The Role of Agent Based Modelling in the Design of Management Decision Processes

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Abstract: Agent based modelling (ABM) is a new modelling paradigm and one of the most advanced practical developments in modelling. ABM promises to have far-reaching effects on the way that business practitioners and academic researchers use information communication technologies to support decision making at different levels of management. Modern design models and architectural structures are opening up new possibilities and new application areas are coming to the foreground. Multi-agent systems as systems of distributed artificial intelligence are now having a significant influence on information systems design, simulation and analysis. This paper focuses on the various modelling methods and technologies that are employed in the development of intelligent decision support systems. Its goal is to evaluate the role of the agent based modelling in the design of management decision processes. The paper considers the main features of intellectual agent modelling methodology, and discusses the different types modelling categorization. It does so from research base that draws from theoretical underpinnings as well as international and domestic industry practices. The basic principles of agent-based modelling are first introduced and areas of application are then discussed from perspective of real-world applications: flow simulation, organizational simulation, market simulation, and diffusion simulation. The classification of modelling types is discussed, together with and business application simulation frameworks.

Keywords: Modelling, Management, Information Systems, Decision Support Systems, Intellectual Agent, Multi-Agent Systems

1. Introduction

The use of modern modelling methods and technologies are now essential components for developing management decision process that will enable companies to succeed in a rapidly changing environment. It is noteworthy that simulation modelling is now considered an essential feature of decision making in companies that actively employ modern information technologies.

Modern modelling tools should facilitate mutual understanding at different organizational levels when making strategic management decisions thus bridging the gaps between a strategic vision and its implementation. One approach involves multi-agent systems (MAS) which, as a class, have developed rapidly over the last decade. The advantage of a multi-agent approach relates to the economic mechanisms of self-organization and evolution that become powerful efficiency drivers and contribute to enterprise's development and prosperity. New intellectual data analysis can be created, through MAS which is open aimed at flexibly adaptive problems solving, and deeply integrated in decision support systems.

Modern business simulation modelling tools use special software, programming languages and systems to develop models of business processes, relations between people and areas for optimization in the organizational structure as a whole.

2. Classification of modelling types

Modelling is widespread as a means to represent reality. Establishing a classification of all possible types of modelling is difficult since the notion of a "model" is used broadly in science and technology, art, and in everyday life. It is nonetheless possibly to distinguish the following types of modelling:

- Conceptual;
- Physical;
- Structured-functional;
- Mathematical and
- Simulation.

All these types of modelling can be employed to study complex systems simultaneously, or in certain combinations. Traditionally computer modelling or computer simulation falls within the domain of simulation and is concerned with the analysis or syntheses of complex systems in order to support

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problem or decision analysis activities. The focus of computer modelling can include: the economic activity of a company or bank, industrial enterprise, data-processing network, technological process or any real object or process.

Computer or simulation models of management information systems display all major factors and correlations characterizing real situations, criteria and limitations. Models should be universal enough to describe the phenomena in question, simple enough to permit research at reasonable cost, and achieve the following objectives:

- Reduce the number of functional roles and management levels, and specifically mid-level workers;
- Rationalize solutions to management problems by implementing mathematical methods of data processing, using simulation and artificial intelligence systems;
- Create a modern, dynamic organizational structure, improving enterprise's flexibility and manageability;
- Reduce administrative costs;
- Reduce time spent to planning activities and decision making;
- Increase competitive advantage.

To clarify the role of computer simulation in modern management the structure function approach to solving business problems should be noted. The essence of computer modelling in business is to obtain quantitative and qualitative results from the existing model. Qualitative results allow discovery of previously unknown features of a complex system including issues such as structure, development trends, sustainability, integrity, and so on. Most quantitative results help forecast certain future values of variables that characterize the system being modeled, or explain existing values from historical data.

The essential difference between computer simulation and structure-function analysis is that the former yields both qualitative and quantitative results (Serova, 2009).

Another well-known application of computer modelling is aimed at solving management problems through mathematics and logic and, as a rule employs Excel spread sheets. Problems susceptible to this approach include stock management as well as transport, industrial and marketing logistics (Gorshkov et al., 2004). The same is possible with problems of linear and multiple regression forecasting, resource utilization review, and so on.

The Computer model used for managerial decision making must, as far as possible, encompass the main factors and interrelations that characterize real situations, and their parameters. The model must be both sufficiently broad so as to include the specificities of management objects and economical in its actions. With this in mind the following are recommended as appropriate areas for exploiting the benefits of computer simulation:

- Where there are incomplete or incorrect formulations of the managerial issues involved and the modelling process involves apprehending the nature of the object to be modelled. Simulation in this case is used in order to study of the phenomena;
- Where analytical methods exist, but mathematical procedures are so complex and labour-intensive that simulation is the simplest path to decision making;
- When observation for behaviour of managerial system's components is required;
- Where simulation is the only way to study a managerial system because it is impossibility to observe the target phenomena in real condition;
- Where new situations are studied in complex systems that are relatively unknown to researches. In this case simulation is used for preliminary checks on a new strategy and decision rules before undertaking experiments on real systems;
- Where the model is used for prediction of bottlenecks in management systems and other obstacles, which may appear as a result of the introducing new components.

It is obvious, that the modelling methods listed above (conceptual, simulation, mathematical logic and structure-function) —are not mutually exclusive and that they can be applied to management systems research simultaneously or in combination.

3. Structure-functional approach for decision support

The most intuitive and popular example of the structure-function computer modelling in modern management is the business process modelling.

Modern management benefits from business-process improvement in that it obtains a comprehensive view of the way a company conducts business; managers should thus know how to conduct process simulation and analysis using the capabilities of modern software packages and platforms.

The market situation most modern companies operate in is quite unstable obliging them to respond to change quickly and accurately. Sooner or later, businesses must adapt and restructure, and managers will rethink business processes in order to improve the enterprise's operations. Thus, a manufacturer may wish to reconsider purchasing, ordering or delivery. Business process reengineering is tied to alterations in the architecture of information systems. The key to success with a reengineering project is close cooperation with of all the groups interested in solving the problem, primarily IT specialists and experts in the business area. This is achieved by building structure-function computer models that reflect business processes which are understandable for all participants. Such models should simultaneously help formalize the current state of affairs, and find room for improvement. There are several computer technologies aimed at automating such structure models—the CASE (Computer Aided Software Engineering) tools which involve various utilities for analysis and modelling that, together represent just a small fraction of the larger class. Organization and structure changes in a company involve serious risks especially when they involve the implementation of an Enterprise Resource Planning System (ERP). The implications of such changes should be carefully studied and analysed before beginning a project. ERPs such as SAP ERP ECC, BAAN, ROSS iRenaissance, and related use methods and tools that are time tested, minimize risks and resolve issues that arise from the reorganization of business processes, including those linked to the implementation of modern IT systems. Today's approach to business process design suggests continuous improvement and modification, analysis and prognosis, as well as timely changes to the business model. The diagnosis should adequately reflect the current state of affairs to lay a comprehensive foundation under business development strategy and business automation. There are steps are recommended for business development or modification (Figure 1)

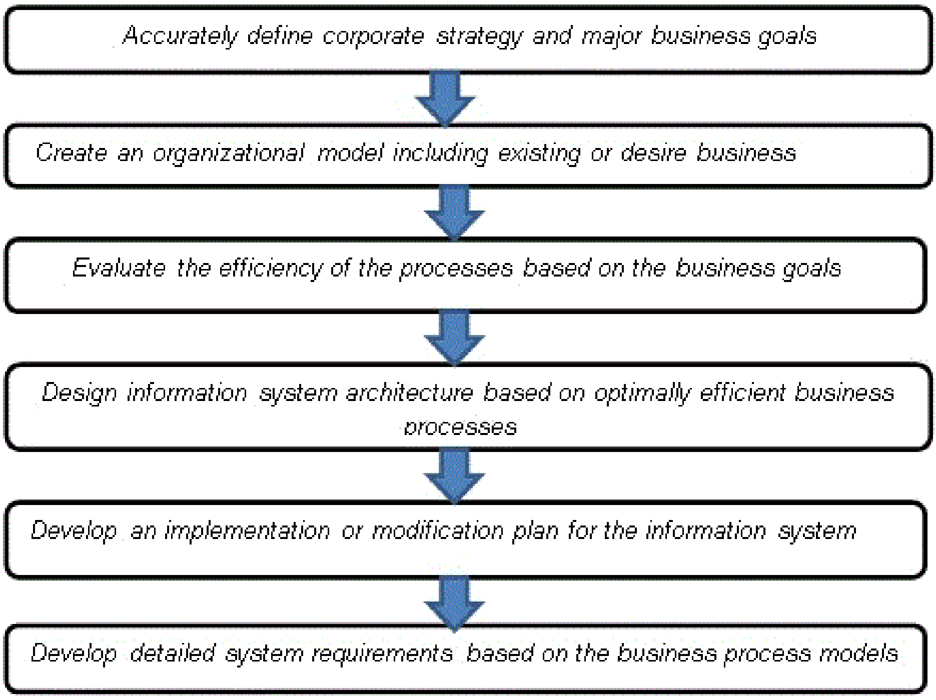

Figure 1: Main steps for business development (or modification)

There are several techniques used when modelling business processes with the most popular being Business Process Modelling, Work Flow Modelling and Data Flow Modelling (Ananiev, Serova, 2008). First discussed in the 1970s by Douglas Ross, the Structured Analysis and Design Technique (SADT) is a foundation for the IDEF0 business process modelling standard (FIPS 183, 1993). The AllFusion Process Modeler 4.1 (aka BPwin 4.1) introduced by Computer Associates (CA) is a modelling tool that is fully compliant with IDEF0 and allows analysing, documenting and planning changes in complex business processes scenarios (Maklakov, 2003).

Another actively used process description methodology is the Work Flow Modelling application — the IDEF3 standard for building process models as job time sequences of jobs (functions, operations). The ARIS source environment provided by IDS Scheer AG which creates methodological and work instructions with eEPS (extend Event-driven Process Chain) models, is based on IDEF3.

DFD (Data Flow Diagramming) notations allow one to portray job sequences within a process and the information flows circulating between different jobs processes. The DFD methodology minimizes the subjectivity of business process analysis and can be efficient when implementing a process approach to organizational management.

The developing UML (Unified Modelling Language) methodology is also widely used. It embraces a series of diagrams (e.g., the Activity Diagram) that can be used to describe business processes, even though business modelling is not what UML's primary objective.

Along with the techniques listed above, there are others offered by various software developers. Corporations as IBM and Oracle offer their own business process description and modelling tools for example Oracle's Workflow technology which is used to automate job flows features tools for process description and formalization. The most popular state-of-the-art business process management standard is BPEL (Business-Process Execution Language) which allows for the creation of an integral platform for all applications. Public and private institutions throughout the world are switching to BPEL. Certain pilot projects have been carried out in Russia which successfully solved IT infrastructure optimization problems.

4. The simulation modelling business application framework

The major approaches (or methods) in simulation modelling are: *System Dynamics* (SD), *Discrete Event* (DE) and *Agent Based* (AB). While SD and DE are traditional approaches, AB is relatively new. The Dynamic Systems (DS) also exists, but as a rule used to model and design "physical" systems.

If one considers the levels of abstraction of these methods, Dynamic Systems or "physical" modelling is situated at the low level. System Dynamics dealing with aggregates is located at the highest level, and Discrete Event modelling is employed at an intermediate level abstraction. Agent Based modelling, is used across all levels of abstraction. Agents may model objects of very diverse nature and scale: at lower levels, for example, pedestrians or cars or robots can be modeled; customer – at intermediate level, market and competition at the highest level. (Figure 2).

Methods	Attributes	Abstraction Level (s)	Management Level (s)	Areas of Application	Simulation Modelling Software
System Dynamics (SD)	Aggregates, Stock-and-Flow diagrams, Feedback loops	High (minimum details, macro level)	Strategic	Population Dynamics, Ecosystems, etc.	VenSim, PowerSim, iThink, et al.
Agent-Based Modelling (AB)	Active objects, Individual behavior rules, Direct or indirect interaction, Environmental model	High Middle Low	Strategic Tactical Operational	Logistics, Manufacturing, IT systems/ Telecommunication, Business Processes, Services, Asset Management, Project Management, Finance, Market place & competition, HRM, etc.	AnyLogic, Academic tools: Swarm, RePast, NetLogo, ASCAPE, et al.
Discrete Event Modelling (DE)	Entities (passive objects), Flowcharts, Resources	Middle (medium details, meso level) Low	Tactical Operational	Business Processes, Manufacturing, Services, Warehouse, etc.	Arena, GPSS, ExtendSim, SimProcess, AutoMod, Promodel, Enterprise Dynamics, et al.
Dynamic Systems (DS)	Physical state variables, Block diagrams and/or algebraic-differential equations	Low (maximum details, micro level)	Operational	Automotive control systems, Traffic micro level, etc.	MATLAB, LabView, VisSim, et al.

Figure 2: Simulation modelling business application framework (National Simulation Society (Russia) and author's own elaborations)

System Dynamics is "…the study of information-feedback characteristics of industrial activity to show how organizational structure, amplification (in policies), and time delays (in decisions and actions) interact to influence the success of the enterprise" (Forrester, 1961). The range of SD applications includes also urban, social, ecological types of systems. In SD the real-world processes are represented in terms of stocks (e.g. of material, knowledge, people, money…), flows between these stocks, and information that determines the values of the flows. SD creates abstracts from single events and entities and takes an aggregate view concentrating on policies. When approaching a problem in SD style one must describe the system behavior as a set of interacting feedback loops, balancing or reinforcing. One of the well-known examples of classic SD model is Bass Diffusion Model.

Discrete Event modelling may be considered as definition of a global entity processing algorithm, with stochastic elements. This modelling approach roots to 1960s when Geoffrey Gordon conceived and evolved the idea for GPSS (General Purpose Simulation System) and brought about its IBM implementations (Gordon, 1961). The term *Discrete Event* modelling or *Discrete Event* simulation are commonly used for the modelling method that represents the system as a process, i.e. a sequence of operations being performed over entities such as customers, parts, documents, etc. These processes typically include delays, usage of resources, and waiting in queues. Each operation is modeled by its start event and end event, and no changes can take place in the model in between any two discrete events. The term discrete has been traditionally used to distinguish this modelling method from continuous time methods, such as SD. With the emergence of *Agent Based* modelling the term *Discrete Event* modelling in its traditional sense created confusion since in most agent based models actions are also associated with discrete events, but there may be no processes, entities, or resources.

Compared to SD or DE models, AB models do not allow the definition of global system behaviour (dynamics). Instead, the modeler defines behaviour at individual level, and global behaviour emerges as a result of the actions of multiple actors, each following its own behaviour rules, living together in some environment and communicating with each other and with the environment (Borshchev, Filippov, 2006).

5. Agent-based modelling concept

Agent technologies offer various types of agents, model of their behavior and characteristics, through a range of architectures and components libraries. The notion "Agent" has developed from the well-known concept of 'object' which is an abstraction from a collection of real-world items with the same qualities and behavioral rules.

Among the various classifications of agents, the most widely known is that of (Kalchenko, 2005):

Intellectual – Mobile – Stationary

Agent qualities are determined by their classification. Intellectual agents have the most comprehensive set of qualities; their intellectual capacity allows them to build virtual worlds where they form action plans. Minimum set of basic characteristics for any agent includes qualities such as (Gavrilova, Muromtsev, 2007):

- Activity – the ability to organize and carry out actions;
- Autonomy (semi-autonomy) – relative independence from the environment and a certain "freewill" given a good supply of behavioural resources;
- Sociability – created by the necessity to carry out tasks in cooperation with other agents and supported by communication protocols;
- Purpose – innate sources of motivation, or more generally – special intentional characteristics.

This concept is close to one of the most popular definitions of agent by Wooldridge – (2002).

In addition to characteristics we can add:

- Adaptability – the ability to learn and reason. Agents may possess partial knowledge or inference mechanisms, as well as specialize knowledge in a subject matter;
- Reactivity – functional perception of the environment and adaptation to changes therein. This includes basic knowledge, creeds, wishes, commitments and intentions.

The technologies that have been used to successfully develop agents and multi-agent systems include (Kalchenko, 2005):

- Knowledge-based systems;
- Neuron networks;
- Clustering algorithms;
- Fuzzy logic;
- Decision trees;
- Bayes' theorem;
- Genetic algorithms;
- Natural language processing.

Multi- (or multiple-) agent systems (MAS), or agent-oriented programming represent a step forward from object-oriented programming (OOP) and integrate the latest advances in the areas of artificial intelligence, parallel computing and telecommunications. Unlike common objects in OOP, an agent is an autonomous object which implies that its behavior is dictated by goals, and that it has competence to achieve them. Agents cannot be called subprograms (or methods in OOP), because they have their own states and continuously work to achieve their goals—much like co-programs that can pass control to one another at any time. Thus, they can only be offered new tasks, which they may accept or decline depending on whether the task meets their goals and interests. To ensure their autonomy, agents can react to events, make and reconsider decisions, and interact with other agents.

As a rule, software implementation of a traditional system is centralized, has a hierarchical structure and executes predetermined algorithms. The code clearly states what, when and how to complete an action. Multi-Agent System is a self-organizing network of agents (software objects) that work continuously and simultaneously on establishing and reconsidering links. This system is decentralized: every agent is autonomous and strives to achieve its goals. Changing an agent’s goal makes other agents adapt their behavior and change their links.
Every MAS consists of the following components:

- A set of organizational units with a subset of agents and objects;
- A set of tasks;
- An environment - a space where agents and objects exist;
- A set of relations between agents;
- A set of agent actions (operations on objects).

There are various approaches to designing Multi-Agent Systems and three levels can be defined: conceptual description, initial design and detailed design. At the first level one should describe the organizational structure, goals, business processes and information support all of which act as a foundation for the next level’s ontology. On the next two levels these elements form the organizational visualization - the virtual world where agents act using the ontology to achieve their goals and carry out the set of tasks.

Multi-Agent Systems distribute tasks among agents, each being considered a member of a group or organization. The distribution of tasks suggests that each member of a group is assigned a role, responsibilities and behavioral requirements.

Agent technologies normally use certain agent typologies and models, as well as MAS architectures, and are based on agent libraries and development support tools for different types of Multi-Agent Systems.

The world’s best known and most widely approaches to Multi-Agent System development are OMG MASIF (Object Management Group), which is based on the concept of mobile agents; specifications by FIPA (Foundation for Intelligent Physical Agents) based on an agent’s assumed intellectuality; and standards by the Defence Advanced Research Projects Agency (DARPA) such as Control of Agent Based Systems.

FIPA is an organization that produces software standards specifications for heterogeneous and interacting agents and agent based systems in order to promote agent-based technology and the interoperability with other technologies. FIPA members include such companies as Avaya, Boeing, Cisco, Siemens, Toshiba, and various universities and public institutions. FIPA specifications aim to ensure interaction between intellectual agents through standardized communications and content languages. In addition to general communications, FIPA also works on ontology and negotiation protocols to support interaction in certain applied areas (transportation, manufacturing, multimedia, and network communications).

The OMG MASIF standard seeks to create conditions for the migration of mobile agents from one multi-agent system to another through standardized CORBA IDL interfaces.

DARPA initiated the Knowledge Sharing Effort that divided agent programming languages into syntax, semantics and pragmatics:

- KIF – Knowledge Interchange Format (syntax);
- Ontolingua – a language for defining sharable ontologies (semantics);
- KQML (Knowledge Query and Manipulation Language) – a high-level interaction language (pragmatics).

An important element for creating multi-agent systems is the Agent Communication Language (ACL). This determines the types of messages that agents will exchange. Inter-agent communications are developed through ACL, a language of content and ontology that determines a set of basic concepts to use in cooperative messages. Ontology here is synonymous to the API (Application Programming Interface) concept and determines a particular interface for intellectual agents.

6. Multi-agent approach to decision making

As systems of distributed artificial intelligence Multi-agent Systems have the following advantages for intellectual supporting decision making:

- They speed up task fulfilment through parallelism and reduce the volume of data transmitted by passing high-level partial solutions to other agents;
- They are flexible since agents of various capacities are used to carry out a task dynamically cooperatively;
- They are reliable given that functions that one agent is unable to carry out will be passed to other agents.

The integration of Multi-agent Systems in a decision support system can offer the following benefits:

- An information system specifically adapted to enterprise needs;
- More flexibility and ability to adapt to the external environment, especially under conditions of uncertainty;
- The ability to search and obtain unorthodox solutions;
- The confirmation of suppositions that previously lacked information;
- Faster decision-making when modelling negotiations;
- The ability to find and resolve potential conflicts of interests in both the external and internal environments;
- More reliable decisions owing to the ability to pass functions from one agent to another and redistribute responsibilities, which is not always possible in real life;
- Optimized access to information for all employees.

A significant advantage of the Multi-agent Systems approach relates to the economic mechanisms of self-organization and evolution which become powerful efficiency drivers for the development and success of an enterprise. The multi-agent approach allows the creation of a new intellectual data analysis which can be open, flexible, and adaptive, and deeply integrated with other systems.

Experienced-based accounts concerning MAS applications point to the following areas of application:

- Distributed or network enterprise management;
- Complex and multi-functional logistics;
- Virtual organizations and Internet portals that sell products and services;
- Academic management of distance-learning systems;
- Companies with developed distribution and transportation networks (e.g., Procter & Gamble);
- Distribution channels management;
- Users' preferences simulation modelling (e.g., Ford Motor Company).

Large companies realize a number of advantages with the Multi-Agent approach including: faster problem solving, less data transmission (since high-level partial solutions are passed to other agents), and faster agreements and order placements.

Distributed companies find advantages in improved supply, supervision and coordination of remote divisions and structures. Companies with a wide and variable products range can react flexibly to changing consumer preferences and forecast changes. Service companies retain client interaction scenarios vis-a-vis problem solutions with MAS technologies.

7. Intelligent Marketing Decision Support Systems

Customer Relations Management (CRM) strategy and design of companies' external information infrastructure are growing in importance, with intellectual information technologies developing (Serova, 2010).

CRM's major goal is to increase efficiency of such business processes as marketing, sales, service and maintenance. With CRM, the following steps to form a client network management system can be made and improved:

- maintaining an extended client database with a history of contacts that allows for classifying and grouping customers;
- forming sales statistics, reports, and sales history;
- interactive customer support, access to certain information they need;
- opportunity to work with customers, which are classified in region groups, industry, etc.; work jointly with remote or regional divisions;
- managing relations with potential clients: collecting initial information, distributing contacts between employees, and monitoring efficiency of initial contact sources.

In contest of implementing a client-oriented strategy, CRM should not be considered simply as a tool set. This is because software is just only one of the components of an infrastructure. First of all, CRM concept implementation is a systemic approach to organizing a company's activities. To increase business efficiency by implementing a CRM system, the company should start with analysing and, if needed, reengineering its business processes. A CRM system may include various modules and use information from other applications and databases the company has. Each customer's value is maximized mostly by three elements of marketing strategy: a system of integrated marketing communication channels; demand stimulation programs; and design products according to customers' needs. Thus, a CRM system's most important technological components are subsystems to interact with customers and monitor current operations, as well as product databases and analytic modules. One of the major trends in the CRM concept development is that most CRM systems are being considered as an additional element to the enterprise information infrastructure and being integrated in it. Another important point is that CRM system should not be considered as simply an IT implementation project. (Serova, 2009). Thus, CRM is an intermediate technology between companies and their customers that helps improve the external information infrastructure.

It's obvious that companies applying Information Communication Technologies (ICT) are paying more and more attention to the ability to build and develop Information Infrastructure. It is no less important that the ability to adapt and hybrid architectures are becoming essential when building information infrastructure. ICT, including computer simulation and intellectual information tools, is a key driver of business efficiency. A company can successfully implement its development strategy by applying on these modern trends, adding intellectual information tools to the CRM, and creating a hybrid adaptive external infrastructure based on the multi-agent approach.
Methodologies of the client-oriented approach to management of company activities and the multi-agent approach can be integrated. In other words, CRM strategy can be carried out with multi-agent systems (Serova, 2009):

- To simulate and forecast clients' behaviour, both adopted and potential ones';
- To coordinate dealers and remote divisions based on multi-agent system;
- To automate and improve the customer support process within the CRM concept;
- To store knowledge and skills of marketing and sales specialists in the relevant agents' databases;
- To develop an integrated multi-agent Internet portal for agents to keep users' personal contents;
- To create a search agents to monitor outside information;
- To organize a distance-learning portal.

Experts note that CRM systems are most efficiently applied, among others, by high-tech and distribution companies. The CRM technology also offers a flexible approach to building the company's business activity. The CRM methodology should not be considered just a concept of interaction with clients; it is rather a system that helps build a long-term client-oriented business.

At the same time, distribution and new high-tech services are leading in using Intelligent Decision Support Systems and multi-agent systems. The CRM and MAS technologies can be mutually complementary. Both of them offer a certain specific approach to management rather than just automating single processes. As a result, production volume, profitability, competitiveness and mobility are growing (Serova, 2010).

8. Conclusion

The increasing demand for optimisation of decision support systems development has caused leading modelers to consider Agent Based modelling and combined approaches in order to obtain deeper insights into complex and interdependent processes.

Multi-agent systems - as systems of distributed artificial intelligence - herald an era of networked organizations that are supported by the interaction of intellectual robots. This facilitates the shift from powerful centralized systems to fully decentralized ones, with hierarchical structure being replaced by a networked organization. Rigid bureaucratic “from top to bottom” management is displaced by negotiation, and planning with flexible arrangements. As a result, production volumes, profitability, competitiveness and mobility are growing. A significant advantage of the Multi-Agent System approach relates to the economic mechanisms of self-organization and evolution which become powerful efficiency drivers for development and success of an enterprise. The Multi-Agent approach allows the creation of new intellectual data analysis which can be open, flexible and adaptive, and deeply integrated with other systems.

This does not mean however that Agent Based modelling is a replacement for System Dynamics or Discrete Event modelling. There are many applications where SD or DE models can efficiently solve the problems. If the problem’s requirements fit well with Discrete Event or System Dynamics modelling paradigms – using these traditional approaches is more appropriate. In cases where the system contains objects with timing, event ordering or other kinds of individual and autonomous behaviour, then applying Agent Based or mixed approaches is more efficient.

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