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SIMULATION MODEL OF SUPPLY NETWORKS DEVELOPMENT

Petr Fiala[(a)], Martina Kuncová[(b)]

[(a),(b)]College of Polytechnics Jihlava

[(a)]pfiala@vse.cz, [(b)]kuncova@vspj.cz

ABSTRACT
The paper is dedicated to network development in the network economy. The current economy needs to look not only at networks with only dynamic flows and with a fixed structure, but as a dynamic system its structure evolves and changes. Structure and behaviour dynamics of network systems can be modelled as complex adaptive systems and use agent-oriented simulation to demonstrate origin, perturbation effects, and sensitivity with regard to initial conditions. Survival of firms is associated with the value of so-called fitness function. Firms whose fitness value falls below a certain threshold will be extinguished. In this way, it is possible to partially model network growth. A simulation model in SIMUL8 is proposed.

Keywords: network economy, supply networks, simulation, dynamics

1. INTRODUCTION

Dynamic models for the description and analysis of economic systems play a crucial role (Fiala, 2009, 2016). Growth dynamics and network development can be modelled by expanding the Utterback industrial growth model (Utterback, Suarez, 1993, Utterback 1994) and using the concept of behavioural patterns to form networks. It can be assumed that the pattern of supply networks will be similar to the bell curve proposed by Utterback. Simulation model divides a complex adaptive network into two basic parts:

- the supply network environment,
- networked firms.

Firms are represented by nodes in the network. The nodes operate on the basis of simple decision-making rules, with an effort to meet the environmental demand. As new industries emerge, supply networks begin to develop, new businesses can enter the market. Some firms are successful and build relationships with others, and there is growth. Some firms are unsuccessful and disappear, either because of local conditions or because they cannot become part of a viable supply network. In time, supply networks can grow into relatively stable structures, based on the interactive effects of local decision rules and environmental factors. CAESAR (Pathak, Dilts, Biswas, 2003; Pathak, Dilts, 2004) and its advanced Complex Adaptive Supply Network simulator (CAS-SIM) version have been designed to monitor supply network developments, including patterns of emergencies and extinctions.

The aim of the paper is to describe a possibility of the conceptual and simulation models creation based on the idea of the Utterback model. The simulation software SIMUL8 is used. Chapter 2 describes the main facts about the Utterback model. In chapter 3 the conceptual model of a network using arcs and nodes is created. Afterwards the architecture and algorithm that can be used in any simulation software to model the behaviour of the supply network are described (chapter 4 and 5). Finally, the SIMUL8 software is used to demonstrate the possibility to model the supply network similar to the Utterback ideas.

2. UTTERBACK MODEL

As new industries emerge, supply networks grow, creating new relationships between firms that cooperate to meet demand. Utterback industrial growth model (Utterback 1994) takes into account that at the beginning are low barriers to entry for firms in the industry and is not clearly defined market structure. At this stage, many firms want to enter the industry by becoming leaders. In the next stage, there is a desire to create a clearly defined market structure with a focus of firms on economies of scale and network externalities. Not all firms are successful, those unsuccessful are pushed out of the market and over time the number of firms is decreasing. The course of the individual phases of the industrial growth cycle creates a bell curve. The Utterback model is used as a premise that is verified by practice but can be modified in the simulation process.

Utterback (1994) also assumes that companies learn to play specialized roles over time. At the beginning of the development of the sector, all companies are trying to play a versatile role, then there remains less and the others either expire or specialize. The Utterback model takes into account the growth of the industry only with regard to the number of entering and exiting firms.

Another dimension that should be taken into account is the size of companies. In one possible scenario, with market growth over time, there is a different growth in firms. Some companies are significantly expanding capacity, while others weaken. An alternative scenario may be the fact that no companies become dominant and the market is relatively evenly distributed among participating firms. In a comprehensive adaptive supply network model, two aspects are considered:

- number of firms,
- size of firms.

3. CONCEPTUAL MODEL

The model (Figure 1) is based on a supply network as a system consisting of an environment (market) in which companies (nodes - N) create interactions (relations - R) based on simple rules of conduct to meet global demand. Stochastic environmental parameters, describing market conditions and demand, a node-based decision-making scheme, so-called fitness functions modelling the strength of companies, all influence the dynamics of structure and behaviour of the developing supply network.

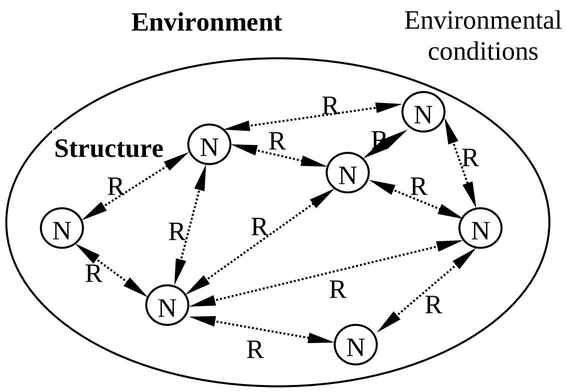

Figure 1: Conceptual model

Complex Adaptive System (CAS) is well suited for modelling systems with structure and behaviour dynamics. The CAS is characterized by three main components:

- environment,
- internal mechanisms,
- coevolution.

Firms (nodes) are emerging, exist and disappear in the environment. The environment is characterized by two main groups of conditions:

- operating conditions,
- setting up the market structure.

Operating conditions specify demand and time and cost information. Market structure settings specify the regulation, policies, and trading rules applied in the system. The environment also sets the fitness threshold, which is the minimum level of fitness required to survive the node in the environment.

Internal mechanisms concern nodes, rules, relations, and decisions in networks. The nodes represent the firms (agents) in the supply network. Nodes focus on achieving local goals, with each node having a set of possible strategies to achieve them. The rules allow the implementation of these strategies to achieve goals while respecting the constraints given by the environment and the node itself.

Nodes make two basic types of decisions:

- with whom to cooperate,
- strategic decisions.

Choosing a node with which to cooperate and create relationships is also partly affected by market rules. Strategic decisions include capacity determination, product prices, outsourcing levels, etc.

Coevolution describes changes in states and the formation of quasi-equilibrium in the system. The results of implementing node strategies in a specific environment generate coevolutionary network structures. Coevolution is the result of interaction between the environment in which the supply network exists and the internal mechanisms used by the nodes in the network. The coevolutionary process will result in different firms' growth relative to the values of built-in fitness functions.

4. SIMULATION MODEL ARCHITECTURE

To understand the growth and development of dynamics, it is necessary to monitor the time-dependent behaviour of the model. Simulation is a frequently used methodology for analysing the time-varying properties of a system. A multi-paradigmatic architecture can be used to create a simulator (Figure 2). In multi-paradigm architecture, some of the model's components fit the discrete-time modelling paradigm, such as Environment, while others fit the discrete-event modelling paradigm, such as individual node behaviour. Environment and Evaluator, which acts as an environment controller, are clustered models that interact with nodes in the system.

Evaluator acts as a coordinator of all nodes and communicates with them through the protocol, launches nodes and sends them information about demand and other messages. After a certain number of demand cycles, he evaluates the nodes by the value of the fitness function and the failed nodes disappear. Nodes are elementary models of discrete events owned and coordinated by Evaluator. Nodes respond to seven basic events:

- break,
- message
- flag,
- demand,
- bid request,
- time

- fitness update.

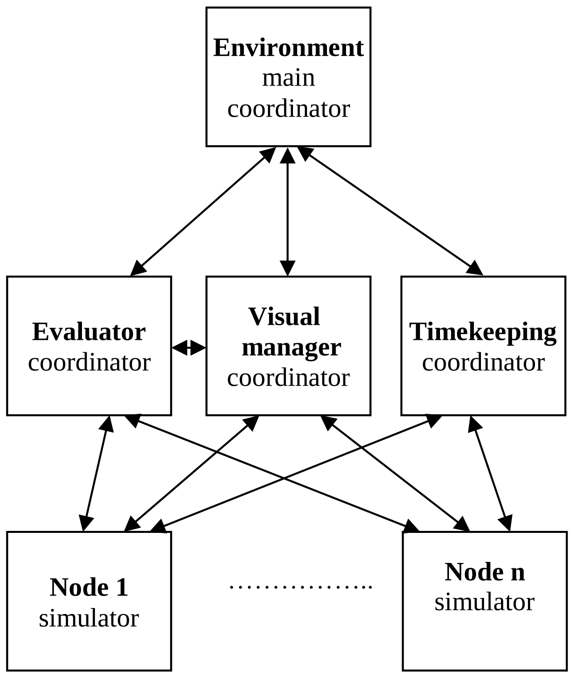

Figure 2: Multi-paradigmatic architecture

5. SIMULATION ALGORITHM

According to the previous conceptual model and the basic architecture of the simulation model connected with the supply network, it is possible to define an algorithm for a simulation model preparation. Figure 3 shows a sequence of events in a simulation algorithm cycle that leads to the development of a supply network. The simulation starts with the initialization of the environment and the setting of external system parameters such as the start of the simulation watch, the creation of a demand function, the activation of Evaluator part and the assignment of values of other conditions. After Environment is initialized, an initial number of network nodes is generated.

Environment triggers a new demand cycle and the Evaluator divides demand between all nodes based on a set market structure. Nodes interact on the basis of internal mechanisms to meet demand in a given period. Final production is delivered through cooperating nodes to end customers. After calculating the gains and losses of individual nodes, the values of their fitness functions are recalculated. Evaluator periodically checks the node condition in the population and takes nodes whose values have fallen below the thresholds. New nodes are introduced into Environment depending on demand and supply. The number of simulated demand cycles is determined during Environment initialization process. The course of time is given explicitly in the supply network by the fact that demand cycles run at regular intervals. Individual behaviour of nodes and their interaction are determined by discrete events.

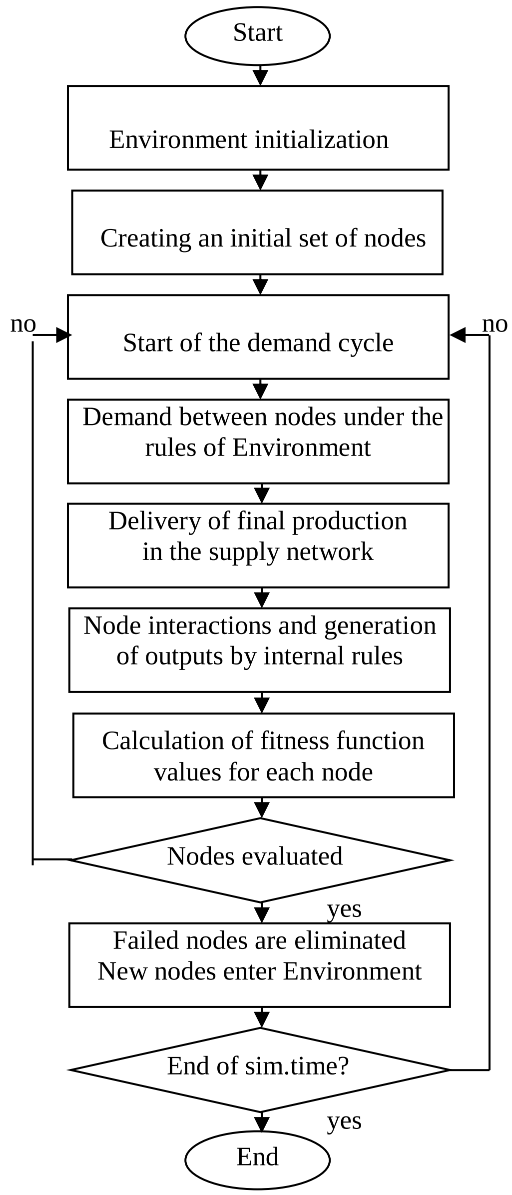

Figure 3: Simulation algorithm

6. SIMULATION MODEL IN SIMUL8

SIMUL8 is a software package designed for Discrete Event Simulation or Process simulation. It has been developed by the American firm SIMUL8 Corporation (www.simul8.com). The software has been used since 1994 and usually every year a new release has come into being. It allows a user to create a visual model of the analysed system by using pre-defined objects and by putting them directly on the screen of a computer. That is why the basic models are easily created. The SIMUL8 software is widely used in mainly for the process simulation mainly to model production/service processes (Greasley 2003; Ficova and Kuncová 2013; Omogbai, Salonitis 2016; Fousek, Kuncova and Fabry 2017; Kuncova, Skalova 2018).

The main 6 pre-defined objects are:

- Work Item – to define the main entity used in the model,
- Work Entry Point – for the entity inter-arrival times generation,
- Storage Bin – or a queue as a space where the entities might gather while waiting for a resource,
- Work Centre – for modelling any activity,
- Work Exit Pont – for the end of the modelled system, where an entity finishes its movement through the model,
- Resource - for modelling of limited capacities of the workers, material or means of production that are used during the activities.

Connectors are the last part that is due in all models to link the objects together, except of resources that are connected via the definition in a Work Centre (Concannon et al. 2007; Fousek, Kuncova, and Fabry 2017).

Although SIMUL8 itself has not the same possibilities as CAS-SIM, we tried to create a basic model of a market to simulate the Utterback model according to the conceptual model at Figure 3.

First, the environment and the set of nodes must be prepared. We model a fictive market driven by demand where the number of companies varies according to the market situation. The size of the companies is not directly modelled but the demand satisfaction is variable for each company and also for each set of companies. To be able to model more different companies in SIMUL8, the easier scheme is created where the 5 sets of companies are used as 5 nodes but behind each node max. 100 of companies may arise – it means max. number of companies on the market can be 500 (set of nodes representation).

As the market is fictive the demand is generated in fictive units and fictive inter-arrival times (exponential distribution was used) but the main idea was to simulate the whole life cycle of a new product. Four different periods were set for the demand increase, demand expansion, demand small decrease and demand big decrease.

After the demand generation the first set of companies (1-100) should try to satisfy it in a given time – the normal distribution for this activity is used with the average fifty times higher than the average inter-arrival time used for the demand generation, standard deviation is taken as 10% of the average activity time (in SIMUL8 named as "Average" distribution – Figure 4). The company is chosen randomly but the queuing time must not exceed one fifth of the processing time (Environment rules - Figure 5). When the demand is increasing and it is not possible by these 100 companies to handle it (the queuing time has reached the pre-set value and all companies are busy), new companies arise on the market – so the new set (1-100) is being used (node interactions representation) but as new-comers on the market they need higher time for the demand satisfaction. In the simulation model the demand (product) is sent to another queue or changes the queue after the long waiting time (as the customer looks for another, not busy, company). The whole model during the demand increase phase is can be seen on Figure 6.

This process continues if necessary based on the demand generated and based on the other companies' success in the demand fulfilment. This is taken as one of the possibilities of node interactions simulation when at the same time the new companies might need more time for the demand satisfaction (modelled via normal distribution with 10% higher average than for the previous set of companies).

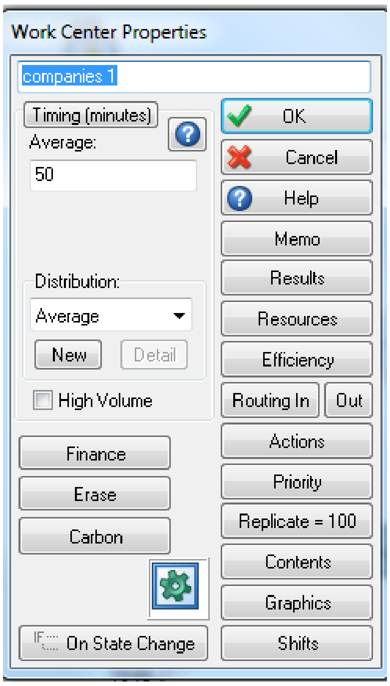

Figure 4: Definition of the work time for the first set of companies

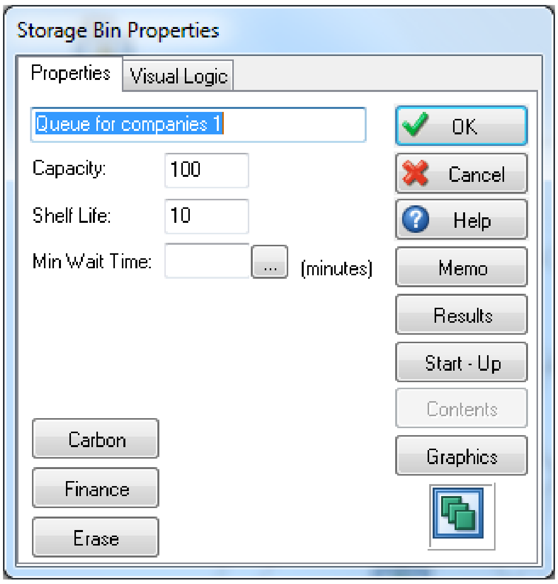

Figure 5: Queue settings for demand waiting for processing

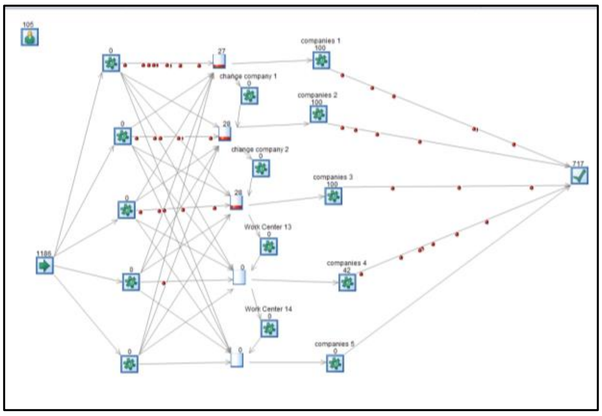

Figure 6: Simulation model in process – higher demand

Finally in each simulation time the number of active nodes (companies) is visible and in any time it is possible to see how productive each company is – so this might be takes as one example of the nodes evaluation (Figure 7).

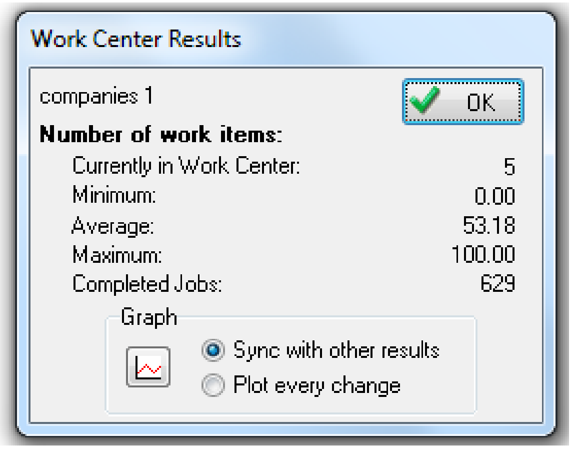

Figure 7: Simulation model results - number of companies (nodes) out of the first companies set needed for the demand satisfaction during the simulation time

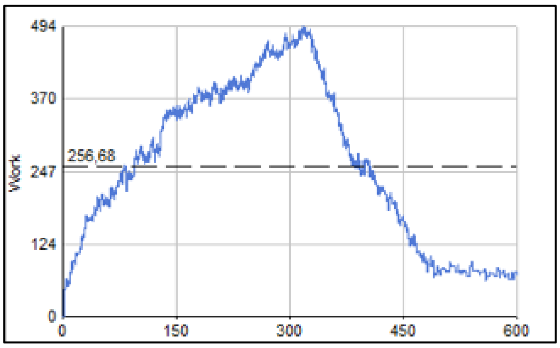

Figure 8: Simulation model results - changes in the number of companies on the market during the time

After the whole economic life cycle simulation (in out example about 600 time units) we might observe the typical curve of the number of companies on the market based on the time under the changing demand conditions (Figure 8).

7. CONCLUSION

The proposed simulation model of network economy development is based on the extension of the Utterback industrial growth model. The article proposes a conceptual model that captures the system being studied as a graphical network structure located in the market (market). Graphic structure nodes represent companies and edges represent interactions between companies. When tracking structure and behaviour dynamics, the problem is taken as a complex adaptive system. Company status is described by a fitness function value that is compared to the minimum level required for survival. The conceptual model is based on the simulation model architecture, which includes 4 coordinators: Environment, Evaluator, Visual Manager and Timekeeping, from which the Environment is the main and triggers the rest. A simulation algorithm is proposed which describes the development of the supply network. A simple model in the SIMUL8 software environment was created to demonstrate the given concept.
The proposed simulation model and algorithm are very flexible and allow modifications and generalizations when analysing a particular system. This tool seems appropriate for modelling the evolution of the network economy. The SIMUL8 itself might be used as the modelling environment but more other aspects should be added in real life situation which requires better and detailed specification of the market conditions using other probability distributions. Also programming some parts of the model via Visual logic in SIMUL8 might be useful.

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AUTHORS BIOGRAPHY

Petr Fiala: He holds the Full Professor degree from the University of Economics in Prague, Czech Republic, where he currently works as the Deputy Head of the Department of Econometrics. He is a member of other Czech universities. Professor Fiala is graduated from the University of Economics in Prague, in 1974, Charles University, Prague, in 1981, and Rochester Institute of Technology, USA, in 1996. His current research interests include modelling of production systems, supply chain management, project management, multi-criteria and group decision making. He is a member of professional societies for Operations Research and Multiple Criteria Decision Making and the Czech Republic representative in EURO (The Association of European Operational Research Societies). He has made research visits to many countries. He is the author of books, lecture notes, papers, and reports in quantitative models and methods in management and economics.

Martina Kuncova: She has got her degree at the University of Economics Prague, Czech Republic, at the branch of study Econometrics and Operational Research (1999). In 2009 she has finished her doctoral study at the University of West Bohemia in Pilsen, Czech Republic (Economics and Management). Since the year 2000 she has been working at the Department of Econometrics, University of Economics Prague, since 2007 also at the Department of Economic Studies of the College of Polytechnics Jihlava (Czech Republic). She is a member of the Czech Society of Operational Research, she participates in the solving of several grants. She is the co-author of four books and the author of many scientific papers and contributions at conferences. She is interested in the usage of the operational research, simulation methods and methods of multi-criteria decision in real life problems.