INTEGRATED PLANNING OF SUPPLY CHAIN BUSINESS PROCESSES AND DISASTER-TOLERANCE INFORMATION SYSTEMS

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KEYWORDS

Disaster-tolerance information system, structural dynamics management, integrated modeling, planning and scheduling, economic efficiency of information systems (IS), total cost ownership, return on investment.

ABSTRACT

This contribution proposed an original modelling and algorithmic tools for integrated (re)-planning of supply chain business processes and disaster-tolerance information systems (DTIS). The following models are jointly used: the model of DTIS recovery (modernization) management; the model of DTIS o peration control; the model of business-processes management as applied to DTIS-aided activities. The combined algorithms of integrated planning of DTIS operation and recovery (modernization) use these models and apply modern results of the control theory and operation research. The essence and novelty of modelling and integrated planning of DTIS lies in the possibility to relate optimization of business-processes goals with executive data-handling procedures, information processing, and DTIS communication. This provides joint finding of optimal business-processes for supply chains using DTIS and management programs for DTIS. The planning algorithms use the fundamental scientific results obtained within the modern control theory operating with complex dynamic objects with reconfigurable structure. The prototype computer program for modelling and integrated planning of supply chain processes and DTIS has been developed.

INTRODUCTION

Information technologies (IT) are one of the most important enablers of new agile and flexible supply chain management concepts. The firms that timely understood the role of IT in their own processes and the inter-organizational processes with their customers and suppliers benefits from the IT deployment.

Supply Chain (SC) planning is composed of setting management goals and defining measures to their achievement (Kreipl and Pinedo 2004). On the basis of the goals of the superordinate level of a SC, plans of a current level are formed. E.g., strategic goals can be referred to service level and costs. The measures are in this case plans of customers' orders realization that in turn are realized on the basis of scheduled operations.

Traditionally, improvements for SC planning and scheduling have been algorithmic. However, in recent years, the works on SC management have been broadened to cover the whole SC dynamics. In the most tactical-operational problems that refer to SCs dynamic to be under control, the modelling supply chain dynamics is mandatory. Although the dynamic feedbacks have been extensively investigated in the systems dynamics, these models have been successfully applied only for strategic issues of network configuration and showed many limitations with regard to the tactical and operation control levels. With regard to these two levels, the recent literature indicates an increasing renewed interest to theoretical background of control theory (Disney *et al.,* 2006; Ivanov *et al.,* 2007; Ivanov *et al.,* 2009; Ivanov, Sokolov 2010a., 2009van Houtum *et al.,* 2008, Wang et al., 2008).

An important practical issue in supply chain (re)-planning is multi-structural design of supply chains. In supply chains, different structures (functional, organizational, informational, financial etc.) are (re)formed. These structures interrelate with each other and change in dynamics. Decisions on SC strategy, design, planning, and operations are interlinked and dispersed over different SC structures. The efficiency and applicability of the decisions decrease if decision-supporting models are considered in isolation for different SC managerial levels and structures (Ivanov et al., 2009a). Furthermore, the SC execution is accomplished by permanent changes of

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internal network properties and external environment. In practice, structure dynamics is frequently encountered. Decisions in all the structures are interrelated. Changes in one structure affect the other structures. Furthermore, the structures and decisions on different stages of SC execution change in dynamics. Output results of one operation are interlinked with other operations (the output of one model is at the same time the input of another model). This necessitates structure dynamics considerations. In the case of disruptions, changes in one structure will cause changes in other relevant structures. Structure dynamics considerations may allow establishing feedback between SC design and operations.

In this paper, we consider the business process and information systems structures as simultaneously. The paper elaborates an approach to integrate (re)-planning of supply chain business processes and disaster tolerant information systems (DTIS).

Also in this paper we consider issues related to the economic efficiency of IS, in particular the disaster tolerant information systems. Nowadays, under conditions of market economy and intense competition the each company tries to improve its position at the market increasing the quality of its services and products through using innovations and raising the efficiency of the business. One of the components to reach the goals above is the close integration between business and IT, including the application of DTIS. Now DTIS are very complex technical and technological systems. The DTIS lifecycle has many scenarios of evolution. At the all stages of DTIS existence the task of optimization of DTIS resources, especially financial resources, is very important. The problem is to estimate the contribution of DTIS to the principal company activity and the economic efficiency of DTIS, including the investment profitability. This problem can be solved using total cost ownership (TCO) and return on investment (ROI).

The feature of TCO is the possibility to estimate the total IT costs with the following analysis which allows to control the company IT-infrastructure expenses. The TCO method allows to find out excess items of expenses and to estimate the return of DTIS investments. The costs are divided to direct and indirect. As direct costs are recognized the hardware and software purchase expenses; the user trainings; the third-party company services expenses; the IT-department wage fund expenses; the company management wage fund expenses; the DTIS used electricity expenses; etc. As indirect costs are recognized the expenses for user self-support; the system idle time losses; etc. In general case the TCO index does not allow to see the direct economical effect from the DTIS application, ROI (return on investment) is used to solve this task. The most difficulty of this method is to mark out the direct benefits received by the company from the DTIS application. In the analysis the business directions and DTIS application goals are marked out, and the benefit received by the company after the goals achievement is calculated. It could be the raising of service quality or the possibility of development and producing of new products, giving the competitive advantages to the company at the market. In the ROI method the important part has the TCO index as it reflects the fact DTIS costs.

$$ROI(t) = \frac{Ef(t)}{TCO(t)}$$

Ef(t) – economic effect of the use DTIS.

The DTIS costs are considered during all its life cycle, thus TCO and ROI indexes are considered in the time interval with the specified periodicity.

Also in this paper we proposed method of multi-criteria evaluation of technical and economic efficiency involves the following steps:

1. Model calculation of the total cost of ownership.
2. Creating a conceptual model of the relationship of business processes, IT services, IT functions, IT resources.
3. Calculation of the total cost of ownership services based on the functional cost analysis.
4. Calculation of the quality and effectiveness of IT-based integrative management and valuation and original multi-model interpretation of the components of information service.
5. The calculation of quality indicators using integrative management and the value of interpretation and original multi-model and service-oriented description of the components of the information environment of the enterprise.

The construction of the complex multi-model intended to describe the process of information services (IS), the concept of service-oriented approach. Under the IT services we mean services provided by IP business process (BP) (business unit), using appropriate IT. Adopted IT service characterized by the following parameters: content (functionality), that is, the composition of the task and set of tools for solving them; availability - the time period during which the MIS support this service; level - the time period during which a guaranteed fix the problem; performance - the volume of activity in a particular category of unit time cost of service for the business units. Later in the construction of specific models of IT will try to accommodate these parameters. The main advantage of a service-oriented approach is that IT services allows on the one hand, to link financial results achieved in the implementation of BP with the volume of services provided by these services, but on the other hand, using the services, you can spend on a constructive level estimation the flows of spending caused by the development, implementation, maintenance and exploitation of information resources

(IR), is the material basis of services. Thus, a specific service (external and / or domestic) is a kind of mediator between the cost of R & D and output (services) at the level of specific BP, allowing for financial calculations inoperable attitude "many to many" (at the BP-IR) to break two completely resectable relationship "one to many" (at the BP service (function), service (function)-IR).

STATE OF THE ART

In modern markets ensuring the continuity of business processes and improving catastrophe resistance of relevant business systems is a critical strategic direction of an organization. After a long-lasting research into optimal SCM, the research community begins to shift to a paradigm that the efficiency of supply chains is to consider with regard to adaptable, stable, and crisis-resistant processes to compete in real perturbed execution environment. Achievement of planned (potential) SC goals can be inhabited by perturbation impacts and crises in a real execution environment. The real SC efficiency is based on a maintaining planed execution and a quick cost-efficient recovering once being disturbed.

In recent literature, a wealth of frameworks for handling disruptions in supply chain business processes has been developed.

However, the developed frameworks and models are concentrated on business-process structure and do not assume that not only the business processes but also information systems may be subject to disruptions. As noted by Lummus and Vokurka (1999) and Childerhouse and Towill (2000), much of the benefit attributed towards adopting supply chain management (SCM) systems, center around the ability of information systems to speed up decision-making; increase visibility of value chain enablers; manage customer expectations better; reduce process cost; and increase the level of control available to management.

Most research on IT value has examined relationships between IT investments and organizational outcomes. Recent research in the business value of IT has raised several questions that must be addressed. Kohli and Grover (2008) articulated the co-creation of IT value as a theme for future research. They proposed that we need to understand how IT-based value is co-created and shared among multiple partners in multi-company relationships (Sharaf et al. 2007).

There are many interesting result in the area of IS economic efficiency estimation (Chernak 2003, HP Utility Data Center 2001, HP Virtualization 2003, Skripkin 2002).

However, no explicit frameworks and formal models of integrated consideration of disaster-tolerant information systems and stable business processes have been identified so far. The paper (Ivanov et al. 2009a) introduced a new conceptual framework for multi-structural planning and operations of adaptive supply chain with structure dynamics considerations. In this study, we will investigate the interrelation of business-processes and information systems structures in terms of disaster-tolerance in details.

MATHEMATICAL MODEL

Basic principles

Supply chain business process and information systems structures change in dynamics caused by planned and unplanned events. The changes in one structure influence the other structure. The goal of the presented model is to investigate the issue of how to (re)-plan supply chain business processes and information systems as an integrated system to relate optimization of business-processes goals with executive data-handling procedures, information processing, and DTIS communication. This should provide joint finding of optimal business-processes for supply chains using DTIS and management programs for DTIS.

The proposed approach is based on fundamental scientific results of the modern control theory in combination with optimization methods of the operations research. This mathematical model reflects the conceptual cybernetic framework of supply chain planning and control presented for different SCM domains in (Ivanov et al. 2007; Ivanov et al. 2009a,b). In the model, a multi-steps procedure for solving multiple criteria task of adaptive planning and scheduling is implemented. In doing so, at each instant of time while calculating solutions in the dynamic model with the help of the maximum principle, the linear programming problems to allocate jobs to resources and integer programming problems for (re)distributing material and time resources are under solution (Kalinin and Sokolov 1985; Okhtilev et al.2006, Ivanov and Sokolov 2010, 2010a). At each re-planning stage, the constructing information system recovery program is subject to supply chain goals extermination.

The modeling procedure is based on an essential reduction of a problem dimensionality that is under solution at each instant of time due to connectivity decreases. In this case, the problem dimensionality is determined by the number of independent paths in a network diagram of supply chain operations and by current economical, technical, and technological constraints. In its turn, the degree algorithmic connectivity depends on a dimensionality of the main and the conjugate state vectors at a point the solving process is being interrupted at. If the vectors are known then the schedule calculation may be resumed after removal of appropriate constraints. As such, the problem under solution can be presented with a polynomial complexity rather then with the exponential one. In contrast, traditional exact scheduling techniques work almost with the complete list of all the operations and constrains in supply chains. For the computations, the Lagrange relaxation is used that has been already applied for the SCM domain. However, in contrast to these conventional mathematical programming approaches, we use the dynamic interpretation of Lagrange multiplications.

Mathematical model of software management of DTIS in Bj node

Mathematical model of the process:

$$\frac{dx_{v\chi}^{(i,j)}}{dt} = \sum_{r=1}^{R_j} u_{v\chi r}^{(i,j)}; \tag{1}$$

$$\frac{dx_{r}^{(i,j)}}{dt} = \sum_{v=1}^{n_j} \sum_{\chi=1}^{S_v} w_{v\chi r}^{(i,j)}; \tag{2}$$

$$\frac{d\tilde{x}_{rS_v}^{(i,j)}}{dt} = \tilde{v}_{rS_v}^{(i,j)}; \tag{3}$$

Restrictions on control actions:

$$0 \le u_{v\chi r}^{(i,j)}(t) \le \left[e_{v\chi r}(1-v_r^{(p,2)}) + \bar{e}_{v\chi r} v_r^{(p,2)}\right] w_{v\chi r}^{(i,j)}; \tag{4}$$

$$\sum_{v=1}^{n_j} \sum_{\chi=1}^{S_v} V_{v\chi}^{(j)} w_{v\chi r}^{(i,j)} \le V_r^{(j)}(1-v_r^{(p,2)}) + \bar{V}_r^{(j)} v_r^{(p,2)}; \tag{5}$$

$$\sum_{v=1}^{n_j} \sum_{\chi=1}^{S_v} u_{v\chi r}^{(i,j)}(t) \le \Phi_r^{(j)}(1-v_r^{(p,2)}) + \bar{\Phi}_r^{(j)} v_r^{(p,2)}; \tag{6}$$

$$\tilde{v}_{rS_v}^{(i,j)}(a_{vS_v}^{(i,j)} - x_{vS_v}^{(i,j)}) = 0; \tag{7}$$

$$\sum_{r=1}^{R_j} w_{v\chi r}^{(i,j)}(a_{v(\chi-1)}^{(i,j)} - x_{v(\chi-1)}^{(i,j)}) = 0;$$

$$\sum_{r=1}^{R_j} w_{v\chi r}^{(i,j)}(t) \le 1, \forall \chi, \forall v; \tag{8}$$

$$0 \le w_{v\chi r}^{(i,j)}(t) \le 1; \tag{9}$$

Edge conditions:

$$x_{v\chi}^{(i,j)}(t_0^{(j)}) = 0; \tag{10}$$

$$x_{r}^{(i,j)}(t_0^{(j)}) = 0; \tag{11}$$

$$x_{v\chi}^{(i,j)}(t_f^{(j)}) = a_{v\chi}^{(i,j)}; \tag{12}$$

$$x_{r}^{(i,j)}(t_f^{(j)}) \in R^1; \tag{13}$$

Indicators of quality of management process

$$J_1^{(i,j)} = \sum_{r=1}^{R_j-1} \sum_{r_1=r+1}^{R_j} \int_{t_o^{(j)}}^{t_f^{(j)}} (x_r^{(i,j)}(\tau) - x_{r_1}^{(i,j)}(\tau))^2 d\tau; \tag{14}$$

$$J_2^{(i,j)} = \sum_{v=1}^{n_j} \sum_{\chi=1}^{S_v} \sum_{r=1}^{R_j} \int_{t_f^{(j)}}^{t_f^{(j)}} a_{v\chi r}^{(i,j)}(\tau) w_{v\chi r}^{(i,j)}(\tau) d\tau; \tag{15}$$

$$J_3^{(i,j)} = \frac{1}{2} \sum_{v=1}^{n_j} \sum_{\chi=1}^{S_v} (a_{v\chi}^{(i,j)}(\tau) - x_{v\chi}^{(i,j)}(t_f^{(j)}))^2; \tag{16}$$

$$J_4^{(i,j)} = \sum_{r=1}^{R_j} (T^{(j)} - x_r^{(i,j)}(t_f^{(j)}))^2; \tag{17}$$

In formulas (1) - (17) variables are interpreted as follows:

- $x_{v\chi}^{(i,j)}$ - variable characterizing the status of $D_{v\chi}^{(i,j)}$ operation (i.e., the current volume of processed information during the execution of $D_{v\chi}^{(i,j)}$ operation);
- $a_{v\chi}^{(i,j)}$ - preset amount of information that is processed during the execution of $D_{v\chi}^{(i,j)}$ operation, that is a part of $A_v^{(i,j)}$ technology of data processing to ensure the execution of $A_v^{(o,j)}$ BP;
- $x_r^{(i,j)}$ - variable, the current value of which is numerically equal to the total duration of use of $B_r^{(i,j)}$ resource information system, belonging B_j of node DTIS;
- $u_{v\chi r}^{(i,j)}$ - the intensity of processing on $B_r^{(i,j)}$ information resource, required for execution of $D_{v\chi}^{(o,j)}$ operation, belonging to $A_v^{(o,j)}$ BP;
- $w_{v\chi r}^{(i,j)}$ - control action, belonging to the class of piecewise continuous functions taking value in the interval [0; 1]. In the papers (Okhtilev et al.2006, Ivanov and Sokolov 2010b) it was shown that the proposed models for program control, these functions take values of either 0, 1. In this case, the interpretation of these values of the variable of the following: taking a value of 1 if the resource is in the $B_r^{(i,j)}$ resource of IS in B_j node is dedicated for execution of $D_{v\chi}^{(i,j)}$ operation, in the opposite case $w_{v\chi r}^{(i,j)}(t) = 0$;
- $e_r^{(j)}, V_r^{(j)}, \Phi_r^{(j)}$ - preset values, characterizing the maximum possible intensity of the execution of $D_{v\chi}^{(i,j)}$ operation in the resource $B_r^{(i,j)}$, maximum possible amount of available RAM of IS in node B_j and maximum possible performance of $B_r^{(i,j)}$ resource before its modernization; $, \bar{e}_r^{(j)}, \bar{V}_r^{(j)}, \bar{\Phi}_r^{(j)}$ - these values have similar interpretation, but after the modernization;
- $v_{\chi r}^{(p,2)}(t)$ - auxiliary control action, taking a value of 1 in time moment t, if a transition from old $(e_r^{(j)}, V_r^{(j)}, \Phi_r^{(j)})$ to new $(, \bar{e}_r^{(j)}, \bar{V}_r^{(j)}, \bar{\Phi}_r^{(j)})$

information resources in B_j node was completed (see comments on the control actions $w_{v\chi r}^{(i,j)}$);

- $V_{v\chi}^{(j)}$ - amount of RAM allocated for execution of $D_{v\chi}^{(i,j)}$ operation of data processing.

Restrictions of type (4), (5) and (6) define the possibilities for processing information in an information resource $B_r^{(i,j)}$.

Restrictions of type (7) define the priorities in the operations $D_{v\chi}^{(i,j)}$, $D_{v(\chi-1)}^{(i,j)}$, related to the processing of information and required to perform operations $D_{v\chi}^{(o,j)}$, $D_{v(\chi-1)}^{(o,j)}$ belonging $A_v^{(o,j)}$ и $A_{v-1}^{(o,j)}$ BP.

Restrictions of type (8) mean that at the current time $D_{v\chi}^{(i,j)}$ operation can run only on a single information resource $B_r^{(i,j)}$ (r=1,…, R_j).

Equations (10) – (13) set the boundary conditions (restrictions on the variable values $x_{v\chi}^{(i,j)}$, $x_r^{(i,j)}$ in the starting and ending times $t_0^{(j)}$ and $t_f^{(j)}$).

Indicator of type (14) is intended to assess the degree of uniformity of the use of resources $B_\rho^{(i,j)}$, $B_{\rho 1}^{(i,j)}$ ($\rho, \rho 1=1,\ldots,R_j$).

Indicator of type (16) is introduced in the event that it is necessary to evaluate the accuracy of implementation types of boundary conditions (12), or minimize the losses caused by the failure of the operation $D_{v\chi}^{(i,j)}$.

Indicator of type (15) allows to evaluate the total quality of the entire operations $D_{v\chi}^{(i,j)}$ with a fixed program of their execution $V_{v\chi r}^{(i,j)}(t)$.

Related models

Analogous to the model of software management of DTIS in Bj node, model of DTIS recovery (modernization) management; the model of business-processes management as applied to DTIS-aided activities are elaborated. To avoid the excessiveness, we will not consider their formal description here. The techniques of such models construction are presented in monographs (Okhtilev et al.2006, Ivanov and Sokolov 2010a). Besides, the model of coordination (harmonization) of the three process models has been developed based on concepts and approaches developed by the authors of theory of structural dynamics management (SDM) for complex technical systems (Okhtilev et al. 2006). This coordination model may be applied both in the case of information system disruption and the following business process adaptation and in the reverse case. The procedures will be analogous. The prototype computer programs for modelling and integrated planning of supply chain processes and DTIS has also been developed.

PROTOTYPE

The models presented above are implemented in software prototype. The software has three modes of operation. *The first mode* includes interactive preparation of data and data input subject to (1)-(17). *The second mode* lies in evaluation of heuristic and optimal supply chain schedules. *The third mode* provides interactive selection and visualization of supply chain structure dynamics control programs and report generation. An end user can select modes of program run, set and display data via a hierarchical menu. In Figure 1, an example interface is presented.

In Figure 1, results of simultaneous re-planning of supply chain information system once being disrupted and business processes in supply chain is presented. As a tool of decision support for solving the problems of calculation, analysis and management of technical and economic efficiency of information resources implemented software prototype based on the software platform 1C Enterprise 8. Software prototype can be integrated in a typical configuration of 1C Accounting 8, and may use data from the accounting company as a source of data for the relevant calculations. Figure 2 shows the ratio of business processes, services, functions and IT resources.

CONCLUSIONS

In this study, we extended the planning and control frameworks for supply chains by taking into account the integrated consideration of supply chain business processes and information systems. The following models are jointly used: the model of DTIS recovery (modernization) management; the model of DTIS operation control; the model of business-processes management as applied to DTIS-aided activities. The combined algorithms of integrated planning of DTIS operation and recovery (modernization) use these models and apply modern results of the control theory and operation research. The essence and novelty of modelling and integrated planning of DTIS lies in the possibility to relate optimization of business-processes goals with executive data-handling procedures, information processing, and DTIS communication. This provides joint finding of optimal business-processes for supply chains using DTIS and management programs for DTIS. The planning algorithms use the fundamental scientific results obtained within the modern control theory operating with complex dynamic objects with reconfigurable structure.

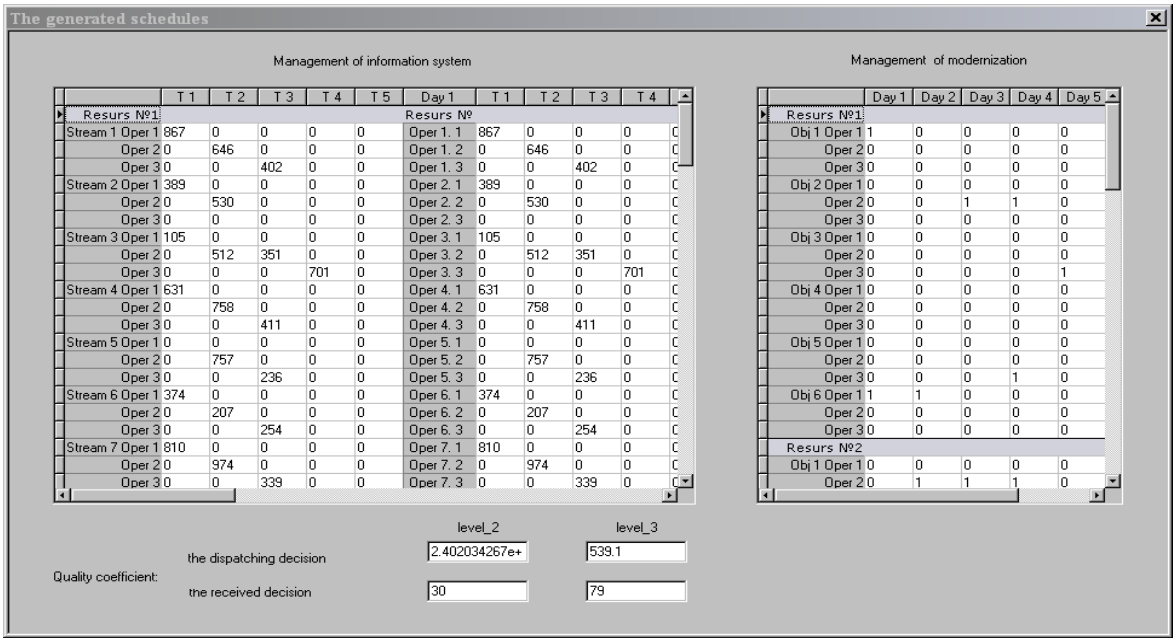

Figure 1: Interface of planning results.

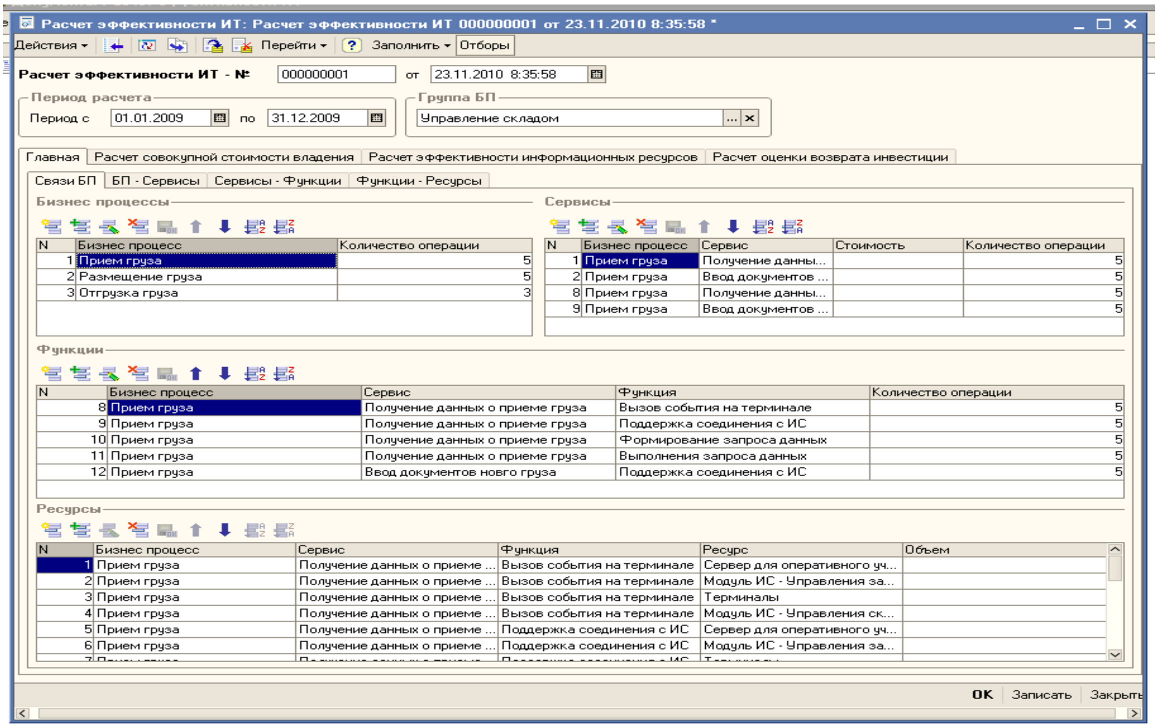

Figure 2: Interface for input data of IT infrastructure.

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