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SERVICES SYSTEMS PROFITABILITY RESEARCH FOR REAL-TIME DECISION SUPPORT USING INTELLIGENT SYSTEMS

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VILNIAUS UNIVERSITETAS

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APTARNAVIMO SISTEMŲ PELNINGUMO TYRIMAI, REALAUS LAIKO SPRENDIMŲ PRIĖMIMUI, TAIKANT INTELEKTINES SISTEMAS

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SUMMARY OF DOCTORAL DISSERTATION

Work Topicality

Globalization and market liberalization influence economic changes. Organizations are beginning to realize that the essential issue is not profit maximization but profit maximization by increasing consumers' satisfaction with the provided services. At present, not only the process of service delivery is important, but it is the way the service is provided that matters. Development of information technologies significantly impacts the provision of services and the entire sector of services. Consumers now have more information and a better understanding of a service therefore the competition is determined by quality and quality determines profitability (Seth et al., 2005).

Gartner (2008) notices, that there have been major changes in the service sector. Traders are beginning to realize that technologies may have critical importance for the increase of profit and operational efficiency. Application of efficient IT solutions determines the survival of low profit service sector. The significance of technologies becomes even more important when sales are declining due to economic crisis, and the increased competition forces to reduce prices of goods and increase the quality of services. Real-time business management systems, able to predict the changes of future business, become the number one priority. It is forecasted, that by 2012, business intelligence systems will have changed from the systems, which "tell why it happened" to the systems which will answer a more important question "what happens in future". The era of predictive analytics began in 2010. Gartner and Forrester companies indicate that by 2010 real-time business analytics systems will have become an integral part of business operational management.

The work analyses the topic of service system productivity and profitability. The work focuses on self-service area, namely the increase of ATM network productivity. The profitability of electronic service systems depends on their productivity and quality of the services provided. It is possible to ensure the productivity of service systems by improving and efficiently planning delivery process. In such systems, it is very important to make timely decisions to avoid affecting delivery process. It is impossible to store services like goods; therefore inadequate decisions are related to the direct loss of income and quality decrease.

The productivity of electronic services may be ensured by implanting advanced real-time decision management systems, changing the realization of service system quality from traditional to predictive. The quality of such systems is ensured by predicting service system behavior. Multi-agent technologies are used for data collection from distributed service points. Intelligent agents evaluate the demand of service system resources according to the collected data, and plan the work to have sufficient resources for services and to maintain high quality and maximum system availability. The work of service system must be managed in real time, applying intelligent systems of resource planning and optimization. Certainly, without service quality management models and systems, the mentioned measures are only tools; therefore performance management models should be applied as well.

Work Relevance

The concept of productivity in service area was started to be analyzed only at the end of the XX century. Service sector is one of the fastest growing economy segments

(Sahay, 2005), still very little empirical survey has been conducted in productivity management area. Gronoroos (2002), Chase and Haynes (2002) structured the elements of service productivity theory. They analyzed the similarities and differences of production and service productivity, and formulated the main definitions of service productivity. Ojasalo (1999) structured the model of service productivity. Sherman (2006) defined service productivity components. Seth (2005) carried out survey on quality management models, created in the period of 1984-2003. It is clearly seen that service delivery process changes from traditional to the one reasoned by information technologies. Application of information technologies in service quality management is becoming highly important. Service sector productivity depends on technologies and process automation measures (Gummesson, 1998), at present, this tendency is even more significant because the competition of service sector is increasing. Service delivery through self-service terminals or computer systems allows increasing the efficiency of service system and the quality of servicing. It is obvious that higher profitability is typical for efficiently operating systems (Sherman et al., 2006).

Various electronic service quality management models are presented in literature (Dabholkar, 1996), (Soteriou and Stavrinides, 2000), (Broderick and Vachirapornpuk, 2002), (Zhu et al., 2002), (Santos, 2003). Most of the proposed models are conceptual, quality evaluation criteria, mechanism and measures are not provided. It is noted on literature, that there are no universal service productivity evaluation measures as in the sector of production, various methodologies and their combinations may be applied for evaluation. Process of services is an open system therefore application of traditional (production) efficiency evaluation systems may determine incorrect results. The main dilemma of service systems productivity is the balancing of income and costs because it is impossible to store services. The problem of balancing may be solved by moving to predictive management of service system resources. For this reason, intelligent real-time systems need to be applied (Muhlen and Shapiro, 2010; Agrawal, 2009; Azvine, 2005; Nguyen Manh et al., 2005; Seufert and Schiefer, 2005; Ranjan, 2008), with their help it would be possible to make fast decisions and predict the behavior of service system, foreseeing the optimum coverage of its management.

In recent years, science has made a huge step forward in the area of intelligent systems. Various methods and measures have been created in order to solve complex problems of business optimization and management. These methods are based on biological and natural intelligence principles. They include artificial neural networks, fuzzy systems, multi-agent systems, evolutionary computing and swarm intelligence systems. All of them are defined as intelligent systems (Engelbrecht, 2002, Konar, 2005, Eberhart and Shi, 2007). A system is intelligent when it can learn and adjust to a new situation, and can generalize knowledge and find association in it. Ability to adapt and adjust is an inseparable quality of a really operating system. The qualities of knowledge generalization and association search provide intelligent systems with advantage against traditional prediction methods. Hu (1964) was the first to apply neural networks for weather forecast in practice. Later, experimental research was carried out by Werbos (1974), he applied neural networks for the prediction of time series. Werbos (1989, 1990) carried out experiments with back-propagation training algorithm and made conclusions that neural networks can provide further more accurate forecasts compared to the methods of statistics: regression analysis and Box-Jenkins forecasting method. Lapedes and Farber (1988) were the first to propose reasoning that a simple neural network can

outstrip traditional prediction methods. Later, there was research of Sharda and Patil (1990), during which they compared Box-Jenkins and neural network forecast quality, using 75 different time-series. After Sharda and Patil, Tang and others (1991) had carried out survey, they formed that ANN forecast accuracy is higher compared to traditional time-series models.

No accurate forecast and appropriate management of services are impossible without correctly and timely collected data, therefore agent systems (Wooldridge and Jenkins, 1995, 1997) are one more important component of realistically functioning business intelligence system. Multi-agent system is one of the most appropriate means for real time data collection from service network points. Application of agent technologies is only in the early stage. Many researches present various application visions; however there are few real implementations (Luck at al., 2005; Wagner, 2005). Agent systems for real-time data collection and management may be successfully applied in the sector of e-services, namely in the service systems of self-service networks. These systems are distributed, their level of computerization is high, and therefore it is possible to successfully collect the necessary data and to perform optimization of service delivery.

Good forecast and data management means do not ensure productive work of self-service systems. Semeijn and others (2005) showed that the work of servicing system is none the less important than the e-service system itself. Implementation of the best and most functional ATMs cannot ensure high level of self-service facilities without an appropriately functioning service system. Voss's (2003) survey shows that service quality expectations in retail banking only approximately fulfill the service received. Problems, which appear in service systems, may disturb delivery process (Zhang and Prybutok, 2005); in most cases unavailable services greatly reduce the loyalty of a service (Watcher, 2002). For this reason it is important to combine internal and external quality criteria. Only one or another group of criteria is usually analyzed in literature, and a common model of self-service network quality is not provided.

Internal quality of a system is ensured by using advanced management means, which allow optimizing operational costs and service delivery process, and internal quality management systems, which are based on sets of productivity criteria. Clearly detailed productivity criteria of ATM network internal quality management systems are analyzed in literature (Aldlaigan and Buttle, 2002) (Bahia and Nantel, 2000), (Jabnoun and Al-Tamimi, 2003) (Joseph and Stone, 2003). Meanwhile, the literature does not provide enough ATM network optimization results in order to create real-time self-service facilities management system. McAndrews and Rob (1996) analyzed optimal ATM network size selection methods. Peculiarity of cash demand is analyzed by Boeschoten (1992, 1998), Viren (1992), Snellman and others (2000), Drehmann and Goodhart, (2000), Drehmann et al., (2002), and Stix (2003).

In order to ensure external quality, process development measures and external quality management systems are necessary. External quality management systems were analyzed by Lovelock (2000), Vargo and Lusch (2004), Johnston and Clark (2001), Edvardsson and others (2006), they settled value-based service quality management models, which analyze economic and social service delivery aspects. At the moment business is using various process development methodologies and methods. The main of them are Six Sigma, Lean and BPI (business process improvement) and process reengineering methodologies. Six Sigma, Lean propose clearly defined tools, how to perform improvements, however they lack systematic principles meant to implement

organizational changes and settled improvements (Brache and Rummler, 1997; Hammer, 2002), including the evaluation of preparation for changes (Jones et al., 2005). They lack clearly defined realization process. It is obvious that the benefit of improvements depends on their systematic implementation (Chong et al., 2001). Literature presents various BPI methodologies, they were generalized by Barry Povey (1998) and Adesola (2005), however there are little applications for service organizations. Jiju Antony (2006) proposed Six Sigma methodology adaptation for the improvement of service processes.

The work presents the increase and management system of self-service systems' operational performance, which is adapted to manage the supply of ATMs' cash. The system is created using multi-agent technologies and artificial neural networks. Flexible neural network model has been created for the forecast of ATMs' cash demand. Evaluation and process improvement methodology has been created to manage performance of self-service systems: value-based self-service quality criteria model, self-service systems' performance criteria model, self-service systems' performance evaluation model, and improvement model of self-service systems' processes.

Research Goals and Objectives

The research goal is to create operational performance improvement method and management tools of service systems for making real-time decisions by applying intelligent systems.

The following **research objectives** have been fulfilled to achieve this goal:

1. To analyze quality and productivity management methods of electronic and self-service facility systems and to propose their generalization.
2. To create operational performance improvement and management system model (ATM cash management) for real-time decision-making after having carried out ATM network management analysis.
3. To create ATM cash demand forecasting model after having analyzed operation and creation principles of artificial neural networks, which are applied for the prediction of time-series.
4. To create self-service system performance evaluation and process improvement methodology after having analyzed process development methods and methodologies.
5. To create self-service system operational performance improvement and management system, adapted to manage ATM cash supply, which allows decreasing service delivery expenses without affecting the quality of provided services.
6. To perform ATM network profitability modeling to assess the value of the created ATM network performance improvement system, compared to various methods of time-series forecasting and used real management methods of banks.

Research Object

Dissertation research object is service system operational performance improvement method and management tools for real-time decision-making, applying intelligent systems. Operational performance is realized as service system profitability increase by improving the quality of provided services or decreasing supply costs. A narrower area of service systems is analyzed in the dissertation: self-service facility systems – ATM

networks, therefore the created method may be hardly applied for the provision of traditional services due to insufficient level of their computerization.

Scientific Novelty

Self-service system operational performance improvement and management system, adapted to manage ATM cash supply has been created. The system applies multi-agent technologies and neural networks. Multi-agent technologies are used for the collection of real-time data and realization of neural network operation. A flexible neural network model has been created, which changes its structure depending on situation and is used to forecast self-service facility demand. Four self-service system performance evaluation and process development models have been created: value-based self-service quality criteria model, self-service system performance criteria model, self-service performance evaluation model, and self-service system process development model. The created system, assessing the methods and technologies proposed in literature, is characterized by ability to adapt, possibility to function in real time and flexibility. Using such system, service delivery is managed in real time, accurately planning the system load. Not only have the means for productive service system management been provided, but also self-service facility quality management and process development methodologies have been created. According to them, ATM network performance evaluation models of two types have been created: of high and low circulations. Model performance criteria have been selected according to a structured self-service performance evaluation model.

Cash usage is constantly growing despite the development of electronic commerce. According to the data of European Payment Council (EPC) the amount of cash on the market of European Union countries increases by 7-10% per year. Internal cash costs in the economy of EU countries make 40-70 billion Euros per year, that is 0.4 – 0.6% of EU gross domestic product. EPC thinks that measures should be taken in order to reduce the price of cash. The created self-service system operational performance optimization and management system and service quality management as well as process improvement methodologies allow decreasing the cost of cash in ATM networks. It is extremely topical if we evaluate the fact that there were 2 million ATMs in the world in 2009. ATMIA research shows that the cost of one ATM service is 20-68 thousand Litas per year. If we make an assumption that the approximate costs of a single ATM is 40 thousand Litas, the upkeep all ATMs in the world would cost 80 billion Litas. This amount includes 26% of cash administration costs, which is 20.8 billion Litas. According to the data of the Bank of Lithuania, there were 1543 ATMs in Lithuania at the end of 2009, 1483 of them are used to withdraw cash, 73 of them accept cash, and 13 ATMs perform both operations. 22.8 billion Litas were withdrawn in Lithuania in 2009. Cash is an important part of finance market. In Lithuania, the costs of ATM network cash make 16.05 million Litas; using more advanced forecast and self-service network management measures the costs could be reduced by 29 percent (in Lithuania this would make 4.7 million Litas per year), ensuring more efficient planning of resource supply. With minor improvements, introducing credit (withdrawal) and debit (insert) cash flow management, the created models would be suitable for the cash management in other areas, like for example cash issue in bank savings departments, or management of supermarkets' cash safes. Other application areas could be shops' supply management systems, integrated demand and supply planning systems (IPTPS) and cooperative shops' business insight systems (BI), Gartner (2008).

Experimental research of three types has been carried out in the work. The USA bank data about ATMs (3433 ATMs, duration from one to three years) were used for the selection of ANN structure. India bank data (5500 ATMs, duration up to 3 months) were used for modeling high load ATM network profitability. Modeling was performed with the data of 361 ATM. Data of Lithuanian banks (21 ATM, duration 6 months) were used for modeling low load ATM network profitability.

Having performed the modeling of high load ATM network profitability, it was found that a network of 5000 ATMs can save 4250 Euros (or 14650 Litas) per day in a group of correctly forecast ATMs, and having lent the free cash it is possible to earn 2660 Euros (or 9200 Litas). Total saving and profit benefit reaches 6900 Euros (or 23800 Litas) per day. Average annual benefit amounts 2.35 million Euros or 8.1 million Litas. Cash management costs are approximately reduced by 25%. Using the created ATM network cash management model for low load ATM network management, the cash-back amounts are reduced by about 24%, compared to a real scenario. Using the created ANN method and optimization procedure, ATM cash management performance may be approximately increased by 33 percent.

The main advantage of the system against traditional planning and management methods, which are applied for the management of ATM networks, is flexibility and real-time planning. The created ANN model is more superior than classical time-series forecast methods (moving average, Holt, Winters, ARIMA/ARMA models). ANN model allows preserving quite good forecast results when working with various ATM cash demand time-series, it flexibly adapts to various time-series processes. The research of 361 Indian ATM cash demand forecast shows that ANN method mean absolute percentage error MAPE is about 33%.

Defensive Propositions

Propositions defended in the dissertation:

It is purposeful to use intelligent systems to ensure real-time decisions in service systems.

It is purposeful to use agent technologies for real-time data collection from self-service points and implementation of intelligent methods in ATM performance improvement and management systems.

It is most purposeful to use neural network model to forecast self-service system facility demand.

The proposed self-service system operational performance improvement and management system (adapted to manage ATM cash supply) allows decreasing the costs of service supply, without influencing the quality of services.

The proposed self-service system performance evaluation and process improvement methodology allows ensuring consistent implementation of self-service system operational performance and management system.

Research Methodology

The following methods were used for the research: theoretical analysis based on the work results and findings of various scientists; systematic analysis; modeling; evaluation; generalization; questionnaires and interview, which were used during the cash management process analysis of ATM network. “Neural Network Based System Identification” tool set was used for neural network implementation (Nørgaard, 2000a)

(Nørgaard et al., 2000b). MATLAB (technical computing system) was used for modeling and testing of algorithms. Multi-agent system was implemented using JADE (Java Agent Development Framework) agent system creation platform (Bellifemine et al. 2003).

Graphic process and demand models were prepared according to "Zachman Framework" organization architecture designing methodology; work-flow models were prepared according to BPMN notation, USE CASE and class diagrams – according to UML 2.0 notation. Modeling system Enterprise Architect was used for preparing of models. Microsoft Excel spreadsheet was used for processing of the research data.

Practical Value

Agent system and artificial neural network method have been created implementing the project funded by EU structural funds "Service systems optimization and management agent" (BPD2004-ERPF-3.1.7-06-06/0045), realized in the product of JSC "Five continents banking technologies", as one of functionality components meant to manage ATM network cash planning. The project lasted 2 years (from 2007.01.01 to 2008.08.31), and it was implemented by a team of 15 specialists.

In 2010, self-service systems performance evaluation and process improvement methodology was applied in bank consultancy product created by JSC "Strategic Decisions Group", using this methodology, Lithuanian, Austrian, Indian and Kazakhstan banks' ATM network profitability research was carried out.

Approval of Work Results

Research results were published in 8 scientific editions (FIHUSO-2007, ASMDA-2009, KORSD-2009, EurOPT-2008, ICEIS 2009, BIS 2009, CIMMACS'07, ICSTC 2008): one article in publications included into the main list of scientific information institute (ISI Web of Science); 8 articles in publications, included into the list of Scientific information institute conference works (ICI Proceedings); 1 article in the report material of foreign conferences.

Awards

Scientific article "*Intelligent Cash Management System for an ATM network*" at 2008 conference "*International Computer Science and Technology Conference*" in the USA was awarded as the best practical application of scientific knowledge.

ATMiQ – ATM network optimization system created by company BS/2 was awarded with Lithuanian innovation prize of the year "*Innovation prize 2008*" in 2008. The same year, ATMiQ product was awarded with a golden medal of Lithuanian product of the year in the group of information technologies. Flexible neural network model, agent system and ATM cash optimization procedures, which are analyzed in the dissertation, were implemented in the ATMiQ product.

Structure of Dissertation

The dissertation consists of 8 chapters and bibliography. Dissertation capacity: 261 pages, 98 pictures and 24 tables. Additional information is provided in 24 appendixes.

SHORT OVERVIEW OF THE DISSERTATION CONTENT

Electronic Services Quality and Productivity Management

Theoretical aspects of services are reviewed in the dissertation chapter. Definitions of service and e-service are provided. Similarity and essential differences of electronic and self-service facilities are discussed. Service systems term is frequently used in the literature of service management, service operations, service marketing, service engineering and service creation. Services may be classified into 8 groups: generating additional value, production, business services, facility services, distribution, authority, personal and consumer (self-service). Most authors group electronic services into information services and self-services.

Meuter (2000) and Lawrence (2009) self-service technologies classifications are analyzed. Meuter classifies self-service technologies according to 2 aspects: service delivery aim and service delivery interface. Lawrence (2009) distinguished six groups of self-service facilities technologies. He grouped them according to two aspects: technology separation from delivered services and complexity of services.

Electronic services quality evaluation determinants are detailed. Surjadjaja (2003, p 39-53) distinguished 3 groups of electronic services delivery factors: service marketing, service design and service delivery. He described 20 factors, which characterize operations of electronic services. Ghosh (2004) groups service factors according to service marketing, delivery and design aspects. He distinguished 5 factors which are reflected in all three groups of factors: reliability, responsiveness, information newness, management and restoration. Ghosh proposed conceptual framework of e-service operations.

Comparison of six e-services quality management models is proposed (Berkley and Gupta, 1994; Dabholkar, 1996; Soteriou and Stavrinides, 2000; Broderick and Vachirapornpuk, 2002; Zhu et al., 2002; Santos, 2003). Most of them are conceptual and do not propose clear measures for services quality evaluation, they only indicate, what groups of criteria should be evaluated. In theory, service quality is realized as difference between consumer expectations and realization after receiving the service. If the provided service value exceeds consumer's expectations, quality is high, and vice versa. Seth (2005, p. 945) evaluated 19 service quality models and distinguished 6 main aspects, which determine quality: clear market and consumer focus, motivated staff, clear understanding of service quality model and features, effective evaluation and feedback system, effective implementation system, and efficient customer care system.

Productivity evaluation system of e-services is discussed (Gronroos, 2004; Ojasalo, 1999; Rutkauskas et al., 2005). Essential services productivity evaluation criteria and methodologies are analyzed. Service productivity management is a very important topic, but very little empirical research has been carried out in this area (Johnston and Jones, 2004). Productivity consists of 4 components (Sherman et al., 2006): price, resource allocation, technological and scale efficiency. The main productivity evaluation methodologies are discussed in the chapter. The main dilemma of productivity is balancing of revenue and costs (Gronoroos, 2000). Depending on demand, it is necessary to ensure efficient use of resources because services cannot be stored. Productivity is divided into internal and external. Internal productivity describes how efficiently resources are used. External productivity shows what service profitability is. Services productivity is the balance of external and internal efficiency (Chase and Haynes, 2000).

Another important element of productivity is demand management or capacity efficiency, because supplier cannot store services (Gonoroos, 2004). Capacity efficiency shows how efficiently system internal resources satisfy the demand. The process of services is an open system therefore application of traditional efficiency evaluation systems may determine false results. Productivity may be evaluated totally or partially. According to Gonoroos (2004), the only theoretically and practically significant way to calculate services productivity is financial measures.

4 groups of service prediction methods are analyzed in the chapter: subjective, causal, time-series and intelligent methods. Predicting the demand of services it is important to regard such aspects as: variation of demand throughout a day or hour; demand variation in regard to days of the week; demand variation within a month, demand seasonality, impact of marketing promotion.

ATM Network Cash Management Multi-agent System Model

Agent definitions are proposed, their application peculiarity is described, and agent classification and creation measures are detailed. Although there is no unanimous agent definition, most scientists (Russel et al., 1995; Maes and Pattie, 1990; Wooldridge and Jennings, 1995; Jennings, 1998; Shoham, 1997; R. Simutis, 2002) distinguish the following essential agent features: ability to get information from the environment, process the information and influence the environment according to it. Agent must be able to learn from its environment, interact with other agents, change place in the environment and systems. The above-mentioned agent systems function in an ideal case only, however, most realized agent systems are much simpler and implement only clearly defined functions.

Two agent system classifications are proposed in literature. Nwana (1996) proposed to classify agents according to the features of their behavior, and Davis (1997) proposed classification according to reasoning features. Nwana (1996) classification classifies agents according to their behavior features: cooperation, study, and autonomy. An agent which possesses all features is called intelligent agent. Davis classification is based upon three intelligent agent features: reasoning, ability to react and ability to think.

Necessary technologies are created for agent system realization, they allow ensuring their communication, data distribution, infrastructure availability and resource usage. 4 groups of technologies are used to create agent systems: Java or C++programming languages, KQML or FIPA ACL agent communication languages, XML message description, and LIF or SL1 content languages. Agent systems have official standard FIPA. Agents can be created using object oriented programming, creation of web services and other technologies (AgentLink III, 2004).

It is rational to apply agent systems when automated system units are distributed geographically, interaction of their units can be more useful than their individual parts. MAS provide great possibilities to solve complex practical problems which exist in dynamic environments. Application of multi-agent systems is especially appropriate in those cases when coordination of several related tasks, which are in the distributed information resource networks, is necessary. Multi-agent systems function decentralized, this helps to avoid information jams. Having lost one agent, the system can keep functioning successfully and its work will not be disturbed; only the quality of decisions may change. Meanwhile, if one component fails to function in centralized systems, all system work is disturbed.

Development of business intelligence systems is analyzed, their features are discussed. Topography of organization analytics decisions is provided. The structure and features of real-time business intelligence systems are detailed.

Business intelligence is business productivity assurance means and information-based decision-making. BI systems analyze data mining, storage and analysis. The main aim of these measures is to get valuable information from cumulative data, and to use it for business performance improvement (Sahay and Ranjan, 2008; Gangadharan and Swamy, 2004; Azvine, 2005). Modern BI systems are only able to diagnose the existing situation of an organization, they are more oriented to organization operational performance evaluation. The forthcoming three years are related to the transformation of BI systems, when BI systems will not only provide information about the existing situation of business, but will become the main means of an organization's decision-making (Gartner, 2008). Modern BI systems will use rich client interface and will be integrated with processes and business rules management systems.

Real-time business intelligence systems (RTBI) include functionality of traditional BI systems but they operate using real-time business process data, which are obtained from real-time functioning systems with zero latency. The main idea of RTBI system is fast transfer of decisions into a real-time functioning system. Azvine et al. (2005) described the problems of traditional BI systems and proposed the vision of real-time BI systems. According to Azvine (2005) RTBI system should include: real-time information delivery, real-time data modeling, real-time data analysis, real-time decision-making according to the analyses performed. Architecture, proposed by Azvine et al. (2005) is of transformational format and is more conceptual. Nguyen Manh et al. (2005) proposed an event-based BI system application model, which performs the analysis of business processes in real time, automatically delivers messages about changes and calls or alters the necessary business processes so that decision-making was timely. Real-time BI system architecture, proposed by Nguyen Manh et al. (2005), is based on SOA (service-oriented architecture) ideology. Seufert and Schiefer (2005) proposed an extended architecture model of BI systems, the aim of which is to reduce decision-making time and to automatically relate decisions with business processes. Sahay and Ranjan (2008) proposed a real-time BI system model, which is adapted to supply chain analytics. Agrawal (2009) proposed technologically-based real-time BI system architecture. Muhlen and Shapiro (2010) proposed exhaustive business process analytics system research and structured new attitude of the distribution of these systems. They divided business process analytics into three stages: process controlling, business activity monitoring (BAM) and process intelligence.

Current BI devices are passive, assessing form the side of consumers, and perform only data provision/analysis and business process monitoring functions. RTBI systems, compared to BI, are characterized by business process controlling possibilities in real time: business process parameters' change in real time, search and implementation of new promising business models. Realization of such systems needs high level intelligent systems which are able to make decisions independently according to business aims defined beforehand (Azvine et al., 2005).

Having conducted ATM network management survey in the markets of the USA, Baltic countries and India, ATM network management models were structured. ATM network management models can be divided into three types: (1) total transfer of functions, (2) partial transfer of functions and (3) retention of functions.

Having analyzed ATM network activity function and system of costs, 5 ATM network optimization models were proposed. One of the models is application of advanced optimization technologies. This could be application of intelligent methods for the forecast of cash demand, failures and stock. For this reason, intelligent algorithms need to be created and implemented into business intelligence systems.

Having carried out the analysis, it was found that costs, related to cash, make 26% of all expenses, therefore optimization of cash management functions may significantly decrease ATM maintenance costs.

ATM cash management process analysis was carried out, cash management system structure is made (Figure 1), its functionality is detailed (Figure 2). Cash supply process consists of 7 function areas. Cash management process controls risk, cash demand management, and cash preparation and protection. It does not control operation control which functions as external auditor. Its function is to observe whether cash operations are performed honestly according to the regulation rules.

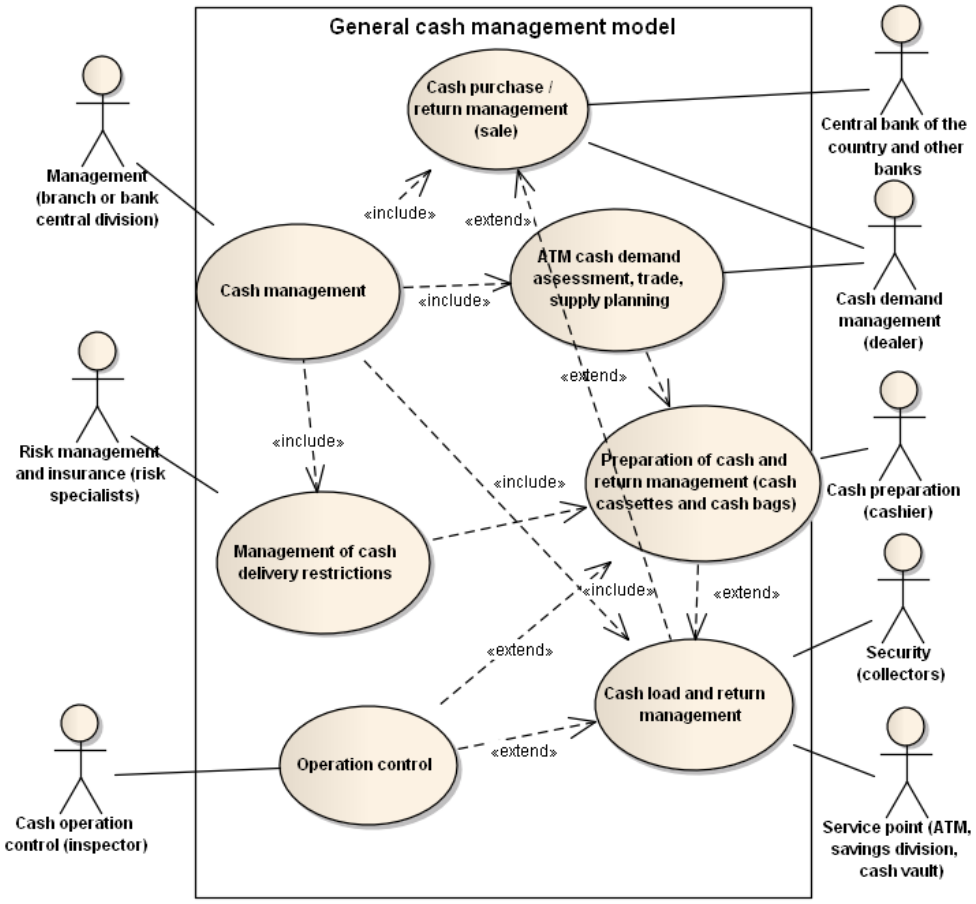

Figure 1 USE CASE model of general cash management process

Dealers perform cash demand evaluation (forecast, monitoring), and prosecute cash trade among banks. They control cash acquisition and return to the central bank. When risk specialists evaluate the factors of services delivery, they set cash planning limitations. Cashiers prepare cash for collection according to the plans, prepared by dealers. The prepared cash is physically loaded/ transported to service points – savings departments, ATMs or vaults. Cash which does not have demand is returned to till, from where it may be redistributed to other bank service points, sold to other banks or returned to the central bank. Optimal cash control needs a tool which would allow all the

participants of the process expeditiously exchange information, plan their work, distribute tasks, and perform service infrastructure monitoring and demand forecast.

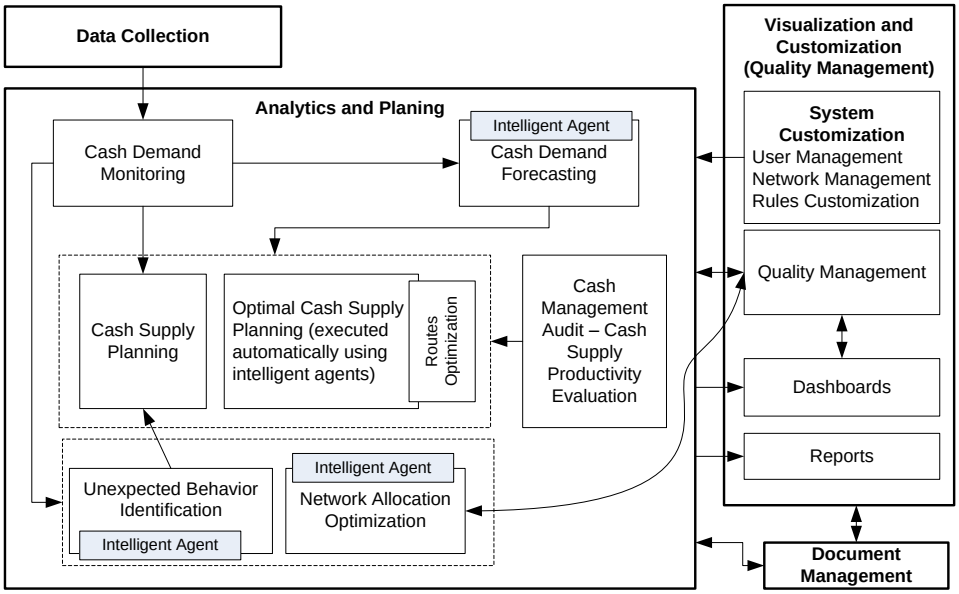

Figure 2 ATM cash management solution functionality (conceptual model)

Analysis of agent technologies application for ATM network management was carried out. Since ATM network is a distributed system, application of agent technologies for the management of cash planning is useful. Having created intelligent agents, ATM network may be managed not as centralized but as decentralized system, where every terminal is able to make decisions about the delivery of services, regarding the changing environment and the condition of nearby ATMs. Possibilities of intelligent agents use for the optimization of ATM network performance were evaluated. Intelligent agents are able to optimize three activity areas: resource supply and extent, selection of ATM location, and identification of unexpected situations.

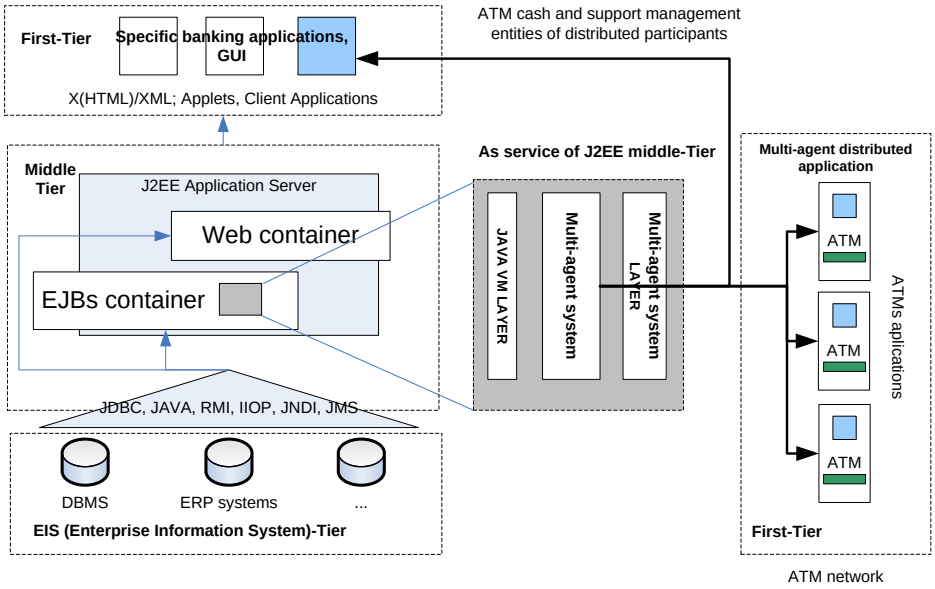

Figure 3 Multi-agent system platform architecture

The analysis of multi-agent system platform development tools was carried out. Multi-agent system creation platform should be standardized, have wide selection of

tools and use stable technologies. Platform J2EE is most suitable for agent platform creation. Platform JADE (Java Agent Development Framework) was selected for the creation of multi-agent system (Bellifemine et al., 2003). It supports agent system development standard FIPA, and is created on the basis of JAVA language.

Regarding the chosen technologies, multi-agent system platform architecture has been created (Figure 4). In the model of architecture multi-agent system is realized as J2EE service through EjB (Enterprise JavaBean™) components. The created multi-agent system (Figure 3) involves 5 areas of functions: neural network training, adaptation, and resource demand forecasting, optimization and data normalization. We detailed global multi-agent system model, which consists of such agents/components as list of agent services, agent management system, broker agent, train agent, forecasting agent, optimization agent, session agent, and data provider agent. The agents are responsible for neural network modeling. Neural network modeling libraries are realized through MatLab RunTime Environment.

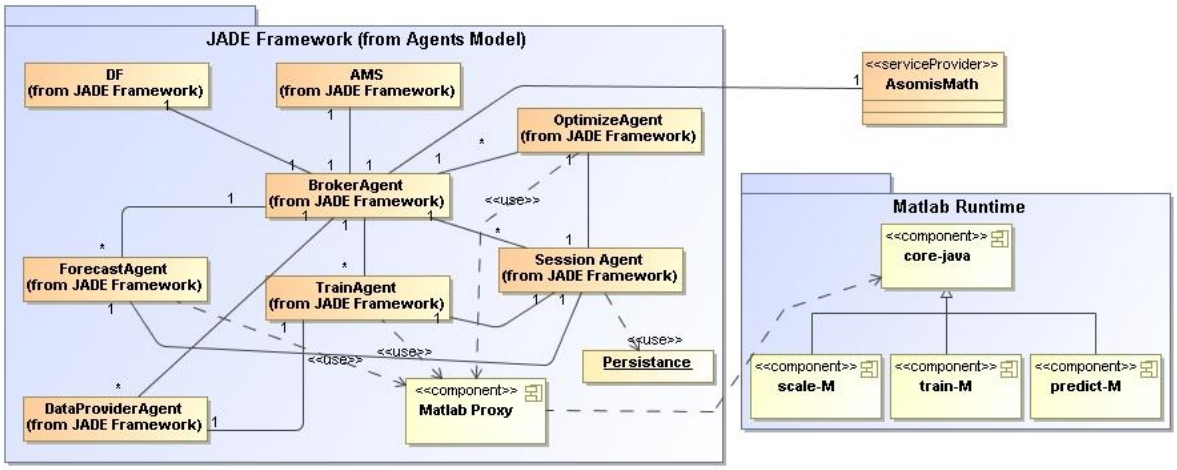

Figure 4 Agent model overview (Global design specification)

Optimal resource supply planning functionality is realized through Web Services. SystemMath broker is created for service delivery. The broker communicates with JADE platform through JADE Web service integration gateway.

Artificial Neural Network Model

The section discusses computational intelligence terms (Bezdek, 1992a; Eberhard et al., 1995). The main aspects of artificial neural networks creation and their application for time series forecasting are discussed. (Ajoy K. et al., 2005).

Neural networks are often used for time series prediction. Neural networks are used when the relationship between input and output data is not known. If this relationship is known, the data can be modeled directly. Neural network can learn the input-output data dependency during training and it is the key feature of neural networks. ANN forecasting methodology includes four steps (Ajoy K. et al. 2005): data preparation, network architecture selection, design of network training strategy, and overall evaluation of network. In most forecast applications a single hidden layer neural network is used.

Neural network and traditional statistic method forecast accuracy research proposes several important propositions (Lapedes and Farber; 1988; Sharda and Patil, 1990; Tang et al., 1991; Hill et al., 1996; Denton, 1995): forecasting data with linear dependencies, better forecast accuracy is reached with statistical methods; meanwhile forecasting data

with non-linear dependencies, better forecast accuracy is reached with neural networks. The quality of neural networks is much higher when low capacity time series are used for forecasting. When high capacity time series are forecasted, the results of traditional and ANN methods are very much alike. Properly chosen neural network is more effective than corresponding traditional algorithms, when time series of various complexities are forecasted.

Analysis of neural network application in the sector of finances was carried out (Refenes and Zapranis, 1993; Odom and Sharda, 1990; Dutta and Shekhar, 1988; Ravi Kumar, 2007; Leung, 2000; et al.). The authors show that better results may be achieved with the help of ANN than using traditional methods of statistics. Their unique training possibilities allow solving complicated finance management problems and ensure higher productivity and efficiency.

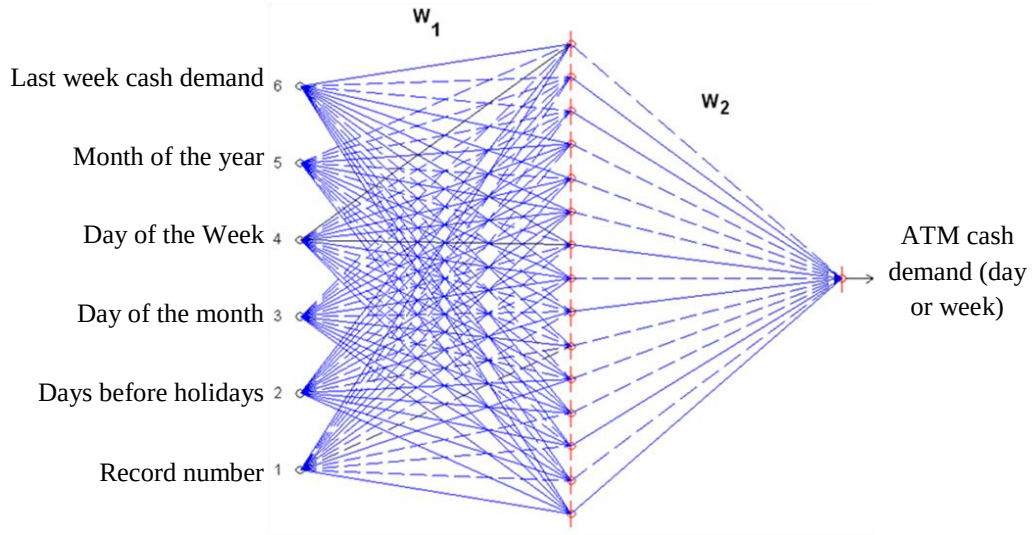

Figure 5 Structure of flexible neural network

Having conducted experimental research, direct spread multilayer neural network with one hidden layer, with fifteen neurons in the hidden layer (transfer function – hyperbolic tangent) and one output (linear neuron) was chosen for ATM cash prediction (Figure 5). Neural network has 6 inputs: average cash demand of the last 7 days, day of the week, month of the year, day of the month, days before holidays and time series record number. The output is ATM cash demand forecast for the following day or week if week discretion data is transferred.

Flexibility of neural network is controlled by limiting the weight of neural networks. For this reason, additional member D is introduced into the neural network prediction error expression, which punishes the network for high weight values (i.e. too high flexibility).

$$E = \frac{1}{2N} \cdot (\mathbf{y}_d - \mathbf{y})^2 + \frac{1}{2N} \mathbf{w}^T \cdot \mathbf{D} \cdot \mathbf{w} \quad , \mathbf{D} = \alpha \mathbf{I}, \qquad (1)$$

where *I – identity matrix, α - penalty for large weights, N – quantity of data.*

Model flexibility (coefficient alpha) can be adjusted separately for each ATM. Weights are optimized by applying gradient methods and Levenberg-Marquard optimization method.

$$\mathbf{w}(p+1) = \mathbf{w}(p) - \alpha \cdot \frac{\partial E}{\partial \mathbf{w}(p)} = \mathbf{w}(p) + \alpha \cdot (y_d - y) \cdot \frac{\partial E(\mathbf{x}, \mathbf{w}(p))}{\partial \mathbf{w}(p)} \qquad (2)$$

Flexibility of neural network D is determined adaptively in real time, depending on process complexity, therefore such network can operate better with unseen data. Modified *Levenberg-Marquardt* algorithm, which uses first order derivatives, is used for training of neural network.

Self-service Systems Performance Evaluation and Processes Improvement Methodology

The main quality evaluation criteria of self-service systems were analyzed. (Aldlaigan and Buttle, 2002; Bahia and Nantel, 2000; Jabnoun and Al-Tamimi, 2003; Joseph and Stone, 2003). Most authors distinguish 5 criteria, which make the basics of ATM service quality: sufficient size of ATM network, safe environment, user-friendly connection, convenient allocation, and ATM functionality.

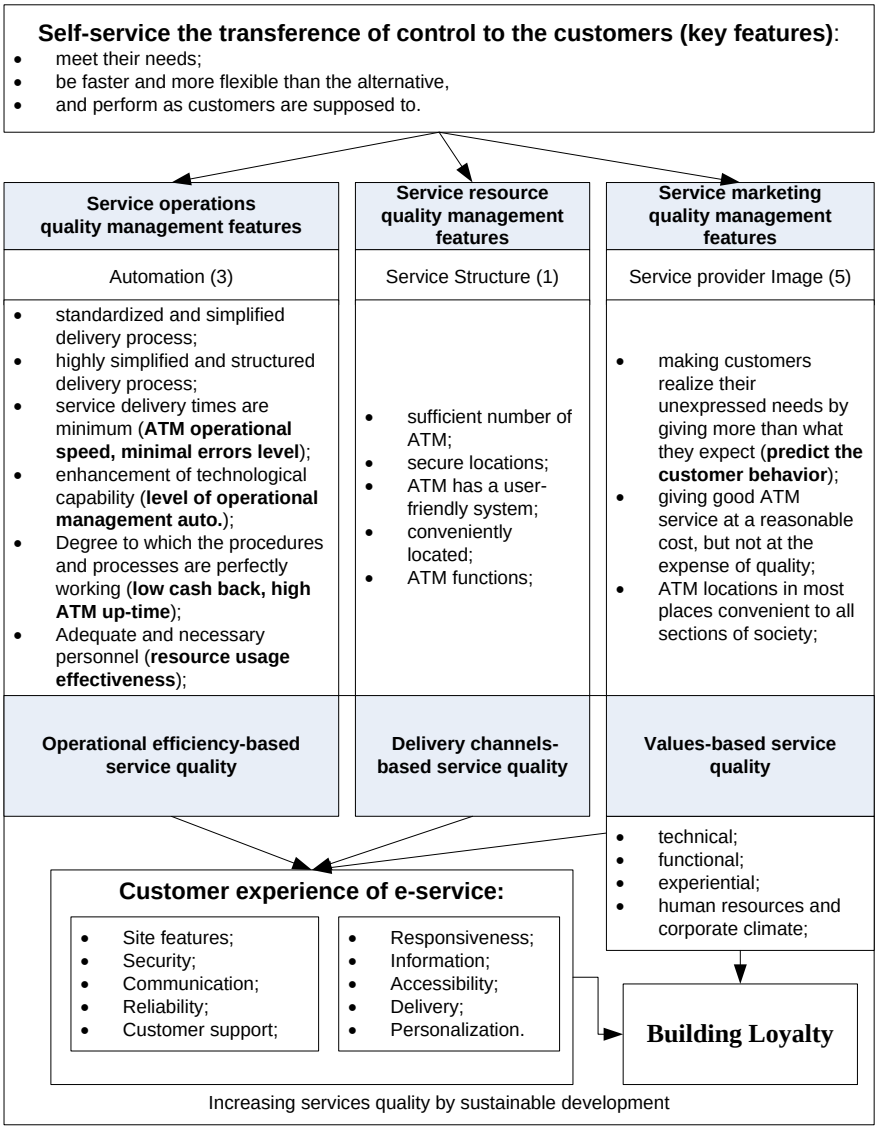

Figure 6 Values-based self-service quality evaluation model

Usage experience of self-service facility was analyzed. Dabholkar, 2000; Sara, 2000; Meuter et al., 2000; Zhu et al. 2002). It was found, that qualitative self-service facility is

the one which satisfies customer's needs, is faster than the existing alternatives, provides the functionality that a customer has expected, and allows personalizing it. Good delivery of e-services must be closely integrated with servicing system, service network, as well as purchase and delivery management. (Cox and Dale, 2001).

Value-based self-service facility quality assessment criteria model was structured (Figure 6). It includes three components of service quality evaluation – operation, resource and marketing management. It was found that the evaluation of service delivery should be carried out according to the criteria of e-service benefit/value: environmental features, security, communication speed, reliability, customer support, responsiveness, information completeness, availability, delivery and personalization (Jennifer Rowley, 2006).

We structured the model of self-service system performance criteria; the model details productivity components and sets of methodologies, which may be applied to ensure internal, external and capacity efficiency. It was found that internal productivity of self-service terminals may be increased by using cheaper maintenance resources if it does not have negative impact on quality, by implementing more advanced technological decisions if it does not have negative impact on quality, and by optimal distribution of resources. Service resources may be optimized the way that their amount in self-service infrastructure would always satisfy the demand, therefore it is necessary to know what the demand will be, and forecast tools must be used for its determination. Knowing the demand, it is possible to foresee necessary amount of resources, and this is especially important in such service systems, where resources are of short validity or are realizable and can be used to earn income by another way.

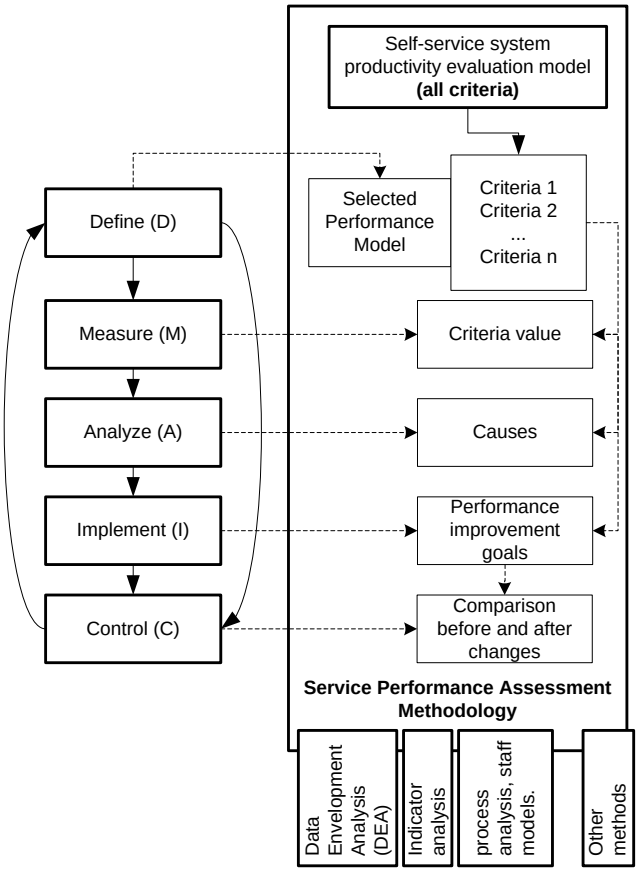

Figure 7 Self-service system performance assessment model

Self-service system performance model was structured and productivity evaluation criteria and their features were detailed. Productivity may be evaluated by physical, financial and combined measures; they may totally or partially evaluate productivity (according to Ojasalo, 1999). All productivity evaluation criteria may be derived from them. DEA analysis is most suitable for evaluation of internal performance of self-service systems. Electronic services quality model is applied for the evaluation of external performance of self-service systems (Santos, 2003). This model provides full set of criteria for the assessment of service content and functionality. IT-based model (Zhu et al., 2002), which assesses IT importance for the delivery of services is applied for evaluation of social aspects: age, mood for using e-services.

Improvement of business processes (with BPI) is a wide term. It analyzes three attitudes: process improvement, process redesign, and business process reengineering (Macdonald, 1995). The main aim of BPI methodology is to identify and implement improvements of business processes. Two BPI methodologies are analyzed in the chapter: Barry Povey (1998) of 14 stages and Adesola (2005) of 7 stages. Barry Povey presented a more detailed methodology compared to Adesola, his methodology coherently details what actions should be made in order to implement improvement of processes successfully. He also described change management tools. Methodologies include the same 6 stages: preparation, determination of core process, detailing of AS-IS process, detailing of TO-BE process, implementation of changes, and review of processes.

It is more expedient to use incremental BPI methodologies for the implementation of service system process changes, because radical changes in those systems can determine significant decrease of productivity, not its increase. The most suitable methodologies are Six Sigma and Lean, but they must be adapted for service sector, because at present they are usually applied in the sector of manufacture. Six Sigma (Hoerl et al., Arnheiter and Maleyeff, 2005) methodology is suitable for the assessment of service process productivity and structuring of control mechanism for its consistent development. A number of various statistical analysis methods exist in the arsenal of this methodology. Lean (Bicheno, 2004; Achanga, 2006) methodology is most suitable for identification of non-value-generating processes and eliminating them from value chain. Before eliminating non value-generating processes, it is certainly necessary to assess whether they are not part of client realized service quality, although they do not create any additional value. Jiju Antony (2006) proposed Six Sigma methodology adaptation for the development of service processes. Service systems are more complicated than production systems, because they are less defined and influenced by human factor. Their productivity is determined by a number of subjective factors, therefore process improvement should be oriented to the internal improvement of service systems by improving three productivity components: costs, resource distribution and capacity productivity. Technological productivity component describes external productivity features: functionality, service delivery speed and other.

The performed analysis of business improvement methods showed that various process improvement methodologies and methods are developed, however they lack systematic principles, which are intended for the implementation of organizational changes and set improvements (Brache and Rummler, 1997; Hammer, 2002). They lack clearly defined realization process. The methodologies are more of management manner rather than oriented to processes. The benefit of improvements depends on their

systematic implementation (Chong et al., 2001); therefore the created self-service system process improvement model is made of process improvement good practice, improvement process and quality management system implementation course. The model is detailed using "Zachman Framework" organizational architecture design methodology (models used: hierarchy of an organization, hierarchy of business processes, and work-flow models – BPMN notation).

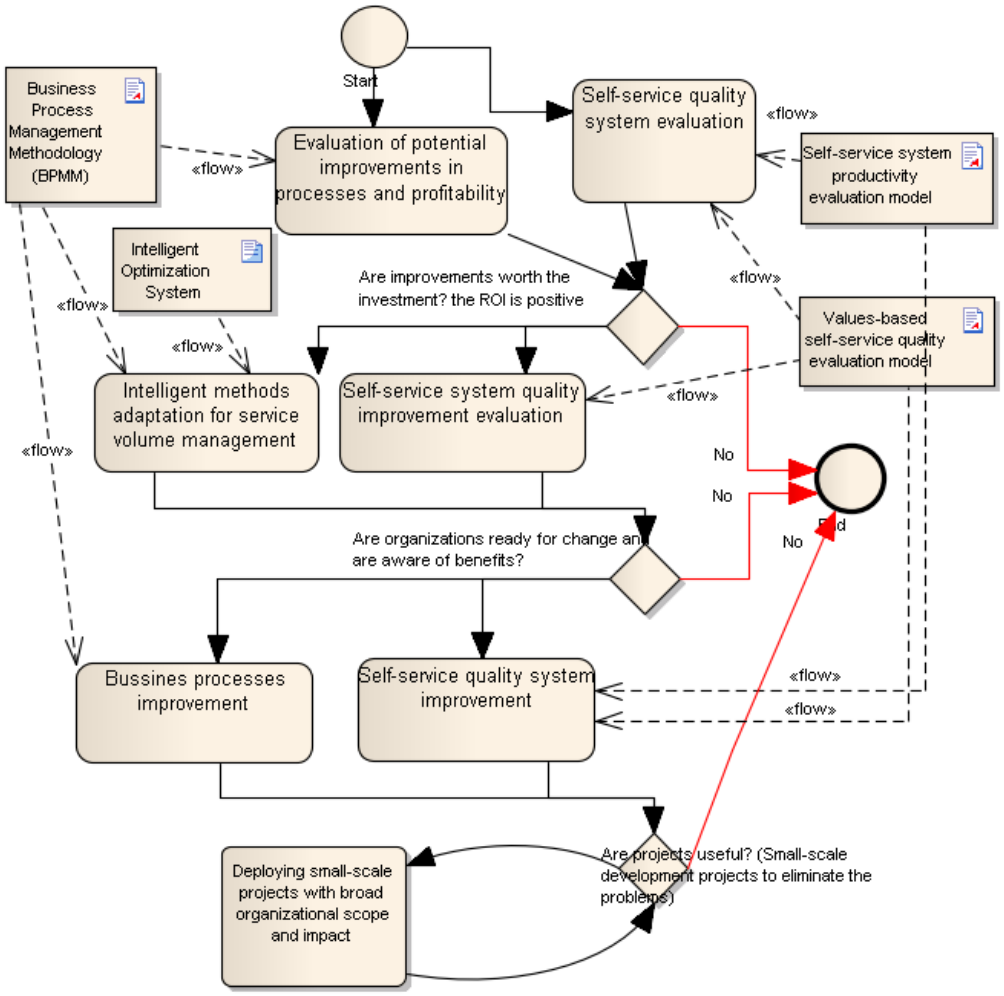

Figure 8 Self-service systems process improvement model (work flow diagram)

Detailed process course, created or used documents (artifacts) are described in work flow models (Figure 8), process owners are indicated. The structures self-service system process development model is based on the methodology of business process maturity model (BPMM, 2008). Its application ensures better realization of process development because typical problems emerge depending on the maturity level of organization processes. Every level has typical sets of improvements, which are used to improve processes up to the following level.

ATM Network Operations Performance Improvement and Management System

ATM network optimization topics include three areas: selection of optimal ATM network size (McAndrews and Ron, 1996), cash demand peculiarity (size of cash on the market) (Boeschoten 1992, 1998; Viren 1992; Snellman et al., 2000; Stix, 2003), and forecast of cash flow demand in ATM networks. Analysis of applied methods showed that most frequently analyzed economic models (dependencies) influence cash market

structure by factors. Real decisions and tools, which would help to optimize ATM cash management, are not provided.

The work describes the created ATM optimization function, which chooses such amounts of cash load, which minimize ATM operation expenses. Optimization is performed according to interest rate, upload costs, forecast recommendations and cash management limitations: cash balance, cash insurance expenses, maximum amount of cash, minimal amount of cash, possible ATM unavailability period. Outlet of optimization function is the date of cash upload into ATM and optimal cash amount, which is necessary to upload in an ATM in order to minimize ATM operation expenses.

$$ATM\ cash\ management\ costs = Cash * Interest + Cash * Insurance + (RUC\ or\ EUC) + Penalty \rightarrow minimize \quad (3),$$ where

Cash - ATM cash amount (limitations: possible minimum and maximum load); *Interest* - interest rate, %; *Insurance* - insurance rate, %; *RUC* - Regular upload costs; *EUC* - Extra upload costs; *Penalty* – penalty if ATM is not accessible more than 2% of all working time.

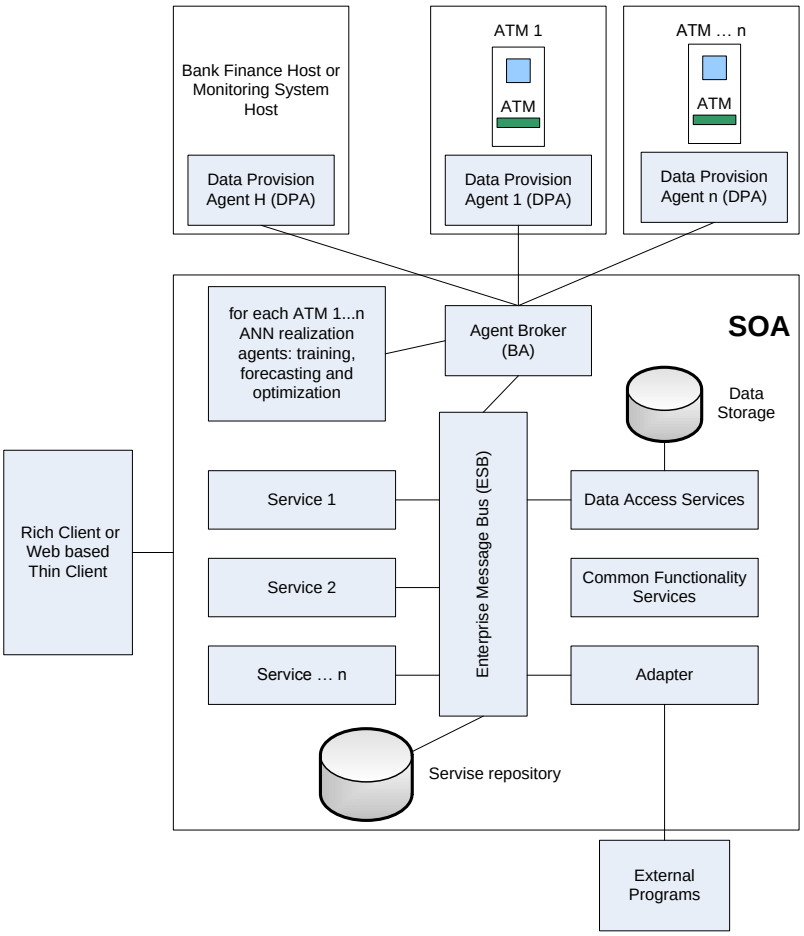

Figure 9 ATMiQ system architecture components

Two algorithms are used for goal function optimization. The essence of the first algorithm is a detailed reset of possible decisions. The essence of the second algorithm is stochastic simulated annealing optimization method, which seeks optimal decisions in a narrower space of decision-making by applying casual solution mutations.

The created agent system and ANN method is realized in ATMiQ product of the JSC “Five Continent Banking Technologies”, as one of modules intended to manage ATM

network cash planning. ATMiQ system platform is created on the basis of SOA ideology (Figure 9), using J2EE technology. System server is made using ESB technology (realized with application server JBossESB 4.4 GA). System application server consists of three servers: agent, services and DB. Agent server realizes agent functionality – manages agent life cycle, data collection from ATM, ant work of neural networks. Each ATM has its set of ANN agents. Service server provides system consumers with functionality. System data is stored on DB server.

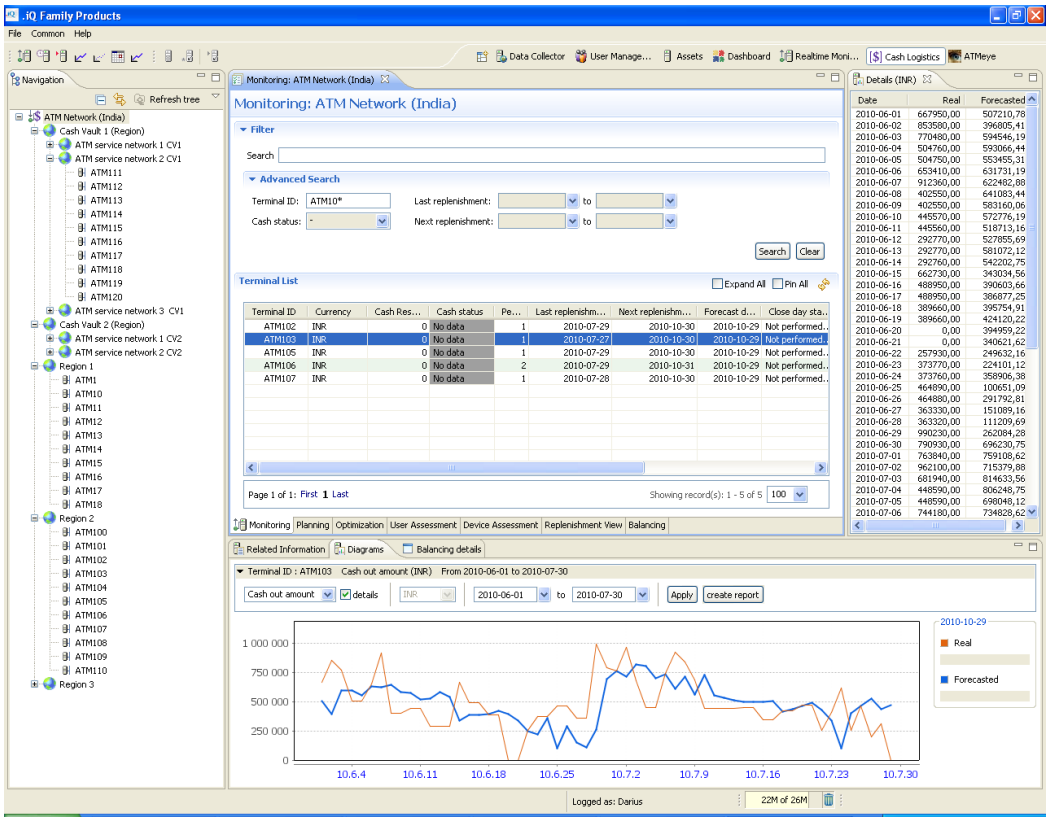

Figure 10 ATMiQ system cash management module window

ATMiQ system cash management module (Figure 10) realizes 5 main functions: cash monitoring, planning, optimization, user audit, audit of self-service equipment, collection plan review and cash management.

ATM Networks Profitability Simulation

Two types ATM network profitability evaluation models were created: high and low circulation. The models' performance criteria were selected according to self-service system performance evaluation model, internal and extent performance were analyzed (amount, price and resource distribution productivity components). Computing was performed with MatLab package. MatLab functions were created, they allow assessing ATM network performance and foreseeing methods for its improvement, compared to traditional forecast methods of time series (by Holt, Winters and ARMA) and neural networks. ANN forecast method quality and its advantage over classical methods are evaluated.

High load ATM network performance design results were detailed. Modeling was performed with the data of 361 ATM, which were received from the bank of India, which manages a network of 5500 ATMs. ANN method forecast accuracy analysis was performed (Figure 11). It was found that cash demand forecast accuracy is high in 28

ATMs (MAPE % is below 23%), moderately accurate in 148 ATMs, average in 115, sufficient in 40, and insufficient in 30. The created ANN forecast method may forecast cash demand quite accurately.

ATM was divided into three groups: accurate, forecast MAPE of these ATMs is within the interval [0; 22], average MAPE [31; 40], and inaccurate [51; 60]. Optimal traditional time series forecast model was chosen and forecast accuracy was evaluated for all the analyzed ATMs. The results of modeling show that ATMs, where forecast MAPE, using ANN methods are within the interval [0; 22], can be successfully forecast by classical time series models. It is recommended to use Winters' models with typical alpha [0,1; 0,4], beta [0,1], gamma [0,1; 0,3], phi is not significant. MAPE of ARMA models is insufficient 51.5%. In the group of average accuracy ATMs, forecast of ANN method was the most accurate, its average MAPE is 40%, MAPE forecast errors of classical models are significantly higher in Holt's models ~69%, in Winters' models ~53%, and in ARMA models are very inaccurate ~144%. In the group of inaccurate models ANN method revealed undoubted advantage, its average MAPE reached ~53.2%, meanwhile forecast errors of classical methods are very big, in Holt models ~290%, in Winters' models ~163%. ANN method is more superior than classical forecast methods of time series, if we assess ATM cash demand forecast. ANN method allows preserving quite good forecast results, working with various cash demand series, it flexibly adapts to various processes of time series.

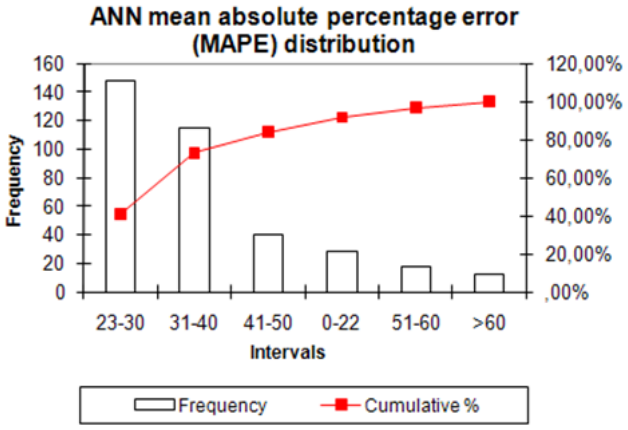

Figure 11 ANN prediction MAPE distribution (high-load networks)

High load ATM network productivity modeling was carried out, optimal (when ANN method is used) and typical models were evaluated. Average productivity of ANN model for a group of accurate ATMs is 17.73 % (assessing losses 11.16%). Optimal model, compared to a typical one is 18% more productive. This criterion characterizes extent productivity component and shows how productively the existing resources can be used. It is attributable to financial productivity criteria, and only partially evaluates productivity. The amounts of cash-back are decreased by 90%. This criterion shows the productivity of resource distribution. ATM model average productivity for a group of average ATMs is 26.27% (assessing losses 12.18%), amounts of cash-back are decreased by 32.2% (assessing loss 11.16%), and the amounts of cash-back are reduced by 653%. Benefit without loss is the highest in the group of inaccurate ATMs, its increase is determined by obvious facts, that is, bigger amounts of cash are uploaded in hardly forecasted ATMs, because standard deviation is much higher than in the case of accurate and average group models.

The comparison of classical models and ANN benefit for certain ATMs showed that there is slight difference of ANN economic benefit when modeling cash upload in the group of accurate ATMs. ANN methods allow achieving higher productivity even when assessing such ATMs where forecast MAPE for Holt and Winters models is lower. In the group of average ATMs ANN is a little more superior when assessing such ATMs where

forecast MAPE for Holt and Winters models is lower. Meanwhile in the group of inaccurate ATMs the difference between ANN and classical methods is high, compared to the results of the former two groups.

ATM network productivity modeling algorithm (cash circulation is high). In this case, money must be loaded into ATMs at least once a day or more. The potential economic benefits are calculated using the ANN forecasting tools. The comparison is done with the linear moving average model, which is generally applicable to banks.

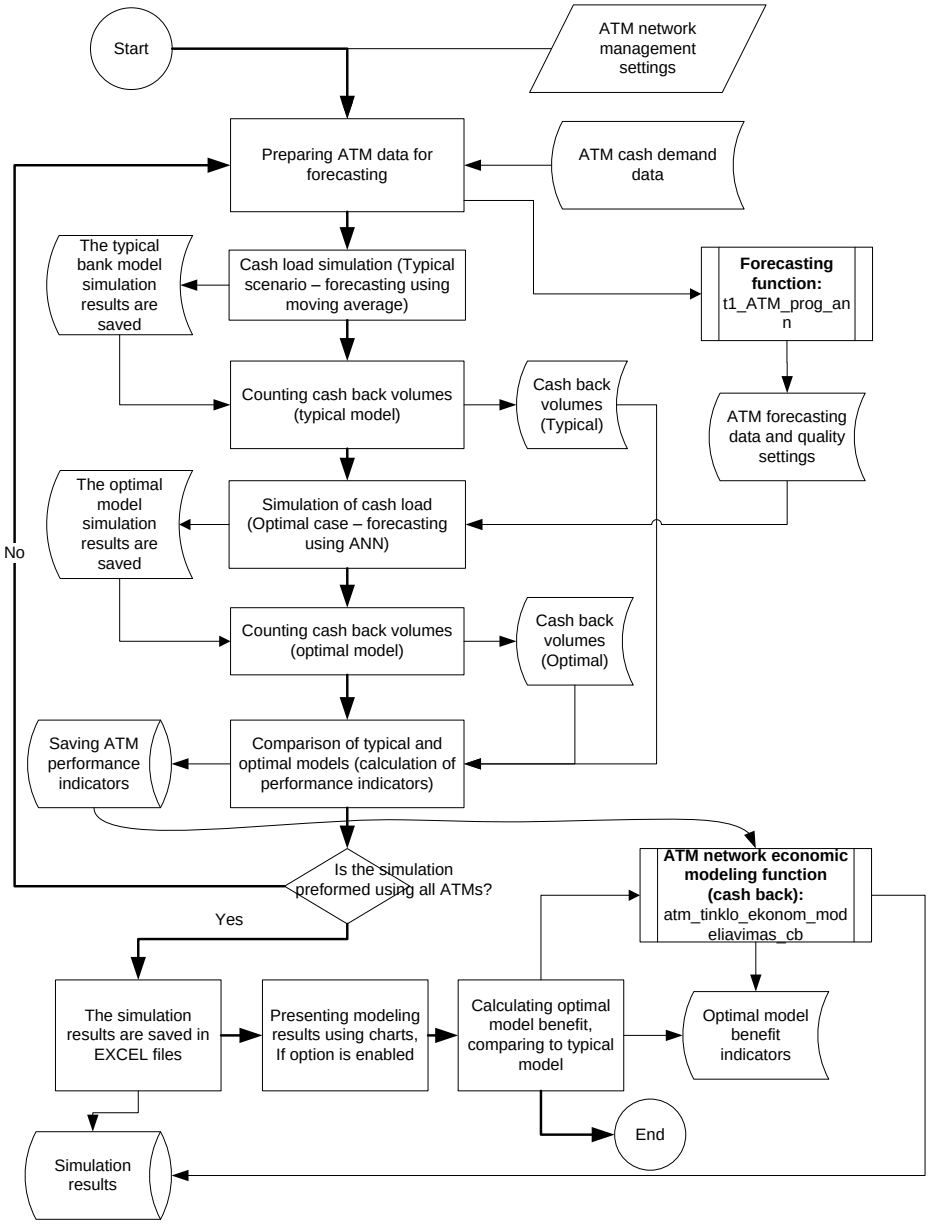

Figure 12 ATM network productivity modeling algorithm (cash circulation is high)

High load ATM network profitability modeling was performed. In regard to accurate ATM group, a network of 5000 ATMs can save 4250 Euros per day, and if the free cash is lent, 2660 Euros may be earned. Total saving and profit benefit would reach 6900 Euros per day, and it would allow making 2.52 million Euro profit per year. Average profit of all model groups is 2.35 million Euros per year.

Low load ATM network productivity modeling results were described. Modeling was performed with the data of 5 ATMs, the data was provided by one bank of Lithuania. ANN method and traditional time series forecast accuracy analysis, using the data of a day and a week, was performed. When forecasting cash demand of a day, ANN achieved

the most accurate results, its average MAPE for all ATMs reached 62.9%. This result shows that the forecast is unreliable, but unreliable results were determined by high fluctuation of cash consumption.

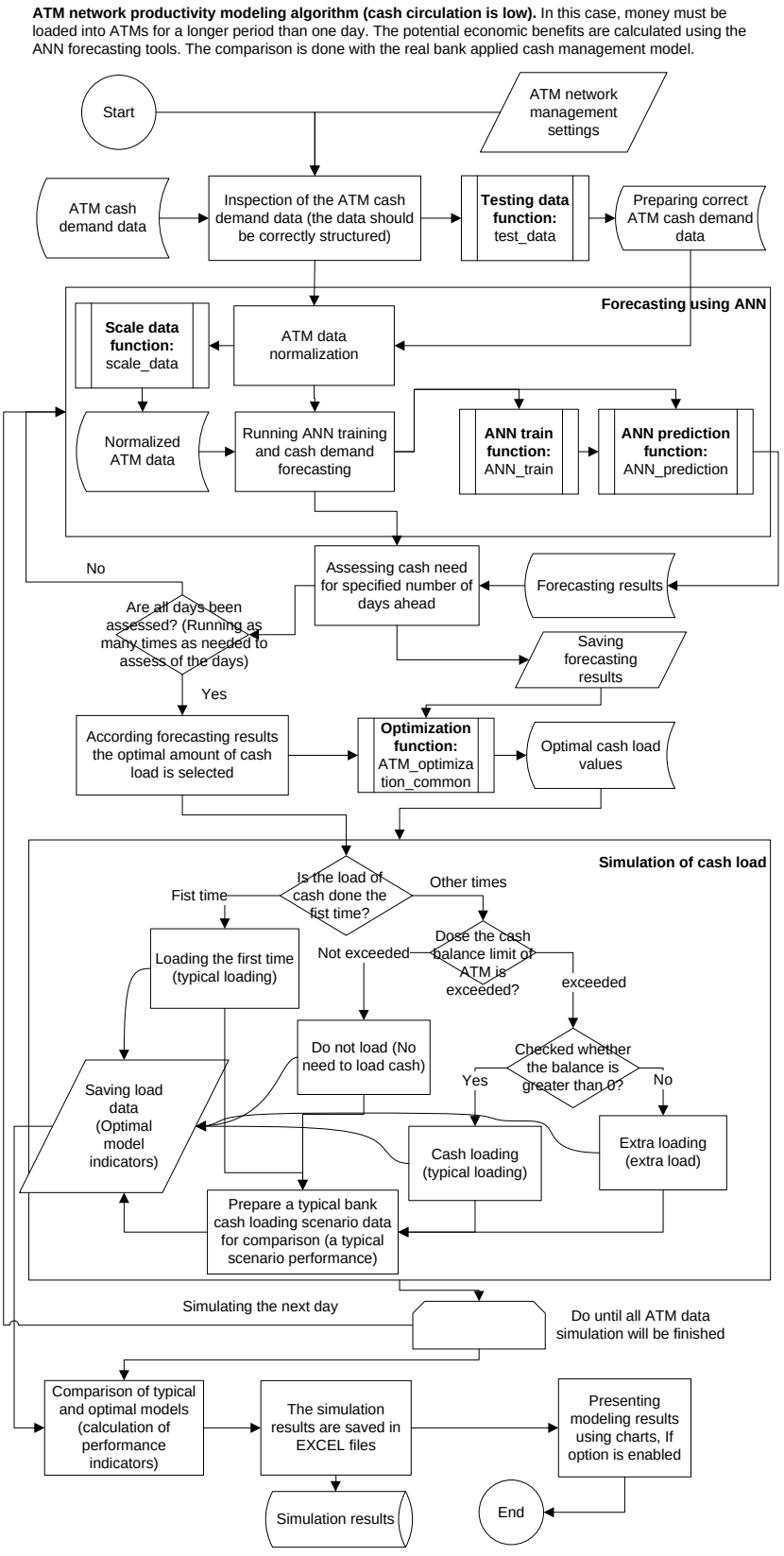

Figure 13 ATM network productivity modeling algorithm (cash circulation is low)

Methods of Holt, Winters and ARMA were inaccurate, their MAPE is respectively ~270%, ~218% and 550%. Week forecast results are better. ANN forecast error MAPE is 22.4%, Holt models ~12%, Winters ~13.7%. In this case classical methods were better than ANN, but this is regular when time series is accurately forecasted with ANN, classical models achieve good results. When ANN forecast is less accurate, their results decline.

Table 1 ATM network management efficiency modeling results of the Lithuania Bank

Optimal model (using ANN forecasting and optimization procedures)					
ATM number	**ATM5011**	**ATM1004**	**ATM1045**	**ATM2001**	**ATM7012**
From	2009-5	2009-2	2009-3	2009-5	2009-5
Till	2010-2	2009-11	2010-2	2010-2	2010-2
Average load	73928	58752	35732	36574	39695
Average Cash back	4225	5462	8277	3687	6938
Cash Back %	5.71%	9.30%	23.17%	10.08%	17.48%
Cash Load Quantity	50	46	36	35	31
Cash Price (interest from cash back)	244	400	723	281	460
Cash Load Price	1225	1125	875	850	750
Total Cash Price (CB)	1469	1525	1598	1131	1210
Frozen Cash (interest)	1469	2188	1709	1457	1264
Total Cash Price (UZ)	3409	3313	2584	2307	2014
Efficiency (CB)	47.11%	59.77%	-2.51%	68.88%	28.80%
Efficiency (UZ)	**44.75%**	**28.20%**	**28.36%**	**45.90%**	**15.18%**
Typical model (typical bank scenario)					
ATM number	**ATM5011**	**ATM1004**	**ATM1045**	**ATM2001**	**ATM7012**
From	2009-5	2009-2	2009-3	2009-5	2009-5
Till	2010-2	2009-11	2010-3	2010-2	2010-2
Average load	147616	88533	58685	46321	41401
Average Cash back	27505	49540	14313	26190	12686
Cash Back %	18.63%	55.96%	24.39%	56.54%	30.64%
Cash Load Quantity	38	49	23	59	34
Cash Price (interest from cash back)	1827	2566	984	2158	850
Cash Load Price	950	1225	575	1475	850
Total Cash Price (CB)	2777	3791	1559	3633	1700
Frozen Cash (interest)	5220	3390	3031	2789	1525
Total Cash Price (UZ)	6170	4615	3606	4264	2375

Low load ATM network productivity modeling was performed, optimal (when ANN method is used) and typical models (real bank process) were evaluated (Table 1). In optimal case, average cash-back amounted 13.15%. In typical case – 37.23%. Using the created ATM network cash management model, the amounts of cash-back were decreased by 24.08%, compared to a real scenario. Model efficiency shows that using the

created ANN method and optimization procedure, the cash supply productivity of certain ATMs may be increased by 44.75% (ATM5011), 45.90% (ATM2001).

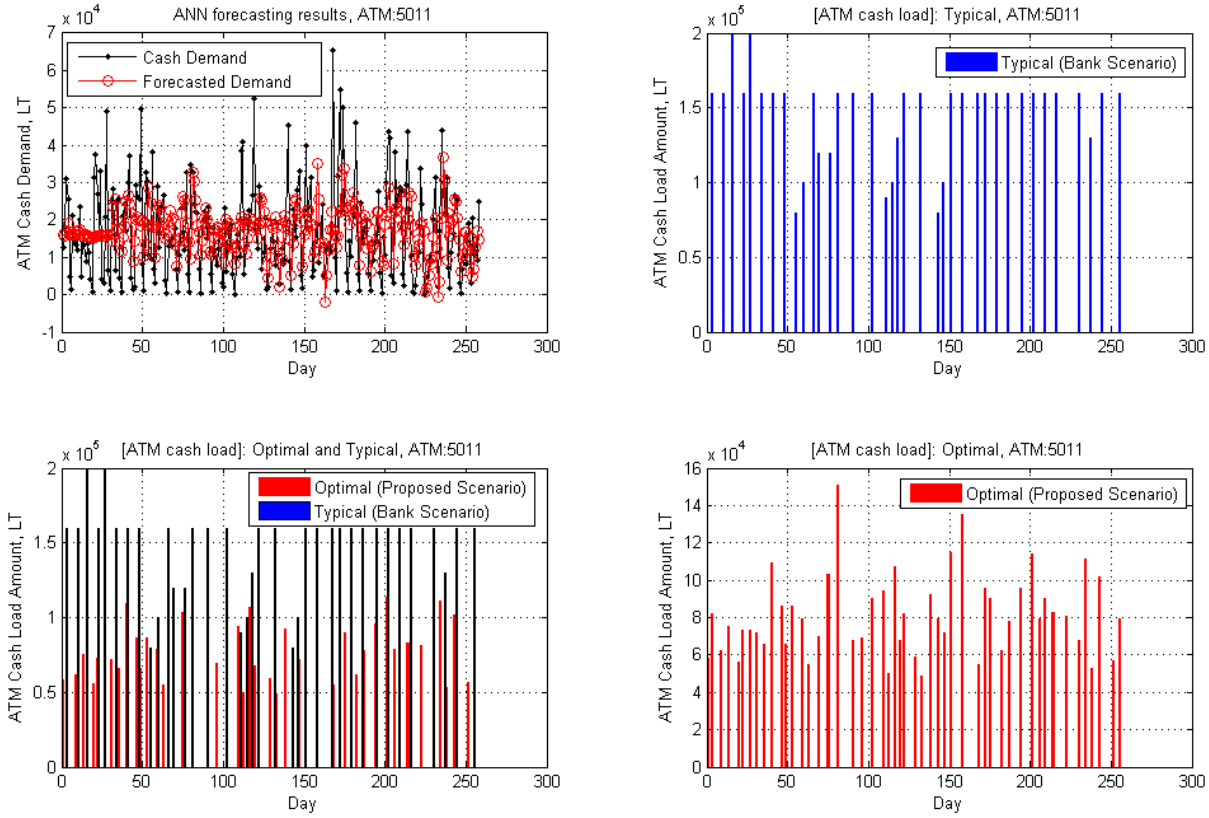

Figure 14 Cash load model: ATM5011

Figure 13 presents graphic generalization of modeling results of ATM No 5011; we notice that in case of optimal scenario, cash collecting is balanced regarding cash demand. Using the created ANN method and optimization procedure, cash supply productivity of ATM5011 is increased by 44.75% (ATM5011), compared to the model which is applied in a bank.

General Conclusions

1. Having performed the quality and productivity management methods analysis of electronic and self-service facilities systems, it was found that
   a) productivity management of services is a very important topic, however, little empirical research is made in this area;
   b) 6 models of quality management of e-services are usually applied: IT alignment model; Attribute and overall affect model; Internal service quality DEA model; Internet banking model; IT-based model; Model of e-service quality;
   c) productivity consists of 4 components: price, resource allocation, technological and scale efficiency;
   d) the main dilemma of productivity is the balancing of income and costs, because services cannot be stored;
   e) the only theoretically and practically significant way to compute productivity of services is financial criteria.

2. The analysis of ATM network management and application of agent systems for ATM network management showed that:
    a) there are 3 management models of ATM networks: (1) total transfer of functions, (2) partial transfer of functions and (3) retention of functions;
    b) ATM network operation efficiency may be increased by implementing more advanced technical decisions, synchronizing operators' work, creating and implementing advanced productivity management systems, using network for the delivery of new services, and increasing security;
    c) cash related costs make 26% of all ATM network maintenance expenses, therefore the increase of cash management functions productivity may significantly decrease ATM maintenance costs if cash or other service functions are not planned efficiently.
    d) Intelligent agents in ATM networks may be used to increase the productivity of resource delivery and volumes, ATM location selection, and identification of unexpected situations.
3. Technological analysis showed that platform J2EE is most suitable for the creation of ATM network cash management platform, and JADE platform is most suitable for multi-agent system creation.
4. The created ATM cash management multi-agent model allows making real-time decisions:
    a) the model consists of the list of agent services, agent management system, broker agent, train agent, forecasting agent, optimization agent, session agent, and data provider agent;
    b) Agents are responsible for the realization of flexible neural network: data preparation (normalization), neural network training, adaptation, resource demand forecasting and realization of optimization procedure.
    c) One set of agents realizing flexible neural network and optimization procedure is created for each ATM in real-time.
5. Analysis of artificial neural network application for the forecast of time series showed that:
    a) the quality of neural networks is significantly higher, when low capacity time series are used for forecasting;
    b) the results of traditional and ANN methods are very similar when forecasting high capacity time series;
    c) Properly chosen neural network is more efficient that the corresponding traditional algorithms when various complexity time series are forecasted.
    d) when forecasting data with linear dependences, statistical methods help to achieve better forecasting accuracy; meanwhile when forecasting data with non-linear dependences, neural networks help to achieve better forecasting accuracy.
6. Analysis of neural network application in the sector of finances shows that better results may be achieved with the help of ANN than applying traditional statistical methods. Their unique training possibilities allow solving complex finance management problems and ensure higher productivity and efficiency.
7. ATM cash demand can be precisely forecasted using:

a) multilayer feed-forward neural network with one hidden layer, fifteen neurons in the hidden layer (transfer function- hyperbolic tangent), and one output (linear neuron);
b) six inputs: average cash demand in the last 7 days, day of the week, month of the year, day of the month, days remaining before holidays, and time series record number.
c) One output: cash demand forecast for the following day or set discretion.
d) Neural network flexibility is regulated by limited neural network weights. Flexibility is determined adaptively, in real time, depending on process complexity, therefore such network operates better with unseen data;
e) *Levenberg-Marquardt* algorithm, using first line derivatives, is used for training of neural network.

8. Analysis of process improvement methods and methodologies showed that:
   a) it is more purposeful to use consistent business process improvement methodologies for the implementation of service system processes;
   b) the most suitable methodologies are Six sigma and Lean. Six Sigma methodology is suitable for the evaluation of service process work productivity and the formation of control mechanism for its consistent improvement. Lean methodology is most suitable for identification of non-value-generating processes and their elimination from value chain;
   c) improvement of service system processes should be oriented to internal service system productivity development, refining three productivity components: costs, resource allocation and extent productivity;
   d) methodologies and methods do not provide clearly defined process of improvements realization;
   e) the benefit of improvements depends on their systematic implementation;
9. The created self-service system assessment and process improvement methodology allows evaluating and systematically implementing the foreseen service system improvements and productivity management tools:
   a) Service delivery evaluation should be performed according to the benefit/value criteria of e-services: environmental features, security, communication speed, reliability, customer support, responsiveness, information completeness, availability, delivery and personalization.
   b) Internal productivity of self-service terminals may be increased by using cheaper maintenance resources, implementing advanced technological decisions if it does not have negative impact on quality, or distribute resources more productively.
   c) More productive distribution of resources may be performed with accurate service demand forecast measures.
10. The created ATM cash management system allows decreasing service delivery costs without influencing the quality of services:
    a) ATM service delivery expenses are decreased by optimizing resource supply costs: cash balance, cash insurance, and collection;
    b) in order to ensure service quality, a penalty member is used which increases servicing costs if more that 2% of customers are serviced;
    c) the created ATM network optimization function selects such cash upload amount, which minimizes ATM working expenses;

d) if ATM network is smaller than 100, a detailed possible decision reset by cash demand step should be used for goal function optimization;
e) if ATM network is larger than 1000, stochastic simulated annealing method should be used for goal function optimization.

11. Analysis of high and low load ATM network profitability showed that:
    a) the created flexible neural network forecast method is more superior than classical methods of time series forecast (moving average, Holt, Winters, ARMA), and is able to quite accurately (MAPE 33%) forecast various time series of ATM cash demand;
    b) ATM cash demand time series, which have clear seasonal dependences (day of the week, day of the month, month of the year, and days before holidays), are accurately forecast applying both flexible neural network model and classical time series forecast methods (moving average, Holt, Winters, ARMA);
    c) Flexible neural network method and the created optimization procedure used in high and low load ATM networks allow decreasing the amounts of cash-back by 24% and increasing cash management productivity up to 33%.
12. The created multi-agent system and flexible neural network model were realized in the ATM network management product of JSC “Five continent banking technologies” as one of modules intended to manage ATM network cash planning.

List of Published Works on the Topic of the Dissertation

Articles published in periodical and occasional journals included in ISI Web of Science Database

1. R. Simutis, D. Dilijonas, L. Bastina, J. Friman, P. Drobinov. Optimization of cash management for ATM network // Information technology and control. 2007, t. 36, No. 1A, p. 117-121.

Articles published in journals included in the ISI Proceedings list

1. D. Dilijonas, D. Krikščiūnienė, V. Sakalauskas, R. Simutis. Sustainability based service quality approach for automated teller machine network. // Knowledge-based technologies and OR methodologies for strategic decisions of sustainable development: 5th international Vilnius conference, EURO-mini conference, September 30-October 3, 2009: Selected papers/edited by M. Grasserbauer, L. Sakalauskas, E. K. Zavadskas. Vilnius, 2009. ISBN 9789955284826. p. 241-246.
2. R. Simutis, D. Dilijonas and L. Bastina, Enhanced supervision of automatic teller machines via auto associative neural networks //Applied stochastic models and data analysis (ASMDA-2009): the 13th international conference, June 30-July 3, 2009, Vilnius: selected papers. Vilnius: Technika, 2009. ISBN 9789955284635.
3. Dilijonas D., Sakalauskas V., Kriksciuniene D., Simutis R. Intelligent systems for retail banking optimization: optimization and management of ATM network system. // ICEIS 2009: 11th international conference on enterprise information systems: proceedings: artificial intelligence and decision support systems, Milan, May 6-10, 2009. Milan, 2009. ISBN 9789898111852. p. 321-324.
4. Simutis R., Dilijonas D., Bastina L. Identification of unexpected behavior of an automatic teller machine using principal component analysis models. // Business Information Systems Workshops 2009: BIS 2009 international workshops, Poznan, Poland, April 2009: revised papers. Book Series: Lecture Notes in Business Information Processing, Vol. 37. Berlin: Springer, 2009. ISBN 9783642011894. p. 53-61
5. D. Dilijonas, D. Zavrid, Retail banking e-services management optimization research for real-time decision support using BDI software agents // Continuous optimization and knowledge-based technologies: 20th EURO Mini conference (EurOPT-2008), May 20-23, 2008, Neringa, Lithuania. Vilnius: Technika, 2008. ISBN 9789955282839. p. 416-421.
6. Simutis R., Dilijonas D., Bastina L., Cash demand forecasting for ATM using neural networks and support vector regression algorithms // Continuous optimization and knowledge-based technologies : 20th EURO Mini conference (EurOPT-2008), May 20-23, 2008, Neringa, Lithuania. Vilnius: Technika, 2008. ISBN 9789955282839. p. 416-421.
7. R. Simutis, D. Dilijonas, L. Bastina, J. Friman. A flexible neural network for ATM cash demand forecasting // 6th WSEAS International Conference on computational intelligence, man-machine systems and cybernetics, Tenerife, Spain, December 14-16, 2007. Tenerife, 2007, p. 163-166.
8. D. Dilijonas, L. Bastina. Retail banking optimization system based on multi-agents technology // 16th WSEAS International Conference on computational intelligence, man-machine systems and cybernetics, Tenerife, Spain, December 14-16, 2007. Tenerife, 2007, p. 204-209.

International conference of foreign material

1. Rimvydas Simutis, Darius Dilijonas, Lidija Bastina; Intelligent Cash Management System for an ATM network // International Computer Science and Technology Conference: ICSTC 2008 PROCEEDINGS, Edited by John Bugado, Mohammad Amin, Pradip Peter Dey, Chuck Brown, and Arun Datta, 256 - 265 p.

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Courses and certificates

2010	Information systems development (UML methodology) courses certificate
2008	ITIL (Information Technology Infrastructure Library) courses certificate
2008	PMP (Project Management Professional) courses certificate
2007	CompTIA Project+ (Computing Technology Industry Association) courses certificate

Awards

2008	Winners of the Innovation Award 2008: Category of Innovative Product. Innovation Award (http://www.inovacijuprizas.lt/) is the annual contest aiming at fostering the entrepreneurial thinking, technological development and providing a possibility for enterprises to self-assess their competitiveness and innovativeness.
2006	Award of Munister, being issued for most talented Baltic states students and young scientists.

DAKTARO DISERTACIJOS SANTRAUKA

Tyrimų sritis

Globalizacija ir rinkos liberalizavimas įtakoja ekonominius pokyčius. Organizacijos pradeda suprasti, kad esminis dalykas yra ne pelno maksimizavimas, o pelno maksimizavimas didinat vartotojų pasitenkinimą teikiamomis paslaugomis. Šiuo metu yra svarbus ne tik paslaugos teikimo procesas, bet ir tai kaip paslauga yra teikiama. Informacinių technologijų vystymasis daro didelę įtaką paslaugų teikimui ir visam aptarnavimo sektoriui. Vartotojas dabar turi daugiau informacijos ir geresnį suvokimą apie paslaugą, todėl konkurencingumą lemia kokybė, o kokybė lemia pelningumą (Seth ir kiti, 2005).

Gartner (2008) pastebi, kad daug kas pasikeitė aptarnavimo sektoriuje. Prekybininkai pradeda suprasti, kad technologijos gali turėti lemiamą svarbą pelno ir veiklos našumo padidinimui. Efektyvių IT sprendimų taikymas lemia mažo pelningumo aptarnavimo sektoriaus išlikimą. Technologijų svarba įgauna dar didesnį vaidmenį, kuomet dėl ekonominės krizės mažėja pardavimai, o išaugusi konkurencija verčia mažinti prekių kainas ir didinti paslaugų kokybę. Realaus laiko verslo valdymo sistemos, galinčios numatyti ateities verslo pokyčius tampa prioritetu numeris vienas. Prognozuojama, kad verslo intelektikos sistemos iki 2012 metų pasikeis iš sistemų kurios „pasako kodėl tai nutiko“ į sistemas, kurios atsakys į kur kas svarbesnį klausimą „kas atsitiks ateityje“. Nuo 2010 metų prasideda prognozuojamosios analitikos era. Gartner ir Forrester kompanijos nurodo, kad iki 2012 metų realaus laiko verslo analitikos sistemos taps neatskiriama verslo veiklos valdymo dalimi.

Darbas nagrinėja aptarnavimo sistemų našumo/pelningumo problematiką. Darbe orientuojamasi į savitarnos paslaugų sritį, konkrečiau į ATM (bankomatų) tinklų našumo didinimą. Elektroninių aptarnavimo sistemų pelningumas priklauso nuo jų darbo našumo ir teikiamų paslaugų kokybės. Aptarnavimo sistemų darbo našumą galima užtikrinti tobulinant ir efektyviau planuojant teikimo procesą. Šiose sistemose labai svarbu priimti savalaikius sprendimus, kad nenukentėtų teikimo procesas. Paslaugų kaip produktų sandėliuoti negalima, todėl netinkami sprendimai yra susiję su tiesioginiu pajamų praradimu ir kokybės mažėjimu.

Elektroninių aptarnavimo paslaugų našumą galima užtikrinti diegiant pažangias realaus laiko sprendimų valdymo sistemas, keičiant paslaugų sistemų kokybės valdymo supratimą iš tradicinio į prognozuojamąjį. Tokiose sistemose kokybė užtikrinama, numatant paslaugų sistemos elgseną. Duomenų surinkimui iš paskirstytų paslaugų taškų naudojamos multi-agentų technologijos. Protingi agentai pagal surinktus duomenis įvertina paslaugų sistemos resursų poreikį, pagal tai suplanuoja jos darbą, kad teikiamoms paslaugoms pakaktų resursų ir būtų išlaikyta aukšta kokybė bei maksimalus sistemos prieinamumas. Paslaugų sistemos darbas turi būti valdomas realiu laiku, taikant resursų planavimo ir optimizavimo intelektines sistemas. Žinoma, be aptarnavimo paslaugų kokybės valdymo modelių ir sistemų, minėtos priemonės yra tik įrankiai, todėl kartu turi būti taikomi ir našumo valdymo modeliai.

Darbo aktualumas

Paslaugu sferoje produktyvumo koncepcija pradėta nagrinėti tik XX amžiaus pabaigoje. Paslaugų sektorius yra vienas iš sparčiausiai augančių ekonomikos segmentų (Sahay, 2005), tačiau paslaugų produktyvumo valdymo srityje atlikta labai mažai

empirinių tyrimų. Paslaugų produktyvumo teorijos pagrindus suformavimo Gronroos (2004), Chase ir Haynes (2000). Jie nagrinėjo gamybos ir paslaugos produktyvumo sąvokų panašumą ir skirtumus, suformavo pagrindinius paslaugų produktyvumo apibrėžimus. Ojasalo (1999) suformavo paslaugų produktyvumo modelį. Sherman (2006) apibūdino paslaugų produktyvumo komponentus. Seth (2005) atliko kokybės valdymo modelių, sukurtų 1984-2003 laikotarpyje tyrimą. Aiškiai galima pastebėti, kad paslaugų teikimo procesas keičiasi iš tradicinio į pagrįstą informacinėmis technologijomis. Informacinių technologijų taikymas paslaugų kokybės valdyme įgauna didelę svarbą. Paslaugų sektoriaus produktyvumas priklauso nuo technologijų ir proceso automatizacijos priemonių (Gummesson, 1998), šiuo metu ši tendencija yra dar ryškesnė, kuomet didėja paslaugų sektoriaus konkurencingumas. Paslaugų teikimas per savitarnos terminalus arba kompiuterines sistemas, leidžia padidinti paslaugų sistemos našumą ir teikiamų paslaugų aptarnavimo kokybę. Akivaizdu, kad našiai dirbančioms sistemos būdingas aukštesnis pelningumas (Sherman ir kiti, 2006).

Literatūroje pristatomi įvairūs elektroninių paslaugų kokybės valdymo modeliai (Dabholkar, 1996), (Soteriou ir Stavrinides, 2000), (Broderick ir Vachirapornpuk, 2002), (Zhu ir kiti, 2002), (Santos, 2003). Dauguma iš pateiktų modelių yra koncepciniai, nepateikia kokybės vertinimo kriterijų, mechanizmo ir priemonių. Literatūroje pažymima, kad nėra universalių paslaugų produktyvumo vertinimo priemonių, kaip produktų gamybos sektoriuje, vertinimui galima taikyti įvairias metodikas ir jų junginius. Paslaugų procesas yra atvira sistema, todėl tradicinių (gamybinių) našumo vertinimo sistemų taikymas gali sąlygoti neteisingus rezultatus. Pagrindinė paslaugų sistemų produktyvumo dilema yra pajamų ir kaštų subalansavimas, nes paslaugų negalima sandėliuoti. Subalansavimo problemą galima išspręsti pereinant prie prognozuojamojo paslaugų sistemos resursų valdymo. Tam reikia pritaikyti intelektualias realaus laiko sistemas (Muhlen ir Shapiro, 2010; Agrawal, 2009; Azvine, 2005; Nguyen Manh ir kiti, 2005; Seufert ir Schiefer, 2005; Ranjan, 2008), kurių pagalba būtų galima priimti greitus sprendimus ir prognozuoti paslaugų sistemos elgseną, numatant optimalias jos valdymo apimtis.

Mokslas per pastaruosius metus stipriai pažengė į priekį intelektinių sistemų srityje. Sukurti įvairūs metodai ir priemones sudėtingų verslo optimizavimo ir valdymo problemų sprendimui. Šie metodai remiasi biologiniais ir natūralaus intelekto principais. Jie apima dirbtinius neuroninius tinklus, neryškių aibių sistemas, multi-agentų sistemas, evoliucinių skaičiavimų ir skaitinio intelekto sistemas. Visi kartu jie yra apibrėžiami, kaip intelektinės sistemos (Engelbrecht, 2002, Konar, 2005, Eberhart and Shi, 2007). Sistema yra intelektuali tada, kai gali išmokti ir prisitaikyti prie naujos situacijos, geba apibendrinti žinias ir jose atrasti asociacijas. Adaptyvumas ir gebėjimas prisitaikyti yra neatskiriama realiai veikiančios sistemos savybė. Žinių apibendrinimo ir asociacijų paieškos savybės intelektinėms sistemoms suteikia pranašumą prieš tradicinius prognozavimo metodus. Hu (1964) pirmasis praktiškai pritaikė neuroninius tinklus oro prognozavimui. Vėliau eksperimentinius tyrimus atliko Werbos (1974), jis laiko eilučių prognozavimui pritaikė neuroninius tinklus. Werbos (1989, 1990) atlikęs eksperimentus su atvirkštinio sklidimo apmokymo algoritmu, padarė išvadas, kad neuroniniai tinklai gali pateikti tikslesnes prognozes lyginant su statistikos metodais: regresine analize ir Box-Jenkins prognozavimo metodu. Lapedes ir Farber (1988) pirmieji pateikė pagrindimą, kad paprastas neuroninis tinklas gali aplenkti tradicinius prognozavimo metodus. Vėliau sekė Sharda ir Patil (1990) tyrimai, kurių metu buvo lyginama Box-

Jenkins ir neuroninių tinklų prognozavimo kokybė, naudojant 75 skirtingas laiko eilutes. Sharda ir Patil, Tang ir kiti (1991), atlikę tyrimus suformavo, kad ANN prognozavimo tikslumas yra didesnis, lyginant su tradiciniais laiko eilučių modeliais.

Jokia tiksli prognozė ir tinkamas paslaugų valdymas neįmanomas be korektiškai ir savalaikiai surinktų duomenų, todėl agentų sistemos (Wooldridge ir Jennings, 1995, 1997) yra kitas svarbus realiai funkcionuojančios verslo intelektikos sistemos komponentas. Multi-agentų sistema yra viena iš tinkamiausių priemonių realaus laiko duomenų surinkimui iš paslaugų tinklo taškų. Agentų technologijų taikymas yra tik ankstyvoje stadijoje. Daug tyrėju pristato įvairias taikymo vizijas, tačiau realių diegimų yra labai mažai (Luck ir kiti, 2005; Wagner, 2005). Agentų sistemas realaus laiko duomenų rinkimui ir valdymui galima sėkmingai pritaikyti e-paslaugų sektoriuje, konkrečiau savitarnos terminalų tinklų paslaugų sistemose. Šios sistemos yra paskirstytos, jų kompiuterizavimo lygis yra aukštas, todėl galima sėkmingai surinkti reikiamus duomenis ir atlikti paslaugų tiekimo optimizavimą.

Geros prognozavimo ir duomenų valdymo priemonės negarantuoja našaus savitarnos sistemų darbo. Semeijn ir kiti (2005) parodė, kad paslaugų aptarnavimo sistemos darbas yra ne ką mažiaus svarbesnis už pačią e-paslaugų sistemą. Pačių geriausių ir funkcionaliausių ATM diegimas, be tinkamai funkcionuojančios aptarnavimo sistemos, negali garantuoti aukšto savitarnos paslaugų lygio. Voss (2003) atlikti tyrimai rodo, kad mažmeninėje bankininkystėje paslaugų kokybės lūkesčiai tik beveik atitinka gaunamą paslaugą. Problemos atsirandančios paslaugų sistemose gali sutrikdyti teikimo procesą (Zhang ir Prybutok, 2005), daugumoje atvejų neprieinamos paslaugos stipriai mažina paslaugos lojalumą (Watcher, 2002). Todėl svarbu suderinti vidinius ir išorinius kokybės kriterijus tarpusavyje. Literatūroje dažniausiai nagrinėjama viena arba kita kriterijų grupė, o bendras modelis savitarnos tinklų kokybės valdymui nėra pateikiamas.

Vidinė sistemos kokybė garantuojama, naudojant pažangias valdymo priemones, kurios leidžia optimizuoti veiklos kaštus ir paslaugų teikimo procesą, ir vidinės kokybės valdymo sistemas, kurios yra paremtos našumo kriterijų rinkiniais. Literatūroje išnagrinėtos ATM tinklų vidinės kokybės valdymo sistemos (Aldlaigan ir Buttle, 2002) (Bahia ir Nantel, 2000), (Jabnoun ir Al-Tamimi, 2003) (Joseph ir Stone, 2003) aiškiai detalizuoti našumo kriterijai. Tuo tarpu literatūroje nagrinėjamų ATM tinklų optimizavimo rezultatų nepakanka, norint sukurti realaus laiko savitarnos paslaugų valdymo sistemą. McAndrews ir Rob (1996) išnagrinėjo optimalaus ATM tinklo dydžio parinkimo metodus. Grynųjų pinigų paklausos specifiką (cirkuliuojančių rinkoje grynųjų pinigų dydis) nagrinėja Boeschoten (1992, 1998), Viren (1992), Snellman ir kiti (2000), Drehmann ir Goodhart, (2000), Drehmann ir kiti, (2002), ir Stix (2003).

Išorinės kokybės užtikrinimui reikalingos procesų tobulinimo priemonės ir išorinės kokybės valdymo sistemos. Išorines kokybės valdymo sistemas išnagrinėjo Lovelock (2000), Vargo ir Lusch (2004), Johnston ir Clark (2001), Edvardsson ir kiti (2006), jie suformavo verte pagrįstus paslaugų kokybės valdymo modelius, kurie nagrinėja ekonominius ir socialinius paslaugos teikimo aspektus. Šiuo metu verslas naudoja įvairias procesų tobulinimo metodikas ir metodus. Pagrindiniai iš jų yra Six Sigma, Lean, bei BPI, ir procesų reinžinerijos metodologijos. Six Sigma, Lean teikia aiškiai apibrėžtus įrankius, kaip galima atlikti patobulinimus, tačiau stokoja sisteminių principų, skirtų įgyvendinti organizacinius pokyčius ir nustatytus patobulinimus (Brache ir Rummler, 1997; Hammer, 2002), apimant ir pasirengimo pokyčiam įvertinimą (Jones ir kiti, 2005). Joms trūksta aiškiai apibrėžto realizacijos proceso. Akivaizdu, kad patobulinimų

duodama nauda priklauso nuo sistemingo jų įdiegimo (Chong ir kiti, 2001). Literatūroje pristatomos įvairios BPI metodikos, jas apibendrino Barry Povey (1998) ir Adesola (2005), tačiau pritaikymų paslaugų organizacijoms yra labai mažai. Jiju Antony (2006) pateikė Six sigma metodikos adaptaciją paslaugų procesų tobulinimui.

Darbe pristatoma savitarnos sistemų veiklos našumo didinimo ir valdymo sistema, adaptuota valdyti bankomatų grynųjų pinigų tiekimą. Sistema sukurta naudojant multi-agentų technologijas ir neuroninius tinklus. Bankomatų grynųjų pinigų poreikiui prognozuoti sukurtas lankstus neuroninių tinklų modelis. Savitarnos sistemų našumui valdyti sukurta vertinimo ir procesų tobulinimo metodika: verte pagrįstas savitarnos kokybės kriterijų modelis, savitarnos sistemų našumo kriterijų modelis, savitarnos sistemų našumo vertinimo modelis, ir savitarnos sistemų procesų tobulinimo modelis.

Darbo tikslas ir uždaviniai

Darbo tikslas yra sukurti aptarnavimo sistemų veiklos našumo didinimo metodą ir valdymo įrankius, realaus laiko sprendimų priėmimui, taikant intelektines sistemas.

Siekiant tikslo išspręsti **uždaviniai**:

1. Išanalizuoti elektroninių ir savitarnos paslaugų sistemų kokybės ir produktyvumo valdymo metodus bei pateikti jų apibendrinimą.
2. Atlikus bankomatų tinklų valdymo analizę, sukurti veiklos našumo didinimo ir valdymo sistemos (bankomatų grynųjų pinigų valdymo) realaus laiko sprendimų priėmimo modelį.
3. Išanalizavus dirbtinių neuroninių tinklų, taikomų laiko eilučių prognozavimui, veikimo ir kūrimo principus, sukurti bankomatų grynųjų pinigų poreikio prognozavimo modelį.
4. Išanalizavus procesų tobulinimo metodikas ir metodologijas, sukurti savitarnos sistemų našumo vertinimo ir procesų tobulinimo metodiką.
5. Sukurti savitarnos sistemų veiklos našumo didinimo ir valdymo sistemą, adaptuota valdyti bankomatų grynųjų pinigų tiekimą, kuri leidžia sumažinti paslaugų teikimo išlaidas, neįtakojant teikiamų paslaugų kokybės.
6. Atlikti bankomatų tinklų pelningumo modeliavimą, siekiant įvertinti sukurtos bankomatų tinklų našumo didinimo sistemos duodamą pelningumą, lyginant su įvairiais laiko eilučių prognozavimo ir realiais bankų taikomais valdymo metodais.

Tyrimo objektas

Disertacijos tyrimų objektas yra aptarnavimo sistemų veiklos našumo didinimo metodas ir valdymo įrankiai, realaus laiko sprendimų priėmimui, taikant intelektines sistemas. Veiklos našumas yra suprantamas, kaip aptarnavimo sistemos pelningumo didinimas, gerinant teikiamų paslaugų kokybę arba mažinant teikimo kaštus. Disertacijoje nagrinėjama siauresnė aptarnavimo sistemų sritis: savitarnos paslaugų sistemos – bankomatų tinklai, todėl sukurtas metodas gali būti sunkiai pritaikomas tradiciniam paslaugų teikimui, dėl jų nepakankamo automatizavimo lygio.

Mokslinis naujumas

Sukurta savitarnos sistemų veiklos našumo didinimo ir valdymo sistema, pritaikyta valdyti bankomatų grynųjų pinigų tiekimą. Sistema taiko multi-agentų technologijas ir neuroninius tinklus. Multi-agentų technologijos naudojamos realaus laiko duomenų surinkimui ir neuroninių tinklų darbo realizacijai. Sukurtas lankstus neuroninių tinklų

modelis, keičiantis savo struktūrą priklausomai nuo situacijos, naudojamas savitarnos paslaugų poreikio prognozavimui. Sukurti 4 savitarnos sistemų našumo vertinimo ir procesų tobulinimo modeliai: verte pagrįstas savitarnos kokybės kriterijų modelis, savitarnos sistemų našumo kriterijų modelis, savitarnos sistemų našumo vertinimo modelis, ir savitarnos sistemų procesų tobulinimo modelis. Sukurta sistema, vertinant literatūroje siūlomus metodus ir technologijas, pasižymi adaptyvumu, galimybe funkcionuoti realiu laiku ir lankstumu. Naudojant tokią sistemą paslaugų teikimas valdomas realiu laiku, tiksliai planuojant sistemos apkrautumą. Pateikiama ne tik priemonė našiam paslaugų sistemos valdymui, bet taip pat suformuotos savitarnos paslaugų kokybės valdymo ir procesų tobulinimo metodikos. Pagal jas sukurti dviejų tipų ATM tinklų našumo vertinimo modeliai: aukštos ir žemos cirkuliacijos. Modelių našumo kriterijai parinkti pagal suformuotą savitarnos sistemos našumo vertinimo modelį.

Grynųjų pinigų vartojimas nuolatos auga, nepaisant elektroninės komercijos plėtros. Europos mokėjimų tarybos duomenimis (sut. EPC) Europos sąjungos šalyse grynųjų pinigų apimtys rinkoje per metus išauga nuo 7-10 %. Vidutiniai grynųjų pinigų kaštai ES šalių ekonomikoje per metus sudaro nuo 40 iki 70 milijardų eurų, tai yra 0,4 iki 0,6 % nuo ES bendrojo vidaus produkto. EPC mano, kad turėtų būti imamasi veiksmų siekiant sumažinti grynųjų pinigų kainą. Sukurta savitarnos sistemų veiklos optimizavimo ir valdymo sistema ir paslaugų kokybės valdymo ir procesų tobulinimo metodikos leidžia sumažinti pinigų kainą, bankomatų tinkluose. Tai yra ypač aktualu, jeigu vertinsime tai, kad 2009 metais pasaulyje veikė 2 mln. bankomatų. ATMIA[1] atlikti tyrimai rodo, kad vieno bankomato aptarnavimas per metus kainuoja nuo 20 iki 68 tūkstančių litų. Jeigu darysime prielaidą, kad vidutiniai vieno bankomato aptarnavimo kaštai yra 40 tūkstančių litų, tai kiekvienais metais visų pasaulio bankomatų išlaikymas kainuotų 80 milijardų litų. Šioje sumoje grynųjų pinigų valdymo kaštai sudaro 26%, o tai yra 20,8 milijardai litų. Lietuvos banko duomenimis[2] 2009 m. pabaigoje Lietuvoje veikė 1543 bankomatai, iš jų 1483 išduoda grynuosius pinigus, 73 priima grynuosius pinigus, o 13 bankomatų atlieka abiejų rūšių operacijas. 2009 m. Lietuvoje per bankomatus išgryninta 22,8 mlrd. litų. Grynieji pinigai yra svarbi finansų rinkos dalis. Lietuvoje bankomatų tinklų grynųjų pinigų kaštai sudaro 16,05 mln. litų, naudojant pažangesnes prognozavimo ir savitarnos tinklų valdymo priemones juos galima sumažinti 29 procentais (Lietuvos mastu tai sudarytų 4,7 milijonus litų per metus), užtikrinant efektyvesnį resursų tiekimo planavimą. Atlikus nežymius patobulinimus, įvedant kredito (išdavimo) ir debito (priėmimo) grynųjų pinigų srautų valdymą, sukurti modeliai būtų tinkami ir kitų sričių grynųjų pinigų valdymui, kaip pavyzdžiui banko taupomųjų skyrių pinigų išdavimui, prekybos centrų grynųjų pinigų seifų valdymui. Kitos pritaikymo sritys gali būti parduotuvių tiekimo valdymo sistemos, integruotos paklausos ir tiekimo planavimo sistemoms (sut. IPTPS) bei korporatyvinės parduotuvių verslo įžvalgos sistemos (sut. BI) Gartner (2008).

Darbe atlikti trijų tipų eksperimentiniai tyrimai. ANN struktūros parinkimui naudoti JAV banko bankomatų duomenys (3433 ATM, trukmė įvairi nuo metų iki trijų). Didelio apkrautumo ATM tinklų pelningumo modeliavimui naudoti Indijos bankų duomenys (5500 ATM, trukmė iki 3 mėn.). Modeliavimas atliktas su 361 bankomato duomenimis. Mažo apkrautumo ATM tinklų pelningumo modeliavimui naudoti Lietuvos bankų duomenys (21 ATM, trukmė 6 mėn.).

[1] http://www.atmia.com/
[2] http://www.lb.lt/lt/mokejimai/mokejimai.htm

Atlikus didelio apkrautumo ATM tinklų pelningumo modeliavimą, nustatyta, kad tiksliai prognozuojamų ATM grupėje, per dieną 5000 bankomatų tinklas gali sutaupyti 4250 eurų (arba 14650 litų), o paskolinus atlaisvintus pinigus uždirbti 2660 eurų (arba 9200 litų). Bendra taupymo ir pelno nauda per dieną siekia 6900 eurų (arba 23800 litų). Vidutinė nauda per metus sudaro 2,35 mln. eurų arba 8,1 mln. litų. Vidutiniškai grynųjų pinigų valdymo kaštai sumažinami apie 25%. Naudojant sukurtą ATM tinklų pinigų valdymo modelį, mažo apkrautumo ATM tinklų valdymui, grįžtančių pinigų apimtys sumažinamos apie 24%, lyginant su realiu scenarijumi. Panaudojus sukurtą ANN metodą ir optimizavimo procedūrą, bankomatų pinigų valdymo našumą galima vidutiniškai padidinti apie 33 procentus.

Pagrindinis sistemos pranašumas prieš tradicinius planavimo ir valdymo metodus, taikomus ATM tinklų valdymui, yra lankstumas ir realaus laiko planavimas. Sukurtas ANN metodas yra pranašesnis už klasikinius laiko eilučių prognozavimo metodus (slankiojo vidurkio, Holto, Vinterio, ARIMA/ARMA modelius). ANN metodas leidžia išlaikyti pakankamai gerus prognozavimo rezultatus, dirbant su įvairiomis bankomatų grynųjų pinigų poreikio laiko eilutėmis, jis lanksčiai pritaiko prie įvairių laiko eilutės procesų. Atlikti Indijos 361 bankomato pinigų poreikio prognozavimo tyrimai rodo, kad ANN metodo vidutinė absoliutinė prognozavimo klaida MAPE% yra apie 33%.

Ginamieji teiginiai

Disertacijoje ginami teiginiai:

Aptarnavimo sistemose realaus laiko sprendimų užtikrinimui tikslinga naudoti intelektines sistemas.

Bankomatų našumo didinimo ir valdymo sistemose realaus laiko duomenų surinkimui iš savitarnos taškų ir intelektinių metodų realizavimui jose, tikslinga naudoti agentų technologijas.

Savitarnos sistemų paslaugų poreikio prognozavimui tikslingiausia naudoti neuroninių tinklų modelį.

Pasiūlyta savitarnos sistemų veiklos našumo didinimo ir valdymo sistema (adaptuota valdyti bankomatų grynųjų pinigų tiekimą) leidžia sumažinti paslaugų teikimo išlaidas, neįtakojant teikiamų paslaugų kokybės.

Pasiūlyta savitarnos sistemų našumo vertinimo ir procesų tobulinimo metodika leidžia užtikrinti nuoseklų savitarnos sistemų veiklos našumo didinimo ir valdymo sistemos diegimą.

Tyrimo metodika

Tyrimų atlikimui naudoti tokie metodai: teorinė analizė, grįsta įvairių mokslininkų darbų rezultatais ir išvadomis; sisteminė analizė; modeliavimas; įvertinimas; apibendrinimas; apklausos ir interviu, naudoti atliekant bankomatų tinklų grynųjų pinigų valdymo procesų analizę. Neuroninio tinklo realizavimui naudotas „Neural Network Based System Identification“ įrankių rinkinys (Nørgaard, 2000a) (Nørgaard ir kiti, 2000b). Algoritmų modeliavimui ir testavimui naudotas MATLAB techninių skaičiavimų paketas. Multi-agentų sistema realizuota naudojant JADE (angl. Java Agent DEvelopment Framework) agentų sistemų kūrimo platformą (Bellifemine ir kiti, 2003).

Grafiniai procesų ir poreikių modeliai paruošti, pagal „Zachman Framework“ organizacijos architektūros projektavimo metodiką, darbų sekų modeliai paruošti pagal BPMN notaciją, USE CASE ir klasių diagramos pagal UML 2.0 notaciją.

Modelių paruošimui naudotas Enterprise Architect modeliavimo paketas. Tyrimų rezultatams apdoroti naudota Microsoft Excel skaičiuoklė.

Praktinė vertė

Sukurta agentų sistema ir dirbtinių neuroninių tinklų metodas, įgyvendinant struktūrinių ES fondų remiamą projektą „Aptarnavimo sistemų optimizavimo ir valdymo agentas“ (BPD2004-ERPF-3.1.7-06-06/0045), realizuotas UAB „Penkių kontinentų bankinės technologijos“ (sut. BS/2) ATMiQ produkte, kaip vienas iš funkcionalumo komponentų, skirtų valdyti ATM tinklo pinigų planavimą. Projektas truko 2 metus (nuo 2007.01.01 iki 2008.08.31), jį įgyvendino 15 specialistų komanda.

2010 metais savitarnos sistemų našumo vertinimo ir procesų tobulinimo metodika pritaikyta UAB „Strateginių Sprendimų Grupė“ sukurtame bankų konsultacijų produkte, jos pagrindu buvo atlikti Lietuvos, Austrijos, JAV, Indijos ir Kazachstano, bankų bankomatų tinklų pelningumo tyrimai.

Darbo rezultatų aprobavimas

Tyrimų rezultatai publikuoti 8 mokslo leidiniuose (FIHUSO-2007, ASMDA-2009, KORSD-2009, EurOPT-2008, ICEIS 2009, BIS 2009, CIMMACS'07, ICSTC 2008): 1 straipsnis leidiniuose, įtrauktuose į mokslinės informacijos instituto pagrindinį (ISI Web of Science) sąrašą; 8 straipsniai leidiniuose, įtrauktuose į Mokslinės informacijos instituto konferencijos darbų (ISI Proceedings) sąrašą; 1 straipsnis užsienio konferencijų pranešimų medžiagoje.

Gauti apdovanojimai

Paruoštas mokslinis straipsnis „*Intelligent Cash Management System for an ATM network*“, 2008 metais „*International Computer Science and Technology Conference*“ JAV vykusioje konferencijoje apdovanotas, kaip geriausias praktinis mokslo žinių pritaikymas.

BS/2 kompanijos sukurta ATMiQ - bankomatų tinklo optimizavimo sistema, 2008 metais apdovanota Lietuvos metų inovacijos prizu „*Inovacijų prizas 2008*“. Tais pačiais metais informacinių technologijų grupėje ATMiQ produktas apdovanotas Lietuvos metų gaminio aukso medaliu. ATMiQ produkte buvo įdiegtas disertacijoje nagrinėjamas lankstus neuroninių tinklų modelis, agentų sistema ir bankomatų grynųjų pinigų optimizavimo procedūros.

Disertacijos struktūra

Disertaciją sudaryta iš 8 skyrių, literatūros sąrašo ir 40 priedų. Disertacijos apimtis: 261 puslapis, 98 paveikslai ir 24 lentelės. Papildoma informacija pateikiama 24 prieduose. Pirmajame skyriuje pateiktas disertacijos įvadas.

Antrajame skyriuje pateikiama aptarnavimo sistemų apžvalga. Nagrinėjamos elektroninių ir savitarnos paslaugų sistemos, jų klasifikacijos. Aprašomas elektroninių paslaugų teikimo koncepcinis modelis ir elektroninių paslaugų veiksniai. Detalizuojami 6 paslaugų modeliai, nagrinėjantys IT poveikį kokybės valdymui. Aprašomi paslaugų produktyvumo teoriniai aspektai, detalizuojamas paslaugų produktyvumo modelis, vertinimo kriterijai. Aptariami paslaugų poreikio prognozavimo metodai.

Trečiame skyriuje aprašomi agentų sistemų teoriniai principai. Pateikiama klasikinė programinio agento architektūra. Aprašomos agentų sistemų klasifikacijos. Pateikiama detali agentų sistemų realizacijos technologijų ir standartų analizė. Aprašomos realaus laiko sprendimų priėmimo sistemos. Nagrinėjami verslo intelektikos sistemų teoriniais

aspektai. Aptariamos tradicinių ir realaus laiko verslo intelektikos sistemų savybės, jų vystymosi tendencijos pagal Gartner ir Forrester tyrimų kompanijų duomenis. Nagrinėjama realaus laiko verslo intelektikos sistemų struktūra. Aptariama verslo intelektikos sistemų plėtra aptarnavimo sektoriuje. Aprašyta sukurta savitarnos sistemų agentų platforma. Nagrinėjami bankomatų tinklų valdymo modeliai, aptariamos galimos jų optimizavimo strategijos. Pateikiamas bankomatų grynųjų pinigų valdymo sistemos modelis. Pateikiama agentų taikymo savitarnos sistemų valdymui analizė. Apibūdinama multi-agentų platforma, detalizuojamas jos funkcionalumas, pateikiamas globalus modelis.

Ketvirtame skyriuje nagrinėjami dirbtinių neuroninių tinklų teoriniai aspektai: įėjimų, išėjimų ir paslėptų sluoksnių parinkimas, perdavimo funkcijos, tinklo modelis ir mokymas. Nagrinėjama prognozavimo neuroniniais tinklais metodologija, vertinamos neuroninių tinklų mokymo strategijos. Pateikiami tyrimai susiję su neuroninių tinklų ir tradicinių metodų prognozavimo rezultatais. Aptariamos dažniausiai taikomos neuroninio tinklo struktūros: viena-sluoksnis ir daugia-sluoksnis perceptronas. Aprašomas sukurtas lankstus neuroninio tinklo modelis. Pateikiama neuroninių tinklų taikymo finansų sektoriuje analizė.

Penktame skyriuje pateikta savitarnos sistemų našumo vertinimo ir procesų tobulinimo metodika. Analizuojami savitarnos kokybės vertinimo kriterijai ir savitarnos paslaugų naudojimo patirtis. Pateiktas sudarytas verte pagrįstas savitarnos kokybės užtikrinimo kriterijų modelis. Detalizuojamas savitarnos sistemų našumo valdymo modelis. Aprašomas savitarnos sistemų tobulinimo modelis ir metodika. Analizuojamos verslo procesų tobulinimo metodikos (tobulinimo, perprojektavimo ir reinžinerijos) ir metodai (Six Sigma, Lean TQM ir JIT). Aprašoma Six Sigma metodo adaptacija, pritaikyta paslaugų procesų tobulinimui.

Šeštame skyriuje detalizuojama sukurta bankomatų tinklo veiklos našumo didinimo ir valdymo sistema. Aprašomas ATMiQ bankomatų tinklų pinigų valdymo sistemos funkcionalumas. Aprašoma optimizavimo sistemos struktūra.

Septintame skyrelyje aprašomi atlikti ATM tinklų našumo eksperimentiniai tyrimai. Pateikti du ATM tinklų našumo vertinimo modeliai: didelio ir mažo apkrautumo rinkų. Vertinama jų darbo kokybė lyginant su tradiciniais laiko eilučių prognozavimo modeliais (Holto, Vinterio ir ARMA). Aprašomos sukurtos našumo vertinimo procedūros ir įrankiai.

Aštuntame skyriuje pateikiamos bendros išvados.

IŠVADOS

1. Atlikus elektroninių ir savitarnos paslaugų sistemų kokybės ir produktyvumo valdymo metodų analizę, nustatyta kad
   a) paslaugų produktyvumo valdymo srityje yra atlikta labai mažai empirinių tyrimų;
   b) dažniausiai taikomi 6 e-paslaugų kokybės valdymo modeliai: IT suderinimo modelis; Atributų ir bendro poveikio modelis; Vidinių paslaugų kokybės modelis, DEA analizė; Internetinės bankininkystės modelis; IT paremtas modelis ir Elektroninių paslaugų kokybės modelis.
   c) produktyvumas susideda iš 4 komponentų: kainos, išteklių paskirstymo, technologinio ir masto našumo;

d) pagrindinė produktyvumo dilema yra pajamų ir kaštų subalansavimas, nes paslaugų negalima sandėliuoti;
e) vienintelis teoriškai ir praktiškai reikšmingas būdas suskaičiuoti paslaugų produktyvumą yra finansiniai kriterijai.

2. Atlikus bankomatų tinklų valdymo ir agentų sistemų pritaikymo bankomatų tinklų valdymui analizę nustatyta, kad:
   a) yra 3 bankomatų tinklų valdymo modeliai: (1) visiškas funkcijų perdavimas, (2) dalinis funkcijų perdavimas ir (3) funkcijų išlaikymas;
   b) ATM tinklų operacijų efektyvumą galima padidinti diegiant pažangesnius techninius sprendimus, sinchronizuojant operatorių tarpusavio darbą, sukuriant ir diegiant pažangias našumo valdymo sistemas, panaudojant tinklą naujų paslaugų teikimui, ir didinat saugumą.
   c) su grynaisiais pinigais susiję kaštai sudaro 26% visų bankomatų tinklo aptarnavimo išlaidų, todėl grynųjų pinigų valdymo funkcijų našumo didinimas gali reikšmingai sumažinti bankomatų palaikymo kaštus, jeigu grynieji pinigai ar kitos aptarnavimo funkcijos nėra efektyviai planuojamos.
   d) protingi agentai bankomatų tinkluose gali būti panaudojami didinti: resursų tiekimo ir apimčių, bankomato vietos parinkimo, bei netikėtų situacijų identifikavimo našumą.
3. Atlikus technologijų analizę, nustatyta kad bankomatų tinklų grynųjų pinigų valdymo platformos kūrimui tinkamiausia yra J2EE platforma, o multi-agentų sistemos kūrimui JADE platforma.
4. Sukurtas bankomatų grynųjų pinigų valdymo multi-agentų modelis leidžia sprendimus priimti realiu laiku:
   a) modelį sudaro agentų servisų sąrašas, agentų valdymo sistema, agentų brokeris, apmokymo agentas, prognozavimo agentas, optimizavimo agentas, sesijos agentas ir duomenų teikimo agentas.
   b) agentai yra atsakingi už lankstaus neuroninio tinklo realizavimą: duomenų paruošimą (normalizavimą), neurninio tinklo apmokymą, adaptavimą, resursų poreikio prognozavimą; ir optimizavimo procedūros realizavimą.
   c) kiekvienam bankomatui realiu laiku yra sukuriamas ir valdomas vienas lankstų neuroninį tinklą ir optimizavimo procedūrą realizuojančių agentų rinkinys.
5. Atlikus dirbtinių neuroninių tinklų taikymo laiko eilučių prognozavimui analizę, nustatyta, kad:
   a) neuroninių tinklų kokybė yra ženkliai didesnė, kai prognozavimui naudojamos mažos apimties laiko eilutės;
   b) prognozuojant didelės apimties laiko eilutes, tradicinių ir ANN metodų rezultatai yra labai panašūs;
   c) tinkamai parinktas neuroninis tinklas yra efektyvesnis už atitinkamus tradicinius algoritmus, kai yra prognozuojamos įvairaus sudėtingumo laiko eilutės.
   d) prognozuojant tiesines priklausomybes turinčius duomenis, geresnis prognozavimo tikslumas yra pasiekiamas su statistiniai metodais; tuo tarpu prognozuojant netiesines priklausomybes turinčius duomenis, geresnis prognozavimo tikslumas yra pasiekiamas su neuroniniais tinklais.
6. Atlikta neuroninių tinklų taikymo finansų sektoriuje analizė rodo, kad ANN pagalba galima pasiekti geresnius rezultatus nei taikant tradicinius statistikos metodus. Jų

unikalios mokymosi galimybės leidžia spręsti sudėtingas finansų valdymo problemas, užtikrina didesnį našumą ir efektyvumą.

7. Bankomatų grynųjų pinigų poreikį tiksliai galima prognozuoti naudojant:
   a) tiesioginio sklidimo daugiasluoksnį neuroninį tinklą su vienu paslėptu sluoksniu, penkiolika neuronų paslėptame sluoksnyje (perdavimo funkcija - hiperbolinis tangentas) ir vienu išėjimu (tiesinis neuronas);
   b) šešiais įėjimais: paskutinių 7 dienų pinigų poreikio vidurkį, savaitės dieną, metų mėnesį, mėnesio dieną, dienos likusias iki švenčių, ir laiko eilutės įrašo numerį.
   c) vienu išėjimu: pinigų poreikio prognozė sekančiai dienai arba nustatytam diskretiškumui.
   d) neuroninio tinklo lankstumas reguliuojamas apribojant neuroninių tinklų svorius. Lankstumas nustatomas adaptyviai realiu laiku, priklausomai nuo proceso sudėtingumo, todėl toks tinklas gali geriau dirbti su nematytais duomenimis;
   e) neuroninio tinklo apmokymui taikomas *Levenberg-Marquardt* algoritmas, naudojantis pirmos eilės išvestines.
8. Atlikus procesų tobulinimo metodikų ir metodologijų analizę pastebėta:
   a) paslaugų sistemų procesų pokyčiams įgyvendinti tikslingiau naudoti nuoseklias verslo procesų tobulinimo metodikas;
   b) tinkamiausios metodikos yra Six sigma ir Lean. Six Sigma metodika tinka įvertinti paslaugos proceso darbo našumą ir suformuoti kontrolės mechanizmą jo nuosekliam tobulinimui. Lean metodika geriausiai tinka identifikuoti vertę negeneruojančius procesus ir juos pašalinti iš vertės grandinės;
   c) paslaugų sistemų procesų tobulinimas turi būti orientuotas į vidinį paslaugų sistemos našumo gerinimą, tobulinant tris našumo komponentes: kaštų, išteklių paskirstymo ir masto našumą;
   d) metodikos ir metodai nepateikia aiškiai apibrėžto tobulinimų realizacijos proceso;
   e) patobulinimų duodama nauda priklauso nuo sistemingo jų įdiegimo;
9. Sukurta savitarnos sistemų vertinimo ir procesų tobulinimo metodiką, leidžia įvertinti ir sistemingai įdiegti numatytus paslaugų sistemos patobulinimus ir našumo valdymo įrankius:
   a) paslaugos teikimo vertinimas turi būti atliekamas pagal e-paslaugų naudos/ vertės kriterijus: aplinkos savybės, saugumas, komunikacijos greitis, patikimumas, vartotojų pagalba, atsakomumas, informacijos pilnumas, prieinamumas, teikimas ir suasmeninimas.
   b) savitarnos terminalų vidinį našumą galima padidinti naudojant pigesnius palaikymo resursus, diegiant pažangesnius technologinius sprendimus, jeigu tai neigiamai neįtakoja kokybės; arba našiau paskirstant išteklius.
   c) našesnį išteklių paskirstymą galima atlikti, turint tikslias paslaugų poreikio prognozavimo priemones;
10. Sukurta bankomatų grynųjų pinigų valdymo sistema, leidžia sumažinti paslaugų teikimo išlaidas, neįtakojant teikiamų paslaugų kokybės:
    a) bankomatų paslaugų teikimo išlaidos mažinamos optimizuojant resursų tiekimo kaštus: pinigų palūkanų, pinigų draudimo, ir inkasacijos.

b) paslaugų kokybės užtikrinti tikslo funkcijoje naudojamas baudos narys didinantis aptarnavimo kaštus, jeigu neaptarnaujami daugiau kaip 2% klientų;
c) sukurta bankomatų grynųjų pinigų valdymo optimizavimo funkcija parenka tokį pinigų užkrovimo kiekį, kuris minimizuoja bankomato funkcionavimo išlaidas;
d) jeigu bankomatų tinklas yra mažesnis už 1000, tikslo funkcijos optimizavimui turi būti naudojamas detalus galimų sprendimų perrinkimas užduotu pinigų poreikio žingsniu;
e) jeigu bankomatų tinklas yra didesnis už 1000, tikslo funkcijos optimizavimui turi būti naudojamas stochastinis modeliuojamo atkaitinimo/ ataušinimo metodas;

11. Atlikus didelio ir mažo apkrautumo bankomatų tinklų pelningumo tyrimus nustatyta, kad:
    a) sukurtas lankstus neuroninių tinklų prognozavimo metodas yra pranašesnis už klasikinius laiko eilučių prognozavimo metodus (slankiųjų vidurkių, Holto, Vinterio, ARMA), ir gali pakankamai (vidutinė absoliutinė prognozavimo klaida yra 33%, vertinant įvairaus sudėtingumo laiko eilutes) tiksliai prognozuoti įvairias bankomatų grynųjų pinigų poreikio laiko eilutes;
    b) bankomatų grynųjų pinigų poreikio laiko eilutės, turinčios aiškias sezoniškumo priklausomybes (savaitės diena, mėnesio diena, metų mėnuo ir dienos iki švenčių) yra tiksliai prognozuojamos tiek taikant lankstų neuroninių tinklų modelį, tiek ir klasikinius laiko eilučių prognozavimo metodus (slankiųjų vidurkių, Holto, Vinterio, ARMA).
    c) didelio ir mažo apkrautumo bankomatų tinkluose, naudojamas lankstus neuroninių tinklų metodas ir sukta optimizavimo procedūra, leidžia sumažinti grįžtančių pinigų apimtis 24 procentais ir padidinti grynųjų pinigų valdymo našumą 33 procentais;
12. Sukurta multi-agentų sistema ir lankstus neuroninių tinklų metodas realizuotas UAB „Penkių kontinentų bankinės technologijos“ bankomatų tinklų valdymo produkte, kaip vienas iš modulių, skirtų valdyti bankomatų tinklo pinigų planavimą.