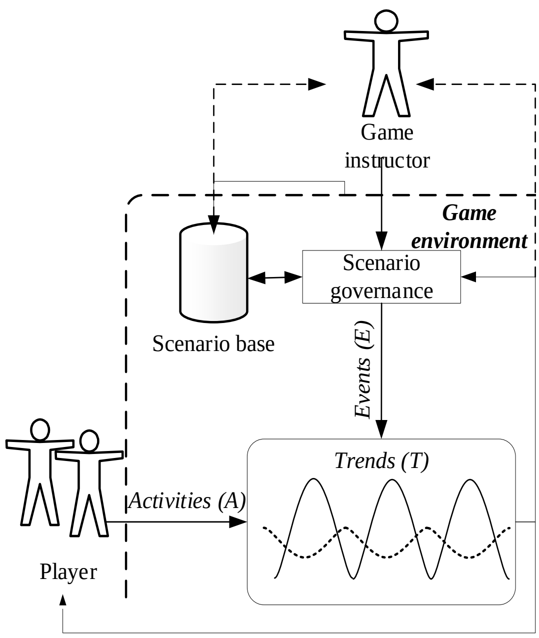


Fig. 1.3. Scenario-based structural framework for planning and managing of simulation games.

Scenario-based simulation games have already been available previously, but all the responsibility for the management of the scenario was taken by the teacher, based on personal experience and knowledge, which makes it difficult to manage the game. An example of this type of game is general management simulation game New ORSIAM Int., which provides the acquisition of key planning, organization, management and control functions and teaches to find a balance in conflict situations between different decisions within the group [2]. An example of a functional game is the ROFA-Plus OPC game, which provides modelling of planning and management of production operations and an opportunity to implement and analyse several planning and management strategies according to the proposed scenario conditions [13].

The aim of the Thesis is to develop a method for formalizing dynamic scenarios of simulation games, which envisages scenario generation, simulation and control.

Conclusions:

1. Simulation-based training in general, including simulation games, continues developing as effective active learning methods under the influence of modern information technologies, which allow finding new areas of use and functional possibilities.
2. Modern simulation games usually model the principles and processes of a complex system according to a certain scenario, which needs to be developed and tested before it is offered to real players. Therefore, the proposed scenario concept, which formalizes the definition of scenario, is essential for the development of the scenario generation, modelling and management procedure, which will be proposed in Chapter 2 of this work.
3. The studied components of the uncertainty of the simulation game scenario should be considered when developing the general procedure for scenario management and proposing the mechanisms for its practical implementation.
4. The definition of a simulation game scenario and its formalization approach provided a scenario-based framework for the planning and management of simulation games, which, in turn, will allow the development of scenario management support tools for both the ECLIPS supply chain management game and the ILMG logistics management game.

2. DEVELOPING AN INTEGRATED APPROACH TO GENERATING, MODELLING AND MANAGEMENT OF SIMULATION GAME SCENARIOS

This chapter discusses scenario modelling methods and procedures, provides definitions of the concepts used in the scenario approach, as well as describes the objectives of scenario development and lists the elements of the scenario.

Scenarios are one of the modern methods for displaying information about the environment and the reaction to the state change of this environment, which determines the basic trends in the development of a system [12]. Depending on the context and industry in which the term 'scenario' is used, several definitions are available.

Depending on the objectives of the study, the functions of the scenarios and the ways in which the obtained results are used, the term 'scenario' may have different meanings. For example, an object behaviour scenario is a model of environmental change, which is related to the occurrence and development of a situation, which can be determined in a discrete time space with a given time step [12].

The purpose of scenario development is not only to unambiguously or probabilistically predict events, but to determine the logical sequence of several events. The aim is not to identify all possible development alternatives, in this case the number of variants quickly becomes opaque, but to identify some qualitatively and substantively different trajectories, which in a concentrated way reflect the spectrum of all possible development directions of the system.

The scenario approach is at the crossroads of forecasting and planning. From these areas, the scenario approach has feature, which is found in both types of activity – systematic development and research of possible development options of the research object.

The concept of scenario can also be considered in a narrower sense depending on the field of application. As this research deals with business simulation games, the definition of the scenario should be clarified in this area. In this context the simulation game scenario specifies the initial conditions, system development trends as well as important events during the simulation [11].

The following requirements were set for the scenarios to be developed:

1. According to the concept in Fig. 1.2, it should describe the set of parameters and trends, as well as the regularities of their changes, referring to various events and activities.
2. The scenario should be dynamic.
3. The scenario should be stable, i.e., resistant to different effects.
4. When developing a scenario, the life cycle of the scenario should be observed (Fig. 2.1).

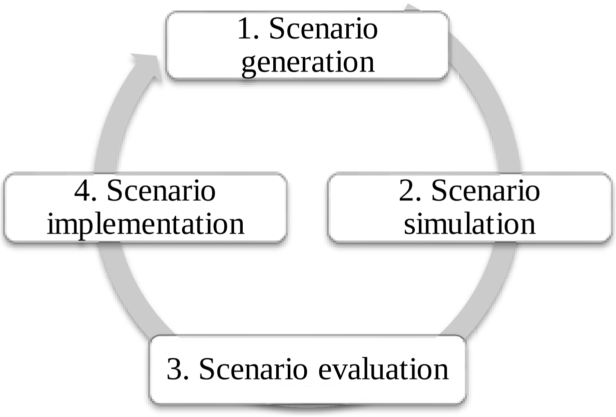


Fig. 2.1. Scenario life cycle.

Game scenario development consists of several stages: 1) goal definition; 2) definition of the initial state; 3) definition of development trends; 4) planning of the events.

The basic function of scenario management is to plan the progress of the game and control the execution of plans, as well as to make the necessary operational changes. The purpose of monitoring is to control the performance of the business environment model. If the values of performance indicators are out of the defined area, the necessary changes are made to the scenario, or an alternative scenario is launched that changes the current situation according to the training objectives.

The scenario management procedure includes three steps (Fig. 2.2).

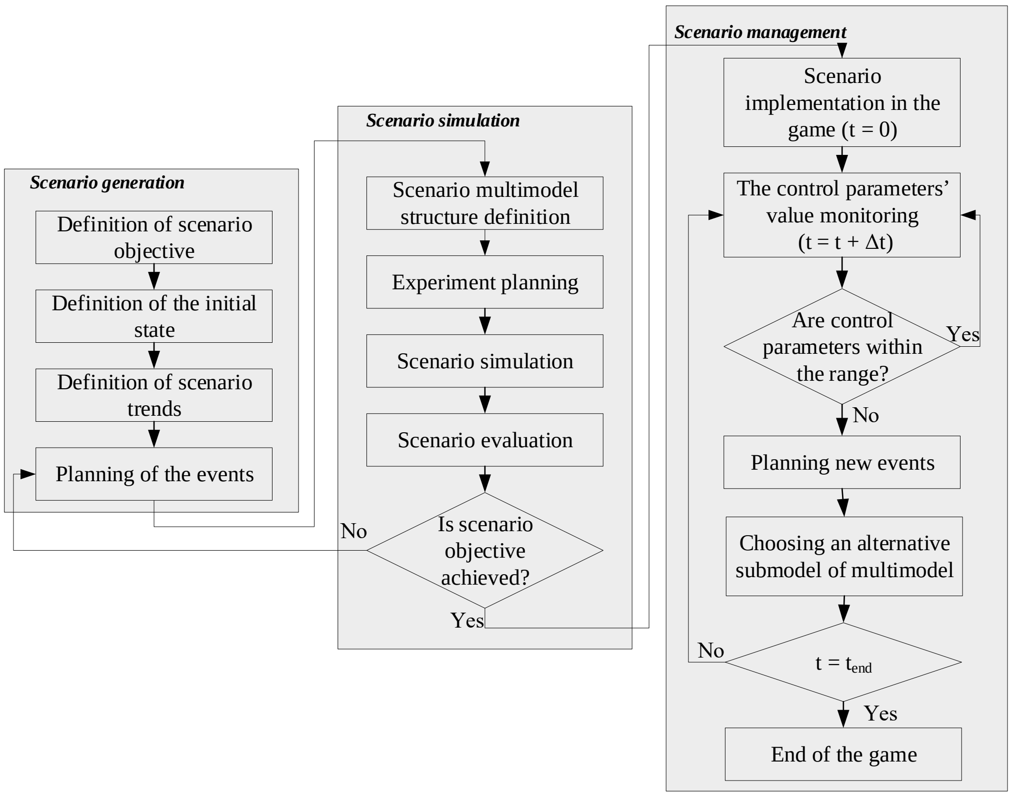


Fig. 2.2. General scenario management procedure.

The first stage is the generation of a scenario, when the objectives of the scenario are defined, the initial state of the system is determined, the development trends of the system are defined and events that will be implemented during the scenario are planned. The second stage involves scenario simulation in order to find out whether the generated scenario corresponds to the training content and training objectives. Here, the multimodel structure of the scenario is defined based on the list of events. According to this structure, a modelling experiment is planned and scenario simulation takes place. Next, the scenario has to be evaluated by checking whether the results of the scenario modelling correspond to the set objective.

If the scenario matches the goal, then it is implemented in the game, which also requires scenario management. With the time step Δt the control variables are monitored and, if the value of an indicator is outside the defined range, the necessary changes are made to the scenario, or an alternative scenario is run that changes the current situation according to the training objectives.

On the one hand, actions can influence the dynamics of trends and cause or reject other actions, but on the other hand, events can influence trends and actions to be taken. Usually the game manager decides on the trends before the game. During the game, participants make decisions, which means, perform actions to meet the learning objective. If this leads to unforeseen results (such as bankruptcy), the game manager includes in the game some events that could motivate players to reach the goal.

In general, the purpose of scenario development can be defined as follows [12]:

- identification of the significant developmental moments of the research object and, on its basis, elaboration of qualitatively different alternatives of its development;
- comprehensive analysis and evaluation of each alternative and discovery of their properties and possible consequences of implementation with the aim to create specific plans and programs for their implementation.

The elements of the scenario can be divided into three groups: development trends, events, and activities [12]. The scenario combines the relevant set of variables and the relationships between them. In general, the scenario is characterised by a set of actions that the desired system development scenario should provide.

A trend depicts the development of the research object in the form of a time series. Trends can refer to the performance indicators of the system, as well as those variables from which the main impact on the system process can be expected. To each trend there can be assigned its change in the time interval. An event may affect the dynamics of certain trends or other events through its implementation or non-implementation. Interactions occur as a result of the activities of some subjects (such as game participants) and affect both trends and events.

The scenario has an initial state, it also contains a list of events that are aimed at reducing the difference between the desired and expected development of the situation.

There is an object behaviour scenario and its management scenario [12]. The purpose of a behavioural scenario is to study the behaviour of an object in conditions where there are no targeted control effects. The aim of the management scenario is to show the consequences of specific control actions (the direct control task is solved), or to find control effects that will lead the object to the desired state (the inverse control task is solved).

The approach to formalizing scenarios is when the studied system is represented in a general decomposed form. It comprises

- an object that is subject to research and impact;
- the entity performing it;
- relationships between the specified object, subject and the external environment.

The same scenario, regardless of form and language of presentation, must be unambiguously interpretable. The basic requirements for scenario representation can be defined as follows [12]:

- simplicity and convenience of analysis for each user in the decision preparation and decision-making process;
- possibility of computer processing in interactive mode;
- scenario structure and relationships between key events.

The quality of the training also depends on the quality of the game scenario and its adequacy; therefore, the methodology for developing such scenarios is offered in the Thesis.

As the development of the system is usually influenced by various uncertainties, not all scenarios can be easily formalized, so they can be classified as follows: (1) formalized, which include automatically computerized scenario generation methods; (2) semi-formalized, based on an automatic generation procedure, but adjusted by experts; (3) informal, based on expert judgment. The Thesis focuses on the second type scenarios. The instructor of the simulation game can be considered an expert.

Agent technology is proposed to implement effective scenario-based simulated game management.

There are several examples in the literature that describe the functions of agents in simulation games. For example, Van Luin [14] proposes to transform the classic "Beer Game" discrete event simulation model into a multi-agent model. Here, the agents act as a retailer, wholesaler, distributor and factory, and their behaviour is essentially similar: each agent receives an order from an adjacent echelon in the downstream chain, as well as sends an order and receives an item from an echelon located in the ‘upstream’. The reaction of agents to these events is determined by production rules. In this way, the authors try different stock replenishment models, but there are no opportunities to train agents based on the experience gained.

Remondino [15], [16] describes the use of agents in business simulation games. On the one hand, they support the decision-making process of the participants and work based on reinforcement learning algorithms, on the other hand, they replace components of a game model, such as a factory or raw material supplier, and the behaviour of these agents is determined by evolutionary algorithms.

Dobson [7] mentions agent technology as the most promising in the development of business simulation games. The following possible functions of agents are offered: replacing a real player or assisting in the decision-making process, monitoring and evaluating player activities, as well as modelling consumer behaviour.

In addition to the above-mentioned functions, another function is offered in the Thesis, which could be described as follows: ensuring the generation and management of the game scenario. When generating the scenario, according to the general structure scheme (see Fig. 1.2), the starting position of the game and the development trends of the situation are determined. During the game, the agent controls the progress of the game by defining events that affect trend functions. Production laws ensure that scenario parameters are set appropriately according to predefined conditions. Scenario control is based on dynamic comparison of business environment parameters and company positions. This is performed by the game manager agent (Fig. 2.3).

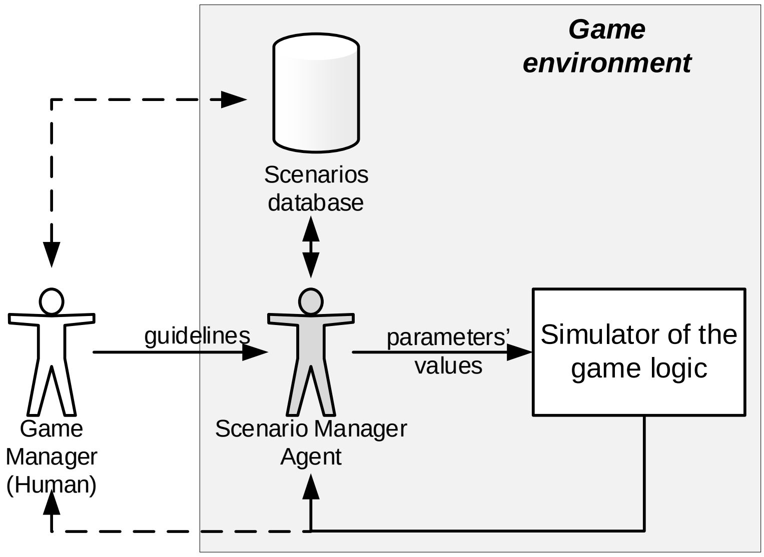


Fig. 2.3. Simulation game management agent.

If a business simulation game is used for individual training, the agent can replace the real opponent by performing appropriate actions (Fig. 2.4).

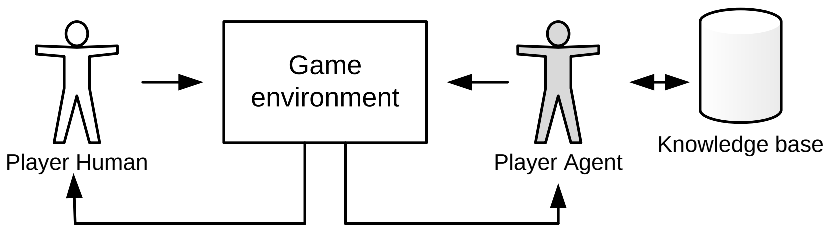


Fig. 2.4. Virtual player interaction scheme with the game environment.

When an agent plays a tutor's role, it defines weak points in the player activities, and may give necessary explanations in the form of causal relationships. Also, it may suggest possible ways of problem solving if the participants need any support in their decision analysis. If the number of participants is large, it may not be so easy to manage the game due to its online mode and lack of time to make a deeper analysis of the current situation. The structural scheme for interactions between the Tutor Agent and trainee is shown in Fig. 2.5. This agent becomes a part of the game environment that was defined above (Figure 2.3), and therefore we now call it the extended game environment.

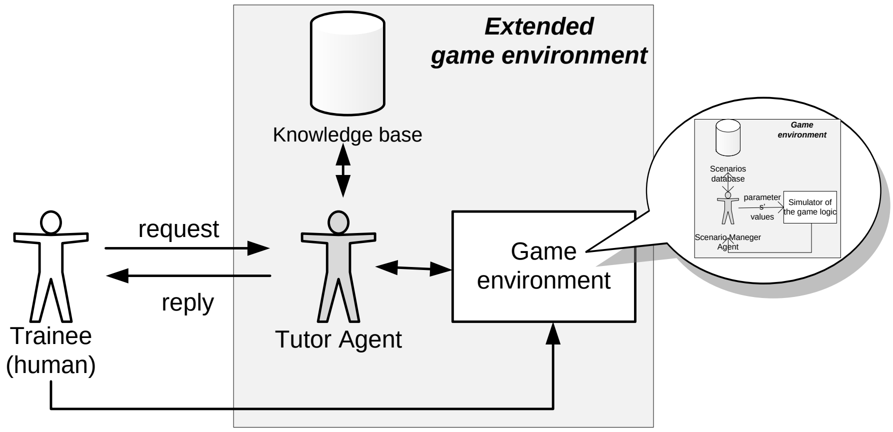


Fig. 2.5. Interaction scheme for a tutor agent.

Effective game scenario management can be ensured by multisimulation, which allows to model different models in parallel with the aim to analyse the impact of various parameters and experimental conditions on the system [8], [17]. The multi-model simulation methodology provides an opportunity to study different models in parallel. Multi-model formalism [10], [18], [19] can be applied to simulate game scenarios.

One of the scenario management functions is monitoring of the game session and making necessary scenario alternations during run-time. Monitoring is aimed at controlling key indicators of the business environment. If any of the indicators is out of its critical value, then necessary changes are introduced to the current scenario or an alternative scenario is applied, which allows changing of the current situation according to the teaching goals.

A multimodel is associated with a dynamic scenario that defines a sequence of scenarios in specific time moments (Fig. 2.6), where S_0 is an initial scenario and *S1*,..., *Sn* are alternative scenarios, *S1.*, ...,*S1.m* and *Sn.1*,..., *Sn.k* correspond to subsequent scenarios.

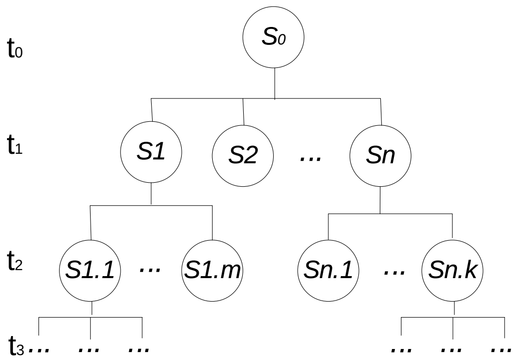


Fig. 2.6. Scenario multimodel structure.

Here, single aspect multimodels when only one submodel is allowed to be active at a given time, with a static structure and adaptive behaviour are introduced [19]. These multimodels are controlled by stationary or adaptive transition policies that can have learning capabilities. Therefore, the task of choosing an alternative scenario is delegated to the agent.

Choosing an alternative scenario requires (1) *observing* the simulation state, (2) *reasoning* to qualify the scenario for update, and (3) *planning* activation of submodels by exploring potential paths within the state space of the problem domain. Each sub-scenario is viewed as an operator that transforms the state of the simulation model. An agent paradigm provides the necessary computational infrastructure to attain these objectives.

The scenario manager agent decouples the simulator of the game logic from the scenario model and performs updates of the game dynamic scenario (Fig. 2.7). The activation conditions of submodels are defined in terms of the production rules. Dynamic submodel replacement requires monitoring simulation conditions in order to determine if any of the potential state variables of interest are changed that could be an indicator for a scenario update in the simulator.

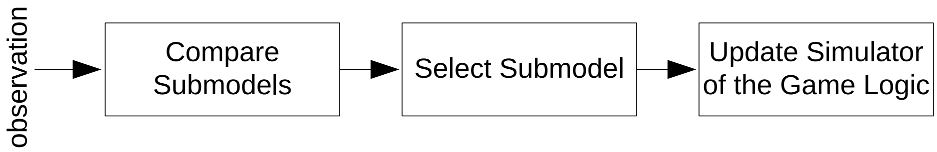


Fig. 2.7. Submodel activation process.

During the model comparison phase, all the submodels whose preconditions are implied by the observed state are identified and their comparison is performed by the Scenario Manager Agent. During the next phase, only a single submodel is qualified for further exploration. Finally, the simulator of the game logic is updated by the selected submodel.

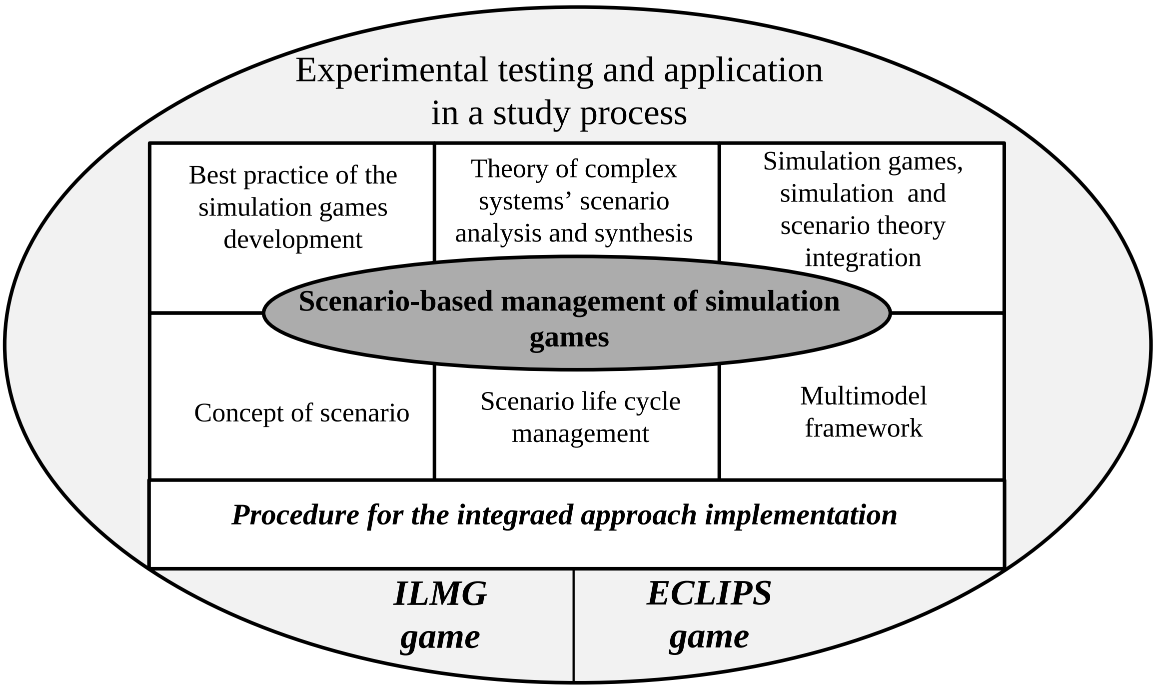


Fig. 2.8. An integrated scenario development approach.

To summarize the research described in Chapter 2, a scenario-based integrated simulation game management approach is proposed (see Fig. 2.8), which covers the good practice of simulation game development, scenario analysis and synthesis methods for complex systems; integration of business games, simulation and scenario theory. Moreover, a definition of a dynamic scenario concept for scenario life cycle management and generation of multi-model simulation scenario parameters is formulated. The developed approach is implemented by a special procedure (Fig. 2.2) and has been experimentally tested in two games: ECLIPS and ILMG.

Conclusions:

1. The compilation and interpretation of scenario concepts in the context of simulation games made it possible to define requirements for the development of this type of scenario.
2. After examining the scenario formalization approaches, it was found that they could not be used directly to generate simulation game scenarios. Therefore, it is proposed to use multomodel structure to represent some conceptually different scenarios that need to be tested before being offered to players.
3. Agent technology is considered as a perspective technology for scenario generation, simulation and management that allows performing most of the tasks previously performed by the game manager automatically using agents, thus making the development process faster and more efficient.
4. The implementation of a scenario management procedure is necessary to define the stages of simulation game scenario generation, modelling and control and their interactions.

3. IMPLEMENTATION OF THE SCENARIO APPROACH AND EXPERIMENTAL ANALYSIS IN THE ECLIPS SIMULATION GAME

This chapter is devoted to the application of the developed approach for the generation and management of ECLIPS game scenarios [20].

The aim of this game is to give the idea of the basic principles of supply chain operations and the advantages of implementing different inventory management strategies, solving one of the main management problems: how to reduce total costs while maintaining a sufficiently high level of service. The object of the ECLIPS game is a multi-echelon supply chain, and the subject is different inventory management policies.

The ECLIPS game involves modelling different supply chain structures depending on the training objective and the level of preparation of the audience, thus, different game scenarios can be generated.

The ECLIPS game provides physical modelling of the supply chain, but to generate new scenarios, a simulation model has been developed in the MS Excel environment, which has the following input data:

- initial stock of the product (pieces);
- demand from the final consumer(-s);
- parameters that determine the replenishment strategy.

Scenario generation also requires data on the structure of the supply chain, i.e., the number of actors (e.g., retailers, wholesalers, factories, etc.) and their interactions (i.e., delivery times). An example of a supply chain and its representation in the ECLIPS game is shown in Fig. 3.1.

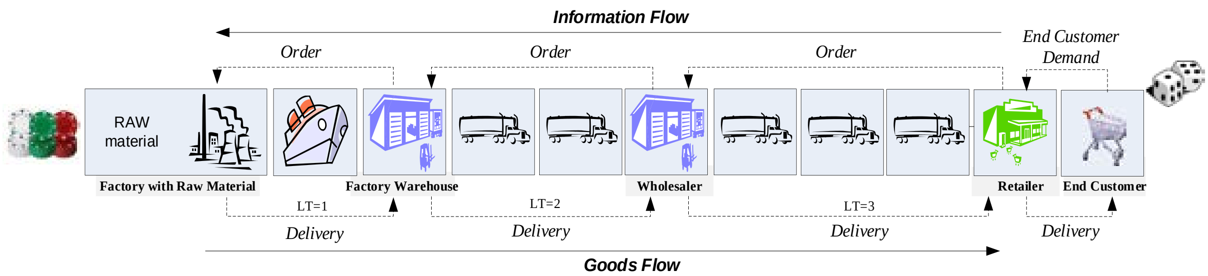


Fig. 3.1. Supply chain example and its representation in ECLIPS game.

The chain shown in Fig. 3.1 has three echelons where stocks are built up: 1) a factory warehouse with the supply and production of raw materials, 2) a wholesaler warehouse, and 3) a retailer warehouse. Lead times between stock points are defined as one period between factory and factory warehouse, two periods between factory warehouse and distributor, and three periods between distributor and retailer. Initial inventories are set at 44 pieces for retailer, 36 for distributor and 28 for factory warehouse.

Once the structure of the supply chain has been defined, its operation is modelled over a number of periods, considering the nature of the final customer demand, the level of initial stocks and the inventory replenishment strategy.

In the provided example, customer demand is dynamic and stochastic with average demand equal to $\mu = 77$ units per period with standard deviation $\sigma = 2{,}452$ units per period, which can be described with a discrete probability distribution shown in Fig. 3.2. It is known that unit storage costs are 1 EUR/time period, order costs are 10 EUR and unit production costs are 3 EUR. The amount of raw materials is unlimited, as well as the storage capacity is not limited.

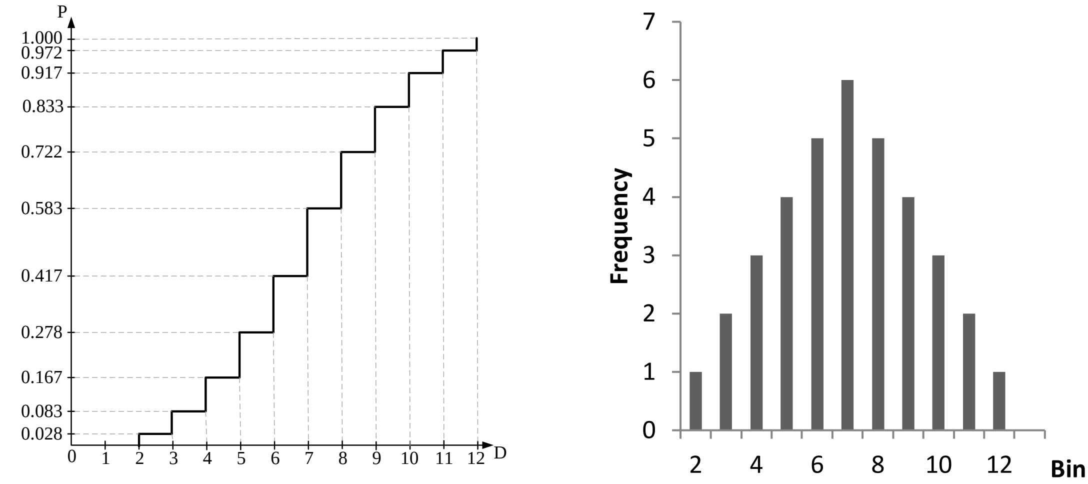


Fig. 3.2. Empirical discrete probability distribution to generate the end customer demand.

The overall objective of the game is to attain 95 % service level at the lowest total cost that consists of producing, ordering and inventory carrying costs. The chain which manages operations with the lowest costs wins. Usually, this kind of problem in the supply chain is solved by using one of the inventory management models. There are several, for example, described in source [21], [22], from which the appropriate one for a particular situation must be chosen. As end customer demand is stochastic, the following models can be used:

- continuous inventory review model with uncertain demand (Fig. 3.3);
- periodic inventory review model with uncertain demand (Fig. 3.4).

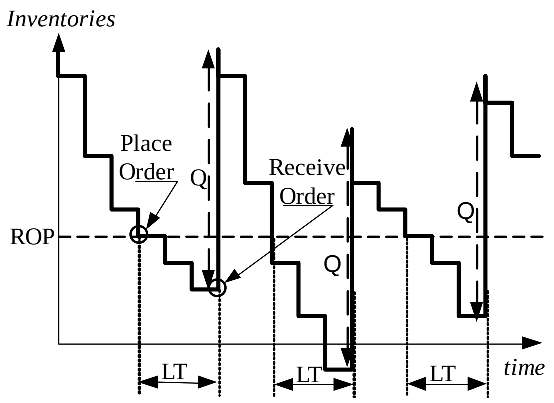


Fig. 3.3. Continuous inventory review model with uncertain demand (adopted from [22]).

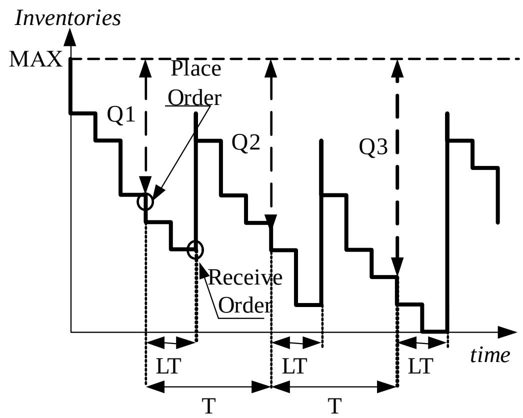


Fig. 3.4. Periodic inventory review model with uncertain demand (adopted from [22]).

The continuous inventory review model is based on the calculations of the optimal order size Q and the reorder point ROP, considering the order delivery time LT. The periodic inventory review model is based on the calculation of parameters such as the order cycle length T and the maximum inventory level MAX, considering the order delivery time LT [23].

To improve the efficiency of the inventory replenishment model, a modification of the periodic inventory control policy with synchronization of supply cycles is being introduced. This means that the echelon can place an order when the previous one has received the product in its warehouse.

Several performance indicators are proposed in the literature to analyse the effectiveness of inventory control policies [24]. The following indicators are defined in the context of the ECLIPS game. Service level is calculated for the end consumer:

$$SL = \frac{P}{D}100\% \quad , \qquad (3.1)$$

where P is satisfied end customer demand and D is end customer demand (no backorders are considered).

P and D are calculated as follows:

$$P = \sum_{t=1}^{T}\sum_{i=1}^{M} P_{ti} \quad , \qquad (3.2)$$

$$D = \sum_{t=1}^{T}\sum_{j=1}^{N} D_{tj} \quad , \qquad (3.3)$$

where

P_{it} – number of products delivered by the *i-th* retailer in period t; $t=1,...T;$ $i = 1,..,M$;

T – number of game rounds;

M – number of retailers;

D_{it} – *i-th* consumer demand in period t, $j = 1,.., N;$

N – number of end customers.

Average inventory in the supply TQ_{vid} chain is calculated as follows :

$$TQ_{vid} = \frac{\sum_{t=1}^{T} TQ_t}{T} \quad , \qquad (3.4)$$

where TQ_t is total supply chain inventory in period t.

Average cost in supply chain TC_{vid} is calculated as follows :

$$TC_{vid} = \frac{\sum_{t=1}^{T} TC_t}{T} \quad , \qquad (3.6)$$

where TC_t is total supply chain cost in period t.

The following was developed in the Thesis:

1. Conceptual model (Fig. 3.5), which defines the basic components of the supply chain and their interaction, as well as their implementation algorithms (Fig. 3.6) for scenario modelling.
2. Methodological protocols that support students' activities during the physical modelling of the supply chain and allow to obtain data for the calculation of performance indicators.
3. A game management tool (Fig. 3.7) that provides scenario generation, modelling and analysis, as well as allows verifying students' results obtained in the game. Within the framework of the Thesis, several game scenarios were generated and modelled.

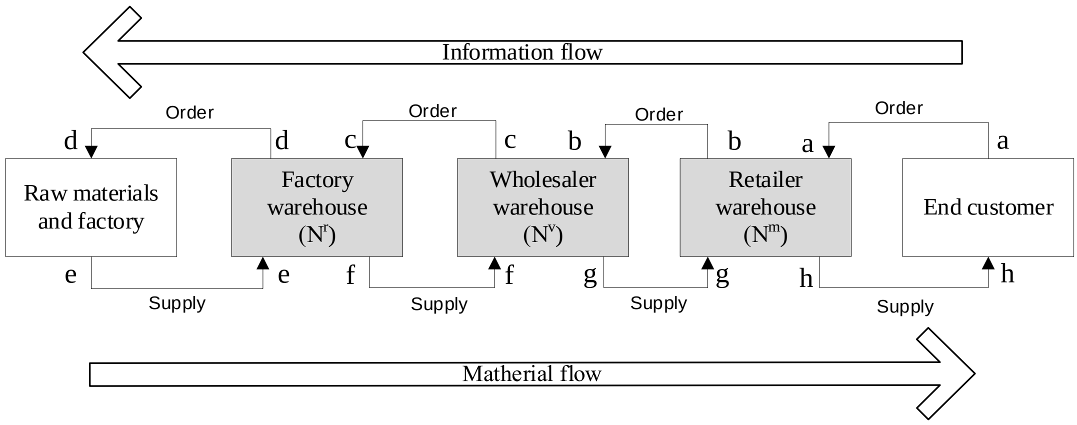


Fig. 3.5. The conceptual model of the ECLIPS game supply chain.

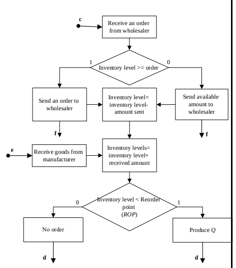
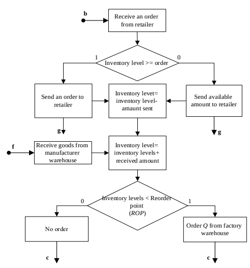
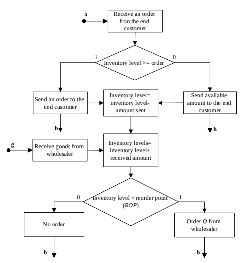
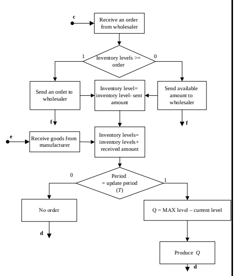
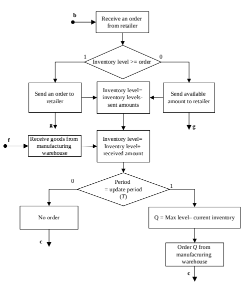
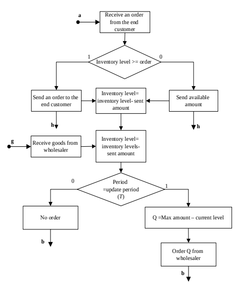
Strategy	Inventory replenishment algorithms			Analysis of performance indicators
	(N^r)	(N^v)	(N^m)	
Continuous inventory review *(S1)*				1. Service level $SL = \frac{P}{D} * 100\%$ 2. Average inventory $TQ_{vid} = \frac{\sum_{t=1}^{T} TQ_t}{T}$ 3. Average cost $TC_{vid} = \frac{\sum_{t=1}^{T} TC_t}{T}$
Periodic inventory review with synchronization of the ordering cycles between supply chain echelons *(S2)*				

Fig. 3.6. Inventory replenishment strategies and algorithms for scenario modelling.

In addition, within each scenario, the management tool allows experimenting with different scenario parameters, analysing how they affect the operation of the supply chain and choosing the most appropriate scenarios for the study process.

For example, in the experiment performed in the Thesis a) data for the empirical distribution (Fig. 3.2) were defined, after which the end consumer demand was generated, the lead time of orders between echelons and costs related to delivery was determined; b) parameters <*Q*, *ROP*> and <*T*, *MAX*> were calculated for continuous and periodic inventory review strategies, respectively; and c) supply chain operation was modelled over several periods and, as a result, performance indicators were defined according to Formulas (3.1)–(3.6). The experimental steps are depicted in screen sections (a), (b), and (c) of the scenario management tool (Fig. 3.7).

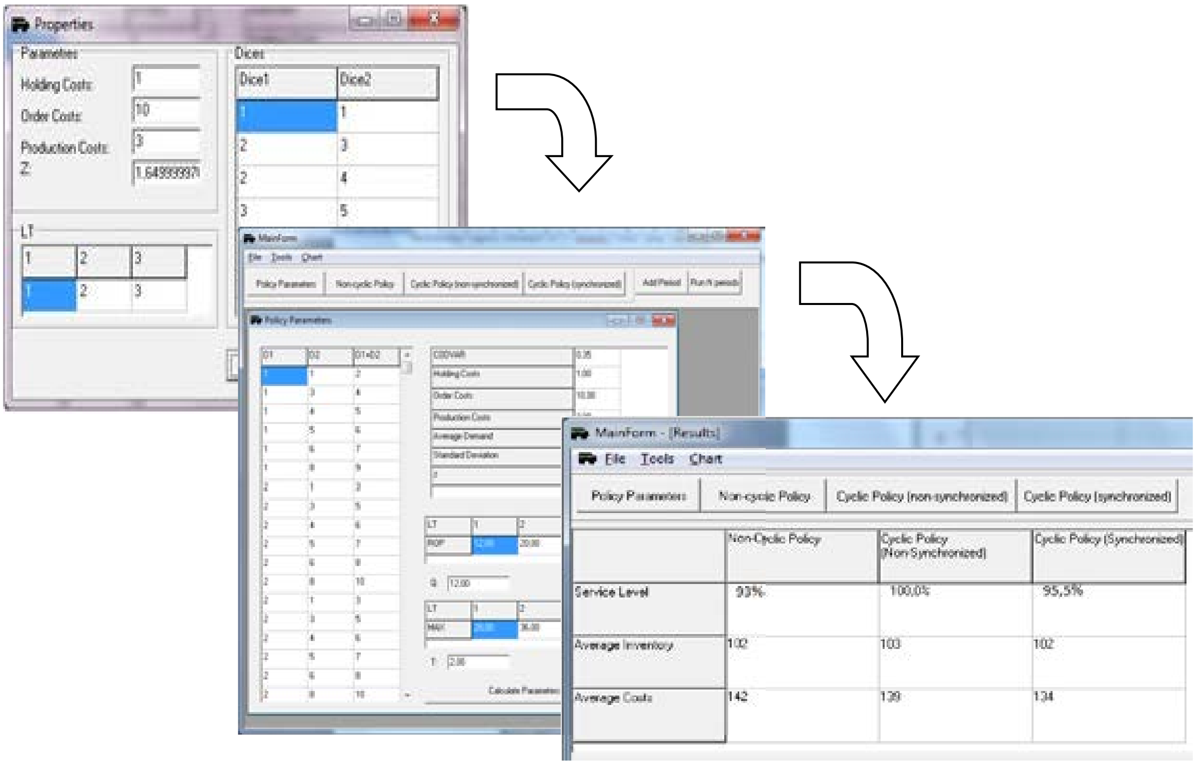


Fig. 3.7. Screenshots of a scenario management tool.

The calculated parameters are given in Table 3.1.

Table 3.1

Parameter Values for Inventory Review Models

Warehouse/ Parameters	***S1***		***S2***	
	***Q* (units)**	***ROP* (units)**	***T* (periods)**	***MAX* (units)**
N^r	12	12	2	28
N^v	12	20	2	36
N^m	12	28	2	44

Supply chain performance modelling in accordance with continuous and periodic inventory review policies (without cycle synchronization and with cycle synchronization) has been performed over 500 periods. The obtained results show that the use of both models provides a service level higher than 95 % (Fig. 3.8).

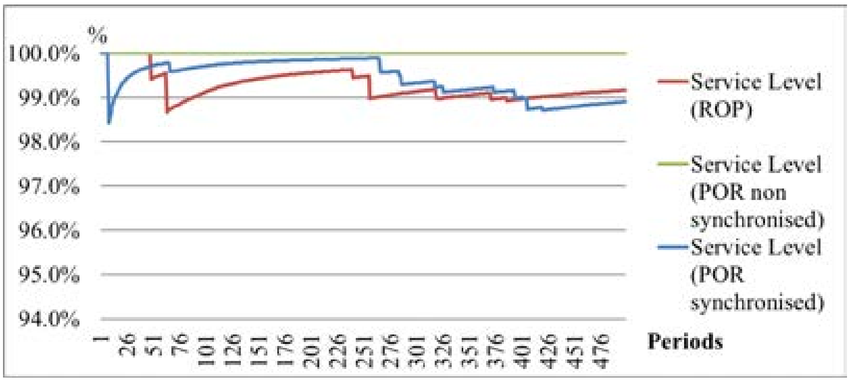


Fig. 3.8. Service level.

However, comparing the average inventory costs (Table 3.2), it can be concluded that the use of a periodic inventory review model with cycle synchronization is the most advantageous for the given system input data.

Table 3.2

Average Supply Chain Costs and Average Inventories

	Average costs (EUR)	***Average inventories (units)***
Continuous inventory review	142.24	102.89
Periodic inventory review without synchronization of the cycles	153.21	117.09
Periodic inventory review with synchronization of the cycles	128.30	94.50

The cumulative mean and confidence intervals are shown graphically in Figs. 3.9–3.11. The cumulative mean in all the graphs is reasonably flat, and the confidence intervals narrow fairly rapidly.

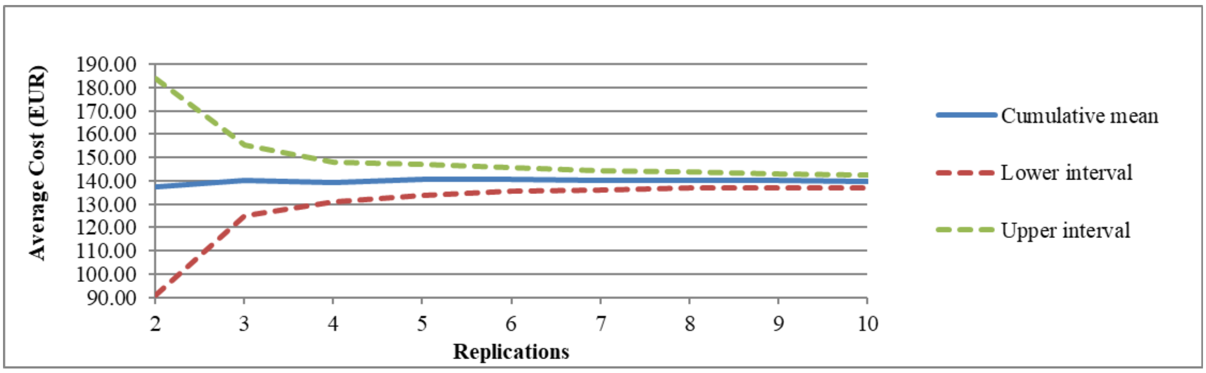


Fig. 3.9. Plot of cumulative mean and 95 % confidence interval for average cost (*S1*).

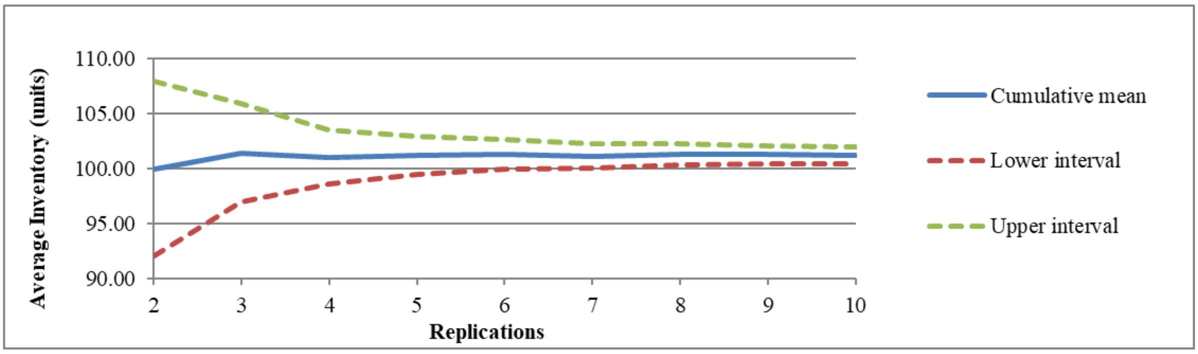


Fig 3.10. Plot of cumulative mean and 95 % confidence interval for average inventory (*S1*).

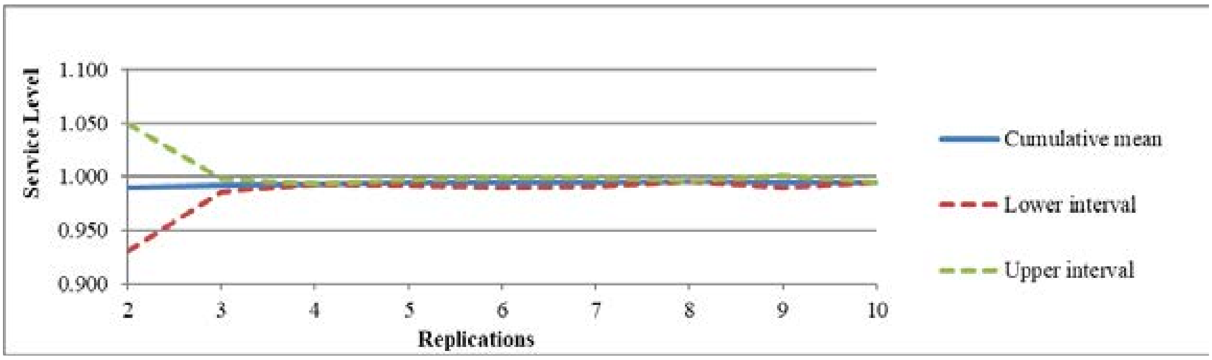


Fig. 3.11. Plot of cumulative mean and 95 % confidence interval for service level (*S1*).

The calculations and their graphical interpretation allow concluding that for average inventory and service level the deviation is less than 5 % at three replications. The interval narrows a bit slower for the average cost, and the deviation is not less than 5 % until the 5th replication. Thus, it is possible to confirm the convergence of the scenario modelling results. Similar calculations were performed for periodic replenishment policy. Therefore, the scenario can be proposed for the implementation with real players. to be played with students.

Conclusions:

1. The proposed conceptual model of the supply chain allows implementing different inventory replenishment strategies in the ECLIPS game, which determine the alternative scenarios of the game according to the concept described in Chapter1.
2. The developed tools for scenario modelling and analysis ensure the practical implementation of the proposed approach.
3. Experimental results obtained both in research and in the learning process over several years show the effectiveness of the developed scenario approach and scenario modelling and analysis tools.
4. The results described in the chapter serve as a methodological support for the use of the ECLIPS game in the teaching of RTU courses Integration of Management Elements (DMI554) and Decision Synthesis Principles and Practice in Logistics (DMI716). Positive feedback has been received from students during the survey, and the survey results are available in the ORTUS environment.

4. IMPLEMENTATION OF THE SCENARIO APPROACH AND EXPERIMENTAL ANALYSIS IN THE ILMG SIMULATION GAME

ILMG is a dynamic web-based online management simulation computer game that provides a virtual business environment for developing decision-making skills in areas such as international logistics, production management, marketing and finance [25]. During the game, participants, representing various international competing corporations, make strategic, tactical and operational decisions in various areas of the corporation's operations with the aim of improving the corporation's performance and achieving specific results, such as increasing profits, gaining market share or providing a high level of service. The author of the Thesis participated in the testing of the game at the universities of Linköping and Ljubljana, as well as in the development of the training methodology.

The components of the game software are as follows (Fig. 4.1): (1) a game server (*Game Control Centre.exe*) that provides business environment modelling, decision processing, and game management; and (2) software installed on the client terminal (*ILMG.exe*), which provides a user interface for the input of decisions and the key performance indicators analysis. As the communication means is Internet, corporations can be physically located in different geographical locations. The game manager (teacher), who has remote access to the game server, following all the activities of the participants, can make changes to the training scenario during the game, if necessary. In addition, it is possible for companies to use satellite terminals, thus sharing decision-making rights among team members.

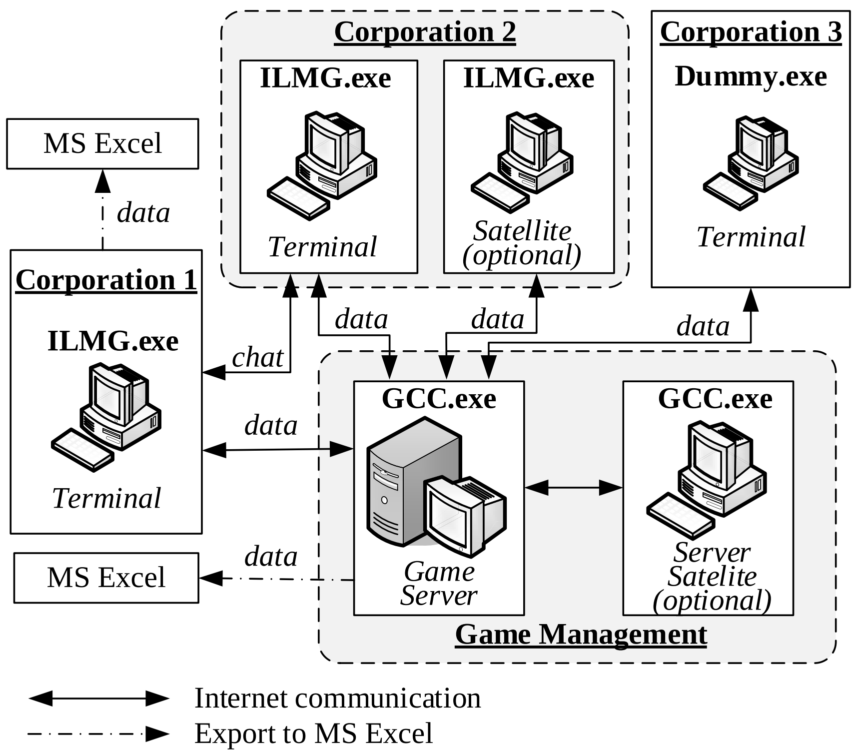


Fig. 4.1. ILMG software structure.

One of the main advantages of ILMG is the possibility of creating scenarios [26], which provides modelling of various real-life situations, thus allowing to gain practical skills and experience in managing the company in different business conditions.

The ILMG game scenario is defined according to certain training objectives. Various scenario parameters determine the initial state of the game and its dynamics. The parameters are grouped into several sets, such as regional parameters, production parameters, market-related parameters, transport tariffs, etc. (see Fig. 4.2). The scenario must be defined before starting the game, but during the game the game manager's ability to change the dynamics of the game is limited.

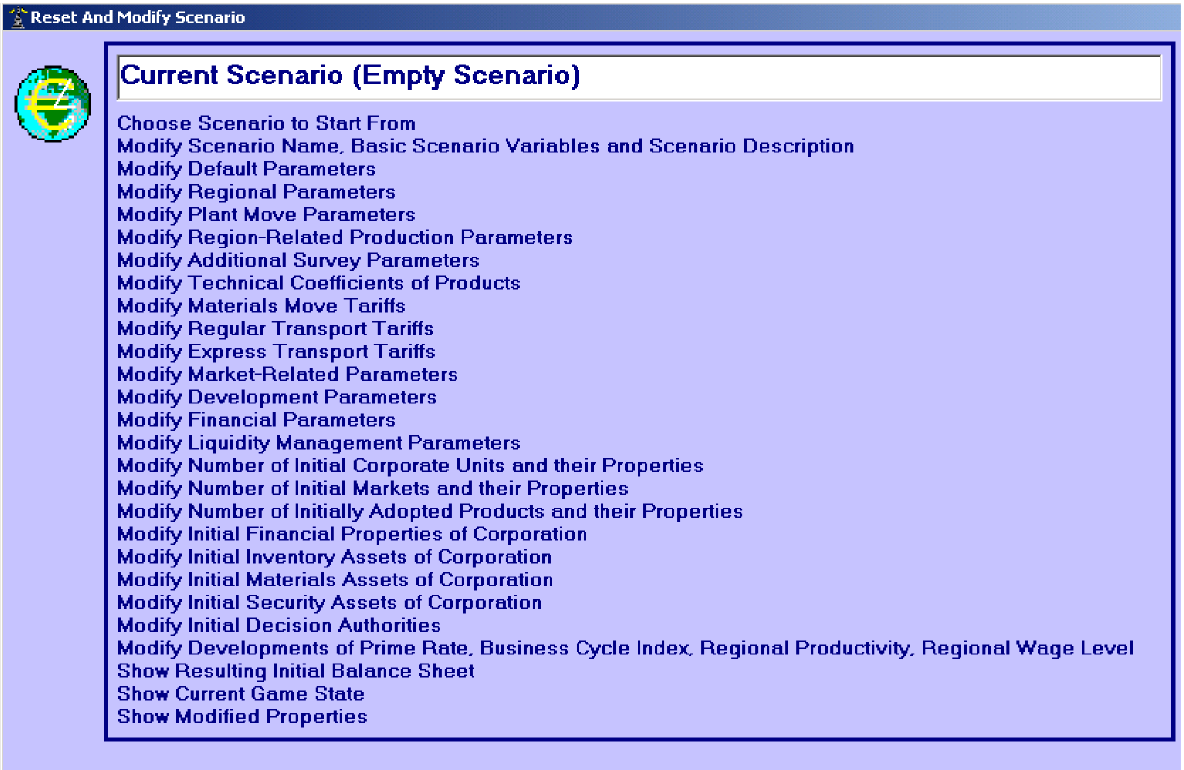
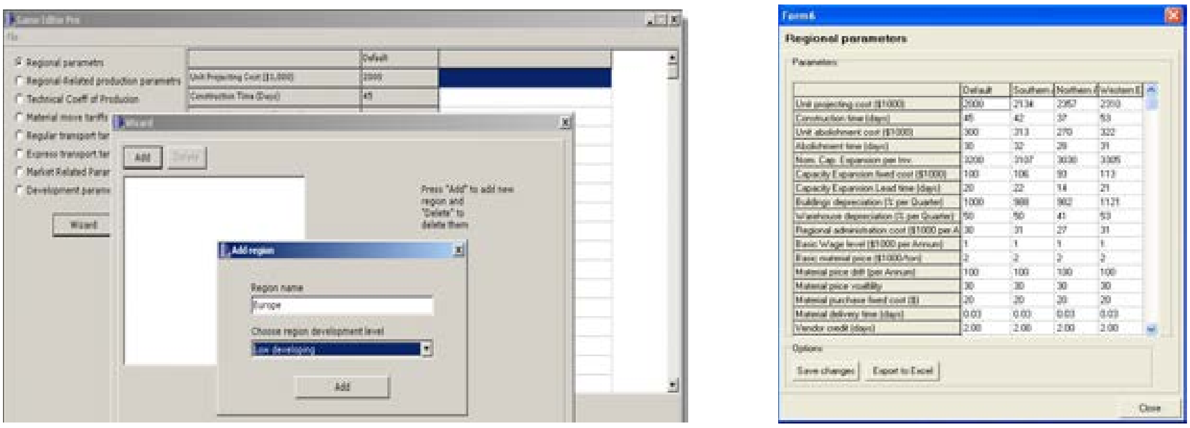


Fig. 4.2. ILMG scenario editor (© R. W.Grubbström).

Scenario development involves several steps related to setting and tuning the game parameter values. It is necessary, firstly, to define the basic variables of the scenario that determine the set of all other parameters and, secondly, to define the values of all parameters according to the training objectives. It is necessary to set more than a hundred different parameters for the simplest scenario (one region, one product, and two bank accounts), which makes it difficult to manage the game.

In the Thesis, the process of scenario development for ILMG is improved and partially automated using the scenario management agent *GameEditorPro*, which is implemented as a separate software module (Fig. 4.3) [27]. The game manager decides on the basic variables of the scenario and their properties, but *GameEditorPro* automatically generates the other values of the dependent parameters. In addition, a virtual player has been introduced for scenario testing, as well as a tutor agent for monitoring key performance during the game.



a) b)

Fig. 4.3. Scenario development with *GameEditorPro*: a) definition of basic parameters; b) generation of parameter values.

The basic variables are defined qualitatively, for example, a region (R) is characterized by the degree of economic development that can be 'high', 'medium' or 'low', while a product (P) is described as 'technological' or 'high-tech'. The other scenario parameters are automatically generated according to the following algorithm:

1. The total number of parameters is calculated.
2. The range of parameter values is defined.
3. Each range of parameter values is divided into three equal groups.
4. Each group belongs to a particular region or product.
5. Within a group, parameter values are generated randomly with the aim of excluding the possibility of creating two or more identical regions or products.

The scenario parameters generated by the *GameEditorPro* are exported to MS Excel tables, and the * .xlsx file is imported to the *GameControlCentre*. Next, the scenario is modelled with the player agent (*Dummy.exe*) (Fig. 4.4), which allows obtaining the system performance results that are evaluated by the game manager according to several indicators and he/she decides on the suitability of the scenario for training purposes.

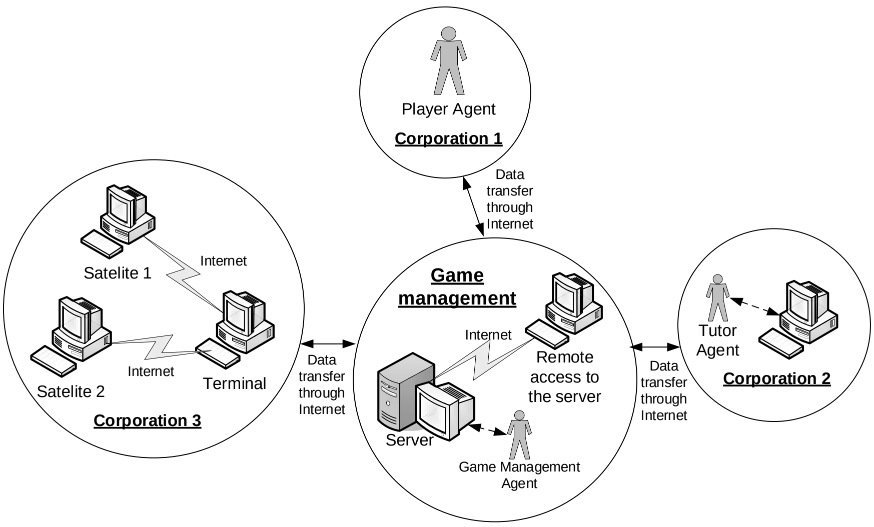


Fig. 4.4. Game management and agents' functions.

If the result is not satisfactory, the scenario generation procedure is repeated. If the scenario is found to be appropriate, it is used during the game with real players, and the teaching agent monitors the progress of the game by monitoring various indicators that characterise both the performance of individual corporations and the situation as a whole. If at some point these indicators no longer meet the training objectives, changes in the values of the game scenario parameters are introduced.

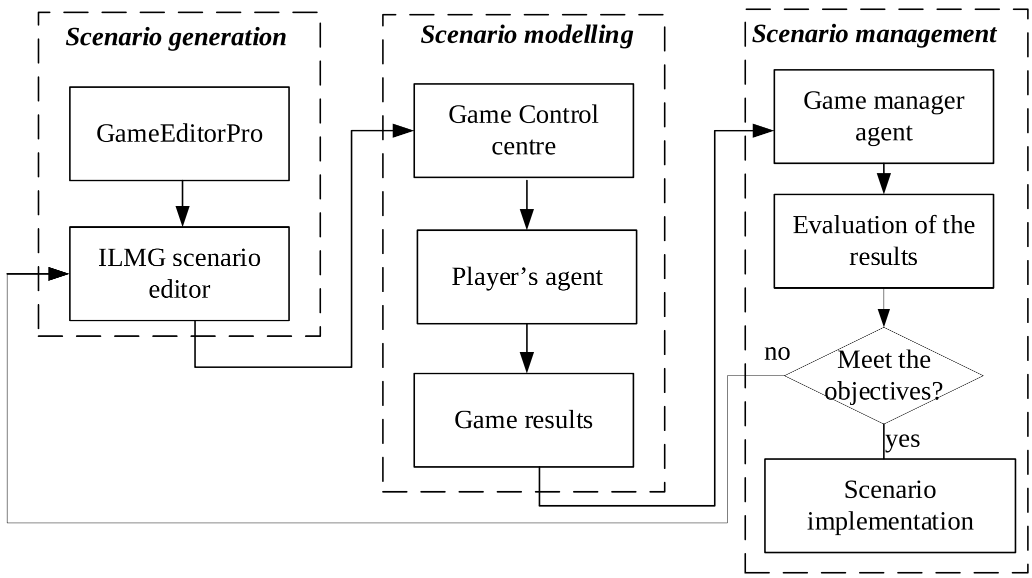


Fig. 4.5. Scenario generation, modelling and management in the ILMG game.

The general scenario management procedure developed in the dissertation (Fig. 2.2), which was implemented for ILMG game scenario generation, modelling and control (Fig. 4.5), provides an opportunity to experiment with potential game scenarios before starting the game, as well as to control its implementation.

Conclusions:

1. The proposed ILMG game agent system, which includes a game manager agent, a player agent, and a tutor agent, allows scenario generation, modelling, and management to be performed according to the general scenario management procedure described in Chapter 2.
2. The developed ILMG game scenario generation tool practically implements the game manager agent and together with the built-in player and tutor agents ensures the implementation of the proposed procedure.
3. The results described in the chapter serve as a methodological support for the use of ILMG game in RTU courses "Management Component Integration" (DMI554) and "Decision Synthesis Principles and Practice in Logistics" (DMI716). Positive feedback has been received from students during the annual survey, and the survey results are available in the ORTUS environment.

RESULTS AND CONCLUSIONS

The goal of the Thesis was achieved by fulfilling the initially defined tasks. The following results have been obtained:

- The general methods of scenario formalization, generation and modelling have been studied, which allowed developing the concept of dynamic scenarios of simulation games and an integrated approach to scenario management.
- The dynamic scenario modelling method has been analysed that allows modelling the system development dynamics within the scenario approach.
- An integrated procedure for dynamic scenario generation, modelling and management has been developed, which ensures the management of simulation games in the context of scenarios.
- An agent-based simulation game design has been studied, which provides a structural framework for the implementation of the dynamic scenario approach.
- The developed scenario modelling and analysis tools ensure the practical implementation of the integrated approach to scenario management in ECLIPS and ILMG simulation games and extend their functionality.
- The developed game scenario approach models, algorithms and tools serve as methodological support for simulation games in the field of logistics and supply chain management and have been used in the study process in several courses.
- The experimental results obtained both in research and in the study process, which have been performed over several years, approve the effectiveness of the developed scenario approach and scenario modelling and analysis tools.

Based on the results obtained, it can be concluded that effective governance of simulation game scenarios, including the use of formal methods for scenario generation, simulation and management, allows more efficient and faster game adaptation to the learning content. It also allows reusing the same game for different learning purposes. In this way, both financial and human resources can be saved by reducing the time required to learn a new game, or to develop and test a game scenario and further implement it in the study process within a course or in other types of learning activities. Thus, the first thesis that the formalization of simulation game scenarios ensures the re-use of the game infrastructure in accordance with different training objectives is confirmed.

Practically implementing a formalized scenario management approach, agent technologies were chosen to provide scenario generation, modelling and management. In the context of simulation games, agents have a number of advantages, namely, they act independently, performing activities that are largely similar to human activities, can operate in parallel with the game manager or participants, and can perform various functions within the game. The general procedure of scenario management, developed within the framework of the dissertation, describes in a structured way the stages of scenario generation, simulation and management, where agents are involved in its execution. The results of the research approved that without this procedure and agents the scenario development process would be much more time consuming, and it would be difficult to integrate the same game into different study courses.

This confirms the second thesis to be defended that the procedure of generating, modelling and managing dynamic scenarios must be introduced to improve the game management processes.

Two simulation games in the field of logistics and supply chain management – ECLIPS and ILMG – were chosen for the practical implementation of the scenario-based approach to simulation games management developed in the Thesis. The games are different in terms of their characteristics and goals, but both have the opportunity to develop different scenarios. Initially, neither ECLIPS nor ILMG had game management automation function. After agents were integrated in these games, it became possible to generate and test different scenarios that allow using them in different study courses, which have different goals and achievable results. Thus, the third thesis to be defended can be confirmed, that the implementation of the scenario-based simulation game management approach allows integrating business simulation games in different study courses.

Practical experiments with game scenarios were performed during several years, when the ECLIPS game was tested within the framework of an international project, as well as within three different courses at RTU, and the ILMG game – within three different courses at RTU, one course at Linköping University (Sweden), as well as within the business simulation competition “Business 24h”, which took place in 2007 in Latvia. More than 200 students from 15 different Latvian higher education institutions participated in this competition, a total of about 100 teams. The business simulation game competition “Business 24h” was organized by the Future Education Centre with the support of the Department of Higher Education and Science of the Ministry of Education and Science of the Republic of Latvia.

Taking into account the wide range of simulation games on the market and their use in new areas, alongside with the expansion of ICT, the wider availability of 5G networks and the spread of the Internet of Things, it can be expected that the field of simulation games will continue to grow rapidly; together with digital twin technology it opens up new possibilities for generating game scenarios that are based entirely on real company data and reflect real-life situations. In addition, according to various forecasts, revenues from the game-based learning market will increase six times between 2018 and 2024 worldwide [28]. Thus, the topic of this dissertation can be further developed in several directions, namely:

- use of digital twin technology to automate simulation game scenario generation;
- use of machine learning methods for simulation and management of simulation game scenarios, which requires proactive action of the virtual player, tutor agent and game management agent.

As a result of the Covid-19 pandemic, there is a worldwide trend towards the distance learning approach, and the issue of learners’ active involvement in the learning process remains relevant. In this regard, simulation games retain their position as a learning approach that provides a collaborative teaching mode for all parties involved, both teachers and students. There is only one condition, specifically, the game must be available electronically, which is currently fully implemented for the ILMG game, whereas the simulation model developed for the ECLIPS game does not work in interactive mode yet. Thus, the next step is to develop an electronic version of the ECLIPS game, which would allow the game participants to enter their decisions in an interactive mode.

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