A Simulation Model for Virtual Manufacturing Environments for Serious Games

Heiko Duin[1], Manuel Oliveira[2], Ali Saffarpour[3]

[1]BIBA, Hochschulring 20, D-28359 Bremen, Germany, du@biba.uni-bremen.de;

[2]Alfamicro, Alameda da Guia, N.192A, 2750 Cascais, Portugal, manuel.oliveira@alfamicro.pt

[3]EPFL, Laboratory for Computer-aided Design and Production, Lausanne, Switzerland, ali.saffarpour@epfl.ch

Abstract

The objective of a serious game is to impart some knowledge and experience for a specific subject, whilst leveraging the "fun" factor of games thereby ensuring user engagement. The European project PRIME develops such a game where the subject is "strategic decision making in global manufacturing". PRIME is a multi-user online serious game that allows the players to manage a business company that may be involved in some or all phases of a product lifecycle within the context of a global market.

This paper describes the simulation model that drives the PRIME serious game. The simulation model is responsible to provide a believable virtual business environment in which the player's business companies can interact with each other and the virtual business environment.

Keywords

Serious games, simulation, games, education in manufacturing.

1 Introduction

Manufacturing systems show the tendency to be large, complex and expensive to construct and operate. Nowadays, issues of globalisation and collaborative networking make the design and operation even more complex. Experienced management staff is often able to take the "right" strategic decisions based on tacit knowledge and experience gained over the years of making decisions leading to both good and bad outcomes. They can mentor younger colleagues what factors do influence manufacturing and what theories, methods and tools are available to analyse them. However, there is no mean to successfully mediate experience to young management staff except by letting them experiencing it. The mediation of soft skills can be done using simulation games, which resemble serious games, but without the user engagement facilitated by gaming solutions (Schwesig et al., 2005; Thoben et al., 2005).

This leads to the assumption, that such kind of games are also suitable to mediate experience, when the virtual environment provided by the game is reflecting reality in a believable way. E.g. the Interactive Trauma Trainer developed by the UK games company Blitz mediates experiences to make appropriate decisions relating to the urgent treatment of an incoming casualty (Stone, 2005).

PRIME (Providing Real Integration in Multi-disciplinary Environments) is a European project that aims to investigate how experiences in strategic manufacturing can be mediated to young management staff by using serious gaming. For that, a multi-player online game is developed to allow young business professionals to play strategic (short, mid and long-term) decision making for manufacturing enterprises and to study the corresponding results (Oliveira and Duin, 2007). Such a game needs to provide an alternate reality where business companies can interact with one another within a global business environment. This paper describes the models and rules behind the virtual world developed for the PRIME game.

2 Relation to Existing Work

Virtual manufacturing can be considered as an approach to achieve an integrated and synthetic environment to be used for concurrently simulating all of the activities involved throughout the life cycle of a product (Souza et al., 2006). The proposal is to integrate all the processes, from engineering to manufacturing, to enhance all levels of decisions and controls providing the product development, validation and manufacturing virtually before realising physically the real product. This view on virtual manufacturing is mainly concerned with the physical and operational processes of manufacturing.

In this paper, the strategic level of manufacturing is in focus, i.e. the business aspects of manufacturing play an important role. The virtual manufacturing environment described later provides a manufacturing business framework including e.g. manufacturing sites in different regions, logistics concepts and mechanisms as well as workforce, skills and consumer demand per region.

McLean et al (2005) analysed the application of video gaming technology to manufacturing applications and came to the conclusion that research, testing and training in manufacturing can benefit from it. This is in line with the serious gaming paradigm, which postulates that the application of computer games can be used to educate and train at the same time (Annetta et al., 2006).

Hoheisel presents an interaction model, which describes playing the simulation game COSIGA (the Concurrent Engineering Simulation Game, (Hoheisel, 2006)), and which also perfectly describes the case of PRIME (see Figure 1).

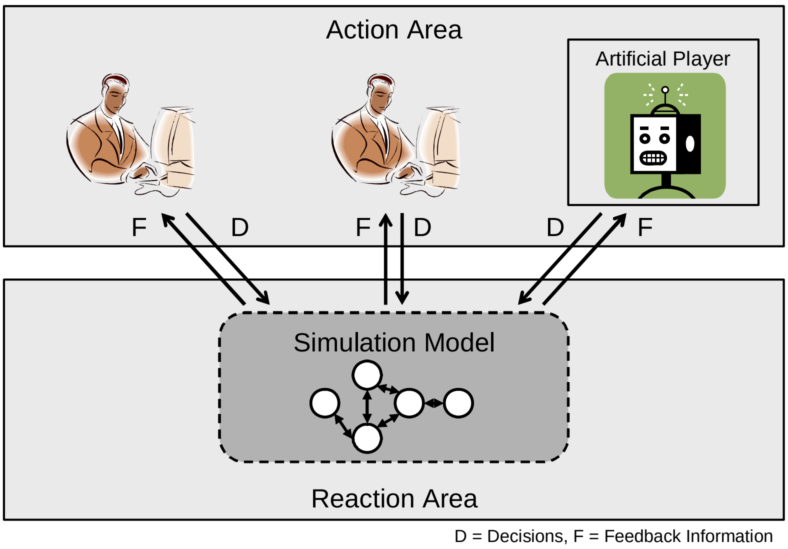

Figure 1: Interaction Model of a Multi-User Game like PRIME

The player interacts with the simulation environment by performing actions that result from decisions. These actions will drive the simulation towards a specific direction, which is displayed as feedback information to the player within the semantics of the game. In difference to the COSIGA game, the PRIME game has a much more complex simulation model. The player is not aware, what caused the feedback to look like it is; it could be caused by (1) the simulation model itself, (2) another human player or (3) an artificial player (which is a computer program, which participates in the game like a normal player, but it is driven by artificial intelligence).

In PRIME, performance feedback information is given as values for Key Performance Indicators (KPIs) that are common across multiple industries. Most of the KPIs have been taken from the ENAPS-Framework (e.g. Browne et al., 1998).

3 Research Approach

Before designing the simulation model, a literature research was carried out on gaming engines and various simulation approaches. Not surprisingly, one of the results is that existing game engines are not suited to develop business strategy games, but rather to support entertainment in the form of fast paced action games, role playing games or a derivative of military strategy games.

In PRIME, unlike the entertainment games, the reality corresponds to a Virtual Business Environment (VBE) that is supported by macroeconomic and microeconomic models. These economic models are combined with enterprise modelling and the rough modelling of manufacturing processes. The approach taken was:

- Setting up of a "Simulation Model" working group designated to develop the simulation model. Within the PRIME project, the three authors have been the main members of that working group.
- Before the group started with the actual development work, the members analysed the documents, which have been generated prior and which serve as a basis for the development work. This included the analysis of
  - PRIME User Requirements,
  - PRIME Game Play Design,
  - An initial set of KPIs defined by PRIME End-Users, and the
  - State of the art report concerning modelling and simulation.

  The game play design is based on a flow of decisions, which is considered as a part of the scope of the project and their impact on the business company and the economic environment. This flow of decisions was derived by the cognitive modelling of experienced managers or consultants with the equivalent managerial experience.
- The main work was the in-depth formulation of the simulation model. The visible part of the model are the KPIs, which are shown to the players comparable to the so-called "management flight simulators" (e.g. Hsueh et al., 2006).
- Implementation of the simulation model
- Validation of the simulation model.

During the whole project life time of PRIME, a user participative and agile approach to the development tasks has been applied as with the development of the simulation model. The list of KPIs has been presented several times to the participating end-users to validate comprehensive-ness and usefulness of the visible part of the simulator.

Implementation and validation are still in progress, but initial results are shown below. As the main objective of the simulation engine is to provide values for the KPIs, the validation of the engine will be done by comparing simulated KPI values to expected values under specific conditions. The approach to validation comprises the following steps (specific to the end-user scenarios):

- Define a set of 8-12 KPIs to be used for the simulation engine validation.
- Define the conditions for a scenario and predict the development of the KPI values (the conditions include assumptions like that the demand for a specific product remains constant, etc.). Define the interval for each selected KPI, where the simulated values must be in to be considered valid.
- Run the simulation engine.
- Compare the simulated values with the expected values and conclude on validity.

4 Results and Findings

Inspired by the Systems Dynamics approach (e.g. Forrester, 1962; 1968; Sterman, 2000), the decision taken was to use time-discrete simulation model similar to Systems Dynamics.

The Model itself can be roughly divided into general concepts, the business units and the business environment.

4.1 General Concepts of the Simulation Model

Three general concepts of the PRIME simulation model have been identified, which are the modelling of time, space and skills:

- **Time model**: The time concept is discrete, meaning that the time is divided into time steps, which represent a specific time span (e.g. a month or a quarter). The simulation clock – as the central instance of the simulation – generates monotonically the event, that a time span has passed (e.g. every five minutes, a time span of a month passes). At the end of each time span, all simulation objects are called to update their state.
- **Region model**: The world is divided into regions (representing continents), which can be further divided into sub-regions, sub-sub-regions etc. This allows a modelling of countries, states, etc. Such a hierarchical model allows the structuring of other areas (e.g. banking: European Bank, national banks and regional banks).
- **Skill model**: Population as well as operating staff for a factory have specific skill levels. Often the skill level in a specific region does not match the needed skill level for a given manufacturing technology. The skill model is a triple taking into account skill domains (e.g. product development, production), the skill itself (e.g. moulding, assembly) and the skill level on a scale from zero (low skills) to one (very good skills).

4.2 The Business Units

The concept model of the business unit is described by the concept map given in Figure 2.

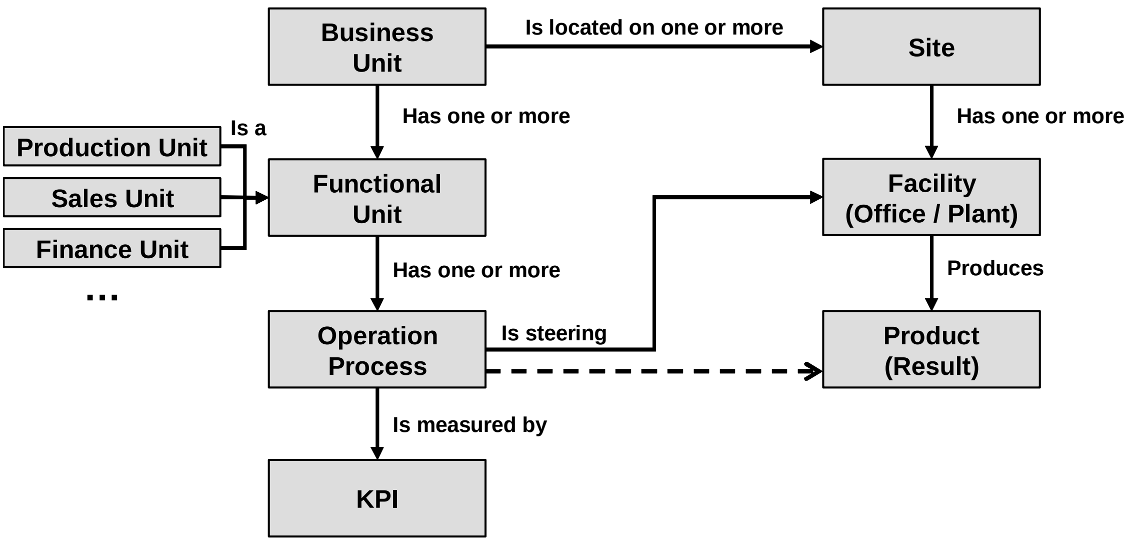

Figure 2: Concept Map of the the Business Unit

The Business Units (BUs) represent the enterprises operating in a given business environment. Each BU is sub-divided into a set of Functional Units (FUs) representing the departments of the enterprise (e.g. production, product development, finance). Each FU has some operational processes, which represent the dynamic components of the business unit. The operation processes are simulated; they actually steer the facility to produce the products. KPIs describe how the operation process is operating. A business unit can be distributed over several sites.

Further on, the BUs can be connected to suppliers and to customers, being part of a supply chain. To produce a specific amount of products, enough raw materials, energy, components as well as machine capacity is needed. The components for one business unit are the products of the supplier business units and that is the way how supply chains emerge in the PRIME virtual world. The actual amount of available components depends on the amount produced by the supplier for that specific customer and the transportation to the specific facility. For simulation purposes, this is realised using buffers (see Figure 3).

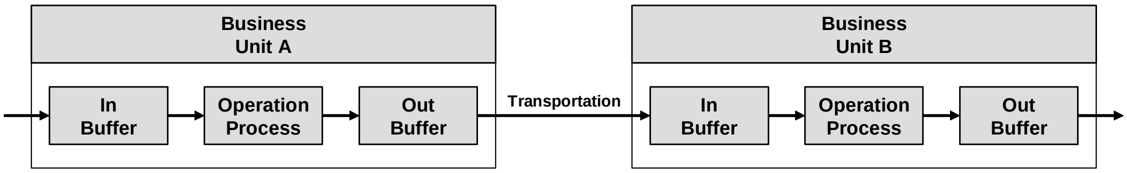

Figure 3: Supply Chain of Business Units in PRIME

4.3 The Virtual Business Environment

The VBE represents the virtual world from mainly a macro-economic perspective, where the virtual manufacturing enterprises can operate in. The model of the VBE integrates several sub-models, which cover multiple facets of a global business environment (see Figure 4). To achieve the factor of believability, the sub-models cover dimensions that are necessary to produce input to the decision processes of the player, as well as see the results of taking those decisions.

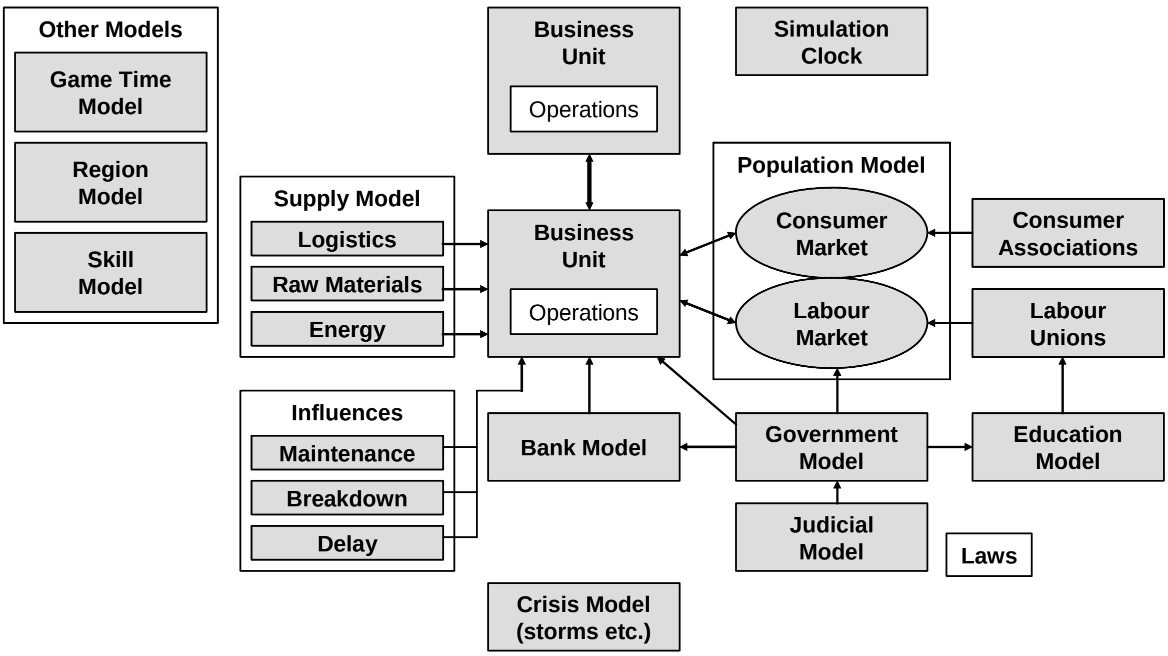

Figure 4: Overview on the PRIME Simulation Model

The most complex model is the population since it covers the workers available for hire and the consumers that define the markets. The main sub-models are:

- **Population Model**. Each region has its own instantiation of the population model, which has associated to it a labour and consumer model. The population is modelled based on a dynamic hierarchical structure where each node corresponds to a family nucleus that is decomposed into both workers and dependents. A family nucleus is based on templates (i.e.: single worker, couple where both are workers, family with one worker and three dependents), which are derived on the statistical analysis of real demographic data available. The nodes are the coarse representation of the population driven by a macro-economic labour model, thus the workers correspond to leafs of the family nodes. When a company within the VBE, either managed by a human or an artificial stakeholder, hires workers, a finer granular labour model is used that keeps track of these workers and their skills developed and their working conditions. In the case that the finer granular labour model becomes representative of the population within a region, then the data will influence the macro-economic labour model in terms of skills and working conditions (i.e.: minimal wage).

The population model also integrates consumer behaviourism, by attributing to each family a particular consumer profile that is influenced by the family dynamics. This consumer profile determines the purchasing traits of a family, which allocates a portion of the purchasing power (based on the average combined salaries) for the products represented explicitly within the VBE. The consumer behaviour profile defines how products are chosen based on a set of characteristics (i.e.: price, aesthetics, innovation, etc) that rate the importance in the decision process, which is also affected by the consumer desire that may be build up over time and be seasonally influenced (i.e.: toys gain preference in Christmas period). However, the outcome of the decision process may not result in an actual purchase, thus the purchasing power may increase until the next period. The execution period of the consumer model is configurable, but by default it is done on a monthly basis due to computational scale and the fact it that most salaries are paid monthly.

- **Education Model**. This model is used to automatically update the skill-set of the population over a long period of time according to an education policy associated to a government of a region. Since the update is gradual, there remains a need for training in case of missing skills for particular operation processes, in order to achieve maximum efficiency of the workforce.
- **Government Model**. The government model has three dimensions to it: Economy, Tax and Legislation. All three are in essence thresholds that impose constraints or provide input for other simulation models of the VBE. The Economy encompasses macro-economic factors such as unemployment, which influence the labour model of the population. The Tax delineates the government’s fiscal plan, such as income tax which affects the consumer purchase power and import taxes on goods that influence trading between different regions. The legislation determines constraints on inputs to other simulation models, such as the minimal wage.
- **Banking Model**. The banking model represents all the existent banks with their branches, each bank with their own set of financial products. Supporting the banking activity is the tracking of credit history of the companies managed by human and artificial players. Any banking branch takes into account the credit history when making decisions on their financial products for a potential client, so a player that has gone bankrupt a few times is considered high risk and susceptible to high interest rate on any loans with low ceilings on the amount available.
- **Logistics Services Model**. The logistics service is not managed by any player but by a model that reflects the limitations of a distribution network in terms of available capacity and the modes of transportation available. The model incorporates the possibility of different service providers, thus providing the grounds for supply-offer behaviour to emerge over particular routes. The model is affected by delay and quality. Although the logistic service providers are not managed by players, there is the need of a contract to establish a distribution route.
- **Innovation Model**. The innovation model is the process by which new products and technologies are introduced into the VBE. There are three modes of accessing innovation: lab research, community research and licensing. Each of the modes presents the player with a different ROI/risk that may determine if innovation plays a role in the company’s strategy for global competitiveness. Lab research involves high risk with substantial costs

to sustain research in an internal lab at one of the sites of the company or sponsor research at an external lab. The community research has medium risk and cost, but the company is no longer an early adopter and consequently may not be the first to market. The final mode of innovation presents the lowest risk and consists on licensing technology or a product from someone else, but this approach has the lowest ROI (Return on Investment). The model also portraits the possibility of reverse engineering by competitors, but this is only available to artificial stakeholders since it is deemed unethical to provide as learning option for human players.

- **Raw Materials and Energy Supply Model**. Both the Raw Materials and Energy Supply are similar models based on the supply and demand pricing model. The available resources (raw material and energy) are finite and have associated distribution costs.

4.4 Overview on the Simulation Model Components

The following figure provides an overview on the PRIME Simulation Model, showing its various areas and sub-models. The arrows between the blocks depict the basic influences between the single sub-models.

4.5 Implementation Issues

The PRIME Serious Game is implemented applying a client-server paradigm (Oliveira et al., 2006), where the server manages the state of the simulation and its integrity. This is the main task of the server; consequently the simulation model supports the use of distributed simulation nodes.

The simulation clock provides a service for objects which implement the interface “Simulatable” to register for simulation. When the clock ticks, each of the registered objects is called to perform the necessary calculations. Distributed simulatable objects use CORBA for communications.

4.6 Validation of the Simulation Model

The two diagrams shown in Figure 5 provide initial results from the simulation model running over 50 ticks. The left diagram shows the measures *Average Availability of Raw Materials* (AVRM) and *Average Availability of Energy* (AVEN) in per-cent per tick. The right diagram shows the *Throughput* (TPU) of a specific production operation process in pieces per tick.

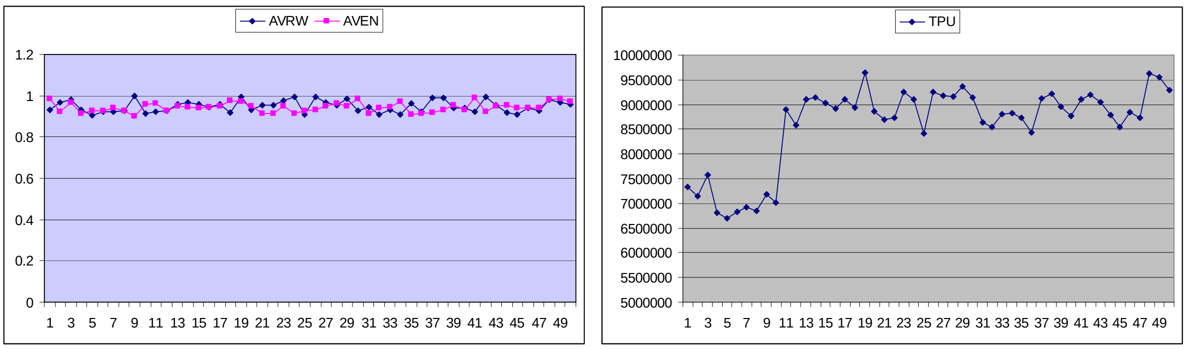

Figure 5: Initial Results from a Simulation Run

The example is based on the production of small toy building blocks. It currently does not provide the overall inter-relationships of the simulation model, but it demonstrates the adequateness of the approach. In the shown example, an increase of the site capacity by the user resulted in an increase of the throughput. Energy and raw materials are available at a high level, but stochastic fluctuations result in fluctuations in the throughput.

5 Conclusions

This paper described the simulation model behind the PRIME serious game aiming for mediating experiences in strategic decision making within the context of global manufacturing.

In comparison with the simulation and gaming architecture developed by McLean et al (2005), the PRIME model includes much more business (microeconomic) and macroeconomic elements. This is due to the strategic perspective taken to manufacturing in PRIME.

The model is still in development (implementation and validation are ongoing tasks), but the initial results presented in this paper are very promising. The authors expect to have a final evaluation of the PRIME game including the simulation components by the end of 2007.

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References

Annetta, Leonard A., Murray, Marshall R., Laird, Shelby Gull, Bohr, Staphanie C. and Park, John C.: Serious Games: Incorporating Video Games in the Classroom. In: *Educause Quarterly*. (2006) 3, pp 16-22.

Browne, Jimmie, Devlin, John, Rolstadas, Asbjorn and Anderson, Bjorn: Performance Measurement - the ENAPS Approach. In: *The International Journal of Business Transformation*. 1 (1998) 2, pp 73-84.

Forrester, Jay: *Industrial Dynamics*. The M.I.T. Press. Cambridge (Massachusetts) 1962.

Forrester, Jay: *Principles of Systems*. MIT Press. Cambridge (Massachusetts) 1968.

Hoheisel, Jens: *Konzeption und Entwicklung eines computergestützten Simulationsspiels zum Üben von Telekooperation im Anwendungsbereich der veteilten Produktentwicklung*. Dissertation, Universität Bremen 2006.

Hsueh, J. C., G. Dogan, and J. Sterman, 2006, Teaching Strategic Management with the Industry Evolution Management Flight Simulator, WWW-Seite, <http://www.systemdynamics.org/conferences/2006/proceed/papers/HSUEH351.pdf>, Accessed April 2, 2007.

McLean, C. R., S. Jain, Y. T. Lee, and F. Riddick, 2005, NISTIR 7256. A Simulation and Gaming Architecture for Manufacturing Research, Testing, and Training, WWW, <http://www.mel.nist.gov/msidlibrary/doc/nistir7256.pdf>, Accessed March 31, 2006.

Oliveira, Manuel, Andersen, Bjorn, Oliveira, Alvaro and Rolstadas, Asbjorn: Using Serious Games to Improve European Competitiveness. In: *Exploiting the Knowledge Economy: Issues, Applications and Case Studies*. Amsterdam, Berlin, Oxford, Tokyo 2006. pp 710-717.

Oliveira, Manuel and Duin, Heiko: Serious Game Development by Distributed Teams: A Case Study Based on the EU Project PRIME. In: *Proceedings of the 3rd International Conference on Web Information Systems and Technologies (WEBIST 2007)*. 2007. pp 296-303.

Schwesig, Max, Thoben, Klaus-Dieter and Eschenbächer, Jens: A Simulation Game Approach to Support Learning and Collaboration in Virtual Organisations. In: *Collaborative Networks and Their Breeding Environments - IFIP TC 5 WG 5.5 Sixth IFIP Working Conference on Virtual Enterprises, 26-28 September 2005, Valencia, Spain*. 2005. pp 547-556.

Souza, Mariella Consoni Florenzano, Sacco, Marco and Porto, Arthur Jose Vieira: Virtual Manufacturing as a Way for the Factory of the Future. In: *Journal of Intelligent Manufacturing*. 17 (2006) 6, pp 725-735.

Sterman, John: *Business Dynamics - Systems Thinking and Modeling for a Complex World*. McGraw-Hill. 2000.

Stone, Bob: Serious Gaming. In: *Defense Management Journal*. (2005) 31, pp 142-144.

Thoben, Klaus-Dieter, Baalsrud Hauge, Jannicke, Echelmeyer, Wolfgang and Morales, Ernesto: Training through Gaming: Applying a Simulation Based Business Game to Train Peaople for Collaboration in Virtual Enterprises. In: *Online Educa Berlin 2005.International Conference on Technology SUpported Learnig and Training*. 2005.