BUILDING DYNAMIC MODELS OF TECHNICAL-ECONOMIC SYSTEMS USING CAUSAL DIAGRAMS

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Abstract

Serious games are one of the most efficient and productive methods of education. They allow to work out practical skills without practice. These are usually interactive computer-controlled business games. Selected fragments of the real economic system are modelled in these games. Environmental computer-aided realization of such games essentially consists of two parts: subsystem implementing the interaction with the participants of the game and simulator, which determine the consequences of decisions. The simulator solves differential and algebraic equations that represent a model of a fragment of reality. This model is created by the mathematisation of relationships between variables. Cause-and-effect (causal) diagrams can be used to model relationships.

The article presents the methodology of dynamic models of technical-economic systems construction using the method of System Dynamics. In this paper its also given the essence of causal diagrams and examples of their practical use a building the structure of mathematical models which is used in serious business games.

Examples of the models come from following developed simulation games for managerial decision and logistics training: SERVICES – Market and Competitors Analysis, LOGCHAIN – Supply Chain Processes and FIRM – IT Firm on Competitive Market. These games are used to train logistics experts-practitioners during postgraduate studies and computer science students as part of raising their level of entrepreneurship and preparing for their entry into the job market. The games were developed as a result of educational project "A new quality of education in the MCSU" financed by European Social Fund.

Keywords: serious games, business decisions games, causal diagrams.

1 INTRODUCTION

Serious games or applied games are the games category which include hardware simulators, educational video games, organisational and simulation decisions computer games [1]. The concept “serious” is associated with the area of using these games [2].

One of the serious games type – simulation decision business games (SDBG) [2], [3], [4] – relies on the organisation of work groups of game participants with a computer model. This model simulates a fragment of reality significant in terms of objectives of the game and game scenario. The games’ participants play roles defined in the scenario. Games can be competitive or not. In the competitive games two or more player’s teams have the same goal. These goals are opposed (e.g. profit maximization, enterprise development, market control, task execution at minimum cost, etc.). SDBGs are the experiment with a common simulation model. This experiment is performed by game participants. The participants play role of managers described in the game scenario. They generate a sequence of decisions and analyse their results. They should have a strategy of play. Usually participants undertake decisions independently and secretly (especially in competitive games). The game arbiter supervises the game. The supervising means organising, explaining, determining etc. It is possible to use simulation games without any supervision, but with less efficiency [5].

The key point of serious games is a game scenario. It should well describe the situation, principles, problems and aims of it resolving. A scenario should determinate the criterion of a results evaluation and the time horizon of the game.

Typical simulation decision business game organisation is presented in the Fig. 1.

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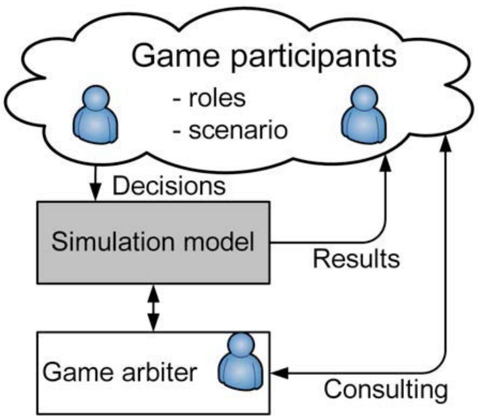


Figure 1. Typical organisation of simulation game [7].

A variety of studies point to the high efficiency of use of serious games in different areas of business education [7], [8], [9]. [10], [11], [12], [13], [14], [15].

2 THE TYPICAL STRUCTURE AND ELEMENTS OF A BUSINESS GAME

SDBG typically use technical means of computing: software and computer network. The typical schema of business game realization components is presented in the Fig. 2.

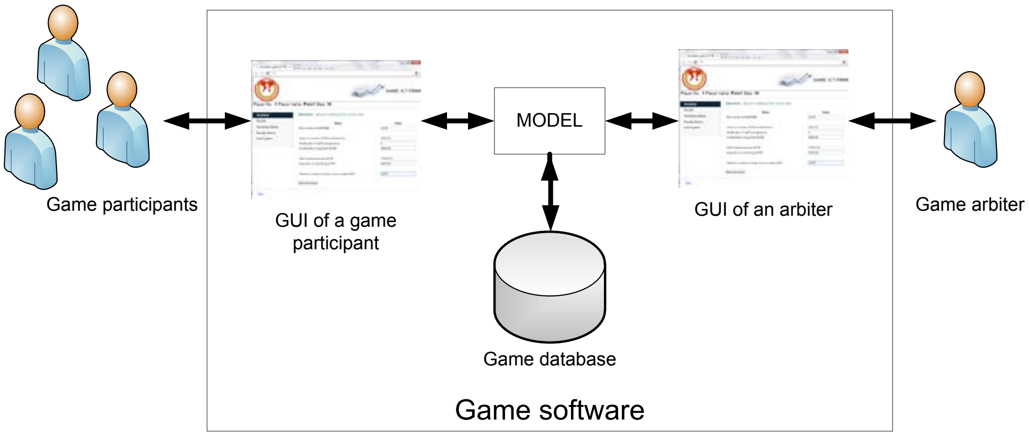


Figure 2. Typical game software architecture.

A key element of any SDBG is a simulation model of the game's environment. This model usually builds using System Dynamics methods [16], [17], [18], [19]. The model included in SDBG map out a certain business scenario. Usually the SDBG's model is dynamic.

The game database (Fig. 2) stores the values of all variables describing the state of the game at any point in time.

User interfaces, usually graphical (GUI), enable communication users of the game (participants and an arbitrator) between the model of the game and each other (if the game scenario foreseen).

3 CAUSAL DIAGRAMS AS A TOOL TO BUILD DYNAMIC SIMULATION MODELS OF TECHNICAL-ECONOMIC SYSTEMS

Construction of system simulation models requires comprehensive research skills, i.e. it is an interdisciplinary art. In the modeling and simulation of systems it requires knowledge and skills in the following areas (disciplines) [20]:

- system analysis,

- control theory,
- systems simulation,
- numerical methods,
- statistics,
- a specific field depended on the modelling system.

Typical stages of building simulation models are as follows:

- verbal model – textual description of the game (it is usually a part of the scenario);
- graphic model of the dynamics of the system - a graphical representation of the relationships between model variables (causal diagrams);
- mathematical model – a system of differential or integral equations binding model variables;
- computer model – an implementation of the software using different development environments.

During the construction of the models the following techniques are used:

- dictionaries (lists) of variables (tables describing the model variables, their meaning and parameters);
- diagrams of the structure of the simulation model;
- causal diagrams (or Causal Loop Diagrams, CLD) or Stock and Flow Diagram (SFD) [21];
- algebraic equations for the model variables, such as:

$$TAX = 0.23 * INCOME \tag{1}$$

- incremental equations for the variables of level type (*t* – means the point in time), such as:

$$LEVEL_t = LEVEL_{t-1} + (INCOME_t - OUTCOME_t) \tag{2}$$

Incremental equations very well correspond to the economic processes. Processes occurring in business have cyclic nature, not continuous. Whereby these cycles have a different length: from the day to a year.

Causal Loop Diagram presents causal relationships between model elements. These graphs are made using a specific notation (Tab. 1).

A simple example of a causal diagram is presented in Fig. 3. In this figure, the mutual influence of two variables (BIRTHS and POPULATION) is mapped.

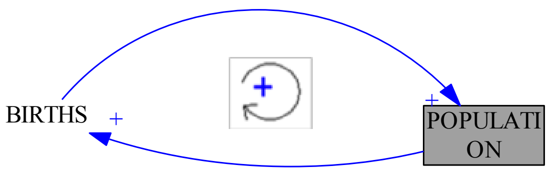
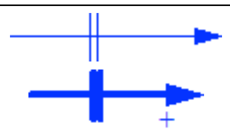


Figure 3. Causal diagram of simple relationships between two values.

All relationships in Fig. 3 are positive, i.e. increases the value of one variable increases the value of the second. But nature (function) of this increase on the causal diagrams is not presented. It is the task of the stage mathematisation model. The structure of relationships between variables in the Fig. 3 is a positive feedback loop.

Table 1. Graphic elements on causal diagrams.

Graphic element	Meaning	Comments
SALARY	Decision variable	Exogenous
GROSS PROFIT	Endogenous variable	In that diagram (model)
TAX RATE	Exogenous variable	Constant or variable
<STAFF LEVEL>	The variable from another diagram (model)	
CASH	Endogenous variable – type level	Accumulating variable
	Dependence of cause-and-effect	Scalar dependence
	Dependence of cause-and-effect	Vector dependence
	Dependence of cause-and-effect with delay	Scalar or vector
+ -	Dependence impact	+ - positive (the growth of the cause increases the effect) - - negative (the growth of the cause decreases the effect)

4 SIMULATION GAMES FOR MANAGERIAL DECISION AND LOGISTICS TRAINING – SHORT DESCRIPTIONS

Economic Department of the Maria Curie-Skłodowska University (MCSU) in Lublin, Poland, has received the grant for realisation of the project called “A new quality of education in the MCSU” [22]. The project was granted for partially financing by the European Union under the European Social Fund, Priority IV, Activity 4.3., “The strengthening of the educational capacity of universities in key areas in the context of Europa 2020 Strategy objectives”. The main aim of this project is to launch postgraduate studies titled “Logistic Process Management” using the active learning and experience-based methods. Simulation games have been chosen as a one of those methods.

The logistics simulation games were developed under this project using the web technology. These are as following:

SERVICES – Market and Competitors Analysis,

LOGCHAIN – Supply Chain Processes,

FIRM – IT Firm on Competitive Market.

The game SERVICES simulates a small service enterprise existing on a competitive and closed local market. The group of game participants should manage of their enterprise. They take a management board role of a construction company providing a kind of building services. The main problem in this game is a high periodicity of market demand, what characterizes the construction industry.

The game LOGCHAIN simulates the cooperation between the manufacturer of LCD TVs and its wholesalers, supplying their products on separated markets. Each game team owns a warehouse. The manufacturer has three production factories situated in different places. Factories' activities are simulated in accordance to the algorithms of its ERP (Enterprise Resource Planning) operation system. Game teams should analyse supply chain processes, their spatial, time and cost determinants.

The game FIRM simulates well defined situation: on a purely competitive market there are beginning to function IT companies providing the same kind of services. At the beginning each company has the same capabilities. Development of the company depends on management decisions made by game teams. The game teams have equal opportunities: the same initial state, equal rights in the game and the same opportunities in obtaining information about the dependencies and behaviour of the system: market-company. The FIRM game is very similar to the game SERVICES.

5 EXAMPLES OF CAUSAL DIAGRAMS MODELS USED IN PRESENTED SIMULATION GAMES

5.1 The model of the common market

In games with the common market (SERVICES and FIRM) the model of the market is important. This model allows to determine the volume of orders (ORDERS) addressed by the market to any company – Fig. 4. The dictionary of variables for model shown in Figure 4 z Fig. 4 is presented in Tab. 2.

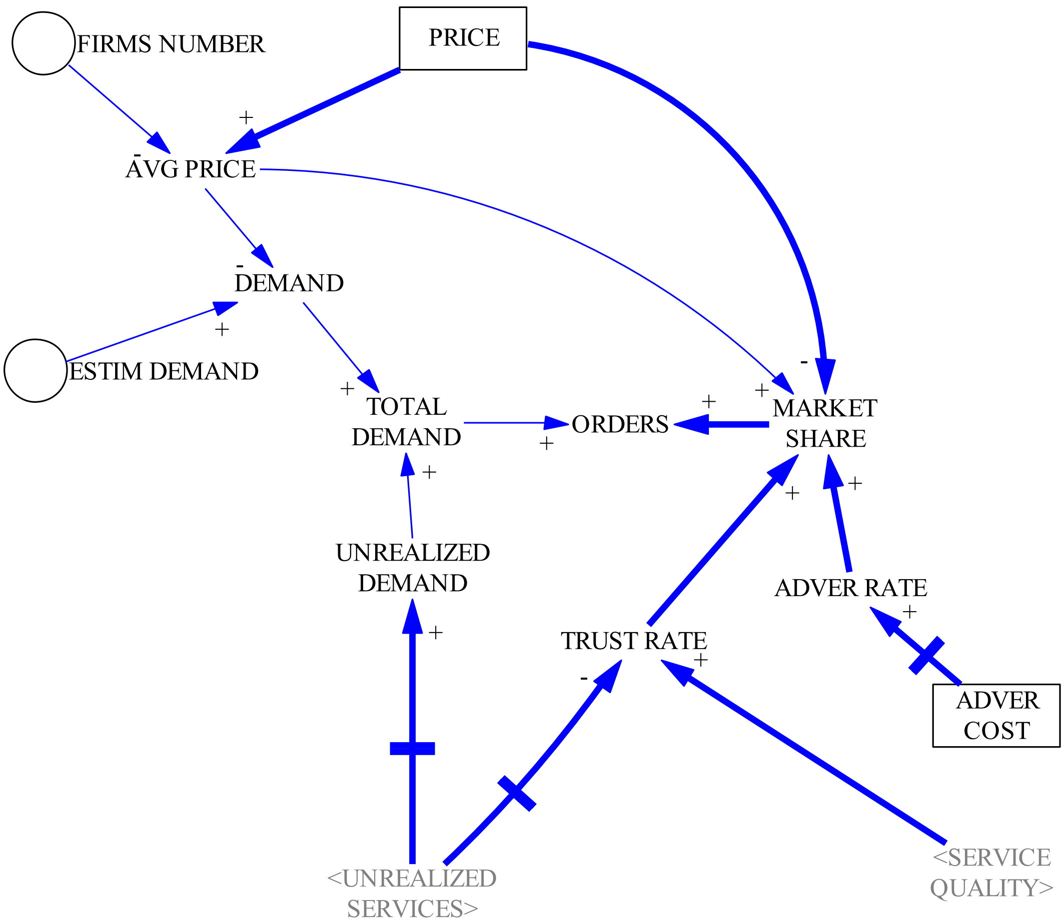


Figure 4. The model of the market.

Table 2. Variables of the market model and their meanings.

Variable name	Type of variable (*)	Model element description
PRICE	D	The asking price of services in this month
ADVER COST	D	The advertizing cost
UNREALIZED SERVICES	X	The volume of services did NOT provide in this month
SERVICE QUALITY	X	The level of service quality provided by a firm
FIRMS NUMBER	P	Number of firms on the market
DEMAND	E	Market demand on services in this month
ESTIM DEMAND	P	Estimated total market demand on services
UNREALIZED DEMAND	E	Unrealized market demand in previous month
TOTAL DEMAND	E	Total market demand with unrealized demand
ORDERS	E	Orders placed from the market to the firm
AVG PRICE	E	Average asking price of services on market
MARKET SHARE	E	Market share of a firm
ADVER RATE	E	Market advertising rate of a firm
TRUST RATE	E	Market trust rate of a firm

(*) D – decisions, P – parameters, E – endogenous variables, X – exogenous variables.

5.2 A company's cash flow dynamic model

A company's cash flow model is one of the most important model in each of the developed game. It allows to calculate the cash (CASH) on the basis of game participants' decisions and their results. The developed model is shown in the Fig. 5. The set of variables and their types and meaning is provided in the Tab. 3.

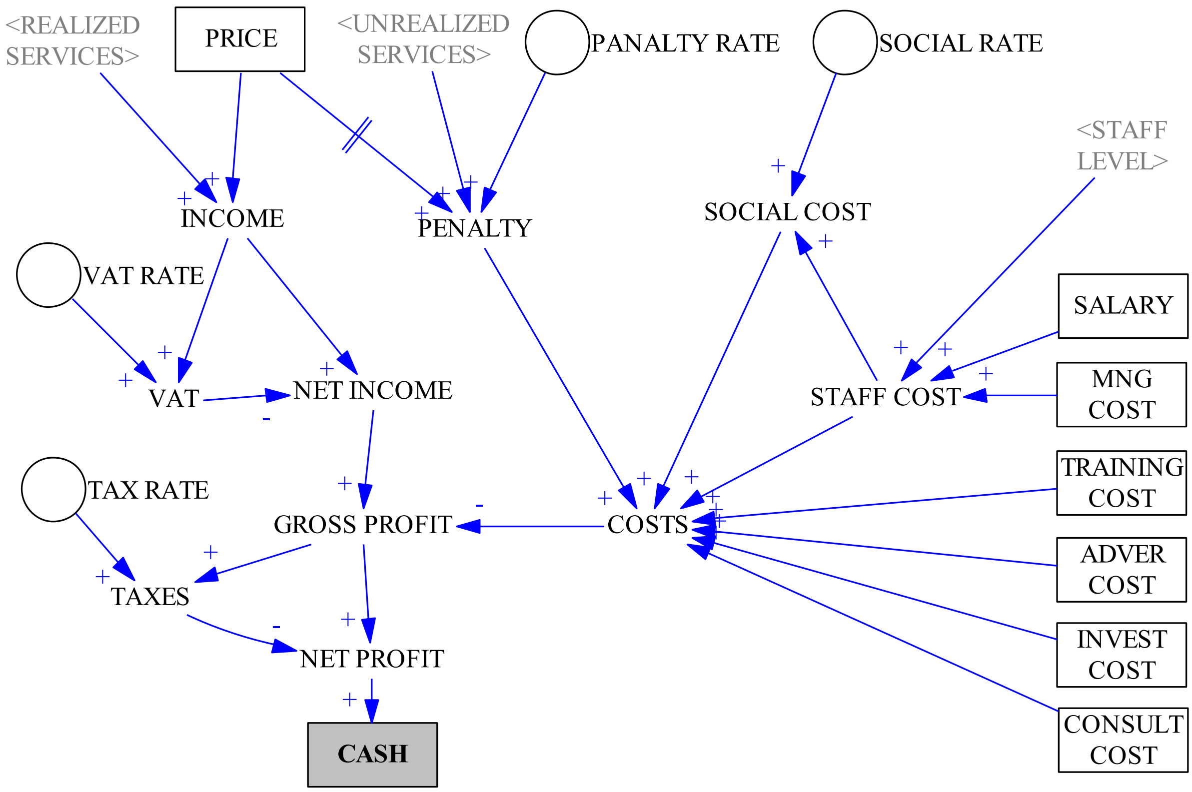


Figure 5. The model of a company's cash flow.

Table 3. Variables of the cash flow model and their meanings.

Model variable name	Type of variable (*)	Model element description
REALIZED SERVICES	X	The volume of services provided in the month
PRICE	D	The asking price of services in this month
UNREALIZED SERVICES	X	The volume of services did NOT provide in this month
SOCIAL RATE	P	The rate of social security charges
SALARY	D	The salary of employees
STAFF LEVEL	X	The level of employment in the company
MNG COST	D	The management staff cost
INCOME	E	Income in this month
PANALTY RATE	P	Penalty rate (in percent of the price) for services did not provide
PENALTY	E	Financial penalty for failure services
SOCIAL COST	E	Social security charges in this month
STAFF COST	E	Enterprise staff salary costs in this month
VAT RATE	P	VAT rate
VAT	E	VAT costs in this month
NET INCOME	E	The net income in this month
COSTS	E	The total costs in this month
TRAINING COST	D	The staff training cost
ADVER COST	D	The advertizing cost
INVEST COST	D	The investment cost
CONSULT COST	D	The cost of consultations
TAX RATE	P	The profit tax rate
GROSS PROFIT	E	The gross profit in this month
TAXES	E	The taxes paid in this month
NET PROFIT	E	The net profit in this month
CASH	E	Cash (working capital)

(*) D – decisions, P – parameters, E – endogenous variables, X – exogenous variables.

6 CONCLUSIONS

The developed simulation decision games were described in the article. These games are used for trainings of managerial decision making and logistics processes. These are following games: SERVICES – Market and Competitors Analysis, LOGCHAIN – Supply Chain Processes and FIRM – IT Firm on Competitive Market.

The typical process of developing of games includes the construction of a simulation model. A causal diagram is a one of the tools useful to do it. Models of two very important sub-systems are presented in detail to show how causal diagrams can be used.

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