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## Education and training of manufacturing and supply chain processes using business simulation games

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### Abstract

Various studies confirm the positive outcomes of business simulation games, which can be effectively used in the education of manufacturing and supply chain processes. The use of them in education increases business knowledge, causes better understanding of business processes, improves decision making, problem-solving, and interpersonal communication skills. General business simulation games with manufacturing functions included are described briefly. Twenty-two specialized manufacturing and supply chain simulations are discussed in detail showing their features and decision-making possibilities. The study is useful for educators, trainers, and companies looking for practical learning methods. The discussion of the games gives them an opportunity to better understand available business simulations and be able to choose the appropriate one for their expected learning outcomes.

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### 1. Introduction

The use of simulation games is an innovative way of improving education [1]. While the idea of computer-based simulations is not new at all, they are still not commonly used [92]. There is a need for change. The traditional formal way of education has not changed much for a long time, but the “virtual generation” needs new learning styles [2, 3]. The informal way of learning by doing and experiencing in practice is gaining popularity in education [3, 4]. Business simulations can help this by deepening the knowledge of the participants by learning in practice [1, 5]. The digital game-based learning environments can be used in many industries [6] and they can be a connection point to previous workplace experiences [7]. Simulations are effective in teaching production management and logistics to prepare participants to solve real-life problems [10]. As most of them are played in groups, they enhance collaborative learning [11].

The topic of this paper to show how they can be used to teach learn manufacturing and supply chain processes. First, the positive effect of business simulation games is discussed through several research worldwide from the last two decades. Next, business simulations appropriate for manufacturing and supply chain education are shown. Several general business simulations are discussed briefly, with the goal to show how manufacturing is included in these games. Specialized manufacturing and supply chain simulations are discussed in more detail. These are useful for manufacturing companies to train or educate their employees.

Simulation games evolve over time. The continuously developing technology results in easier-to-use simulations in education. The current trend is to use the internet in the gameplay by developing online games [8, 9]. Simulation games do not get outdated as fast as other computer-based games. Their main idea is to show how a company operates. Commonly they do not include advanced graphics. This results in that a

well-programmed simulation model can be used for a long time. Software updates are common, moving a game to a new platform to be compatible with the newest computer operating systems. This is the reason while older games are also discussed here: they are proved to be useful and with the appropriate software updates they can remain in the education for a long time.

## 2. Using business simulations in the formal education

### 2.1. What are business simulations?

Naylor [12] defines business simulations as mathematical models describing the behavior of a complex system over a given time period using computer software. The terminology of business simulations differs in the literature. Names used include business games or simulations, management flight simulators, learning environments or laboratories, micro-worlds. [13, 14]. In this paper, the term business simulation is used synonymously to the names mentioned above similar to many other researches [15, 16]. In this paper business simulation refers to a software that simulates a company, where groups of participants have to make decisions in teamwork. Other groups of students or the computer act as competitors. The more team members exchange their ideas, the more they can learn from the simulation game [17].

### 2.2. Advantages of using business simulations

There are several examples of positive outcomes using business simulations in education [2]. This study concentrates on business and management applications in formal higher education. An e-mail survey with 1085 faculty member respondents in the USA showed that the main goal of using simulations is to give the students a decision-making experience and to integrate theories with practice [18].

A way to research the usefulness of simulation games is to ask professors with questionnaires. A survey using such a data collection method examined the reasons for using them at 35 business universities in Thailand by sending out 700 questionnaires to professors with a response rate of 23%. The researchers compared their results with a study carried out in the UK. They found that in both countries the simulation game increased the interaction of the students and provided experiential learning. [19] A similar study was done in Australia and Taiwan by sending out 4000 questionnaires. The research concluded that the three primary reasons for using simulation games were providing experimental learning; illustrating the subject taught and increasing the student's interaction and teamwork. [20] A survey on Hong Kong universities showed that simulation games are mostly useful to understand functional interrelationships, to develop general problem identification and analytical skills, and develop decision-making skills. [21]

Surveys about the experimental use of simulation games are another method to collect data on their usefulness. A pre- and posttest data of business simulation games show that they result

in significantly higher improvements in self-efficacy than case studies [22]. In a Netherlands-based survey many participants outlined the deeper learning (understanding, experiencing, interpreting) the simulation offered [23]. Canadian business and management students who participated in a web-based international business simulation game had to make decisions on production, sales, marketing, and finance. The simulation game provided an interesting and participative learning environment. Participants evaluated it as an effective learning tool [24]. A four-year survey in Finland of Production and Operations Management courses concluded that a simulation game used to help to maintain the task-orientation of the participants and understanding how different business processes elaborated, emerged, and linked together [25]. A study compared the performance of ten teams of students between the first and last run of a production and inventory control simulation. The performance of the teams was increased. The simulation helped a better understanding of the interaction between different production units [26]. A survey conducted in Taiwan stated that simulation game participants became more interested in the course and got involved more in the discussion with teammates to work on appropriate game strategies. Students even desired to play the game one more time to increase their scores [27]. A pre- and post-survey of UK, German and Italian students after four one-day simulation sessions about new product development concluded that the game gives first-rate technical and marketing knowledge, to understand customer needs. The sessions actively facilitated communication within the organization and helped the working of cross-functional project teams. The simulation developed mostly the student's skills of collecting information, negotiation skills, and problem-solving skills [28]. Research in the Republic of Dominica concluded that simulations took a more pragmatic dimension and put the participants to think about realities that occur in the business world allowing them to integrate their knowledge in a single business exercise [29]. Student attitudes and learning were measured in MBA courses in the USA before and after the courses. Results show that students developed positive attitudes to the topic of the simulation and increased knowledge as well [30]. A German survey measured the outcomes of using a manufacturing plant planner game. Participating students felt that the game was fun and the learning outcomes were reached [31].

It is also possible to directly compare the traditional education methods such as lectures, individual work, or group work to simulation games [3]. A comparison of simulation games with case studies and exercises concluded that participants preferred the simulations to case studies and other exercises [32]. A similar experience found that business simulations are better than textbooks for increasing the interest in the course and for developing decision-making and problem-solving skills [33]. A study compared simulation groups, game groups, and case study groups. The research shows that simulation groups had significantly better enjoyment and usefulness than the other methods included in the research. It also had better achievement orientation, directiveness, team leadership, impact, and influence [34]. A study surveyed over

800 students about their learning experience after playing with a management simulation game. Students claimed that the game experience was superior to the traditional lectures [35]. A similar study in Spain concluded that those students who participated in a simulation game had better conflict management handling modes than those students who were not involved in such a game [36]. A longitudinal study of 20 years in Hungary showed that students who learned with simulation games developed managerial skills more. Using an environment-conscious simulation the green attitude of the students was developed as well. Graduated students experienced higher enjoyment than undergraduate students with a game involving a lot of calculations. [37]

A Finnish study about a simulation of business dynamic in manufacturing conducted research by asking participants to share their gaming experience and team processes in essays [38]. Participants who showed interest in leadership roles felt that they had the opportunity to develop their leadership skills. Students had to write a report in similar research in Japan after playing with a simulation game. The reports included attributes, consequences and values and concluded that the most important experiences were strategic management control, strategy formation and implementation, assertive or cooperative action and communication. [39]

Simulation games can also increase student satisfaction with courses. Such an example is a research using a manufacturing and distribution simulation in Canada. The game showed an opportunity for participants to experience an integrated enterprise. Both undergraduate and graduate courses with the simulation game ranked in the first quintile of all the courses at the university. [40]

Though most researches prove the positive effects of using simulation games, there are other opinions as well. Research showed no significant difference for the outcomes of a strategic management course when using a simulation game and case studies together compared to using only case studies. However, 77% of the students who participated in the simulation game definitely recommended this teaching method. [41] Marketing students learning with the simulation game did not perform better on an examination than the control group who did not use them. This study suggests that the pedagogical value of simulations should be around the development and acquisition of decision-making skills and interpersonal communication skills instead of the acquisition of business knowledge. [42]

### 3. Manufacturing in business simulations

Most business simulation games are built around the functional areas of a firm as parallel processes, such as production, marketing, and finance [43]. There are specialized software to teach functional areas of the firm. In the following, some general-purpose business simulations with manufacturing included are discussed briefly to show how they can incorporate manufacturing processes into the more complex gameplay. Later, manufacturing and supply chain specialized simulations are described.

#### 3.1. The role of manufacturing in general business simulations

General business simulations are simulating the operation of a whole company, which can operate in any kind of industry. In most cases, this company produces some kind of products and sells them to the customers. This involves several internal processes connected to each other. Manufacturing has an important role in these processes. There are a lot of general business simulations on the market. It is not the goal of this study to discuss all of them. Some simulations representing different styles were chosen to be introduced here.

The complexity of simulation games is different. Simulations described here are ordered by increasing complexity. A CD-racks production game used at Leigh University, USA has its advantage being very simple. The production in this game needs only one raw material [44]. A similar simple game is the Hot Shot Business with the target group of teenagers [45]. GoVenture offers several simulations to suit different needs. The Any Business Simulation is a customizable platform allowing to simulate any industry [46, 47]. The Entrepreneur game simulates a small entrepreneurship company, while the World game simulates a multinational company. Each includes manufacturing, but on different levels of complexity. In the World game participants can not only sell the products to the retailers, but they can negotiate with each other to buy each other's products.

Virtonomics is a massively multiplayer online game for beginners to show the basics of economics and management [48]. Participants can decide on resource allocation, the amount of raw materials to buy, manage the inventories, decide if a product should be bought or manufactured [49].

Games can have different approaches to demonstrate and teach to participants. The Multinational Management Game (MMG) simulating PC production shows a global view of manufacturing supply chains. Participants can choose the place of production from three different main areas of the world. This allows to use of cheap Asian labor costs but makes more complexity in logistics [50, 37]. The INTOPIA simulation is very similar to the MMG as it also simulates a multinational PC manufacturing company in a similar environment with similar decision options [51, 52].

The Business Simulation Challenge is an environment-conscious 'green' simulation. Participants can choose to produce ordinary, green, or cheap products. Each of these product types has their own raw materials which differ in costs. Furthermore, the equipment used for production can be ordinary, green, or cheap as well. The demand is higher for green products but they are more expensive to produce. The evaluation system and the parameters are well-balanced so the game can be won by using ordinary or cheap production strategies as well. [43] While in most simulations, the internal structure of the calculation remains hidden [53], in the Business Simulation Challenge, it is visible to the player [43]. The Excel spreadsheet-based Green Decision Game is built around the same idea, but with the possibility to include unexpected environmental events into the gameplay.

Enterprise simulations, such as the SimVenture which is simulating a small computer assembly company, have the goal to teach young people to develop an entrepreneurship. Its focus is on product development. The software includes four main macro-groups, one of them is operations which contains production [54, 55, 46, 45, 56]. With the Enterprise Game participants can learn how to manage an enterprise, including the production function. The game puts pressure on participants as they have to make decisions in a short time and there is no way of correcting bad decisions [45].

The IBM Innov8 simulation game had three modules, one of them is the smarter supply chain. The games used scenarios to teach supply chain issues [57, 58]. The game was very popular at its time, but it is discontinued by IBM so it is not discussed in details here.

### 3.2. Manufacturing simulations

Manufacturing simulations commonly deal with production planning, inventory, and cost control. Planning the production ensures that the simulated company produces the needed products in the needed quantity. Production control is about the proper implementation of the production plan, including reacting to events [59]. Simulation can be used to validate a system [60] and to show the uncertainty of demand and processing time [61]. The interaction of production processes has effects on each other and the final output, mainly by material flows [62]. In the following, manufacturing simulations mostly cited in the literature are shown in an order of increasing complexity.

The Goldratt's Game is a very simple game of a production process. Originally the game used dices, but it was computerized in Excel. The production line in this simulation is made of two workstations. The game shows that the output of products is randomly fluctuating. [63, 64]

Participants can plan a high-voltage cable production manufacturing plant in the Factory Planner game. It is a board game originally, but it is enhanced with an application, that's why it is discussed here. Participants should design a material flow in the game, furthermore, they should react to digitalization and sustainability events. [31]

In the Littlefield Technologies game participants have to manage a factory assembling digital satellite systems. The assembly process is made in three workstations in four steps. The goal is to earn the highest amount of cash. The game has two assignments. The first one is the Capacity Management Game which teaches queuing concepts and forecasting methods. In the second assignment, the Customer Responsiveness Game participants make capacity, scheduling, inventory, and lot-sizing decisions. [65]

The RealGame simulates business processes, such as the order-delivery process. The game clock is continuous, so the material flows and other processes are visible in real-time. The instructor has the possibility to stop the internal clock of the software. The game can be customized, but with the original parameters, it simulates a cattle feed manufacturing company, an automotive glass manufacturer or a pharmaceutical analysis

instrument manufacturer company. Participants have to make decisions on raw material purchasing, production planning, and deliveries. The game has three different speed options. The middle one is optimal to get a holistic view of production, but the production can be best optimized in the slowest gameplay setting. When improving the speed of the game, some decisions become automatic not to interfere with the gameplay [53, 38].

In the Trading Agent Competition game, participants have to manage a manufacturing plant that assembles personal computers from components. The maximum capacity of the manufacturing plant is limited. The participants should offer prices for the component suppliers, who sell them to companies offering the best prices. The overall goal is to reach the highest market share. Participants should avoid high inventories and late deliveries. [66, 67] Choosing the right suppliers can cause significant differences in costs and quality [68].

Table 1. Summary of manufacturing simulation games

Simulation game	Description	Decision scope
Factory Planner	Plan a manufacturing plant for high-voltage cable production	Planning material flows, monitoring, ramp-up support, reacting to events
Goldratt's Game	Simple production process	Material use
Littlefield Technologies	Manufacturing of digital satellite systems	Equipment utilization, queuing, scheduling, forecasting
RealGame	Manufacturing cattle feed, automotive glass or pharmaceutical analysis instruments	Raw material purchasing, production planning, deliveries in real time
SAP ERPsim	Manufacturing company in a competitive market	Inventories, material ordering, production, downstream logistics
Trading Agent Competition	Personal computer assembly plant	Purchasing, bidding on prices, assembling products, inventories

In the SAP ERPsim Game there are different rounds which are about inventories and production. In the first round, participants get a fixed inventory with the goal to maximize their profit. In the second and third rounds manufacturing plays a crucial role by using the appropriate raw materials and planning the production [30]. Participants have to develop logistics operations by serving multiple markets from a central distribution center as downstream operations. Through upstream operations, participants should provide a proper incoming raw material inventory [69]. This simulation game received the best use of technology award by an instructor's faculty [40].

The summary of manufacturing simulation games can be seen in Table 1.

### 3.3. Supply chain simulations

Supply chains can be defined from a process view by integrating upstream and downstream operations by material,

cash and information flow [70]. A manager of a supply chain should behave similarly to an “orchestra conductor”, aligning the processes with each other. The interactions in the supply chain are very complex: each decision has an effect on other decisions and processes. [71] A clear advantage of using supply chain simulations is that different scenarios can be set up by changing the parameters in the simulation [72]. The most cited supply chain simulation games from the literature are discussed below, in an order of increasing complexity of their model.

Teaching supply chain management should include practice, which is challenging in education [73, 74]. An early and well-known simulation game is the Beer Game developed at MIT and played originally as a non-computerized board game. Later it was digitalized and now it is a computer-based simulation game. The game has four parts: factory, distributor, wholesaler, and retailer. Orders are going through the process from the retailer to the factory. Order processing and delays are built into the game to make it more real. The goal is to minimize the total inventory and backorder costs. The game shows that the major problems in supply chain management are the high cost from the fluctuation of inventory levels, backorders, and the irrational behavior of the management. The Bullwhip effect, centralization and the lead time effects are also taught by this simulation. [75] The game also teaches that most issues are coming from a wrongly planned system and not from individual mistakes which is an important phenomenon of quality management [76, 77]. The success of the Beer Game in education induced newer, modified versions of the game. One of them, the Columbia Beer Game uses stochastic customer demand, different information delay of players, and decreasing inventory holding costs while moving upstream the supply chain [78]. The Beer Game 2.0 includes two wholesalers to make the game more complex [79]. The Hulia Game is an online version of the Beer Game [80]. The Internet Based Supply Chain Challenge Simulation Game (ISCS) is an enhanced digital version of the original Beer Game which includes a management information system to support decision making [81].

In the LOGI-Game simulation game, participants manage a company that is part of a distribution network. The market can be a durable or consumer product market, which is decidable at the beginning of the game by the instructor. Companies can trade with each other. The logic of the game is very similar to the Beer Game. There are four parts: producers, main wholesalers, retailers, and shops. Participants can simulate the first three of these and they can control their sales, purchase, and inventories. Unexpected events can happen during the game, like strikes, international currency fluctuations, receiving export orders. The game is based on Excel, which makes it very easy to modify or update. [82]

The Supply Chain Game is an online game that consists of simulated and human players. While the customers and suppliers are simulated, retailers and manufacturers are human participants in the game. The game environment is a spot market where buyers can contact several sellers and make decisions on acquiring the products. [83, 84]

Different information-flow scenarios are used by the SBELP simulation, where the player can have zero or full information on the market based on the settings of the game [84]. SBELP simulates a supply chain where the player is an electronic equipment manufacturer. While there are several functions built into the simulation, such as inventories and backorders, the main goal of the game is to show the Bullwhip effect [85] to which the changes of demand can lead [86]. The success of the player is judged by the total cost that occurred in the supply chain, which can be done by minimizing the inventory and the backorder costs, contradictory to each other. [85]

Similar to the SBELP simulation, the Excel spreadsheet-based RSS-POD Supply Chain Management Game also shows the outcome of different information levels. The player is in the role of an inventory manager of medical countermeasures at a receipt, storing, and staging facility. Items should be allocated to multiple places of use. The goal is to minimize the waiting of the customers, who are the patients in this case. [87] A model can be drawn of control charts by simulating a supply chain in the pharmaceutical industry [88].

The Global Supply Chain Management Simulation V2 simulates a supply chain where players have to deliver two different mobile phones. New mobile phone features can be added, and the demand should be estimated. Geographically different suppliers can be chosen. A flexible supply chain should solve the problem of unexpected changes in demand. [89]

The Automobile Supply Chain Management Game (AUSUM) is an online simulation game. Participants have to fulfill orders in time with correct order quantities and efficient costs. They can choose the logistic providers. The game is based on Toyota’s North American Supply Chain scaled to 1:50. [90, 84]

The SIMPLE (Simulation of Production and Logistics Environment) is an online simulation game about decision making. It uses an integrated circuit chip as the product of the simulated production system. The game has three flows: material, cash, and information. As the materials flow in one direction, the cash flows reverse direction. Information can come from the system, another participant in the game or from the decision of the player. The game has four main decision elements: make-to-order production planning, capacity management, inventory management, and outsourcing. Providing the outsourcing opportunity of production is a unique feature, as outsourcing possibilities are rare in simulation games. In the SIMPLE simulation production can be outsourced at a fixed cost for any of the players. Outsourcing capacity is unlimited in the game. [27]

The IndustrySim game takes an engineering approach. In this simulation manufacturing copes not only with material flows, but also with engineering and chemistry models, such as energy flows and chemical reactions. The game allows participants to build virtual manufacturing plants. [91].

The summary of manufacturing simulation games can be seen in Table 2.

Table 2. Summary of supply chain simulation games

Simulation game	Description	Decision scope
Automobile Supply Chain Management (AUSUM)	Supply chain of automobile manufacturer	Supply chain network design and management, inventories, logistics
Beer Game and its improved versions	Beer production and distribution	Order processing as a factory, distributor, wholesaler or retailer
Global Supply Chain Management Simulation V2	Supply chain of mobile phones	Forecasting, managing suppliers
IndustrySim	Build virtual manufacturing plants	Material and energy flows
LOGI-Game	Company in a distribution network	Sales, purchase, inventories
RSS-POD	Supply Chain Management Game	Inventory manager of medical countermeasures
SBELP	Manufacturer of electronic equipment	Inventory, backorder, supply chain cost
SIMPLE	Manufacturer of integrated circuit chips	Production, inventory, outsourcing
Supply Chain Game	Manufacturers or retailers in a distribution network	Production planning, scheduling, purchase, inventory control

#### 4. Conclusions

The use of business simulations is an efficient way to make manufacturing and supply chain education more practical. Various studies examined the positive effects of business simulation games in many countries of the world. Most of the studies used questionnaires before and/or after using the simulation game. Some of them required writing essays by the participants. The studies confirm the positive effect of business simulations, increasing business knowledge, a better understanding of business processes, improving decision making, problem-solving and interpersonal communication skills. An overall conclusion can be drawn that simulations can be mostly useful in acquiring new skills. Therefore, they can be used for single courses or as additional practical sessions for theoretical courses.

Most of the general business simulations include manufacturing processes as the simulated company sells some kind of product that needs to be produced. Several of these simulations were shown in an order of increasing complexity. Some of these simulations are specialized on something, like multinational or environment-friendly operations. Most of the simulations have some unique features. Some can include unplanned events to the gameplay, others provide time pressure on the participants. There are specialized manufacturing and supply chain simulations. The goal of these simulations is to show the interconnecting processes and decision dilemmas in these processes. Three parallel flows can be identified in supply chain simulations: the flow of materials, cash, and information. Simulations highlights wrongly organized processes and

systems and incorrect individual decisions. They also show that the major problems in supply chain management are the high costs arising from the fluctuation of demand, high inventory costs, delayed deliveries, or lost sales because of the inappropriate level of production or missing raw materials.

When considering the use of simulation games in a course, the educator should decide if any unique features of the game can be useful to reach the learning outcomes. As the industry of simulations are different, the game should be chosen on the topic of the program it is used. More complex simulations can be better used in masters programs or specialized training, while the simpler ones in bachelor programs. The order of the discussion in this paper going from the simpler to the more complex models is helping in this decision.

The implementation technology of the software is an important criterion. Choosing online or Excel-based simulations decreases the issues with compatibility in long term, which is often caused by operation systems updates. Another advantage is that the participants can use a mixture of different systems, such as PC and Mac computers.

The limitation of the study is that it does not include all business simulation games. The games described were chosen to show different approaches of games including manufacturing. The specialized manufacturing and supply chain simulation games were chosen by the amount of citing to them in the literature. Non-computer business simulations, such as board games were not included as they are out of the topic of this study and can be a subject of future research.

#### CRedit author statement

Roland Schmuck: Conceptualization, Methodology, Formal analysis, Investigation, Resources, Data Curation, Writing-Original draft, Writing- Review & editing, Visualization, Supervision, Project administration.

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